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NEW ENGLAND DIVISION
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DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

FROST EFFECTS LABORATORY
JUNE 1949

DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

VOLUME I

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DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

SYNOPSIS

This report presents, in three volumes, a summary of the frost investigations which were conducted under the supervision of the Frost Effects Laboratory from 1943 through 1949, together with all data obtained from these investigations.

Frost studies were first initiated at Dow Field, Bangor, Maine, in the winter and spring of 1944 to determine the influence of frost action in the subgrade soils beneath both rigid and flexible pavements upon the load carrying capacity of the pavements during the frost melting period. The need for such studies became apparent during the pavement evaluation program in 1943 when it became obvious that, during the spring thaws, evaluations of many airfields in the northern United States were controlled by conditions resulting from frost action in the subgrade soils. Since limited data were available at that time on the effects of frost action under airfield pavements, an extensive program of investigations were authorized by the Chief of Engineers for the purpose of developing and establishing design and evaluation criteria for such pavements.

Frost investigations were conducted in the New England Division, the Missouri River Division, and the Great Lakes Division under the direction of the Frost Effects Laboratory, New England Division. The observations and testing of the effects of frost action were studied during the fiscal years 1943 - 1946 at 17 airfields located in the northern United States.

Several laboratory studies were made on different phases of the frost-soil problem in addition to investigations conducted at various airfields to study the field effects. Theoretical studies to determine rates and depth of frost penetration were made. Thermal and physical constants necessary for mathematical analysis were obtained from tests performed under controlled temperature conditions to determine the thermal conductivity of frozen and unfrozen cohesionless materials. Work of previous investigators in this field was reviewed. A study was made of methods of making frost susceptible soils nonfrost susceptible by the use of various admixtures and also of methods of preventing the leaching out of salt admixtures.

The data in the Data Report were presented in 36 separate reports that were prepared during the various stages of the frost investigational program.

I. INTRODUCTION

1-01. Authorization. The preparation of this Data Report as part of the frost investigation program for fiscal year 1948-1949 was authorized by letter dated 26 October 1949 from the Office, Chief of Engineers to Division Engineer, New England Division, subject: "Authorization - New England Division FY 1949 Airfields Investigational Program".

1-02. Purpose. The overall purpose of the frost investigational program is to develop and establish design and evaluation criteria for concrete and flexible pavements placed on subgrade or base soils subject to seasonal frost action. The specific purpose of this report is to present in unified form all data and results of tests obtained during the four years of frost investigations conducted at 17 different sites in northern United States together with results of the supplemental laboratory and theoretical studies.

1-03. Scope. This report presents all data obtained from frost investigations for both field and laboratory tests conducted under the supervision of the Frost Effects Laboratory. No analyses of data or conclusions are presented.

1-04. Locations of Field Investigations. The field investigations were conducted at the following Army Air Force installations:

NEW ENGLAND DIVISION

SITE	NORTH LAT.	WEST LONG.	ELEV. ABOVE MSL	PHYSIOGRAPHY
Presque Isle Airfield Presque Isle, Maine	47°	68°	500	Glaciated region of rolling hills.
Houlton Airfield Houlton, Maine	46°	68°	470	Narrow valley flanked by high hills
Dow Field Bangor, Maine	45°	69°	170	Glaciated region of rolling hills
Bedford Airfield Bedford, Massachusetts	42°	62°	130	Rolling terrain of low relief
Otis Field Sandwich, Massachusetts	42°	70°	120	Flat outwash plain

GREAT LAKES DIVISION

SITE	NORTH LAT.	WEST LONG.	ELEV. ABOVE MSL	PHYSIOGRAPHY
Truax Field Madison, Wisconsin	43°	89°	860	Low level marsh
Selfridge Field Mt. Clemens, Michigan	43°	83°	580	Level lake plain

MISSOURI RIVER DIVISION

SITE	NORTH LAT.	WEST LONG.	ELEV. ABOVE MSL	PHYSIOGRAPHY
Pierre Airfield Mt. Clemens, Michigan	44°	100°	1720	Ravines to predominating flat plateau
Fargo Municipal Airfield Fargo, North Dakota	47°	97°	900	Bed of ancient lake - very flat.
Bismarck Municipal Airfield Bismarck, North Dakota	47°	101°	1650	Ascending and descending benches
Watertown Airfield Watertown, South Dakota	45°	97°	1730	Flat to rolling
Casper Airfield Casper, Wyoming	43°	107°	5320	Gullies to rolling hills, mountains to south

SITE	NORTH LAT.	WEST LONG.	ELEV. ABOVE MSL	PHYSIOGRAPHY
Sioux Falls Airfield Sioux Falls, South Dakota	44°	96°	1420	Flat flood plain
Fairmont Airfield Fairmont, Nebraska	41°	98°	1630	Flat plain
Great Bend Airfield Great Bend, Kansas	39°	98°	1890	Wide flat valley
Garden City Airfield Garden City, Kansas	38°	101°	2880	Flat to slightly undulating prairie land
Pratt Airfield Pratt, Kansas	38°	99°	1950	Gently rolling prairie land interspersed with low knolls and occasional shallow ponds or "buffalo wallows"

1-05. Frost Investigation Reports. The data presented originally appeared in 36 separate volumes covering various phases of the frost investigational program, from 1943 to 1949 and have been combined and assembled in this Data Report. The complete list of reports on frost investigations prepared by the Frost Effects Laboratory is as follows:

TESTS IN FISCAL YEAR	TITLE OF REPORT	REPORT DATED
1943-1944	Frost Investigations and Pavement Behavior Tests at Dow Field	Jan. 1946
1944-1945	Frost Investigation 1944-1945 (prepared by Missouri River Division - contains reports on Sioux Falls Airfield, Fairmont Airfield, Great Bend Airfield, Garden City Airfield, and Pratt Airfield)	Jul. 1945

TESTS IN FISCAL YEAR	TITLE OF REPORT	REPORT DATED
1944-1945	Comprehensive Report, Frost Investigation 1944-1945	Feb. 1947
	Appendix 1 Dow Field	
	Appendix 2 Presque Isle Airfield	
	Appendix 3 Otis Field	
	Appendix 4 Houlton Airfield	
	Appendix 5 Truax Field	
	Appendix 6 Pierre Airfield	
	Appendix 7 Watertown Airfield	
	Appendix 8 Casper Airfield	
	Appendix 9 Fargo Municipal Airfield	
	Appendix 10 Bismarck Municipal Airfield	
1944-1945	Appendix 11 Subsurface Temperature Investigations at Pierre and Watertown Airfields	
	Appendix 12 Subsurface Temperature Investigations at Dow Field and Presque Isle Airfield	
	Appendix 13 Laboratory Tests on Frost Penetration and Thermal Conductivity of Cohesionless Soils	
	Appendix 14 Laboratory and Field Test Procedures for Boston District, New England Division, Great Lakes Division and Missouri River Division	
	Appendix 15 Bibliography	
1944-1945	Report on Frost Investigations 1944-1945 (Published)	Apr. 1947
1945-1946	Comprehensive Report, Frost Investigations, 1945-1946	June 1947
	Appendix 1 Dow Field	
	Appendix 2 Presque Isle Airfield	
	Appendix 3 Bedford Airfield	
	Appendix 4 Truax Field	
	Appendix 5 Pierre Airfield	
	Appendix 6 Sioux Falls Airfield	
	Appendix 7 Watertown Airfield	
	Appendix 8 Fargo Municipal Airfield	
	Appendix 9 Great Bend Airfield	
1945-1946	Report on Frost Investigations and Traffic Tests - Selfridge Field	June 1946

TESTS IN FISCAL YEAR	TITLE OF REPORT	REPORT DATED
1945-1946	Report on Studies of Base Course Treatment to Prevent Frost Action	June 1946
1946-1947	Comprehensive Report, Frost Investigations, 1946-1947 Appendix 1 NED Investigations (Dow and Bedford) Appendix 2 GLD Investigations (Selfridge) Appendix 3 MRD Investigations (Sioux Falls and Fargo)	Apr. 1948
1946-1947	Report on Studies of Base Course Treatment to Prevent Frost Action	Aug. 1947
1947-1948	Summary Tabulation of Airfield Pavements (Draft)	June 1948
1947-1948	Addendum No. 1 to Report on Frost Investigation, 1944-1945 (in draft form - to be published)	June 1948

1-06. Presentation of Data Report. The Data Report is presented in three volumes as follows:

a. Volume I presents a summary of the frost investigation program together with a list and description of airfields investigated and the tests performed. Reports on special studies are presented as appendices in Volume I as follows:

Appendix A Report on Studies of Base Course Treatment to Prevent Frost Action.

Appendix B Report on Laboratory Tests on Frost Penetration and Thermal Conductivity of Cohesionless Soils

Appendix C Report on Mathematical Studies of Thermal Changes in a Soil Mass.

Appendix D Report on Special Test Section at Dow Field, Bangor, Maine.

Appendix E Laboratory and Field Test Procedures

Appendix F Bibliography

b. Volume II presents the data obtained from all fields investigated in the New England Division as follows:

(1) Presque Isle Airfield
(2) Houlton Airfield
(3) Dow Field
(4) Bedford Airfield
(5) Otis Field

c. Volume III presents the data obtained from all frost investigations conducted in the Great Lakes Division and the Missouri River Division. The following fields are located in the Great Lakes Division:

(1) Truax Field
(2) Selfridge Field

The fields investigated in the Missouri River Division are:

(1) Pierre Airfield
(2) Fargo Municipal Airfield
(3) Bismarck Municipal Airfield
(4) Watertown Airfield
(5) Casper Airfield
(6) Sioux Falls Airfield
(7) Fairmont Airfield
(8) Great Bend Airfield
(9) Garden City Airfield
(10) Pratt Airfield

1-07. Description of Frost Action. Frost action is defined as the physical phenomenon by which layers or lenses of ice are built up within a soil mass. Three conditions must occur simultaneously for these ice layers to form. These are as follows:

a. SOIL. Frost Action within a soil is a function of its void size which may be conveniently expressed as a function of grain size. In this investigation, any soil which contains three per cent or more by weight of grains smaller than 0.02 mm. is considered frost susceptible and a soil in which frost action is possible.

b. WATER. Frost Action depends upon the availability of water either by virtue of an adjacent ground water table, a capillary supply, or water within the soil voids.

c. TEMPERATURE. Frost action within soils requires the maintenance of freezing temperature slightly below the surface of ice lens formation. The greatest accumulation of ice will occur when the penetration of the freezing temperature is slow; a rapid penetration may result in few or no ice lenses.

The process of frost action may be described as follows: The water in the void spaces becomes cooled below the normal freezing temperature of water. This supercooled water has a high molecular attraction to ice crystals. Thus, the supercooled water travels to ice crystals, which form in the larger voids, solidifying upon contact. This process repeated forms an ice lens. A single lens will continue to grow in thickness, always against the direction of heat transfer, until the formation of a lens at a lower elevation cuts off the source of water, or until the temperature rises above freezing.

Frost heaving is directly associated with frost action and is the visible evidence on the surface that ice lenses have formed in the soil mass. The frost boils, as referred to by highway engineers, are caused by a rapid thawing of an area of severe frost action beneath a flexible pavement. Such thawing occurs largely from the surface down and the excess water liberated from the thawed area is prevented from draining downward by the still frozen underlying soil and ice layers. The excess water causes the thawed soil to become exceedingly soft. Likewise the pumping of water from joints in concrete slabs during the spring may be the result of excess water liberated from thawed ice layers in the subgrade.

1-08. Definitions. In this report certain terms and words are used with specialized meaning. They are defined as follows:

(1) TEST AREA. The test area is the portion of the airfield selected for observations and investigations.

(2) TRAFFIC TEST AREA. The traffic test area is the portion of the test area subjected to traffic tests.

(3) TEST LANE. A test lane is the portion of the traffic test area subjected to a specific number of repeated wheel loads per day.

(4) TURNAROUND. A turnaround is the portion of the traffic test area used for turning traffic equipment.

(5) PASS. A pass is one movement of the traffic test equipment over a test lane.

(6) TRAFFIC. Traffic is the operation of making passes of the testing equipment over the traffic test areas.

(7) COVERAGE. One coverage is one application of a definite wheel load over each point in a given test lane.

(8) CYCLE. One cycle of coverages equals the coverages applied during one day.

(9) PAVEMENT. The term pavement is defined as a covering of a prepared or manufactured product superimposed upon a subgrade or base to serve as an abrasive and weather resisting structura medium.

(10) BASE. The term base applies to the course of specially selected soils, minerals, aggregates or treated soils placed and compacted on the natural or compacted subgrade.

(11) SUBGRADE. The term subgrade applies to the natural soil in place or to fill material upon which a pavement or base is constructed.

(12) FLEXING. Flexing is the visible spring or vertical elastic movement of the pavement under a moving wheel load.

(13) MAP CRACKING. Map cracking is the development of a definite crack pattern in the pavement surface under the action of repeated loadings

Map cracking is distinguished by the formation of continuous connected cracks enclosing polygonal pavement segments.

(14) CONSOLIDATION. Consolidation is the increase in unit weight per unit volume, or decrease in volume of a given weight of a material due to the action of applied loadings. Consolidation is considered to be synonymous with compaction in this report.

(15) PERMANENT OR VERTICAL DEFORMATION. Permanent or vertical deformation is the accumulative non-elastic part of the total vertical movement of the surface of the pavement which remains after the load is removed.

(16) FROZEN SOIL. Frozen soil is referred to in this report as follows:

(a) Homogeneously Frozen Soil. A homogeneously frozen soil is a soil in which water in the soil is frozen within the natural voids existing in the soil, without observable accumulation of ice lenses of frost forms exceeding in volume such natural void spaces.

(b) Stratified Frozen Soil. A stratified frozen soil is a soil in which a part of the water in the soil is frozen in in the form of observable ice lenses, occupying space in excess of the original soil voids.

(17) ICE CRYSTALS. The formation of ice particles found in the pores of homogeneous frozen soil is referred to as ice crystals.

(18) ICE LENSES. Ice lenses are the ice formations in stratified frozen soil occurring in repeated layers essentially parallel to each other and normal to the direction of heat loss.

(19) FROZEN ZONE. The limits of depth within which the soil is frozen is referred to as the frozen zone.

(20) FORST PENETRATION. The maximum depth from the surface to the bottom of the frozen soil.

(21) DEPTH OF FREEZING TEMPERATURE PENETRATION. The depth of freezing temperature penetration is the maximum depth below the surface of freezing temperature.

(22) FROST ACTION. Frost action is the accumulation of water in the form of ice lenses in the soil under natural freezing conditions.

(23) FROST HEAVE. Frost heave is the raising of the pavement surface due to the accumulation of ice lenses. The amount of heave in most soils is approximately equal to the cumulative

thickness of ice lenses.

(24) FROST SUSCEPTIBLE SOIL. Frost susceptible soil is a soil in which frost action is possible. Any soil which contains three per cent or more by weight of grains smaller than 0.02 mm. diameter shall be considered susceptible to frost action.

(25) NON-FROST SUSCEPTIBLE MATERIALS. Non-frost susceptible materials are crushed rock, clean sand and gravel, gravel, slag, cinders, or any other cohesionless material in which frost action is not possible.

(26) DEGREE-DAY. Each degree in any one day that the mean daily temperature varies from 32°F is called a degree day. The difference between the daily mean temperature and 32°F equals the degree-days for that day. The degree-days are plus when the daily mean temperature is below 32°F and minus when above. A cumulative degree days-time curve is obtained by plotting cumulative degree-days against time.

(27) DEGREE HOUR. A degree hour is the cumulative total of degrees per hour below 32°F.

(28) FREEZING PERIOD. The freezing period is the time during which the frost is in the ground and there is no reduction in strength of foundation materials due to frost action.

(29) FROST MELTING PERIOD. The frost melting period is the time of the year during which the frost in the foundation materials is returning to a liquid state.

(30) NORMAL PERIOD. The normal period is the time of the year, summer and fall, when there is no reduction in strength of foundation materials due to frost action.

(31) FREEZING INDEX. Freezing index is a measure of the combined duration and magnitude of below-freezing air temperatures occurring during any given winter and is the maximum ordinate of the degree days time curve.

(32) NORMAL FREEZING INDEX. Normal freezing index is computed for normal air temperatures based upon a long period of record, usually 10 years or more.

(33) GROUND WATER TABLE. The ground water table is the free water surface nearest to the ground surface.

(34) DENSITY. Density is the unit dry weight in pounds per cubic foot.

(35) WATER CONTENT. Water content is the ratio, expressed as a percentage, of the weight of water in a given soil mass to the weight of solid particles.

(36) DEGREE OF SATURATION. The ratio, expressed as a percentage, of the volume of water in a given soil mass to the total volume of intergranular space. Pre cent saturation is synonymous with degree of saturation in this report.

II. INVESTIGATIONS

2-01. General. The effects of frost action were studied at 17 airfields located in the northern United States as shown on map, Plate 1. A total of 44 test areas were investigated at these airfields. Twenty-four test areas had flexible pavements and sixteen test areas had rigid pavements. Four turfed areas adjacent to paved areas were investigated. The individual test areas were selected to encompass as closely as possible the full range of the following variables influencing frost action.

a. Air temperatures ranging from mild to extreme in severity.

b. Ground water table varying from an elevation near the surface of the pavement to an elevation greater than 90 feet below the pavement surface.

c. Precipitation prior to freezing period varying from light to relatively moderate.

d. Base and subgrade materials varying in water content from relatively dry to saturated.

e. Subgrades varying from plastic fat clay to non-plastic silty gravelly sand.

f. Base materials varying from plastic sand-clay-gravel to crushed rock.

g. Rigid and flexible pavements.

h. Pavement designs which would support light to heavy aircraft.

2-02. Tests Conducted. Conditions beneath pavements were observed by means of test pits and auger borings during the various seasons of the year, particularly during and shortly following the frost melting period. A great many variables were involved and to encompass them the following observations and measurements were made:

a. Comprehensive Investigations. At some sites more extensive or comprehensive investigations were conducted than at others. Comprehensive investigations consisted generally of observing and recording the following data and performing the indicated tests in selected test areas as follows:

(1) Continuous air temperature during the freezing and frost melting period.

(2) Subsurface temperatures under pavements during freezing and frost melting period.

(3) Precipitation prior to and during freezing period.

(4) Measurement of pavement heave.

(5) Location of ground water table in base and subgrade.

(6) Ice lens formation in base and subgrade during the freezing and frost melting period.

(7) Water content and density variation with depth in base and subgrade during summer, winter and spring.

(8) Conditions under turfed areas with and without snow cover.

(9) Pavement bearing tests.

(10) California Bearing Ratio tests on subgrades during normal and frost melting periods.

(11) Laboratory tests on soil samples obtained from test areas.

b. Limited Investigations. Some airfields were selected for obtaining the minimum data believed to be basic for understanding the effect of frost action at the site. These less comprehensive studies, referred to hereinafter as limited investigations, consisted generally of items (1) through (7), as listed above.

Subsurface temperatures were measured by means of thermocouples and/or thermometers installed at various depths below the pavement (and turf) in selected areas.

The reduction in bearing capacity of the runways was measured by pavement bearing tests conducted on the surface of the pavement and also on top the base during the frost melting period for comparison with similar tests conducted in the summer and fall. Tests were also performed with a 24-inch diameter steel plate placed at corners of rigid slabs to determine loads required to cause rupture during normal and frost melting periods. Field CBR tests were performed at some of the sites.

Traffic tests with light and heavy wheel loads were conducted at four of the sites to obtain quantitative results for immediate application in evaluating pavements at airfields where a reduced strength during the frost melting period would limit the evaluation. Traffic tests were conducted at Dow Field, Truax Field, Selfridge Field, and Pierre Airfield.

The types of investigations conducted at each airfield during the various fiscal years are shown in the following tabulation:

PRESQUE ISLE AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X	X	
LIMITED				
TRAFFIC TESTS				

HOULTON AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE				
LIMITED		X		
TRAFFIC TESTS				

DOW FIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X	X	X
LIMITED	X			
TRAFFIC TESTS	X	X		

REMARKS: Special Test Section constructed for study during 1946-47. Results of observations and details of construction presented in Appendix D.

BEDFORD AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE				
LIMITED			X	X
TRAFFIC TESTS				

OTIS FIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE				
LIMITED		X		
TRAFFIC TESTS				

TRUAX FIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X	X	
LIMITED				
TRAFFIC TESTS		X		

SELFRIDGE FIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE			X	
LIMITED				X
TRAFFIC TESTS			X	

PIERRE AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X	X	
LIMITED				
TRAFFIC TESTS		X		

REMARKS: Surface water infiltration studies conducted during 1944-45

FARGO MUNICIPAL AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X		
LIMITED			X	X
TRAFFIC TESTS				

BISMARCK MUNICIPAL AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X		
LIMITED				
TRAFFIC TESTS				

WATERTOWN AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X		
LIMITED			X	
TRAFFIC TESTS				

REMARKS: Surface water infiltration studies conducted during 1944-45

CASPER AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X		
LIMITED				
TRAFFIC TESTS				

REMARKS: Surface water infiltration studies conducted during 1944-45

SIOUX FALLS AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X	X	
LIMITED				X
TRAFFIC TESTS				

REMARKS: Surface water infiltration studies conducted during 1944-45

FAIRMONT AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE				
LIMITED		X		
TRAFFIC TESTS				

REMARKS: Surface water infiltration studies conducted during 1944-45

GREAT BEND AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE				
LIMITED		X	X	
TRAFFIC TESTS				

REMARKS: Surface water infiltration studies conducted during 1944-45

GARDEN CITY AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE		X		
LIMITED				
TRAFFIC TESTS				

PRATT AIRFIELD

TYPE OF INVESTIGATION	FISCAL YEAR 1943-44	1944-45	1945-46	1946-47
COMPREHENSIVE				
LIMITED		X		
TRAFFIC TESTS				

REMARKS: Surface water infiltration studies conducted during 1944-45

2-03. Methods and Tests Procedures. The methods and test procedures that have been used in connection with the frost investigations in each of the three Divisions are presented in detail in Appendix E, Volume I.

III. DATA FOR AIRFIELD INVESTIGATED

3-01. General. A description of each airfield at which tests were conducted is presented in the following paragraphs. Weather data, grain size curves, classification of base and subgrade materials, typical logs and other pertinent data for each airfield are presented on plates in Volumes II and III. The selection of airfields was based upon particular characteristics such as weather, ground water, soil type, and other conditions which would influence frost action. These conditions are noted for each airfield. A geographic location map showing the location of all airfields is presented on Plate 1, Volume I. Temperature data, precipitation data, and normal freezing data are shown in Fig. 2, Plate 2, Volume I.

3-02. Descriptive Airfield Data.

a. Presque Isle Airfield. This site was selected due to detrimental frost action experienced during previous winters. The airfield is located in the northeastern part of Maine in the city of Presque Isle. The region is hilly and glaciated. The normal freezing index, based on a 31-year record, is 2061. The normal rainfall for the three month period of September, October and November is 10 inches. Three test areas representing portland cement concrete, bituminous concrete pavements, and turfed surfaces were selected for investigation. The rigid pavement, seven inches thick, is constructed on 30 to 36 inches of sand and gravel base; the flexible pavement, four inches thick is constructed on 24 to 30 inches of sand and gravel base. The subgrade is a frost susceptible clayey silt, sand and gravel mixture (GC) with 10 to 35 per cent by weight finer than 0.02 mm. grain size. The ground water table is slightly below six feet in depth, except during the frost melting period when it rises to about two feet below the pavement surface. During the winter of 1942-1943 approximately 500 square yards of runway pavement heaved.

Comprehensive frost investigations were conducted for a period of two consecutive years at this site, during 1944-1945 and 1945-1946. The results of tests and observations obtained during these periods are presented in Volume II on Plates 6 to 43 inclusive.

b. Houlton Airfield. This site is in Aroostook County, Houlton, Maine. The terrain and weather are similar to Presque Isle Airfield. Houlton Airfield is located in a narrow valley flanked on the sides by relatively high hills. The normal freezing index is 1780 based on a 41-year record. The normal rainfall during the three months period preceding freezing is 9 inches. Two test areas were selected. One test area is located on the parking apron and has a soil cement base with 1-1/2 inches of bituminous concrete wearing course. The other test area, located on the N-S runway, has six inches of sand and gravel base underlying four inches of bituminous concrete wearing course. The subgrade is a frost susceptible silty sand and gravel (GF) with 6 to 15 per cent by weight finer than 0.02 mm. grain size. The ground water table was generally below the explored depth of six feet. No serious heaving or pavement failures due to frost action have been noted during the operation of the airfield.

Limited frost investigations were conducted at Houlton Airfield during 1944-1945. All data are shown on Plates 44 to 49 inclusive, Volume II.

c. Dow Field. This site was selected because of detrimental frost action during previous winters and the availability of data obtained from previous frost study at this airfield. Dow Field is located two miles west of the city of Bangor, Maine. The region consists of rolling terrain with hills composed of a thin mantle of slightly gravelly silt (glacial till) overlying bedrock. In the low areas the glacial till is overlain by a layer of silty clay. The normal freezing index is 1275 on the basis of a ten-year record. The normal rainfall during the three month period preceding freezing is 11 inches. Fourteen test areas were investigated which included six with portland cement concrete pavement, seven with bituminous concrete pavement and one with turfed surface. Generally the rigid pavement is seven inches thick, overlying approximately 15 inches of sand and gravel base. The flexible pavement in the test areas is generally 3.5 inches thick overlying a sand and gravel base varying from 24 to 63 inches in thickness. The subgrade underlying pavements and turfed areas is generally a silty clay (CL) with 40 to 97 per cent by weight finer than 0.02 mm. grain size. The ground water table is from four to six feet below the surface and rises to a depth of one to four feet during the frost melting period. Frost action was studied at Dow Field in three test areas as a part of the Pavement Evaluation Program during the summer and fall of 1943 and winter of 1943-1944. During this previous investigation, a glacial till subgrade (GC) was encountered in addition to the silty clay (CL) subgrade. Comprehensive frost investigations were conducted at Dow Field for a period of four years, beginning in the fall of 1943. Eighteen test areas were investigated at this site including runway shoulders and a turfed area. Locations of the test areas investigated are shown on Plate 50. Complete data from investigations at Dow Field are presented on Plates 50 to Plates 151, inclusive. Traffic tests* using various wheel loads were conducted during the spring of 1944 and 1945 on both

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* Traffic tests conducted in the Spring of 1944 are referred to on the plates as Pavement Behavior Tests.

bituminous and rigid pavements to determine the load carrying capacity of the pavements over a weakened subgrade caused by frost action. Photographs of equipment used during these tests and data obtained are shown on Plates 117 to 151, inclusive.

d. Bedford Airfield. This site which is located approximately 14 miles northwest of the city of Boston in the towns of Bedford, Concord and Lexington, Massachusetts, was selected chiefly to determine the extent of frost development in non-frost susceptible soils and to augment the tests made and data obtained in the frost investigations at other airfields. The airfield site is an area of rolling terrain of low relief. The hills surrounding the field are composed of glacial till with bedrock generally at shallow depths or exposed. The low area at the site generally consists of a glacio-fluvial deposit of sand with gravelly phases varying in thickness from 3 to 10 feet overlying silt and fine sand of depths in excess of 15 feet. The normal freezing index based on 56-year record is 680. The normal rainfall for the three month period prior to freezing is 10.2 inches. Two test areas were selected. One test area is located in a portland cement parking apron. The other test area is located on a portion of bituminous paved runway. The free draining sand and gravel base in both areas consists of a GW material with three per cent by weight finer than 0.02 mm. The subgrade consists of a well graded sand (SW) with from zero to ten per cent by weight finer than 0.02 mm. The ground water table ranges from 4 to 8 feet below the surface.

The limited investigations at this site were conducted for two years, 1945-1946 and 1946-1947. Results are shown on Plates 152 to 161, inclusive.

e. <u>Otis Field.</u> Otis Field, selected because of previous occurrences of frost action, is located within the limits of Camp Edwards, Massachusetts. The site is of glacio-fluvial origin and is part of an extensive outwash plain. The area is generally flat consisting of extensive deposits of variable sands and gravels with occasional boulders. Winter temperatures at Otis Field are fairly mild, with a normal freezing index of 202 based on a 21-year record. The normal rainfall for three months period preceding freezing is 13 inches. The test area is located in a cut section on the NE-SW runway. The flexible pavement, five to seven inches thick, overlies a non-uniform subgrade generally consisting of intermixed pockets of sands, silts, and gravels resulting in several gradations of frost susceptible soils in the upper portion of the subgrade. The subgrade at greater depths consists of fine to medium sand with occasional gravel and small quantities of silt. Ground water was not encountered at an explored depth of 15 feet. Frost action was observed in January 1943 when pavement heaves had developed at several locations on the paved runways. Differential heaves of three to six inches occurred in unsealed portions of the bituminous concrete pavement.

Limited frost investigations were conducted during one year only, 1944-1945. Results of observations, including some data obtained in 1943 are presented on Plates 162 to 167, inclusive.

f. <u>Truax Field.</u> Truax Field is located on a low-lying level area forming one of the upper reaches of the marshes along the Yahara River and Lakes Mendota and Monona at Madison, Wisconsin. The winter temperatures are severe with a normal freezing index of 1227 based on a 43-year record. The normal rainfall for the three month period preceding freezing is 7 inches.

Three test areas were selected. Two test areas consisted of bituminous concrete and one consisted of portland cement concrete pavements. The bituminous concrete pavement, 2.5 inches thick, is constructed on a crushed rock base, and a sandy clay and gravel (GF) sub-base. The two flexible pavement test areas, located on a runway and taxiway, differ in the thickness of base and sub-base. The taxiway test area has eight inches of base and 15 to 17 inches of sub-base. The runway test area has 20 inches of base and 21 to 31 inches of sub-base. The portland cement concrete test area, located on the parking apron, consists of a six-inch slab which was constructed on a base of sand-clay-gravel (GF) varying from about three to five feet in thickness. The original subgrade is a silty clay (CL) with lenticular deposits of fine sand occurring at varying elevations. The ground water table is fairly uniform throughout the field, normally varying from six to eight feet below the pavement surfaces.

In addition to comprehensive investigations in both the rigid and flexible pavement test areas for two years, 1944-1945 and 1945-1946, a traffic test was conducted during the first year of investigations. The test results and observations are presented on Plates 168 to 207 inclusive, in Volume III of this report.

g. Selfridge Field. Selfridge Field is located about 3 miles east of Mt. Clemens and 30 miles northeast of Detroit, Michigan. The field is located on a level lake plain adjacent to Lake St. Clair. The normal freezing index based on a 46 year record is 521. The normal precipitation for the three month period, September to November inclusive, is 7.7 inches. A test area on the portland cement concrete parking apron was selected for observation and study. The 10-inch concrete slab thickened to 12 inches on the edge is placed on approximately 12 inches of sand and gravel (GF). The subgrade immediately beneath the base consists of a sandy silt (ML) overlying a sand with a high percentage of fines (SF) underlain by lean clay (CL). The base contains from two to five per cent by weight finer than 0.02 mm. All the subgrade soils are frost susceptible. The ground water table varies from approximately 3.5 feet to 6.0 feet below the surface.

Comprehensive frost investigations were made during 1945-1946, including a traffic test. The specific purpose of the traffic test at this site was to determine the supporting capacity of the portland cement pavement by means of a 60,000-pound load on a B-29 dual wheel assembly during and directly after the frost melting period. Limited frost investigations were conducted during 1946-1947. The results of these investigations are presented on Plates 208 to 232 inclusive.

h. Pierre Airfield. Pierre Airfield, approximately three miles northeast of the city of Pierre, South Dakota, is located on a relatively level plateau about two miles north of the Missouri River. The normal freezing index is 1294 on basis of 46-year record and the ground water table is at a depth greater than 25 feet from the surface. The normal rainfall during the three months preceding freezing is 2 to 4 inches. This airfield was selected to determine the effects of frost in an area having a low annual precipitation, low water table, and naturally dry subsurface soil conditions. Three test areas consisting of portland cement concrete, bituminous concrete, and turfed surfaces were selected for investigations. The rigid pavement, seven inches thick, was constructed on 7 to 14.5 inches of sand and gravel base. The flexible pavement, 5.5 inches thick, overlies a sand and gravel base of 6 to 15.5 inches thickness. The subgrade is a mixture of clay, silt, and sand (CL) susceptible to frost action. No serious heaving of pavements or pavement distress due to frost action has been noted during the period of operation of the airfield.

Comprehensive frost investigations were conducted for a period of two years, 1944-1945 and 1945-1946. Results of tests and observations are shown on Plates 233 to 268, inclusive in Volume III.

i. Fargo Municipal Airfield. Fargo Municipal Airfield is located approximately 1.5 miles northwest of the city limits of Fargo, North Dakota. The airfield is located on a generally smooth, flat plain, originally the bed of an ancient glacial lake. Winter temperatures at Fargo Airfield are the most severe of all the 17 airfields investigated. The normal freezing index, based on a 63-year record, is 2646. The normal rainfall for the three month period preceding freezing is 3.7 inches. One test area was investigated which consisted of 1.5 inches of bituminous concrete wearing surface constructed over a soil cement base course having a thickness of approximately 6.5 inches. A sub-base of sand and clay material (CL-SF), approximately 15 inches in thickness, overlies about eight inches of black clay with sand gravel and cinders (OH-CH). The subgrade is a medium fat to fat clay (CL). The ground water table during the freezing period varies from five to seven feet in depth below the pavement. During the frost melting period it rises to a depth of three feet. The sub-base and subgrade materials are considered susceptible to frost action. A moderate amount of frost action occurred during this investigation but is not considered detrimental to the pavement.

Comprehensive tests and observations were conducted during 1944-1945 and limited investigations were made during the following two years in the same bituminous paved area. The results of tests and observations are presented on Plates 269 to 277, inclusive, Volume III.

j. Bismarck Municipal Airfield. Bismarck Municipal Airfield is located south of the southeast limits of the city of Bismarck adjacent to Fort Lincoln, North Dakota. The airfield site is on a relatively flat, elevated bench about two miles east of the Missouri River. Winter temperatures are extreme with a normal freezing index of 2552 based on a 69-year record. The normal rainfall for the three month period preceding freezing is 2.6 inches. One test area of bituminous concrete pavement located on a runway was selected for investigation. The pavement is 4.5 inches thick and was constructed on a six-inch sand and gravel base course and approximately three feet of frost susceptible silt and fine sand (CL-ML) subgrade overlying sand and gravelly materials to a depth of approximately 12 feet where a very compact clay is encountered. This results in the formation of a perched water table at a depth of about 12 feet below the surface. The normal elevation of natural ground water is approximately 40 feet below the surface. Prior to the period of frost investigation, no indications of frost heaving or other major pavement changes due to frost action have been noted.

Comprehensive frost investigations were conducted at Bismarck Municipal Airfield during one year only 1944-1945 in a flexible pavement area. Result of tests and observations are presented on Plates 278 to 282, inclusive.

k. Watertown Airfield. Watertown Airfield is located adjacent to the northwest city limits of Watertown, South Dakota. The general terrain of the airfield site varies from flat to rolling. Winter temperatures are generally severe with a normal freezing index of 1742 based on a 40-year record. The normal rainfall for three month period preceding freezing is 4.4 inches. Three test areas were selected. A portland cement concrete area consists of an eight-inch slab constructed directly on the subgrade which consists principally of frost susceptible silty, clayey sand (SF-OL). A bituminous concrete test area, consists of five inches of asphaltic concrete overlying eight inches of sand and gravel base on the silty, clayey sand subgrade. A turfed area with subgrade conditions similar to those encountered under the paved areas. A well defined water table at approximately 12 feet below the surface exists in more gravelly materials which is found in the deeper subgrade. No serious heaving of the pavement or pavement failures due to frost action have been observed.

Comprehensive tests were conducted during the first year, 1944-1945, and limited to tests and observations the following year under both rigid and flexible pavements. Test results are presented on Plates 263 to 297, inclusive.

1. Casper Airfield. Casper Airfield is located approximately eight miles northwest of the city of Casper, Wyoming. This site was selected to determine the effects of frost in an area having a comparatively low annual precipitation, an extremely low water table, and dry subsurface conditions. The general terrain of the airfield site is substantially flat. The weather conditons in the airfield region are moderate with the normal freezing index of 532 based on a five year average. The normal rainfall for the three month period preceding freezing is 4.4 inches. Two test areas were selected. One test area on the apron consists of portland cement concrete

pavement, seven inches thick, placed directly on a compacted frost susceptible sand and sandy clay subgrade. The other test area consists of a flexible pavement taxiway section constructed of five inches of asphaltic concrete on 7 to 13 inches of sand and gravel base. The ground water table is in excess of 90 feet below the surface of the airfield. Pavement heave or distress due to frost action has not been serious at this airfield.

Comprehensive frost investigations were conducted during one year only, 1944-1945. Results of tests and observations are presented on Plates 298 to 302, inclusive.

m. Sioux Falls Airfield. Sioux Falls Airfield is located northwest of the city of Sioux Falls, South Dakota. The airfield is located in a flat flood plain just above the Big Sioux River. Levee construction along the north and northwest side of the airfield protect the airfield from flood waters of the Big Sioux River. Severe winter weather conditions are indicated by a normal freezing index of approximately 1100 based on a 46-year record. The normal rainfall for three month period preceding freezing is 5.5 inches. Two test areas were selected. One is on a taxiway pavement of two inches of bituminous concrete with approximately 9.5 inches of gravel, sand, and clay base overlying 12 inches of select silty clay sub-base (CL). The subgrade soils consist of a mixture of clay, silt and sand (CL-CH). The second test area is located on the portland cement concrete apron. The concrete pavement was placed directly upon the frost susceptible compacted subgrade. The normal elevation of ground water is approximately nine feet below the surface. During flood stage the level of the Big Sioux River is above the surface elevation of the airfield. However, no appreciable back drainage through subterranean water courses has been recorded. No severe pavement distress due to frost action has been observed. A previous investigation of frost conditions existing under a taxiway pavement at this airfield was made in March 1944. Excavations made at that time indicated the presence of appreciable ice lenses extending from the top of the subgrade to a depth of approximately three feet.

Studies were conducted at the airfield for a period of three years in the same test areas. Comprehensive tests were made during 1944-1945 and 1945-1946 and limited investigations the following year, 1946-1947. Results of these tests are presented on Plates 303 to 323, inclusive.

n. Fairmont Airfield. Fairmont Airfield is located on a level plain approximately two miles south of the town of Fairmont, Nebraska. Moderate winter weather conditions are indicated by a normal freezing index of 581 based on a 46-year record. The normal rainfall for three months preceding freezing is 6.5 inches. The test area consisted of an eight-inch portland cement concrete pavement constructed directly on a silty clay (CL-CH) subgrade. The ground water is located approximately 90 feet below the pavement surface.

Only limited investigations were conducted at this site during 1944-1945 in a rigid pavement area. Results are presented on Plates 324 to 326, inclusive.

p. Great Bend Airfield. Great Bend Airfield, approximately three miles west of the city of Great Bend, is located in the wide, flat valley of the Arkansas River. Winter temperature conditons in the airfield region are extremely variable, with extremes of very mild to occasionally severe winters. The 46-year normal freezing index is only 28. The normal rainfall for the three month period preceding freezing is 5.3 inches. One test area consists of a seven-inch portland cement concrete pavement constructed on a six-inch sandy gravel base. The subgrade consists principally of a silty clay (CL) and sandy silt (CL-SF). The water table ranged from 12 to 15 feet below the surface during the period of this investigation. No pavement failure due to frost action has been observed.

Limited frost investigations were conducted for two consecutive years in a rigid pavement test area. Results are presented on Plates 327 to 331, inclusive.

q. Garden City Airfield. Garden City Airfield, approximately nine miles southeast of Garden City, Kansas, is located on flat to slightly rolling prairie land with the Arkansas River approximately one mile south and west of the airfield. The 44-year normal freezing index is 56. The normal rainfall for the three month period preceding freezing is 4.1 inches. One test area was selected and is located on a runway pavement consisting of bituminous concrete having a thickness of 1.5 inches constructed on a sand, gravel, and clay (SC) base course with a thickness of approximately 10.5 inches, overlying a silty clay (CL) subgrade. Ground water elevation is more than 90 feet below the surface. Pavement distress due to frost action has not been previously recorded at this arifield. In a previous investigation made on the airfield pavement in January 1944, the presence of ice lenses and frost formations were observed in the subgrade. The freezing index for the 1943-1944 season was approximately 244.

Comprehensive frost investigations were conducted during one year only, 1944-1945. Results are presented on Plates 332 to 335, inclusive.

r. Pratt Airfield. Pratt Airfield is located approximately three miles north of the city of Pratt, Kansas, on a gently rolling prairie land interspersed with low knolls and occasional shallow ponds. Mild winter weather conditions are indicated by the 46-year normal freezing index of 28.

The normal rainfall for the three month period preceding freezing is 6.3 inches. One test area was selected and is located on a taxiway pavement consisting of a seven-inch thickness of portland cement concrete, overlying a silty sand cushion (SF-CL) of average thickness of three inches, but ranging from zero to 12 inches. The subgrade consists of a silty clay (CH-CL). The ground water elevation in the airfield region is approximately 90 feet below the surface. The sand cushion tends to pond water after periods of precipitation. The source of the water in the sand cushion is believed to be surface water infiltrating through cracks and joints in the pavement, and also entering at the juncture of the pavement and turf shoulder.

Limited frost investigations were conducted in a rigid pavement test area during one year only, 1944-1945. Test results are presented on Plates 336 to 338, inclusive.

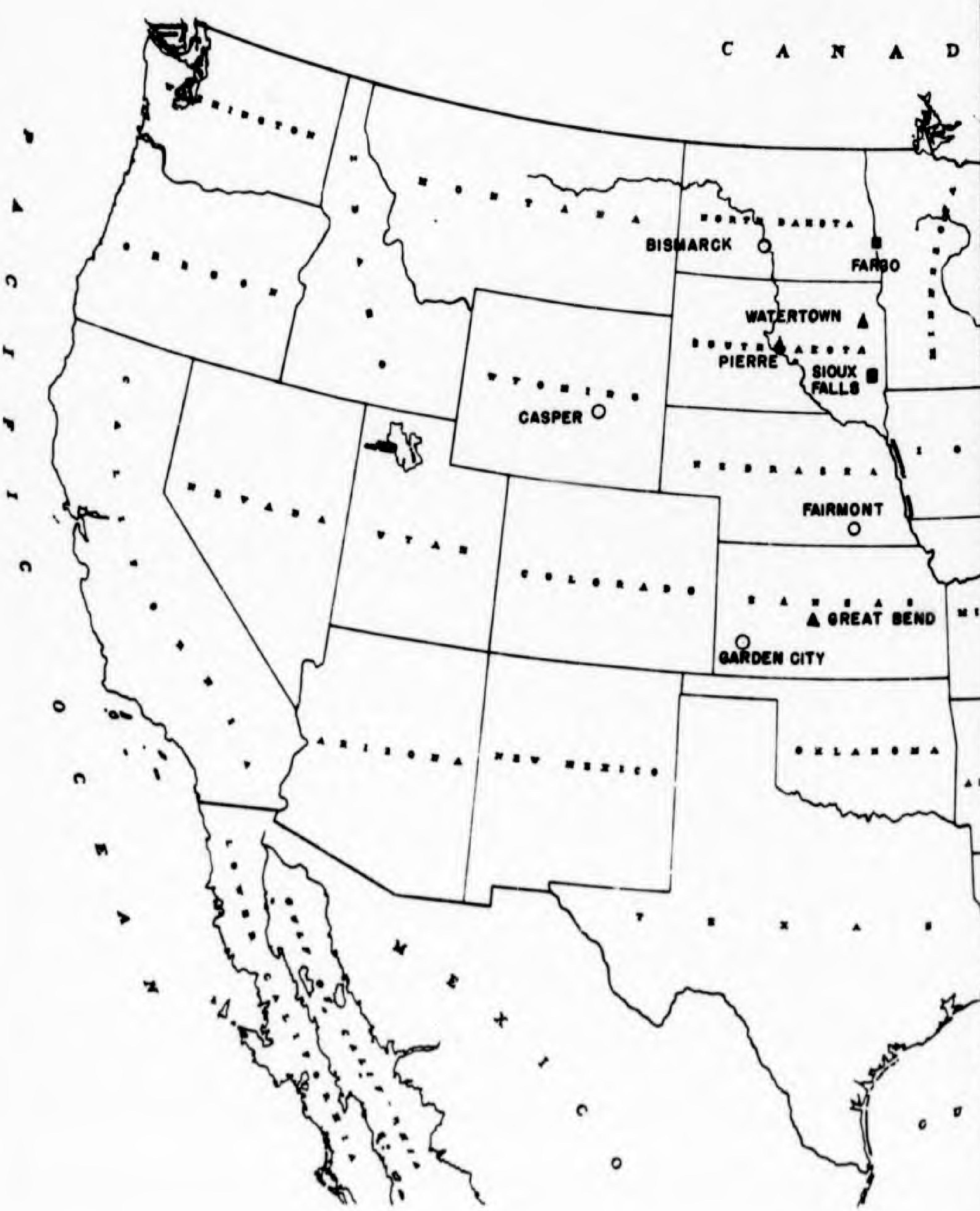
3-03. Drainage Data. The surface and subsurface drainage facilities at the several test areas are summarized in the following tabulation:

AIRFIELD	TEST AREA	SURFACE DRAINAGE	SUBSURFACE DRAINAGE
Presque Isle	A	Surface runoff from pavement collected by catch basins in valley in apron area.	Base course continued through shoulder to edge of fill on one edge.
	B	Surface runoff from pavement and shoulder collected by shallow turf or rock gutters which drain to a catch basin at end of taxiway.	6-inch open joint pipe, 4-foot depth backfilled with sand and gravel at outside edge of surface treated gravel shoulders.
Houlton	A	Surface runoff from apron collected in ditch at pavement edges	Open joint pipe, 5-foot depth, to intercept sidehill seepage at east edge. Backfilled with sand and gravel.
	B	Surface runoff from ℄ pavement collected by combination drains and catch basins at runway edges and ditches along outside edge of landing strip.	Open joint pipe, 5-foot depth, at edges of bit. conc. runway. Backfilled with sand and gravel.
Dow	A	Surface runoff from ℄ pavement collected by catch basins located 75 feet from ℄ and spaced 225 feet longitudinally.	8-inch non-reinforced concrete open joint pipe, 4-foot depth backfilled with bank-run sand and gravel.
	B and C	Surface runoff from ℄ pavement collected by catch basins located at edge of pavement spaced 225 feet and catch basins at edge of bit. treated shoulders and at 250 feet from ℄ in turfed area.	Open joint pipe at bit. conc. pvt. edges and skip pipe at 175 feet from ℄ runway at bit. surf. treated shoulder edges.

AIRFIELD	TEST AREA	SURFACE DRAINAGE	SUBSURFACE DRAINAGE
Bedford	A	Surface runoff collected by catchbasins and carried away by closed joint drains to large open ditches and natural drainage outlets.	None
	B	Surface runoff collected by catchbasins and closed joint pipe generally located 250 feet from centerline of runway, also by surface inlets located 75 feet on each side of centerline of the runways and spaced 250 feet apart.	Open joint pipe located 75 feet on each side of the centerline in trenches backfilled with bank run sand and gravel. Top of trenches paved.
Otis	A	Surface runoff collected by longitudinal turf swales located 150 feet from ℄ runway with catch basins to closed joint pipe.	6-inch non-reinforced open joint pipe laid in 2-foot wide trenches at edge of pavement, backfilled with well-graded sand and gravel. Pipe inverts are about 4 feet below pavement edge.
Truax	A	Surface runoff from ℄ of pavement to edge of shoulder collected by catch basins in shallow gutter at shoulder edge.	None
	B	Surface runoff from ℄ of pavement to edge of shoulder collected by catch basins in shallow gutter at shoulder edge.	Perforated tile pipe in trenches filled with coarse sand at edges of pavement. Top 2 inches is clay top soil.
	C	Surface runoff from pavement and adjoining turfed area collected by catch basins in turfed area at low points.	Trench filled with sand and gravel and containing a V. C. pipe with open joints along south edge. None at north edge.
Selfridge	A	Surface runoff from pavement collected by shallow gutters at edges and into catchbasins, thence to one of three pumping stations.	6-inch perforated bell and spigot tile pipe around periphery of apron at 5-foot depth in trench backfilled with clean sand and gravel. Top 12 inches compacted top soil.

AIRFIELD	TEST AREA	SURFACE DRAINAGE	SUBSURFACE DRAINAGE
Pierre	A and B	Surface runoff collected by shallow swale at edge of shoulders.	None
Fargo	A	Surface runoff from pavement collected by combination drains at pavement edges.	Combination drains backfilled with coarse aggregate located in shoulder with open joint pipe in trench.
Bismarck	A	Surface runoff collected by shallow swale at edge of shoulders.	None
Watertown	A and B	Surface runoff drains to open shallow swale at edge of pavement.	None
Casper	A	Surface runoff collected by catch basins located in shallow swale in pavement area.	None
	B	Surface runoff collected by shallow swale at edge of pavement.	None
Sioux Falls	A and B	Drainage of airfield principally by surface runoff. Temporary ponding relieved by seepage into subsurface permeable strata.	None
Fairmont	A	Drainage provided by surface drainage and by comprehensive storm sewer system.	None
Great Bend	A	Drainage secured by drainage ditches and by drainage into sump ponds.	None

AIRFIELD	TEST AREA	SURFACE DRAINAGE	SUBSURFACE DRAINAGE
Garden City	A	Drainage secured by surface drainage and storm sewer system. Interceptor drainage ditch protects the paved areas from water draining from higher area.	None
Pratt	A	Drainage secured by surface drainage and a storm sewer system.	None



C A N A D
BISMARCK
FARGO
WATERTOWN
PIERRE
SIOUX FALLS
CASPER
FAIRMONT
GREAT BEND
GARDEN CITY

FROST INVESTIGATION
1945-1947

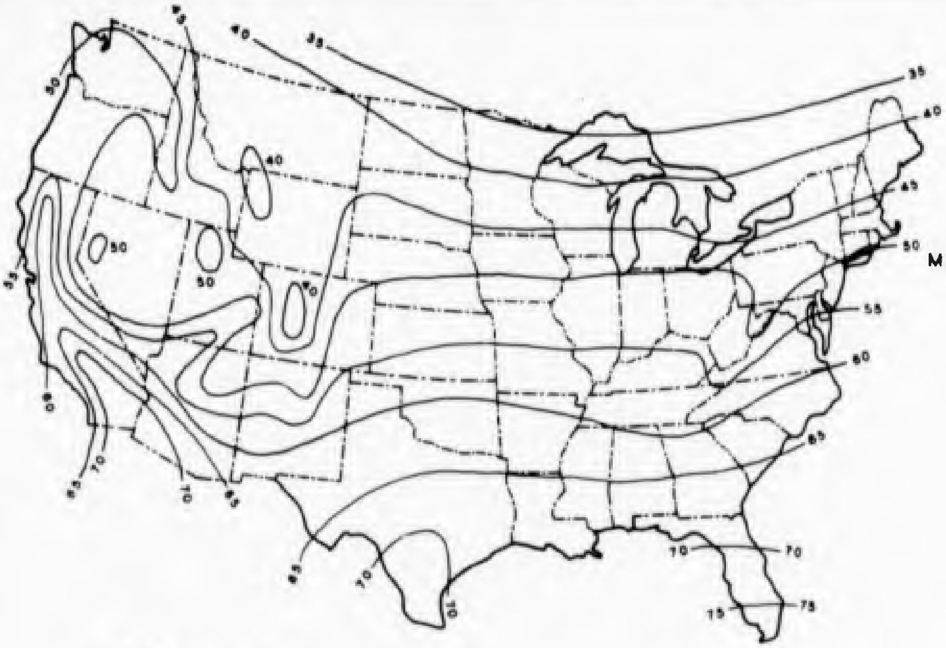
GEOGRAPHICAL LOCATION MAP

SCALE IN MILES

APRIL 1948

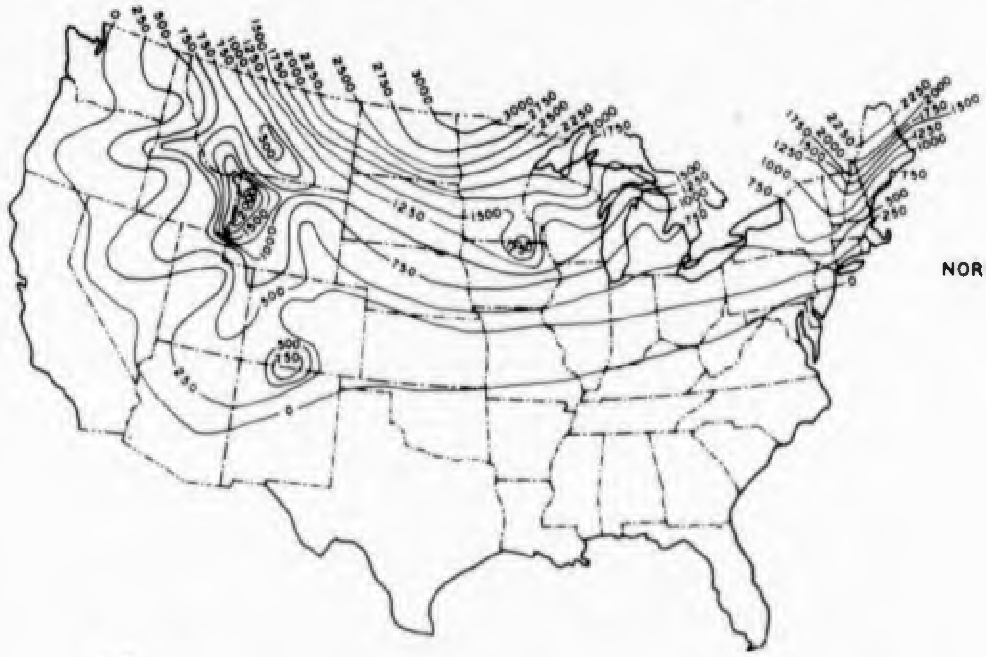
FROST EFFECTS LAB. BOSTON, MASS.

PLATE 1



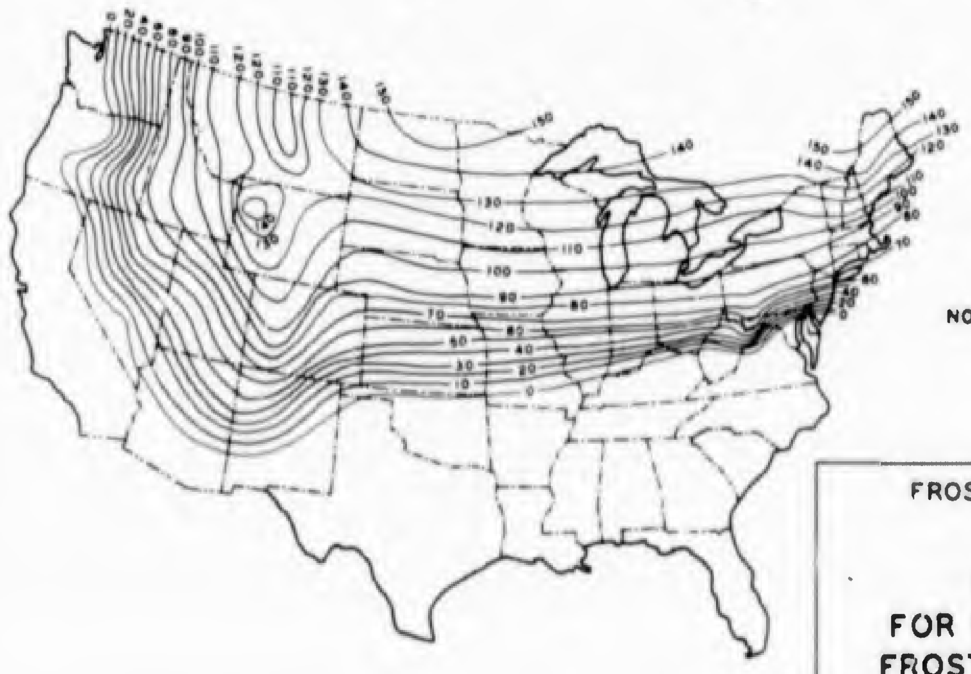
MEAN ANNUAL AIR TEMPERATURE
(DEGREES FAHRENHEIT)

FIG. 1



NORMAL FREEZING INDEX
(DEGREE DAYS)

FIG. 2



DURATION
OF
NORMAL FREEZING INDEX
(DAYS)

FIG. 3

FROST INVESTIGATION
1945 - 1946

ISOGRAMS FOR PREDICTION OF FROST PENETRATION

JUNE 1946
FROST EFFECTS LABORATORY, BOSTON, MASS

PLATE 2

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U. S. ARMY
BOSTON, MASSACHUSETTS

DATA REPORT OF FROST INVESTIGATIONS
Fiscal Years 1943 - 1949

APPENDIX A

REPORT ON STUDIES OF BASE COURSE TREATMENT TO PREVENT FROST ACTION
1945 - 1947

FROST EFFECTS LABORATORY

June 1949

Report of
STUDIES OF BASE COURSE TREATMENT
TO PREVENT FROST ACTION
1945 - 1947

SYNOPSIS

I INTRODUCTION

II STUDIES OF BASE COURSE TREATMENT TO PREVENT FROST ACTION, FISCAL YEAR 1945 - 1946

REPORT OF STUDIES OF BASE COURSE TREATMENT
TO PREVENT FROST ACTION

LIST OF PLATES

Plate No.	Title
	FISCAL YEAR 1945 - 1946
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A-2	Resinous Water Repellents for Soils, Classification Data, U. S. W. E. S.
A-3	Summary of Data of Slow Freeze Tests, Resinous Water Repellents Investigation
A-4	Heave Data, Silty Clay, Sample 3
A-5	Heave Data, Clayey Silt, Sample 5
A-6	Heave Data, Clayey Silt, Sample 6
A-7	Heave Data, Sandy Silt, Sample 7
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A-11	Sample Molding Equipment
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REPORT ON STUDIES OF BASE COURSE TREATMENT TO PREVENT FROST ACTION

SYNOPSIS

This report presents studies and results of tests, using admixtures, on frost susceptible base course and subgrade soils. These studies and tests were conducted by the Frost Effects Laboratory under controlled temperature conditions for the purpose of developing methods of preventing or reducing frost action in frost susceptible soils. Frost action is defined as an accumulation of water in the form of ice lenses in the soil under natural freezing conditions.

The design of airfield pavements at locations where frost penetrates into the base is founded upon the assumption that the base is not weakened or adversely affected by frost action. However, in some geographical areas, such non-frost susceptible bases are not economically available and methods to make frost susceptible bases non-frost susceptible may prove to be economically feasible and allow for speedier construction. The success of these methods depends first upon the permanency of the treatment and second upon the economy of the treatment in contrast to the importation of non-frost susceptible materials.

The laboratory studies were conducted over a period of two years. During the fiscal year 1945-1946 tests were performed to determine the suitability of various economically available admixtures in preventing frost action. Tests were also made to determine whether leaching of salt admixtures could be retarded or prevented by the use of bituminous materials. The works of other investigators was reviewed and are summarized in this report. Admixture studies were continued during the fiscal year 1946-1947 and, in addition, investigations were made (a) to verify the hypothesis that the amount of salt required to prevent frost action is a function of the void ratio and (b) to determine the influence of rock content in a frost susceptible soil on type and quantity of admixture required to prevent frost action.

The admixtures selected for use in these studies were flake calcium chloride, Bunker "C" oil, Tarmac T-2 (RT-2) and "Darex A.E.A." The materials selected for testing consisted of a glacial till, a silt, a frost susceptible sand and gravel and mixtures of the latter two materials.

The results obtained from admixture tests were in general agreement with those obtained by Winn and Rutledge (summarized in this report). Results of tests indicate that (1) Bunker "C" oil and RT-2 may be used to prevent frost action singly or in combination with calcium chloride, (2) "Darex A.E.A." is not effective in preventing frost action in silt when used in quantities up to two per cent of the dry weight of the soil, (3) addition of bituminous material with salt retards leaching only slightly, (4) that the air temperature and void ratio may be used to determine the approximate quantity of salt required to prevent frost action, (5) no relationship between the rock content of the soil and the amount of admixture required to prevent frost action is indicated for the three soil mixes tested.

I INTRODUCTION

1-01. Authorization. The 1945-1946 frost investigation program was authorized by the Chief of Engineers by letter to the Division Engineer, New England Division, dated 4 August 1945, subject "Frost Investigation, During Fiscal Year 1945-1946" and subsequent indorsements, File SPEER. The program for the fiscal year 1946-1947 was authorized by the Chief of Engineers by two letters to the Division Engineer, New England Division, dated 25 July 1946 and 12 August 1946, subject "Funds for Investigational Program for Fiscal Year 1947." The investigations reported herein constitute a part of the authorized program.

1-02. Purpose. The purpose of these investigations has been to study methods and perform laboratory tests to develop treatments to prevent frost action in soils susceptible to frost action.

1-03. Scope. This report presents (1) a summary in the form of excerpts from the conclusions of reports of investigations performed by others on the effect of admixtures on frost action, (2) a sutdy of previous investigations to determine the relationship between void ratio and the amount of salt required to prevent frost action, (3) the results of laboratory tests performed to determine the suitability of various admixtures and combinations of admixtures to prevent frost action in frost susceptible materials, (4) the results of laboratory tests to determine whether leaching of salts could be retarded or prevented by the addition of bituminous materials, (5) the results of laboratory tests to determine the effect of rock content of soils on the amount of admixture required to make them non-frost susceptible. Representative data are presented herein. A complete record of test data is on file at the Soils Laboratory of the New England Division. No field tests were performed for these investigations.

1-04. Acknowledgments. Frost action tests were conducted in the Soil Mechanics Laboratory, Harvard Graduate School of Engineering. Dr. A. Casagrande of Harvard University and Dr. P. C. Rutledge of Northwestern University were employed as consultants on these investigations. The investigations reported herein were conducted along the lines established by previous investigations at Purdue University.

1-05. Definitions. The description of the tests and analyses of results involve a specialized use of certain terms and words. The words and terms used in this report are defined in the "Glossary" at the end of this report.

II STUDIES OF BASE COURSE TREATMENT TO PREVENT FROST ACTION, FISCAL YEAR 1945 - 1946

2-01. Purpose. The purpose of this investigation has been to study methods and perform laboratory tests to develop treatments to prevent frost action in base materials susceptible to frost action.

2-02. Scope. This report presents (a) a summary of previous investigations performed by others, to study the effect of admixtures on frost action, in the form of excerpts from the stated conclusions of these investigations, (b) the results of laboratory tests performed to determine the suitability of various admixtures and combinations of admixtures to prevent frost action in materials susceptible to frost action, and (c) the results of laboratory tests to determine whether leaching of salts could be retarded or prevented by the addition of bituminous materials. Representative data are presented herein. A complete record of test data is on file at the Frost Effects Laboratory. No field tests were performed during this investigation.

2-03. Review of Previous Investigations. The following three studies, of the treatment of base courses to prevent frost action all conducted by personnel of Purdue University, were reviewed:

a. "Frost Action in Highway Bases and Subgrades" by H. F. Winn and P. C. Rutledge, May 1940.

b. "Use of Calcium Chloride in Subgrade Soils for Frost Prevention" by F. L. Slate, December 1942.

c. "The Migration and Effect on Frost Heave of Calcium Chloride and Sodium Chloride in Soil," by Charles Slosser, July 1943.

The studies reported in paragraph 2-03a above were made "to determine the resistance to frost action of various types of treated soils and soil mixtures now in common use as road bases and subgrades." Three basic soils were selected for study, a sandy clay, a pit run gravel, and a fairly uniform, washed, concrete sand. The results of classification tests on these soils are summarized on Plate A-1. These three soils were combined in the following percentages to form seven different soil mixtures: 10, 20, 40 and 60 per cent sandy clay with 90, 80, 60 and 40 per cent sand respectively, and 15, 16.5 and 20 per cent sandy clay with 85, 83.5 and 80 per cent pit run gravel, respectively.

These soils and soil mixtures were tested in a remolded compacted state at varying per cent saturation, with and without the following admixtures: calcium oxide, sodium chloride, calcium chloride, portland cement, tar, cutback asphalt, road oil, emulsified asphalt and vinsol. The method of testing was briefly as follows:

a. The remolded moist soil or soil mixture with or without admixture was compacted in a cylindrical form three inches inside diameter and seven inches high.

b. Water under a pressure of 30 pounds per square inch was then forced to flow through a selected number of the specimens for about 24 hours.

c. The specimens were then placed in a freezing cabinet and the air temperature at the top of the sample was progressively reduced over approximately 21 days from about 30°F. to minus 10°F. or minus 15°F. During this period, the air temperature immediately below the bottom of the specimen was maintained at about 40°F. Some specimens were provided with a source of water at the base of the specimen.

d. During the period of below freezing top air temperatures, daily measurements of the elongation or heave of the specimens were made. At end of test the specimens were frozen either to or nearly to the bottom. The specimens were examined for ice lenses and tested for water content variation with depth.

The conclusions arrived at as a result of this investigation are quoted as follows:

"1. Estimates as to the extent to which frost action may be expected to occur in natural soil, treated soil, or stabilized soil can be made only when the limiting conditions of initial and attainable moisture content are known."

"2. In general, the natural fine-grained sandy clay started to heave sooner, heaved at a greater rate, reached a greater total heave, reached capillary saturation more readily, and had less resistance to moisture content fluctuation than did treated and stabilized sandy clay exposed to the same condition."

"3. The available dataindicate that the frost line penetrates a graded-soil mixture at a greater rate than it does a natural fine-grained sandy clay. Rapid freezing results in less ice segregation and less total heave for the same depth of frost penetration."

"4. Percentage-of-heave data from individual tests should not be used as criteria for rigid comparisons of the frost action resistance of natural soils, treated soils, or stabilized soils, but may be used as a basis for general classifications of the materials into heaving and non-heaving groups."

"5. Once capillary saturation is reached and ice segregation begins in a treated sandy clay, the rate of heaving is only slightly less than for the same soil untreated."

"6. The available data indicate that there is a critical density for sandy clay at which frost action occurs most readily, when material is saturated. Below the critical density, frost action is directly proportional to density above the critical density, frost action is inversely proportional to density. Increasing the density above the critical density increases the period of inactivity before heaving starts and decreases the rate of heaving and total heave in a manner similar to the addition of admixtures."

"7. Groups of specimens of natural or treated sandy clay included in this investigation, which had no variables except density and moisture content at the time of compaction, approached the same ultimate dry density during air drying."

"8. Any of the types of soils, treated soils, or stabilized soils included in this investigation can be saturated by water under a pressure of 30 pounds per square inch applied for 24 hours or less."

"9. The available data on field soil temperatures indicate that periodic fluctuations of short duration in air temperature do not cause corresponding fluctuations in the temperature of the subgrade soil; soil temperatures are a function of cumulative air temperatures."

"REGARDING ADMIXTURES."

"10. All the admixtures tested are much more effective in reducing frost action when used with well-graded soil mixtures than when used with natural sandy clay."

"11. Calcium oxide (2, 6, 10 per cent in sandy clay; 4 per cent in graded soil mixture)* does not increase the mixture's resistance to frost action or moisture content fluctuation sufficiently to warrant its use for these purposes. The mixtures take on water readily, and, provided water is available for capillary rise, the degree of saturation at the beginning of the freezing period is of little consequence."

"12. Sodium chloride (natural sandy clay plus 1, 2, 3, 6 per cent; graded soil mixture plus $\frac{1}{2}$, 1, 2, 3 and 4 per cent) and calcium chloride (natural sandy clay plus 2, 4 per cent) provide good resistance to frost action primarily because of the lowering effect of the admixture on the freezing point. The data indicate that as long as the soil retains the chemical in its full concentration, 2 per cent or less chemical prevents freezing at -10° to -15°F. and thereby prevents frost damage."

"13. The resistance to frost action of a soil cement mixture (natural sandy clay plus 4, 6, 8, 10, 12 per cent; graded soil mixture plus 4, 6, 8, 10 per cent) is inversely proportional to the degree of saturation of the mixture at the beginning of the freezing period."

"14. In general, the resistance to frost action of bituminous mixtures is inversely proportional to the degree of saturation at the beginning of the freezing period."

"15. Portland cement, tar, cutback asphalt, road oil, emulsified asphalt, and vinsol** add stability to a sandy clay by inhibiting

* Percentages investigated. All percentages are given in terms of dry weight.

** A by-product of turpentine distillation.

capillary motion of the water to various degrees, the amount being closely related to the percentage of admixture and moisture content of the mixture at the time it is exposed to the water."

"16. Vinsol is effective as a waterproofing agent and frost action preventive when the moisture content of the sandy clay-vinsol mixture is between 4 and 10 per cent."

"17. On the basis of the data presented in this paper, the following group classifications can be made:

Group No. 1, damaged by frost action at all percentages of initial moisture content. Sandy clay (natural); graded mixtures of clay plus gravel and clay plus sand; sandy clay plus 2, 6, 10 per cent CaO; graded soil mixture plus 4, 6 per cent CaO; sandy clay plus 1 per cent NaCl; sandy clay plus 1 per cent $CaCl_2$; sandy clay plus 4 per cent portland cement; sandy clay plus 2, 4, 6 per cent TC; sandy clay plus 2, 4 per cent AES-1; sandy clay plus 2, 4 per cent MC-1.

Group No. 2, damaged only when initial moisture content was approximately 100 per cent saturation. Sandy clay plus 6, 8, 10, 12 per cent Portland cement; sandy clay plus 4, 6, 8 per cent TM-2; sandy clay plus 4, 6, 8 per cent AES-1; sandy clay plus 4 per cent SC-3; graded soil mixture plus 2 per cent AES-1; graded soil mixture plus 2, 4, 6 per cent RC-3; sandy clay and graded soil mixtures plus 1, 2, 3, 5 per cent vinsol (also when moisture content is below 4 per cent).

Group No. 3, no frost damage at all degrees of initial moisture content. Sandy clay plus 3, 4, 6 per cent NaCl; graded soil mixture plus $\frac{1}{2}$, 1, 2, 4, 6 per cent NaCl; sandy clay plus 3, 4, 6 per cent $CaCl_2$; graded soil mixture plus 1, 2, 4 per cent $CaCl_2$; graded soil mixture plus 4, 6, 8 per cent portland cement; graded soil mixture plus 4, 6 per cent TM-2; graded soil mixture plus 4, 6 per cent AES-1; graded soil mixture plus 4.4 per cent Bitumuls Stabilizer; sandy clay plus 6, 8 per cent SC-3; graded soil mixture plus 2, 4, 6 per cent SC-3."

The studies reported in paragraph 2-03b were performed to determine the percentage of calcium chloride necessary to prevent frost action. One soil, a silt, was selected for study. The results of the classification tests are shown on Plate A-1.

The test procedure was similar to that reported by Winn and Rutledge as briefly described on Page A-6. The principal conclusions from his investigations are quoted as follows from his report, page 440, "(1) The presence of a small percentage of calcium chloride in silt will usually protect that soil from damaging frost heave. (2) Small quantities, as low as one-half of one per cent, of calcium chloride in silt will reduce the frost heave appreciably. (3) A soil that has heaved because of frost contains a moisture content greater than normal. This water makes up the ice lenses causing the heave, and it is drawn up from the ground water. (4) The water rising to form ice lenses carries calcium chloride upward with it. (5) As a general average, it can be said that protection from frost heave in silt is afforded by 2 per cent calcium chloride, in clay by 1 per cent calcium chloride, and in graded mixes by ½ per cent calcium chloride." These tests indicate that under the conditions tested the silt required at least 4 per cent calcium chloride to prevent frost action at

9°F., with a gradually decreasing temperature.

The studies reported by Charles Slesser were made to "trace the movement of calcium chloride and sodium chloride in various soils and to evaluate the important variables governing this movement" and "to determine the practicability of treating subgrades with those chemicals in order to reduce or eliminate frost heave."

The soil tested consisted of a silt, called LaPorte silt, for which classification data are summarized on Plate A-1.

The principal conclusions from his investigations are quoted as follows from Page 14 of his report:

"It was found that calcium chloride and sodium chloride migrated differently under similar conditions of exposure. Under the influence of soil capillarity and natural evaporation, sodium chloride tended to form a white crust on the surface of the unpaved road, and, hence, was more susceptible to lateral surface-washing during rain periods than was calcium chloride. On the other hand, calcium chloride did not tend to accumulate on the unpaved road surface to the same extent as sodium chloride, under the influence of soil capillarity and natural evaporation, because of its greater moisture-attracting power and its higher solubility. With exposed fine-grained soils, lateral movement proceeded primarily by surface washing from the top of the road proper to the side ditches, rather than by lateral movement below the surface."

"Important variables affecting the movement of water-soluble chemicals in soil and hence their permanence included: (1) evaporation, (2) soil texture, (3) percolating water, (4) soil cover, and (5) temperature, when high enough or low enough to effect a change of phase of the water. As regards base-exchange phenomena, the calcium and sodium cations were more persistent in fine-grained soil than the chloride anion."

"In general, increased effectiveness in reducing heaving in soil resulted from increases in the amount of calcium chloride or sodium chloride added -- up to a certain percentage of chemical, above which no heaving took place. In a coarse-textured soil, heaving was greatly reduced by an admixture of only 0.33 per cent of either chemical. One or two per cent of either chemical was effective in reducing heaving in a silt which had, in the untreated state, heaved badly both in the field and in the laboratory."

The Mississippi River Commission, U. S. Waterways Experiment Station in connection with the water repellent investigation performed slow-freeze tests* on five soils with and without several water repellents. Information regarding tests performed was furnished this office be letter. The method of testing was similar to that described in paragraph 2-03, page A-6. Grain size distribution curves and the Atterberg limits are shown on Plate A-2. A summary of the data for these tests is included as Plate A-3. Five photographs with the degree hour curves and rate of heave curves as prepared by U. S. Waterways Experiment Station, Vicksburg, Mississippi are included as Plates A-4 to A-8 inclusive. The principal conclusions from these tests are summarized as follows: All soils in the untreated state when tested were subject to severe frost action. Two per cent Stabinol** effectively reduced the heave in the clayey silt (sample 6), sandy silt (sample 7), and the gravelly clay sand (sample 8) but was ineffective in the silty clay (sample 3)

* The term slow-freeze tests used in the report by the Waterways Experiment Station is synonymous with the term frost action as used in this report.

** Stabinol as used in these experiments consisted of 3 parts of portland cement and 1 part of a complex salt consisting of unneutralized abietic acid, sodium resinate and calcium resinate.

and the clayey silt (sample 5). One per cent 321* will not materially reduce the heave. The heave was reduced by the addition of one per cent of 321 plus 0.4 per cent of $FeSO_4$ in the silty clay (sample 3) and the gravelly clay sand (sample 8) but not in the other three soils.

Investigations by others indicate that the addition of calcium chloride or sodium chloride to water will result in lowering the freezing temperature of water to a minimum after which the freezing point will be raised by the continued addition of salt. Commercial producers of these salts report that the percentage of salts which will produce the minimum freezing temperature of water are as follows:

SALT	PER CENT SALT BY WEIGHT OF WATER	FREEZING POINT
Calcium Chloride (Pure)	48	-59.8°F.
(77-80% Flake $CaCl_2$)	61	-59.8°F.
Sodium Chloride (Pure)	30.4	-6°F

The addition of salt to soil for the purpose of making it non-frost susceptible is based upon the fact that the salt lowers the freezing point of the water thus lowering the temperature at which frost action will occur. The maximum benefit from the salt in reducing frost action appears to occur when the water in the voids contains the percentage of salt tabulated in the preceding paragraph. Hence, based upon these percentages for calcium chloride and sodium chloride, the percentage of pure calcium chloride by weight of dry soil which will give lowest freezing temperature varies from about 5 to 18 per cent for

* 321 is a finely powdered, white resinous substance formed by reacting sodium hydroxide with rosin in such proportions that one-fourth of the abietic acid in the rosin is neutralized, thus resulting in a complex salt of three parts abietic acid and one part sodium abietate.

soils with void ratios from 0.27 to 1.0 respectively and the percentage of sodium chloride by weight of dry soil which will give lowest freezing temperature varies from about 3 to 11 per cent for soils with void ratios from 0.27 to 1.00 respectively when the soils are 100 per cent saturated.

2.04. Description of Laboratory Cold Room and Equip t. The investigations were carried out in the cold room laboratory at Harvard University Graduate School of Engineering. General layout of the cold room and equipment is shown in Plate A-9.

a. Cold Room. The cold room is a walk-in refrigerator with inside dimensions six feet nine and one-half inches long by six feet nine and one-half inches wide. It is insulated on all six sides with four inches of cork. A pressure controlled unit cold blower and externally located freon compressor cools the room to 40°F. to an accuracy of 1.0°F.

b. Freezing Cabinet. Within the cold room is a freezing cabinet located as shown on Plate A-9. This cabinet consists of an air space at the top cooled by longitudinal coils hung from the top of the cabinet using a second compressor with sulphur dioxide refrigerant. Beneath this air space are four drawers arranged side by side. The temperature within the top of the cabinet may be fixed at any desired temperature with an accuracy of plus or minus 0.5°F. The temperature may be made equal to or less than that of the cold room by adjustment of a bimetallic DeKhotinsky type temperature control located in the air space above the drawers. With the cold room at approximately 40°F., the freezing cabinet can be lowered to a temperature of minus 5°F. A small fan in the air space at the top aids in maintaining a uniform temperature throughout the air space. The drawers are effectively sealed in place by slightly inflating an inner tube installed around the lower side of each drawer.

2-05. Frost Action Tests.

a. Materials Tested. Three types of soil with selected admixtures were tested for frost action. The soils consisted of (1) that portion of a glacial till passing thru ¼-inch sieve, designated East Boston Till, (2) a silt designated New Hampshire silt, and (3) a sand and gravel designated frost heaving gravel with 100 per cent passing the ½-inch sieve which was prepared in the laboratory so that it would have frost heaving characteristics. The East Boston till was a grey, well-graded boulder clay (GC) composed mainly of sub-angular particles. It was obtained from Breed's Hill, Winthrop, Massachusetts, a glacial drumlin deposit. The New Hampshire silt (ML) was a brown uniform silt with a small percentage of sand sizes obtained from a varved deposit located south of Manchester, N. H. The frost heaving gravel (GF) was a combination of a washed pea gravel, a bank run gravelly sand and the New Hampshire silt. The pea gravel was brown with subangular particles, 100 per cent passing the ½-inch sieve and 98 per cent retained on the No. 8 sieve. The bank run gravelly sand was a clean brown uniform gravelly sand with subangular particles. The frost heaving gravel was prepared using 25 per cent gravel, 45 per cent gravelly sand and 30 per cent silt. The grain size distribution curves with the specific gravity, Atterberg limits and classification of these materials are shown on Plate A-10.

b. Admixtures. The selection of admixtures for testing was made to add information on new and combinations of admixtures to the existing data. Flake calcium chloride (77-80 per cent pure) was selected as a salt. Studies by Slesser indicate that there is less lateral migration under a pavement of calcium chloride than sodium chloride. Calcium chloride in solution with water as the solvent gives a much lower freezing point than does sodium chloride. However, based upon the Purdue freezing tests either calcium chloride or sodium chloride appear to be equally effective in preventing frost action. Bunker "C" oil which conformed to specifications in Bureau of Standards Bulletin No. CS 12-40 for No. 6 fuel oil was selected as one of the admixtures. This material was selected because it is one of the least expensive bituminous materials and had not been tested previously. Tarmac T-2 (Federal Specification RT-143 Grade RT-2 as amended 30 August 1944) was chosen for a comparison of the results of the previous tests with the tests using the Bunker "C" oil. Following is an analysis of the RT-2:

Engler Specific Viscosity 40°C	8.8
Specific Gravity at 25°C/25°C	1.119
Water, % by volume	1.7
Total Bitumen, % by weight	94.3
Distillation, % by weight	
To 170°C	1.4
200	1.9
235	7.5
270	22.4
300	32.8

Softening point of Distillation Residue (R & B)	37.8°C
Sulfonation Index (total distillate to 300°C)	4.4
Sulfonation Index (total distillate 300 to 355°C)	0.43

The following admixtures and combinations of admixtures on basis of percentage of the dry weight of the soil were used:

SOIL	PERCENT BUNKER "C" OIL	PERCENT RT-2	PERCENT CALCIUM CHLORIDE
East Boston Till	0, 2, 4 and 6	-	-
	0, 1, 2 and 4	-	0.5
	0, 2, 4 and 6	-	1
	0, 2, 4 and 6		2
	-	0, 2, 4 and 6	
	-	0, 1, 2 and 4	0.5
		0, 1, 2 and 4	1
New Hampshire Silt	0, 2, 4 and 6	-	-
	-	-	3, 6, 8 and 10
Frost Heaving Gravel (Dense)	-	-	0, 1, 2 and 3
	1, 2, 3 and 4	-	2
Frost Heaving Gravel (Loose)	-	-	2, 3.5, 4.5 and 5.5

c. Preparation of Samples. Each of the three soils was air dried, thoroughly mixed and lumps broken down. All sizes retained on a No. 4 sieve were removed from the East Boston till.

Two types of test specimens were prepared; those without admixtures and those with admixtures. Specimens without admixtures were prepared by compacting soil at a predetermined water content into a split container 3.3 inches in diameter and 6.5 inches high, (see Plate A-11) to a selected unit dry weight. Where salt only was used as an admixture, it was first dissolved in water and then the solution added to the soil. Where a bituminous material only was used as an admixture, the required quantity of water was first added and mixed then the bituminous material was added and mixed. Where both salt and bituminous material were added, the salt was dissolved in water and thoroughly mixed with the soil followed by the addition of the bituminous material.

Most specimens were compacted to 95 per cent Modified A.A.S.H.O. density at the optimum water content for that density. Where admixtures were used the Modified A.A.S.H.O. density was determined for each different admixture percentage and combinations of admixtures. Some specimens of New Hampshire silt were compacted to a relatively low unit dry weight to investigate the effect of compaction.

The following table summarizes the average molding data for the specimens tested:

Material	Water Content % Dry Weight Soil and Admixture Avg.	Range	Unit Dry Weight of Soil Lbs. per cubic ft. Avg.	Range	Degree of Saturation Percent Avg.	Range	Void Ratio Avg.	Range
East Boston Till 28 samples	8.1	5.6-9.7	123	117-127	59	36-77	0.40	0.35-0.47
New Hampshire Silt 4 samples (molded at 95±% mod. AASHO density)	13.8	13.0-14.9	102	101-103	57	53-65	0.66	0.64-0.66
New Hampshire Silt	19.0	18.1-20.3	85	84-87	56	53-60	0.97	0.93-1.00
Frost Heaving Gravel 8 samples	6.3	5.7-6.7	130	127-132	61	57-65	0.29	0.27-0.32
Frost Heaving Gravel 4 samples	8.2	7.9-8.6	115	114-117	50	48-52	0.46	0.44-0.47

All specimens were numbered consecutively and all numbers skipped represent samples which were not tested.

After the samples were molded, they were photographed, dipped in paraffin so that they were covered with two thin coverings about 1/32 of an inch thick and then placed in a greased cardboard tube. Just prior to placing in the freezing cabinet the paraffin was removed from one end of the sample and the open end was placed on a piece of filter paper on a porous stone. The cardboard tube was sealed to the drawer pan by the use of a rubber membrane and a clean dry sand placed around the samples for insulation. Prior to placing the sample on the porous stone the water level was adjusted to the elevation of the top of the porous stone so that water was available at the bottom of the sample. A schematic diagram showing the samples ready for freezing is shown on Plate A-9. All samples in series B and C were weighed prior to placing on the porous stone.

The capacity of the freezing cabinet was 16 samples and a total of 48 samples were tested in three series. These series have been differentiated by letters A, B, and C before the sample number. Twenty-eight samples were prepared using the East Boston till, eight samples using the New Hampshire silt and 12 samples using the frost heaving gravel.

d. Test Procedure. All samples were allowed to absorb water by capillarity for approximately three days prior to freezing while they were being brought to temperature equilibrium. The samples were frozen by a gradual lowering of the cabinet temperature at the top of the sample while maintaining a constant temperature (40°F) at the bottom of the sample. The following table shows the temperatures applied during the tests. Zero time for each test is designated as the date when the temperature of the cabinet was reduced to 32°F. The last date of the test is the day on which the samples were taken from the cabinet to the cold room where the temperature was approximately 40°F.

Days	Series A Temp.	Series A Accumulated Degree hrs.	Series B Temp.	Series B Accumulated Degree hrs.	Series C Temp.	Series C Accumulated Degree hrs.
-2	34	0	34	0	40	0
-1	35	0	34	0	35	0
0	32	0	32	7	32	0
1	32	24	31	31	31	24
2	31	48	31	58	31	48
3	30	96	30	106	55	4*
4	29	168	29	181	30	70
5	29	240	29	255	27	190
6	28	336	28	354	27	312
7	27	456	27	474	26	456
8	26	600	26	618	26	600
9	25	768	25	789	25	772
10	24	960	24	982	24	966
11	23	1176	23	1206	23	1185
12	22	1416	22	1447	22	1426
13	20	1704	20	1734	20	1719
14	18	2040	18	2070	18	2057
15	16	2424	16	2454	14	2486
16	14	2856	14	2886	14	2920
17	12	3336	12	3368	13	3374
18	10	3864	10	3893	11	3879
19	5	4512	5	4530	5	4526
20	5	5160	5	5193	5	5164
21	5	5808	5	5854	5	5802
22	5	6456	-	-	5	6393
23	5	7104	-	-	-	-

The air temperatures in the cold room and cabinet were determined by means of mercury thermometers, thermocouples and recording thermographs. One recording thermograph was placed in the cold room. The second recording thermograph was placed in the freezing cabinet above the drawers. These thermographs were used to determine

* Temperature of cabinet rose to 55°F. between 2nd and 3rd day cancelling degree hours accumulated.

the range of temperatures during the tests. Two thermometers reading to 1/5°F. were placed in the cold room and two in the freezing cabinet. Two copper constantan thermocouples were placed in anti-freeze in the cabinet near the top of the drawers, and two were placed in water in the cold room. Two additional thermocouples were placed in the cabinet drawers beneath the porous stone to determine the temperature of the water at thebase of the specimen during the test.

The temperature control of the freezing cabinet was erratic during series C and adjustments in the applied temperatures were made in an attempt to make the degree hour curve agree with that of series A and B without extending the period of testing. The degree hour curves for each series are shown on Plate A-12. Water was available at the bottom of all samples during the freezing period. It was maintained level near the top of the porous stone by means of a discharge pipe adjusted to the level of the stones as shown on Plates A-9 and A-13. Water was admitted to the system at a rate that would allow a very slow runoff from the overflow discharge pipe. This was adjusted to the rate at which the sample took on water and was checked frequently each day. Heave measurements were taken three times a week during the test. At the start of series A a scale was used to measure from the top of the sample to a straight edge laid across the freezing cabinet drawer. This method was replaced by one using a 0.001 inch Ames dial extensometer permanently mounted on a steel bar that would span the drawer. Two shims were provided which were machined to ± .001 inch and three extensions were provided for the extensometer. This arrangement permitted the measurement of approximately four inches of heave as shown on Plate 14. Those samples which heaved more than four inches were measured with a scale. At the completion of the tests the actual length of each sample was measured as it was removed from the drawers to check the heave measurements.

At the conclusion of the freezing period the samples were removed from the drawers, weighed, the cardboard tube and paraffin removed and photographs taken. The samples were then broken up for the ice lens observation and increment water content determination. Water contents were taken at approximately every 1.5 inches of height or closer to obtain a water content profile after frost action or freezing had occurred.

e. Summary of Test Results. The three soils tested were affected by frost action in the untreated state. For the percentage of admixtures tested the initial minimum percentages which prevented frost action are presented in the tabulation below. These minimum percentages were reduced an amount which is difficult to evaluate due to the capillary action which took place prior to freezing.

INITIAL PERCENTAGE OF ADMIXTURE

Admixture	East Boston Till	New Hampshire Silt	Frost Heaving Gravel
Calcium Chloride	1%	3% (loose)	1% (dense) 2% (loose)
Bunker "C" Oil	6%	6%	Not Tested
RT-2	6%	Not Tested	Not Tested
Bunker "C" Oil and Calcium Chloride	1% 0.5%	Not Tested	1% 2%
RT-2 and Calcium Chloride	1% 0.5%	Not Tested	Not Tested

A summary of the data from the frost action tests is shown on Plate A-15. On Plates A-16 to A-20 inclusive, the water content data is plotted with the photographs taken before and after freezing for the samples with no admixture, for those with a maximum of admixtures which heaved, and those with the minimum of admixtures which did not heave. As shown on Plate A-15 the dry weight in pounds per cubic foot before testing was computed for the soil alone from the wet weight, the water content, and the percentage of admixture. The void ratio and degree of saturation shown on this table were computed from the dry weights computed as shown above, the specific gravity of the soil and the water content of the soil before and after testing.

All samples tested in the freezing cabinet absorbed water. The increase in water content is shown on Plate A-15 in the columns "Water Content" and "Water Content of the Bottom Inch." The samples which were not frozen or only partially frozen and which did not show heave as a result of frost action might have heaved if the temperature conditions had been such that the additional water had been frozen.

2-06. Leaching Tests.

a. Material Tested. The soil used in the leaching tests was the East Boston till as described in paragraph 2-05a.

b. Admixtures. The admixtures consisted of flake calcium chloride alone and in combination with Bunker "C" oil. The following admixtures and combinations of admixtures on basis of percentage of dry weight of the soil were used:

Series	Soil	Compaction % Mod. AASHO Density	Percent Bunker "C" Oil	Percent Calcium Chloride
1	East Boston Till	95	0, 0.5, 1, 1.5 2 and 4	2
2	East Boston Till	95	0	0.5, 1, 1.5 and 2
2	East Boston Till	86	0	0.5, 1, 1.5 and 2
2	East Boston Till	76	0	0.5, 1, 1.5 and 2

c. Test Procedure. Two series of tests were performed to determine the rate of leaching of calcium chloride. For all tests the soil was prepared as described in paragraph 2-05c and compacted in either a consolidation ring or a lucite cylinder at density indicated in above table. In those samples tested in the consolidometer, water was forced upward through the test specimens, 1.25 inches thick, under a pressure of six pounds per square inch equivalent to a hydraulic gradient of 133. Larger pressures than this resulted in the washing of fines from the specimen. The tops of the specimens were loaded to a unit pressure slightly greater than six pound per square inch. The thickness of the samples in the lucite cylinder varied. In the samples tested in the lucite cylinder, water was forced down through the test specimens by a vacuum of approximately nine inches of mercury equivalent to a hydraulic gradient of from 87 to 145. The water which passed through the sample was collected.

The tests in the first series contained both Bunker "C" oil and calcium chloride and in the second series calcium chloride alone. The percentages of calcium chloride and the void ratios were varied in the second series to determine the effect of void ratio on the rate of leaching of the salt. Tests with the lucite cylinder were observed to detect any change in particle arrangement due to the flow of water thru the sample under the head used.

The water passing through the specimens was periodically tested to determine the presence of calcium chloride in solution. This was accomplished by noting the presence of a white precipitate with the addition of silver nitrate and when no precipitate was formed, it was assumed that all calcium chloride was washed from the specimens. The number of changes of water, computed from the volume of voids in the sample and the total amount of water passing through the sample, required to wash the salt completely out of the sample was determine.

In conjunction with the first series of leaching tests, permeability tests were performed on duplicate samples using a falling head permeameter.

d. Summary of Test Results. A summary of the leaching test data is shown on Plate A-21. Several samples were discarded as the pressures used in washing were high enough to cause piping through the samples. Data from these tests have been omitted from this report as they were not completed.

Test results are generally not consistent. It is believed that the inconsistencies are due to stratification accompanying compaction of remolded soil of the type used for these tests. The stratification is believed to have caused large variations in the average coefficient of permeability, thus affecting directly the time for leaching.

III STUDIES OF BASE COURSE TREATMENT TO PREVENT FROST ACTION, FISCAL YEAR 1946 - 1947

3-01. Purpose. The purpose of the investigation was to continue the study of methods and to perform additional laboratory tests to develop treatments for preventing frost action in base materials susceptible to frost action by investigation of (a) the hypothesis that the amount of salt required to prevent frost action is a function of the void ratio, (b) the influence of rock content of frost susceptible base materials on the type and percentage of admixtures required to render the materials non-frost susceptible, (c) methods of permanently retaining salt within the base materials.

3-02. Scope. This report presents the results of the investigations made since those reported in "Report on Studies of Base Course

Treatment to Prevent Frost Action" - Part 1. It presents (a) a study of previous investigations to determine the relationship between void ratio and the amount of salt required to prevent frost action, (b) the results of laboratory tests to determine the effect of rock content of soils on the amount of admixture required to make them non-frost susceptible, and (c) the results of laboratory tests to determine the effectiveness of "Darex AEA" as an admixture for preventing frost action. Representative data are presented herein. A complete record of test data is on file at the Soils Laboratory of the New England Division. No field tests were performed during this investigation.

3-03. Review of Previous Investigations.

a. Review of Admixtures Tested. Numerous laboratory tests have been performed using various admixtures in soils to determine their effectiveness in preventing frost action (1), (2), (3), (6), (7)*. Brief mention of these admixtures is made below. For a more detailed account, reference has been made to the reports of the original investigations.

(1) Calcium Oxide. Three different soils were used with varying amounts of admixture and with a wide range of water content at the start of the test. In each test the frost action was severe. Each specimen gained considerable in water content during the test. Calcium oxide did not increase the soils resistance to frost action.

(2) Water Repellents. The water repellents, Stabinol, 321, and a combination of 321 and ferrous sulphate were tested in five different soils. None of the admixtures prevented frost action.

* Figures shown thus (1), (2) refer to bibliography.

In three specimens treated with Stabinol and two specimens treated with 321 plus ferrous sulphate, frost heave was reduced to minor proportions. Additional tests using varying quantities of these admixtures in specimens tested with varying water contents are required before any definite conclusions can be drawn.

(3) Sodium Chloride and Calcium Chloride. These salts have been tested in a wide variety of soils. They have been found to be effective in preventing frost action. A smaller percentage by weight is required to prevent frost action than with other admixtures tried. They have one serious defect, namely, a marked tendency to migrate. Treatment with sodium or calcium chloride will give temporary protection from frost action.

(4) Portland Cement. A limited number of tests were performed using portland cement as an admixture. In these tests there appears to be a definite relationship between density or void ratio and percentage of frost heave. As the density decreased or the void ratio increased, the percentage of heave increased. More test data are required before any definite conclusions can be made concerning this admixture.

(5) Vinsol Resin. Tests performed using vinsol resin in sandy clay and sandy clay plus sand revealed one significant relationship. The amount of heaving which occurred, varied with the water content of the specimens at the start of the test. Specimens with a high or low degree of saturation heaved considerably those in the middle range showed a marked decrease in heaving. Vinsol as

an admixture to prevent frost action is of doubtful value due to its apparent dependence on the water content of the soil, a factor obviously difficult if not impossible to control.

(6) Bituminous Materials. Asphalt emulsions, asphalt cutbacks, tars and oils have been tested in a variety of soils. Each of these materials used as an admixture has been effective in preventing frost action. The amount of admixture required to prevent frost action varies for different soils and the void ratio or density to which the soil is compacted. Bituminous admixtures are the only ones which show any promise of providing effective permanent treatment to prevent frost action.

b. Analysis of Previous Investigations. A further study of all tests which have been performed using admixtures to prevent frost action was made. As a result of this study, certain significant relationships, not previously developed, are set forth concerning sodium chloride, calcium chloride and bituminous materials.

(1) Sodium Chloride. The average concentration of sodium chloride in the brine for the various specimens testedwas computed and the freezing point of the brine taken from tables compiled by the International Salt Co. The freezing temperature of the brine was plotted against the air temperature at which frost action started and a curve developed showing the probable start of frost action in soils treated with sodium chloride. This curve is shown on Plate A-22. The air temperature at which frost action starts was found to be considerably lower than the freezing point of the brine. This can be explained in part by the fact, as

determined by laboratory tests (3), that the sodium chloride migrates towards the top of the sample resulting in a concentration of salt at the top of the specimens greater than the computed average. It is also partly due to the fact that during freezing the soil temperature remains higher than the air temperature. Laboratory tests have been performed in which the magnitude of the difference between air and soil temperatures during cooling for certain cohesionless soils has been determined (4). Another factor which probably accounts for some of this difference is the phenomenon, determined by laboratory tests (5), which permits soils to be cooled below the freezing temperature of water without freezing.

Using the aforementioned brine tables, calculations have been made to determine the quantity of sodium chloride required per cubic foot of dry soil to lower the freezing point of the brine to various temperatures in soils with 100 per cent saturation of brine for varying void ratios of soil. The results of these calculations are shown graphically on Plate A-23. Using the difference between the air temperature at which frost action started and the freezing point of the brine, as determined from Plate A-22, it is possible to prevent frost action at that predetermined air temperature. Since Plate A-22 is based on a small number of laboratory tests and no field test data are available to check the results of these tests, the method of designing the admixture should be expected to yield only approximate results. It should also be borne in mind that treatment with sodium chloride will give only temporary protection, sodium chloride having a marked tendency to migrate or leach out of the soil (3). To date, attempts to find some method which will prevent or retard leaching have been unsuccessful.

(2) Calcium Chloride. The average concentration of calcium chloride in the brine for the various specimens tested was computed and the freezing point of the brine was taken from tables published by the Solvay Technical and Engineering Service. As was done for sodium chloride, the freezing temperature of the brine has been plotted against the air temperature at which frost action started and a curve developed showing the probable start of frost action in soils treated with calcium chloride. This curve is shown on Plate A-24. Plate A-25 has been prepared showing the weight of flake calcium chloride required per cubic foot of dry soil to lower the freezing point of the brine to various temperatures for various void ratios of soil. The soil is assumed to be 100 per cent saturated with brine. These two plates furnish sufficient information to design a mixture of soil and calcium chloride which will not be frost susceptible for the range of temperatures commonly encountered in soils. The above method of design is based on laboratory test data. No field tests have been performed to check the results of these laboratory tests. Treatment with calcium chloride will give only temporary protection from frost action due to the fact that this salt will eventually leach out of the soil.

(3) Bituminous Materials. There are two factors which possibly could lead to the development of a quantitative method of

design for bituminous admixtures. The first is the percentage of fine soil particles in the soil of such a size (0.02 mm. in diameter) as to make the soil frost susceptible. The susceptibility of a soil to frost action appears to be proportional to the quantity of fine soil particles. The second factor is the waterproofing property of bituminous materials. If this waterproofing is effected by filling the voids in the soil with bituminous material up to a point where capillary water is shut off, then the void ratio with admixture of the soil gives a measure of this waterproofing. For any soil, therefore, there could be a critical void ratio with admixture at which frost action would be eliminated. Such a critical void ratio is well defined in the tests performed on Bunker "C" oil and tar (RT-2) at the Soils Laboratory of the New England Division.

A study of the test data using asphalt cutbacks and asphalt emulsions indicates that a similar critical void ratio with admixture exists. In this latter case the critical void ratio with admixture is not too clearly defined but by observing whether the sample gains any water during the test and considering that frost action has been stopped in those samples showing very little or no gain in water even though a slight heave has been recorded, it is possible to arrive at an approximate void ratio with admixture at which frost action is prevented. In the tests using tars, definite critical void ratios with admixture are indicated. The admixture, TC, exhibits a characteristic not observed in other tests. Frost heave was prevented in some of the samples tested even though considerable gain in water content occurred during the test.

The void ratio with admixture at which no frost action occurred has been plotted against the percentage of soil particles finer by weight than 0.02 mm. in diameter and the results are shown on Plate A-26. Before any definite conclusions can be arrived at, it appears necessary to test each admixture with a number of soils with various percentages of soil particles finer by weight than 0.02 mm. in diameter. It may even be necessary to run tests on soils of varying gradations of soil sizes with a view to determining the void ratio with admixture at which frost action is prevented in each soil in a family of grain size curves. From the tests already performed it is evident that bituminous admixtures if used in sufficient quantity can prevent frost action. All bituminous admixtures are not equally effective. Those admixtures which prevent frost action at the highest void ratios with admixtures (that is filling the least volume of void space) can be considered at the most effective frost action preventives. From Plate A-26 it is, therefore, apparent that asphalt emulsion, "AES-1," gives the best results, followed by tar and asphalt cutbacks and lastly by Bunker "C" oil. The percentage of admixture used is meaningless unless accompanied by the density and grain size characteristics of the soil tested.

3-04. <u>Description of Laboratory Cold Room and Equipment</u>. The laboratory tests were carried out in the Soil Mechanics Laboratory, Harvard Graduate School of Engineering. General layout of the cold room and equipment is shown on Plate A-9. (For description of Cold Room and equipment used, see paragraph 2-04, Part 1).

3-05. Tests for Frost Action.

a. Soils Tested. Three gradations of soil were tested with Bunker "C" oil as an admixture. They have been designated as Soil Mix No. 1, Soil Mix No. 2, and Soil Mix No. 3. A silt, designated "New Hampshire Silt" was tested with "Darex A.E.A." The three soil mixes consisted of varying percentages of silt, washed sand and washed gravel passing a ½-inch sieve. The percentage of each soil mix according to the Bureau of Soils Classification was as follows: Soil Mix No. 1, 17% silt, 58% sand and 25% gravel; Soil Mix No. 2, 17% silt, 33% sand and 50% gravel; Soil Mix No. 3, 17% silt, 15% sand and 68% gravel. The silt in each mix was that designated as "New Hampshire Silt" (ML), a brown uniform silt obtained from a varved deposit located south of Manchester, N. H. The grain size distribution curves with the specific gravity and properties of these materials are shown on Plate A-27.

b. Admixtures Tested. Two admixtures were used for testing, namely, Bunker "C" oil, which conformed to specifications in Bureau of Standards Bulletin No. CS 12-40 for No. 6 fuel oil and "Darex A.E.A.," a product of the Dewey and Almy Chemical Company consisting substantially of a triethanolamine salt of a sulfonated hydrocarbon. Bunker "C" oil had been tested previously and proved to be effective in preventing frost action. It was desired to obtain further information concerning this material when used in soils having a varying gravel content. "Darex A.E.A." was selected for testing because it had not been tried before and because if it did prove successful in preventing frost action, judging from the small quantities usually added to concrete for air entraining purposes it might provide an economical means for treating soils. The following percentages of admixtures by dry weight of soil were used in the samples tested:

Soil	Per Cent Bunker "C" Oil	Per Cent Darex A.E.A.
Soil Mix No. 1	0,2,4,5,6	--
Soil Mix No. 2	0,2,4,5,6	--
Soil Mix No. 3	0,2,4,5,6	--
Silt	--	0.05, 0.10, 0.60, 0.90 1.20, 2.00

c. Preparation of Samples. Each of the soils was air dried, thoroughly mixed and lumps broken down.

(1) Soil Mix No. 1, Soil Mix No. 2, and Soil Mix No. 3 were tested with and without admixture. The silt was tested with admixture only having been previously tested without admixture. All specimens were prepared by compacting with a ten-pound hammer with area of face equal to 3.14 sq. inches dropped eighteen inches for a varying number of blows in seven layers. They were prepared with a predetermined water content in a split container 3.3 inches in diameter and 6.5 inches high (See Plate A-11) to a selected unit dry weight. The predetermined water content used was the optimum water content required for Modified A.A.S.H.O. density. The unit dry weight used was approximately 95 per cent of Modified A.A.S.H.O. density.

(2) Prior to preparing the test specimens using silt and "Darex A.E.A.," tests were performed to determine the effect of mixing time on density under Modified A.A.S.H.O. compaction. The "Darex A.E.A." was added to the water and then mixed into the soil

with a mechanical mixer for a time ranging from one to ten minutes. A summary of these tests are shown in tabular form below. No significant effect on density was caused by varying the mixing time when the soil was mixed for two or more minutes.

Per Cent Darex A.E.A.	Water Content*	Dry Density Lbs/Cu.Ft.**	Mixing Time Minutes
0.25	14.4	103.6	1
0.25	14.2	106.7	2
0.25	14.1	106.5	3
0.25	16.1	107.5	4
0.25	15.9	107.4	5
0.25	15.3	107.7	6
0.25	15.9	109.0	7
0.25	13.8	106.2	8
0.25	14.1	106.7	9
0.25	14.0	106.8	10
0.70	14.8	106.6	2
0.70	14.4	107.0	4
0.70	14.4	106.7	5
0.70	14.3	106.8	6
0.70	14.3	106.6	8
0.70	14.2	107.2	10

*Determined from wet weight and oven dry weight. The latter included "Darex A.E.A." residue

**Oven dry weight. No correction for "Darex A.E.A." in sample.

(3) In the preparation of the test specimens using Bunker "C" oil as an admixture, the required water was first added and mixed, then the Bunker "C" oil, preheated to a temperature of 140°F, was added and mixed.

(4) Photographs were taken of samples for each percentage of admixture used in each soil immediately after molding, with the exception of those samples which were room dried, and the samples were then dipped in paraffin. The samples were then slipped into greased cardboard tubes. Samples of silt molded with 0.10 and 0.90 per cent

"Darex A.E.A." were tested as molded and also air dried from one to four days in order to determine the effect of initial water content of the sample on frost action. Those samples which were air dried were weighed as molded and weighed again at the end of the drying period to permit calculation of the water content just before dipping into the paraffin. Prior to placing in the freezing cabinet, the paraffin was removed from one end of the specimen and the open end was placed on a piece of filter paper on a porous stone. The cardboard tube was sealed to the drawer pan by use of a rubber membrane and clean dry sand was placed around and level with the top of the samples in the drawer for insulation. The water level was adjusted to the top of the porous stone so that water was available at the bottom of the sample throughout the tests. A schematic diagram showing the samples in the freezing cabinet is shown on Plate A-9.

(5) The capacity of the freezing cabinet was sixteen samples. Fifteen samples were tested together in Series D. This series consisted of three sets of five samples, each set molded with Soil Mixes 1, 2 and 3. One sample of each set contained no admixture and four samples contained varying percentages of Bunker "C" oil. Sixteen samples were tested together in Series E. All of this series was run using "New Hampshire Silt" with "Darex A.E.A." as an admixture.

d. Test Procedure.

(1) The test procedures followed in these tests are described in paragraph 2-05d. with the exception that cabinet air temperatures were measured separately for each drawer. Two mercury thermometers were suspended directly over the samples in two alternate

drawers. Two copper constantan thermocouples were placed in an anti-freeze liquid near the tops of the samples in the other two drawers. The thermometers and thermocouples were used to obtain daily temperatures in each drawer during the test. The degree hour curves for each test were computed and they are shown on Plates A-28 and A-29.

e. Summary of Test Results.

(1) All the soils tested were affected by frost action in the untreated state. In series D, frost action was reduced to a very slight amount in Soil Mix No. 1 by the addition of six per cent Bunker "C" oil, frost action was prevented in Soil Mix No. 2 by the addition of five per cent Bunker "C" oil and frost action was prevented in Soil Mix No. 3 by the addition of six per cent Bunker "C" oil. Soil Mixes No. 2 and No. 3 with four per cent or more Bunker "C" oil showed no gain in water content during the test. In the untreated samples, water migrated to the top. Samples treated with Bunker "C" oil generally had a higher water content at the bottom. The addition of this admixture apparently retarded the tendency of the water to pass through the sample and accumulate in the upper soil layers. The addition of the larger percentages of admixture waterproofed the soil and thereby prevented the samples from taking on additional water through capillary action. Soil samples which compacted to higher densities showed no gains in water with the addition of smaller percentages of Bunker "C" oil. Gains in water content stopped at approximately the same void ratio with admixture in each soil mix. Water content profiles for Series D with photographs taken before and after

freezing for the samples with no admixture, for those with a minimum of admixture which heaved and those with a minimum of admixture which did not heave are shown on Plates A-30 through A-35. A summary of frost action test data for Series D is contained in Plate A-39.

(2) All the samples tested in Series E were severely affected by frost action. No relationship between the amount of heave which occurred and the amount of "Darex A.E.A." used, or the initial water content or any other predetermined characteristic of the sample was apparent as a result of these tests. Water content profiles for selected samples in Series E and a sample in Series B (tested in a previous investigation) without admixture, together with photographs taken before and after freezing are shown on Plate A-19 and on Plates A-37 through A-39. A summary of frost action test data for Series E is contained in Plate A-40.

GLOSSARY

Certain terms and words which have a specialized use in this report are defined below.

Admixture is a material which is added to a soil to prevent frost action.

Degree Hour is the cumulative total of the algebraic difference between 32 degrees Fahrenheit and the hourly mean temperature below 32 degrees Fahrenheit.

Density is the unit weight in pounds per cubic foot.

Dry Density is the unit weight in pounds per cubic foot obtained from the wet density, by deducting the weight of water and admixture, i. e. the unit weight of the soil particles.

Frost Action is the accumulation of water in the form of ice lenses in soil or base materials under natural freezing conditions.

Frost Heave is the raising of the surface due to the accumulation of ice lenses. The amount of heave in most soils is approximately equal to the cumulative thickness of the ice lenses. Expressed as a percentage, it is the ratio (multiplied by 100), of the increase in height of the soil sample divided by its original height.

Frost Susceptible Base consists of a soil which contains more than three per cent of grains smaller than 0.02 mm. in diameter, placed and compacted on a subbase or subgrade.

Ice Lenses are the ice formations in frozen soil occurring in repeated layers essentially parallel to each other and normal to the direction of heat loss.

Non-Frost Susceptible Base consists of a soil which contains less than three per cent of grains smaller than 0.02 mm. in diameter placed and compacted on a subbase or subgrade.

Degree of Saturation is the ratio, expressed as a percentage, of the volume of the water to the volume of the voids.

Rock Content in this report is the portion of a soil retained on a No. 10 sieve.

Void Ratio is the ratio of the volume of the voids to the volume of the soil particles.

Void Ratio with Admixture is the ratio of the volume of the soil not filled by the soil particles and admixture to the volume of the soil particles and admixtures.

Void Ratio without Admixture is the ratio defined as "Void Ratio."

Volume of the Voids is the volume of the soil not occupied by the soil particles.

Water Content is the ratio, expressed as a percentage, of the weight of water in a given soil mass to the weight of soil particles.

Wet Density is the unit weight in pounds per cubic foot of the soil, including the weight of water and any admixture.

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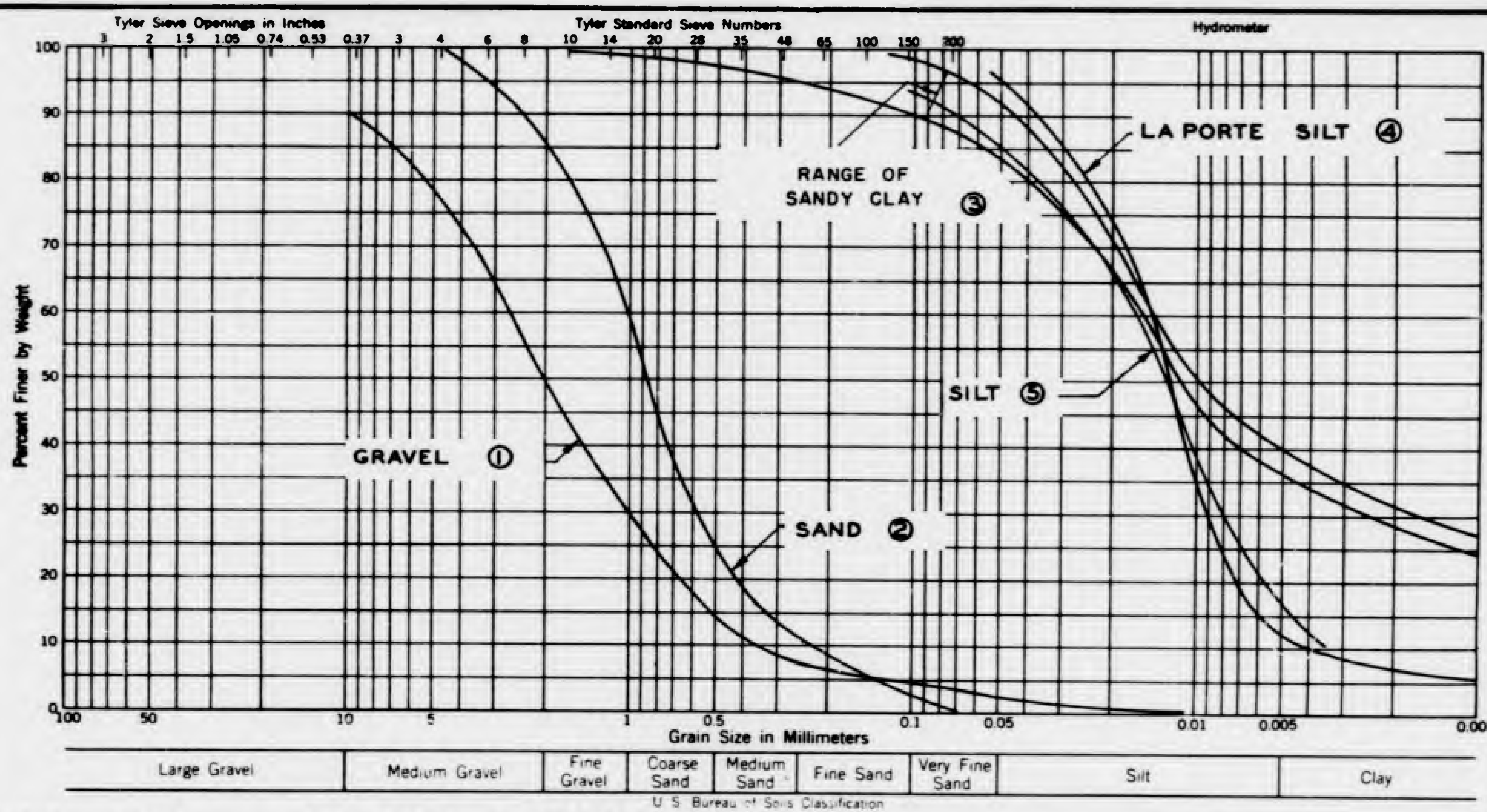
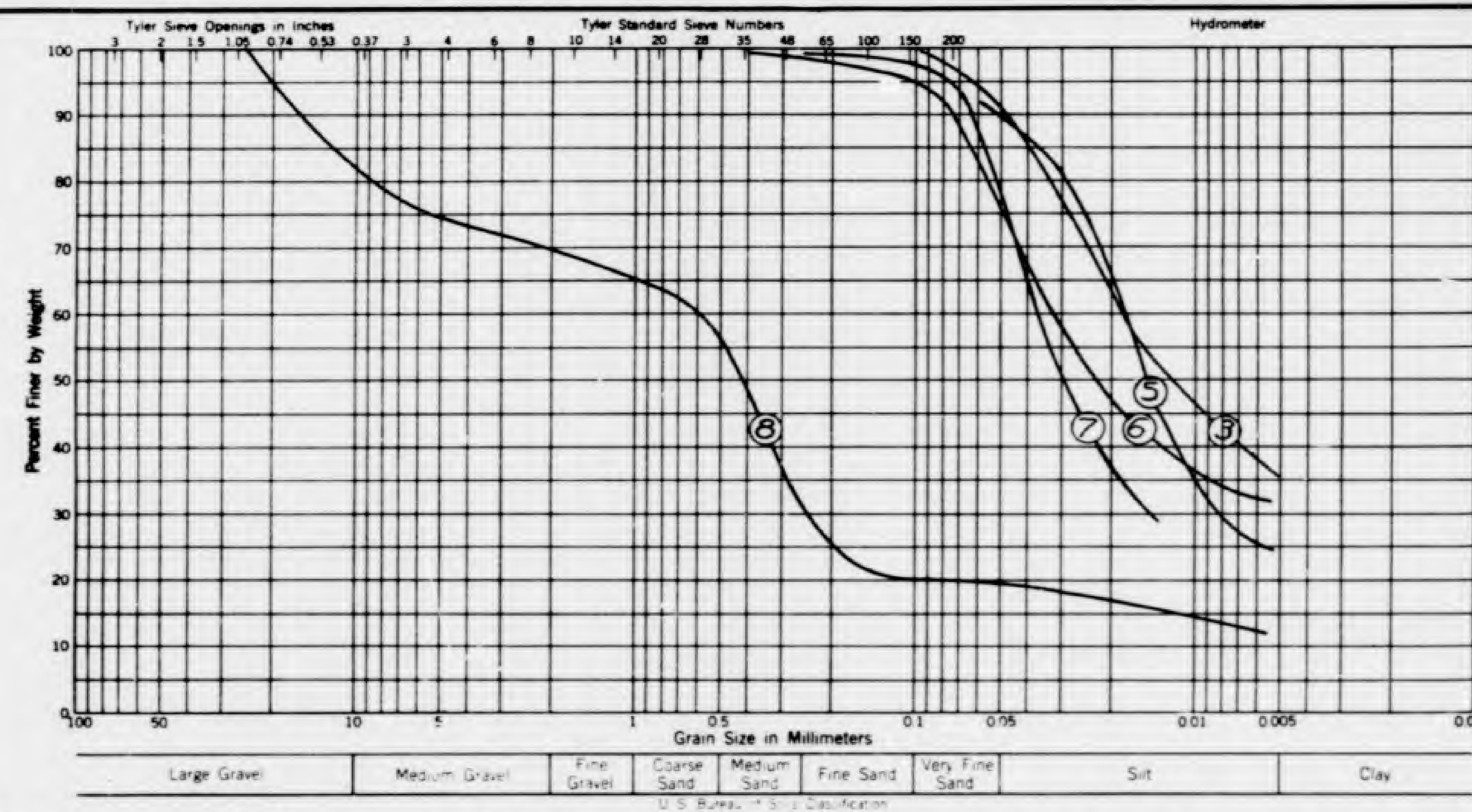


CURVE	MATERIAL	FROM REPORT BY	SPECIFIC GRAVITY	L.L.	P.L.	P.I.
①	GRAVEL	WINN & RUTLEDGE		NON-PLASTIC		
②	SAND	WINN & RUTLEDGE		NON-PLASTIC		
③	SANDY CLAY	WINN & RUTLEDGE	2.71	46	18	28
④	LAPORTE SILT	SLESSER	2.72	27	24	3
⑤	SILT	SLATE	2.72	22	19	3

CLASSIFICATION DATA PREVIOUS INVESTIGATION

PLATE A-1



CURVE	MATERIAL	S	L.L.	P.I.
③	SILTY CLAY	2.70	49	30
⑤	CLAYEY SILT	2.70	38	12
⑥	CLAYEY SILT	2.69	41	20
⑦	SANDY SILT	2.67	32	8
⑧	GRAVELLY CLAY SAND	2.67	25	11

RESINOUS WATER REPELLENTS FOR SOILS
CLASSIFICATION DATA
U.S.W.E.S.

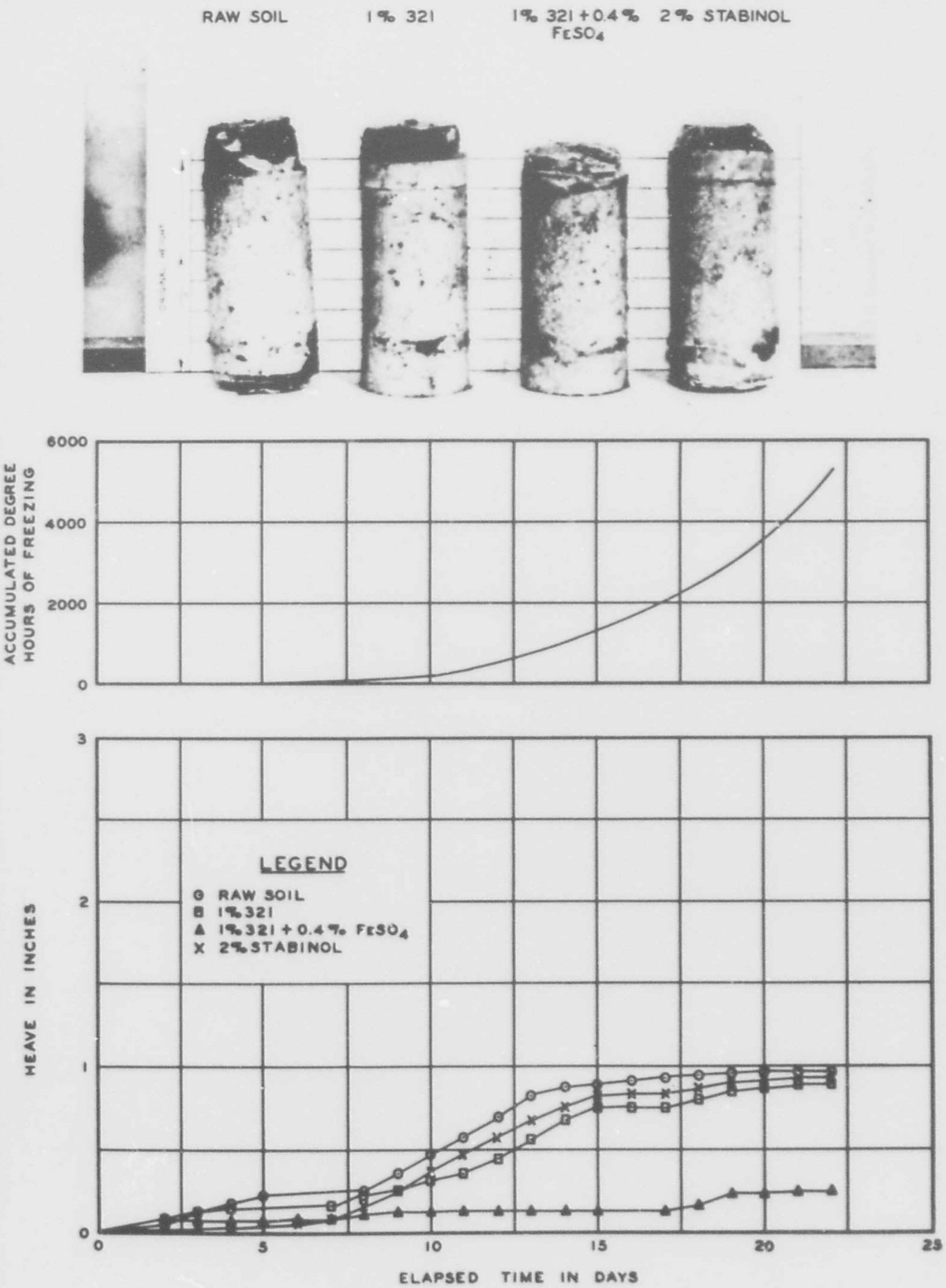
SUMMARY OF DATA OF SLOW FREEZE TESTS

RESINOUS WATER REPELLENTS INVESTIGATION (1)

Soil	Admixture	Specific Gravity	Water Content As Molded	Water Content After Curing	Water Content After Soaking	Dry Weight pcf	Per Cent Saturation	Per Cent Heave
3 Silty Clay	-	2.70	20.1	10.0	27.7	98.7	77	14.3
	1% 321		20.3	10.2	27.5	97.0	75	11.4
	1% 321 + 0.1% $FeSO_4$		19.1	8.0	25.5	95.7	68	3.6
	2% Stabinol		19.5	9.2	22.0	97.9	73	13.5
5 Clayey Silt	-	2.70	19.6	7.0	30.0	97.0	72	41.0
	1% 321		18.3	8.9	26.2	95.9	65	19.3
	1% 321 + 0.1% $FeSO_4$		19.8	8.6	23.5	95.4	70	19.3
	2% Stabinol		17.6	7.5	18.2	98.1	66	21.2
6 Clayey Silt	-	2.69	18.2	8.8	24.3	103.5	78	14.3
	1% 321		17.7	8.6	20.7	103.3	76	21.4
	1% 321 + 0.1% $FeSO_4$		18.2	8.9	19.8	101.6	74	9.3
	2% Stabinol		17.9	7.9	15.4	102.9	76	1.5
7 Sandy Silt	-	2.67	17.1	8.0	25.4	102.8	73	14.4
	1% 321		17.4	9.6	22.9	101.1	72	17.2
	1% 321 + 0.1% $FeSO_4$		15.2	7.2	24.6	98.6	59	17.2
	2% Stabinol		16.6	8.5	13.9	101.7	69	4.3
8 Gravelly Clay Sand	-	2.67	7.5	3.6	15.9	119.6	50	12.9
	1% 321		9.2	4.5	13.8	121.1	65	10.0
	1% 321 + 0.1% $FeSO_4$		8.0	4.2	15.7	118.3	52	3.6
	2% Stabinol		8.9	5.5	11.8	121.5	64	1.5

(1) Mississippi River Commission, U. S. Waterways Experiment Station, Draft of Interim Report of Water Repellents Investigation and pertinent data supplied by letter.

PLATE A-3



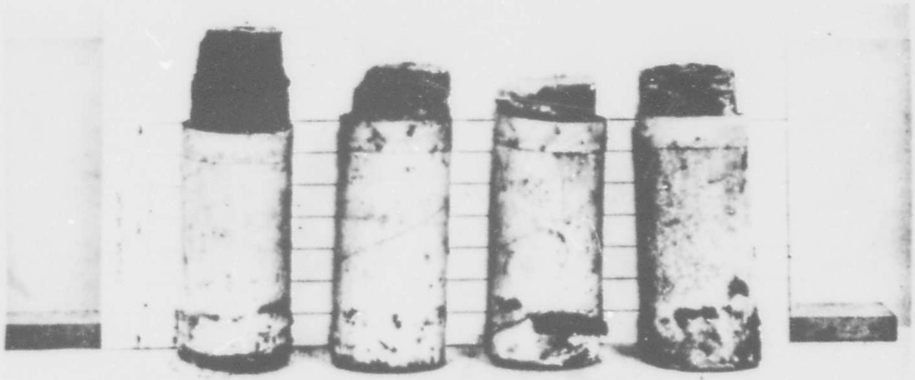
RESINOUS WATER REPELLENTS FOR SOILS

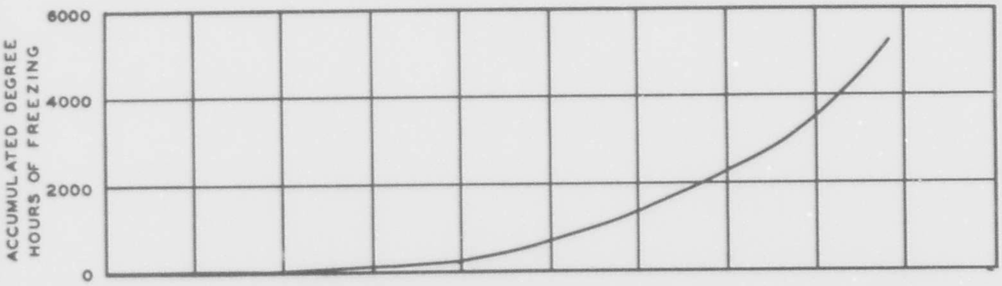
SLOW FREEZE TEST

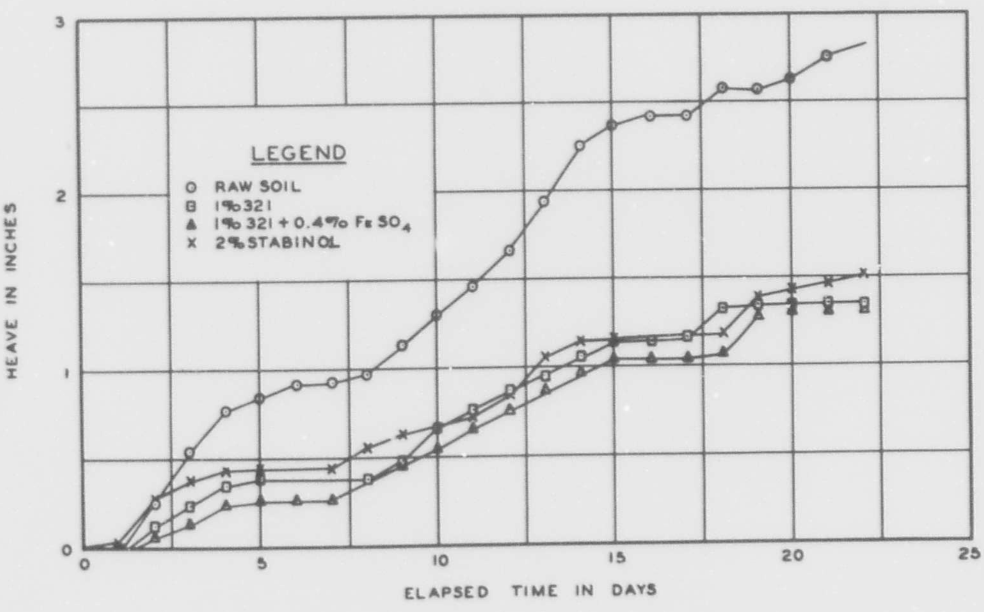
SAMPLE 3 SILTY CLAY

PLATE A-4

RAW SOIL 1% 321 1% 321 + 0.4% $FeSO_4$ 2% STABINOL





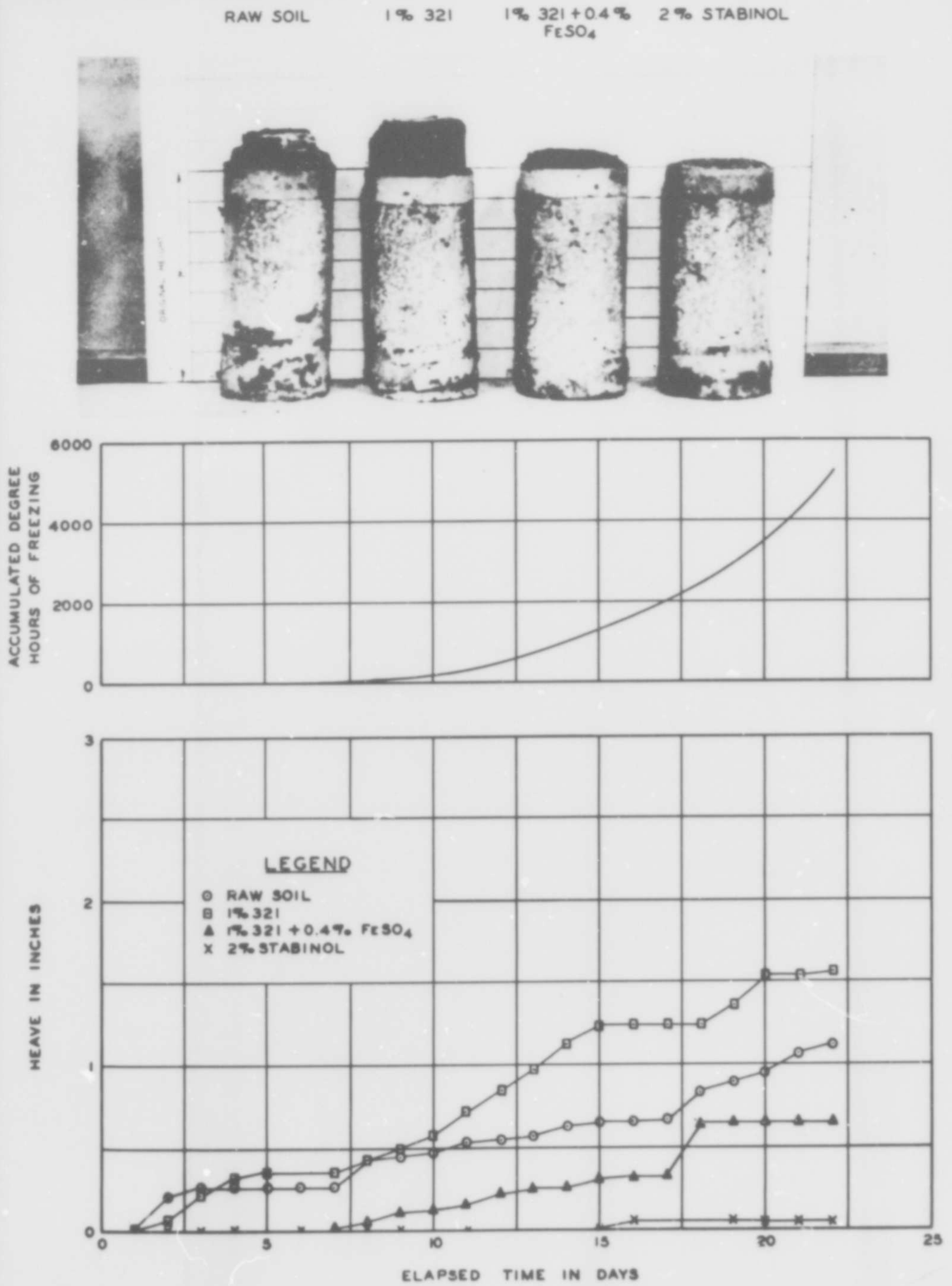


RESINOUS WATER REPELLENTS FOR SOILS

SLOW FREEZE TEST

SAMPLE 5 CLAYEY SILT

PLATE A-5

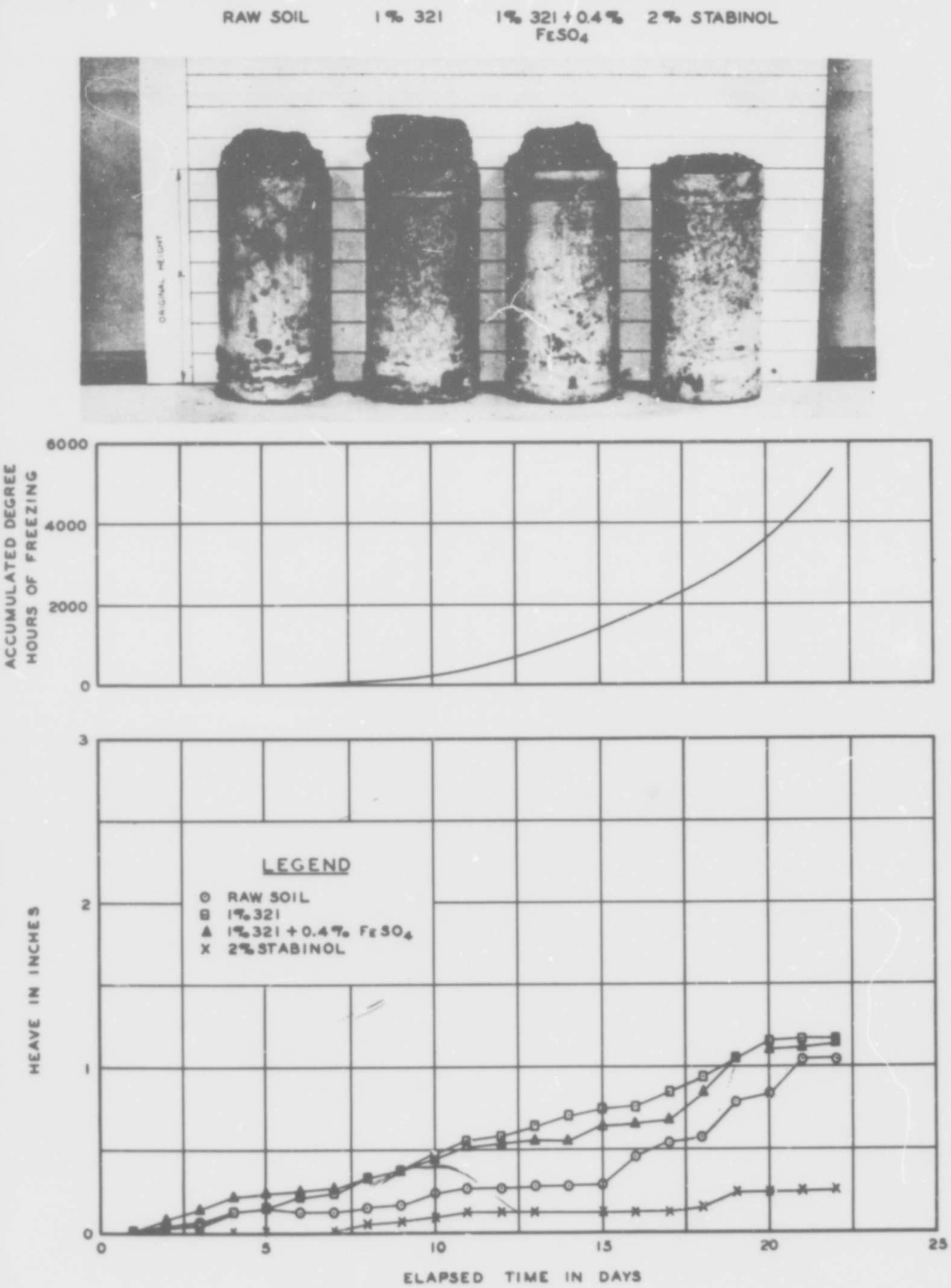


RESINOUS WATER REPELLENTS FOR SOILS

SLOW FREEZE TEST

SAMPLE 6 CLAYEY SILT

PLATE A-6

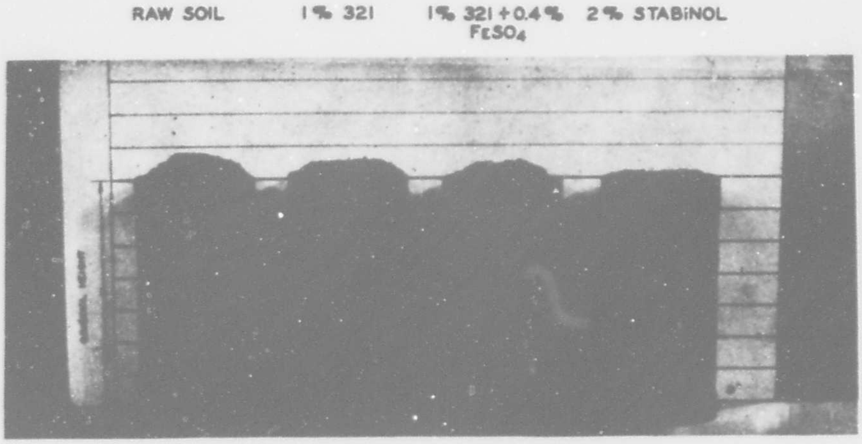


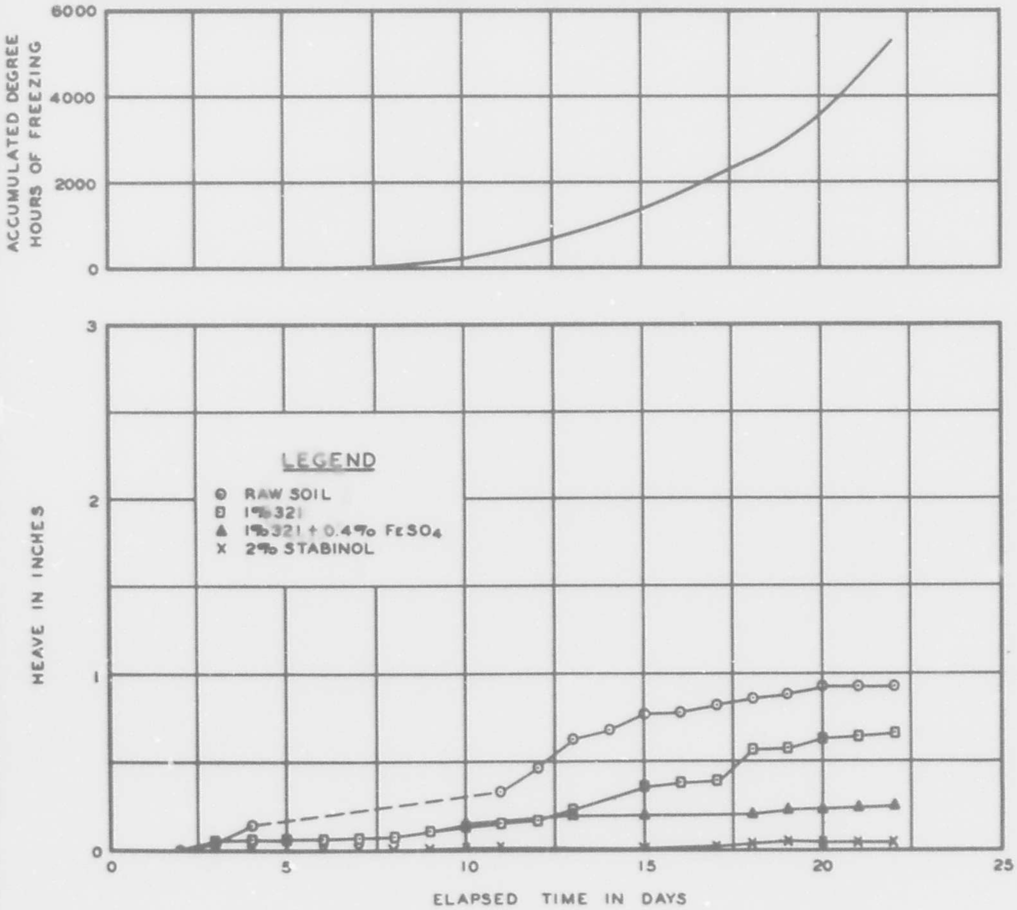
RESINOUS WATER REPELLENTS FOR SOILS

SLOW FREEZE TEST

SAMPLE 7 SANDY SILT

PLATE A-7



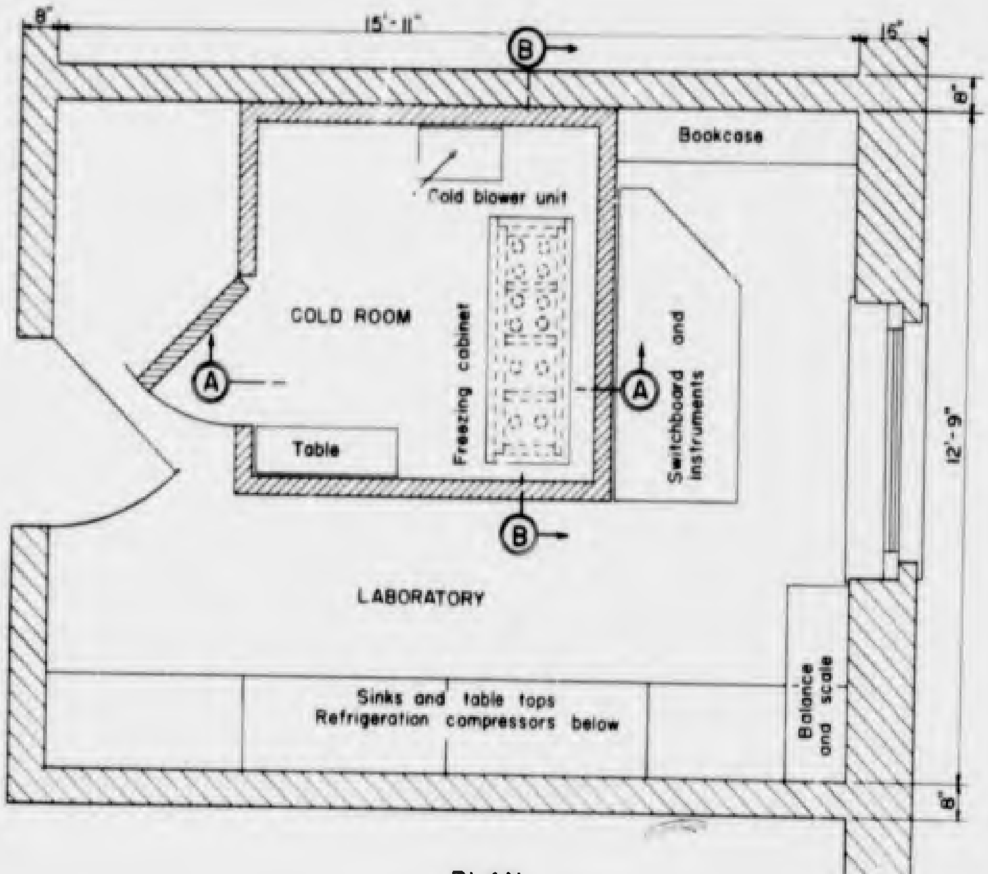


RESINOUS WATER REPELLENTS FOR SOILS

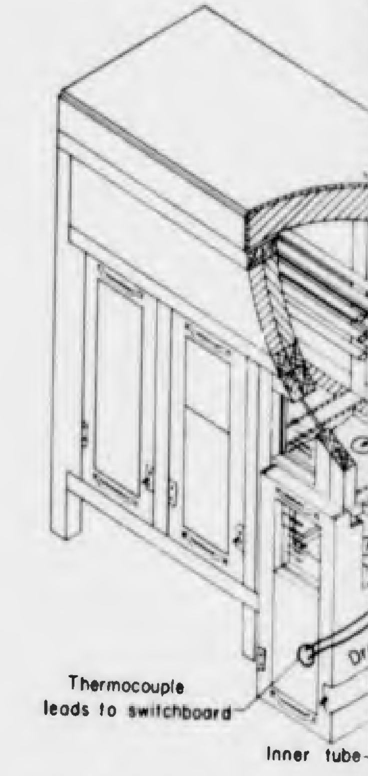
SLOW FREEZE TEST

SAMPLE 8 GRAVELLY CLAY SAND

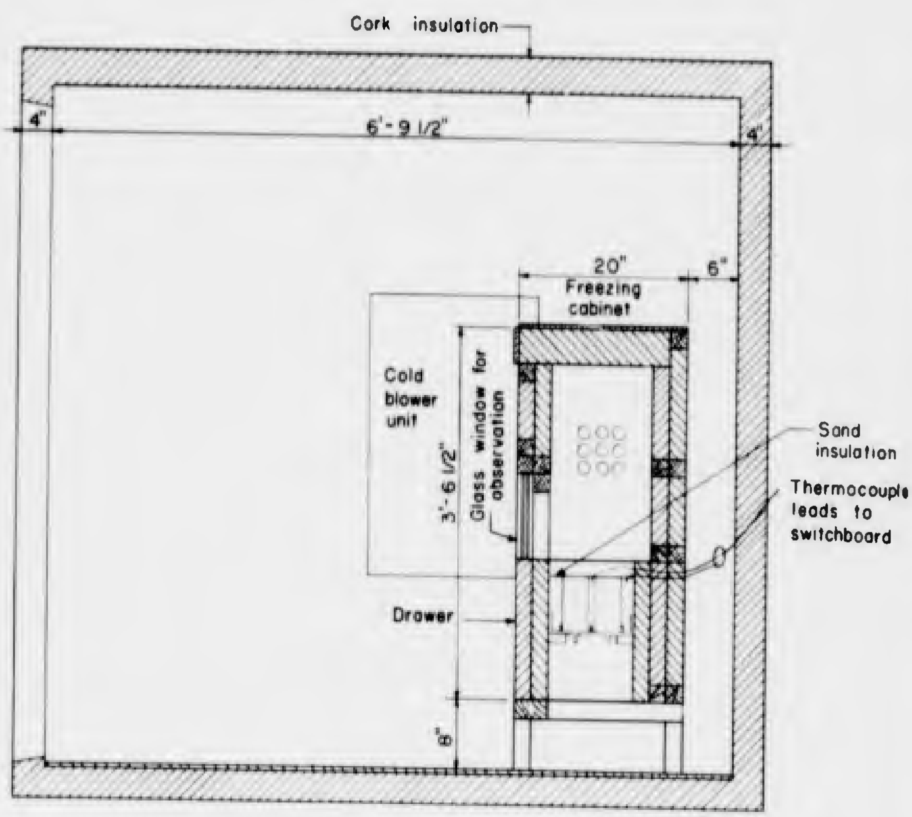
PLATE A-5



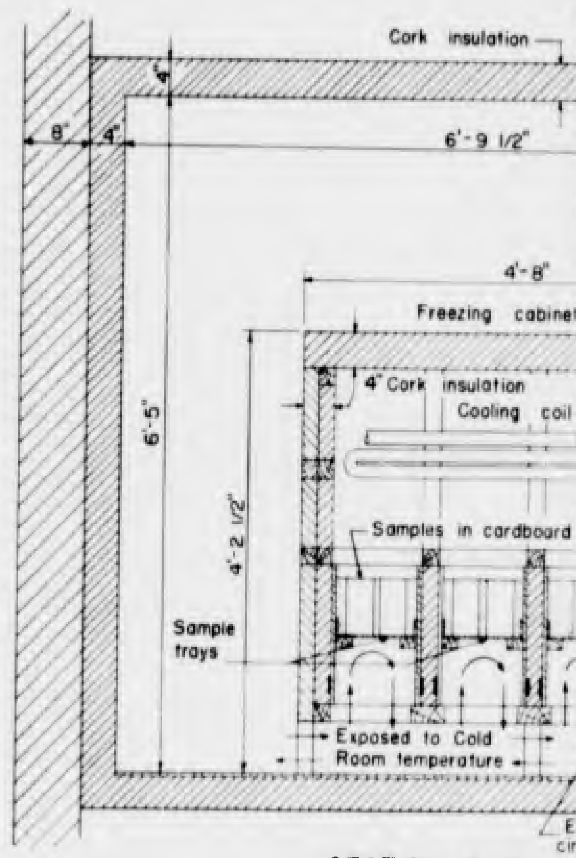
PLAN



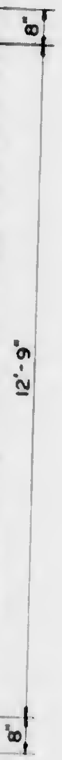
ISOMETRIC VIEW OF FRE

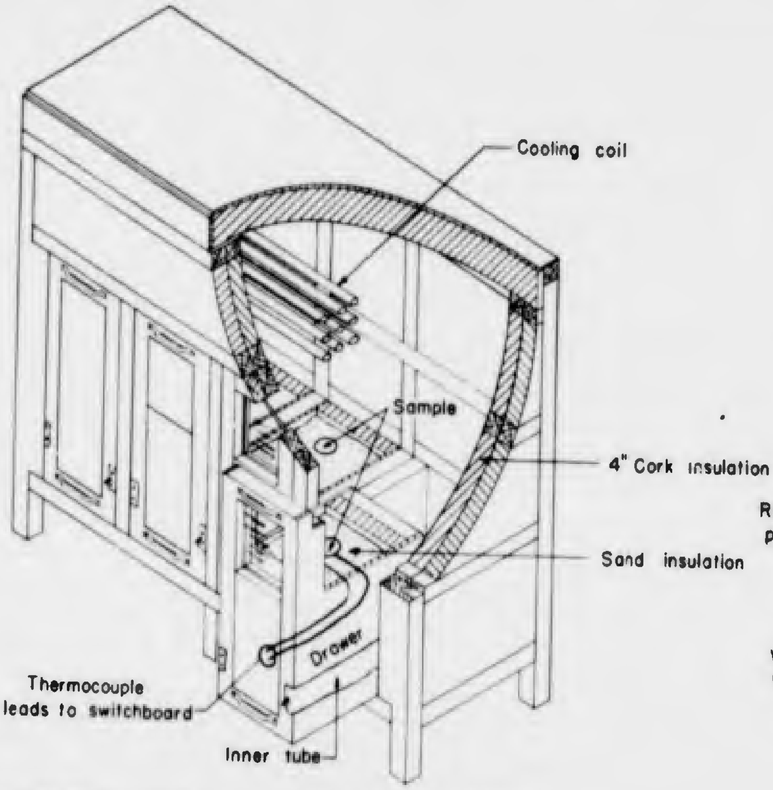


SECTION A-A



SECTION B-B





ISOMETRIC VIEW OF FREEZING CABINET

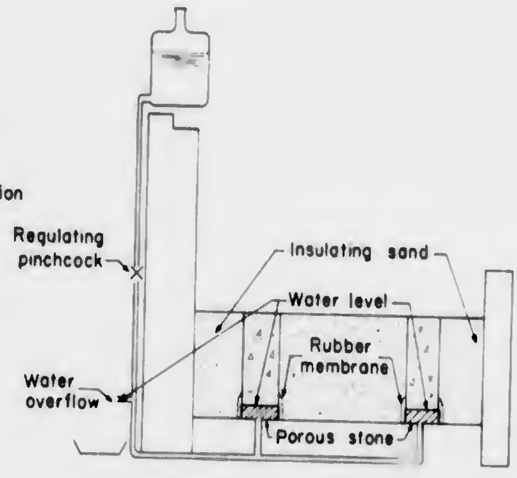
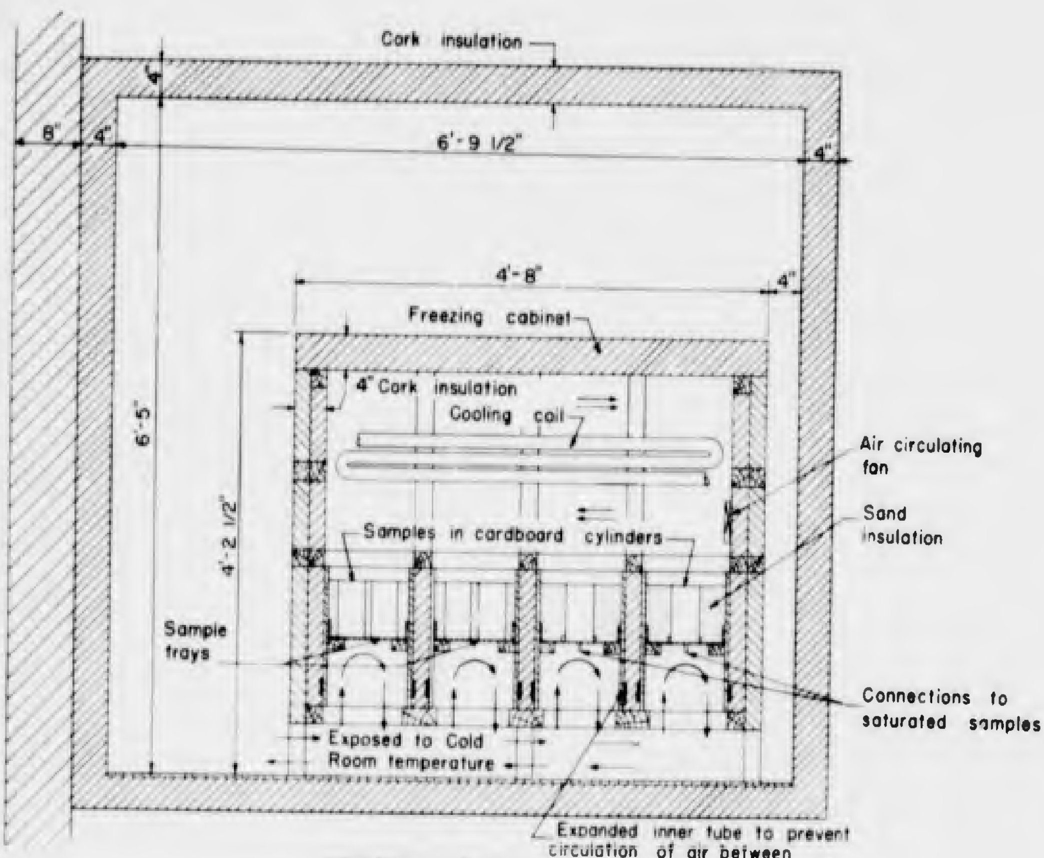


DIAGRAM OF SAMPLE DRAWER



SECTION B-B

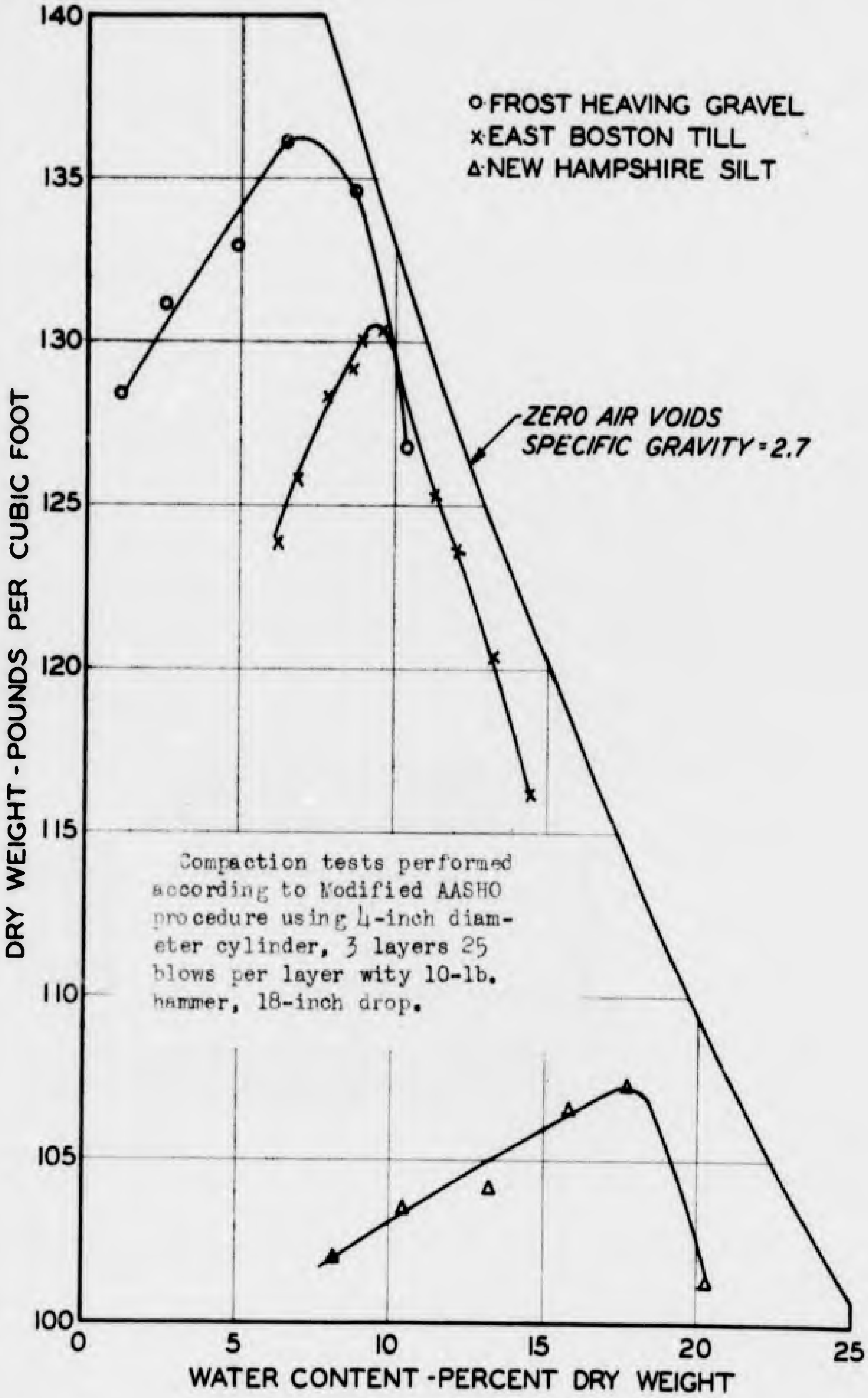
FROST INVESTIGATION
1946-1947

DETAILS OF COLD ROOM
AND TEST APPARATUS

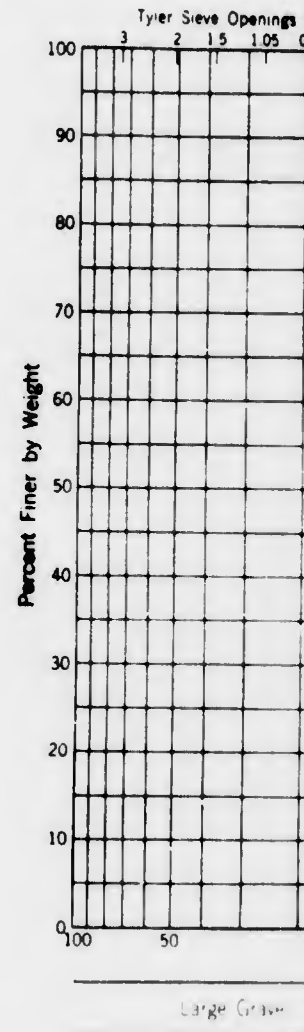
SOILS LABORATORY
NEW ENGLAND DIVISION

JUNE, 1947
BOSTON, MASS

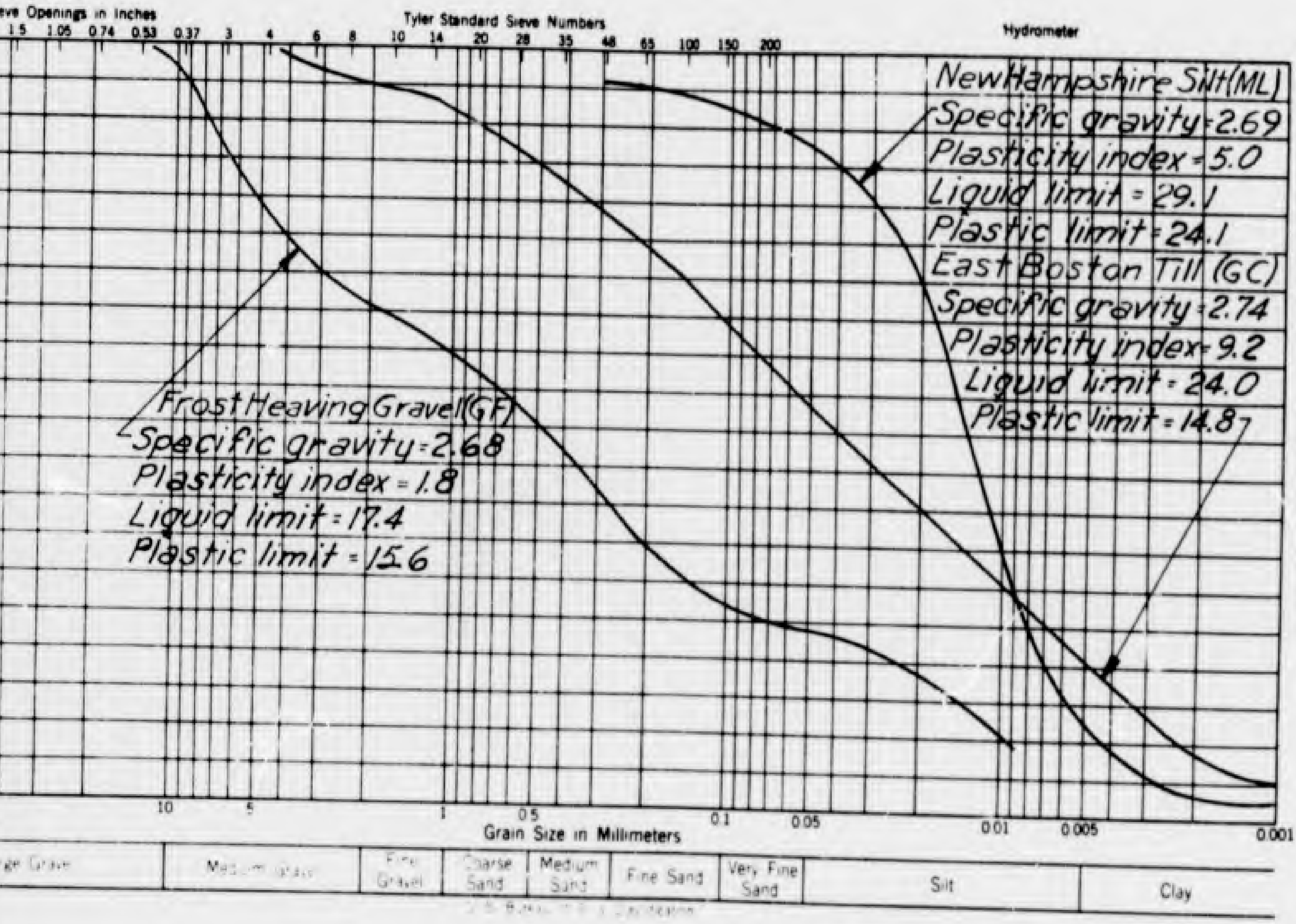
PLATE A-9



140
135
130
125
120
115
110
105
100
0
5
10
15
20
25
DRY WEIGHT - POUNDS PER CUBIC FOOT
WATER CONTENT - PERCENT DRY WEIGHT
o FROST HEAVING GRAVEL
x EAST BOSTON TILL
Δ NEW HAMPSHIRE SILT
ZERO AIR VOIDS
SPECIFIC GRAVITY = 2.7
Compaction tests performed according to Modified AASHO procedure using 4-inch diameter cylinder, 3 layers 25 blows per layer wity 10-lb. hammer, 18-inch drop.



Tyler Sieve Openings
3
2
1.5
1.05
Percent Finer by Weight
100
90
80
70
60
50
40
30
20
10
0
100
50
Large Grave

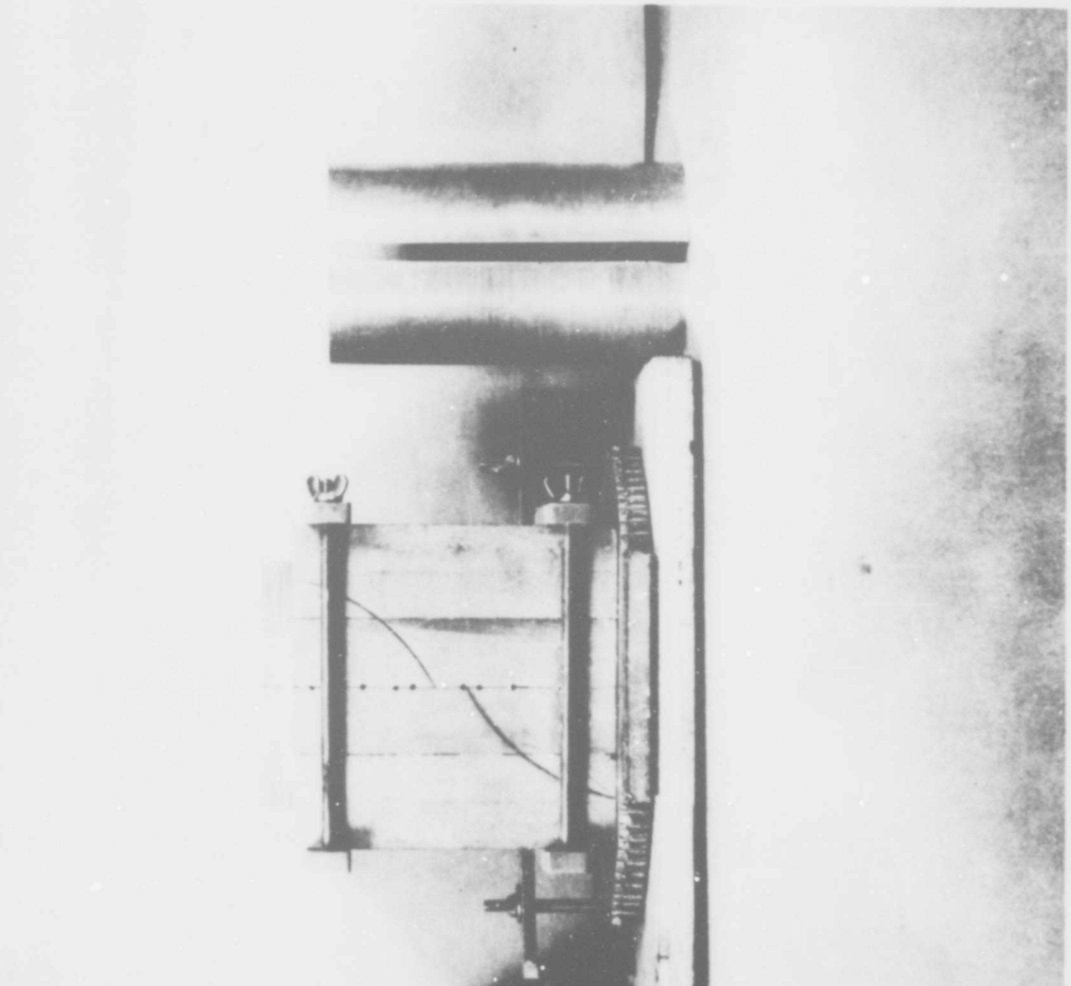


FROST INVESTIGATION
BASE COURSE TREATMENT
TO PREVENT FROST ACTION

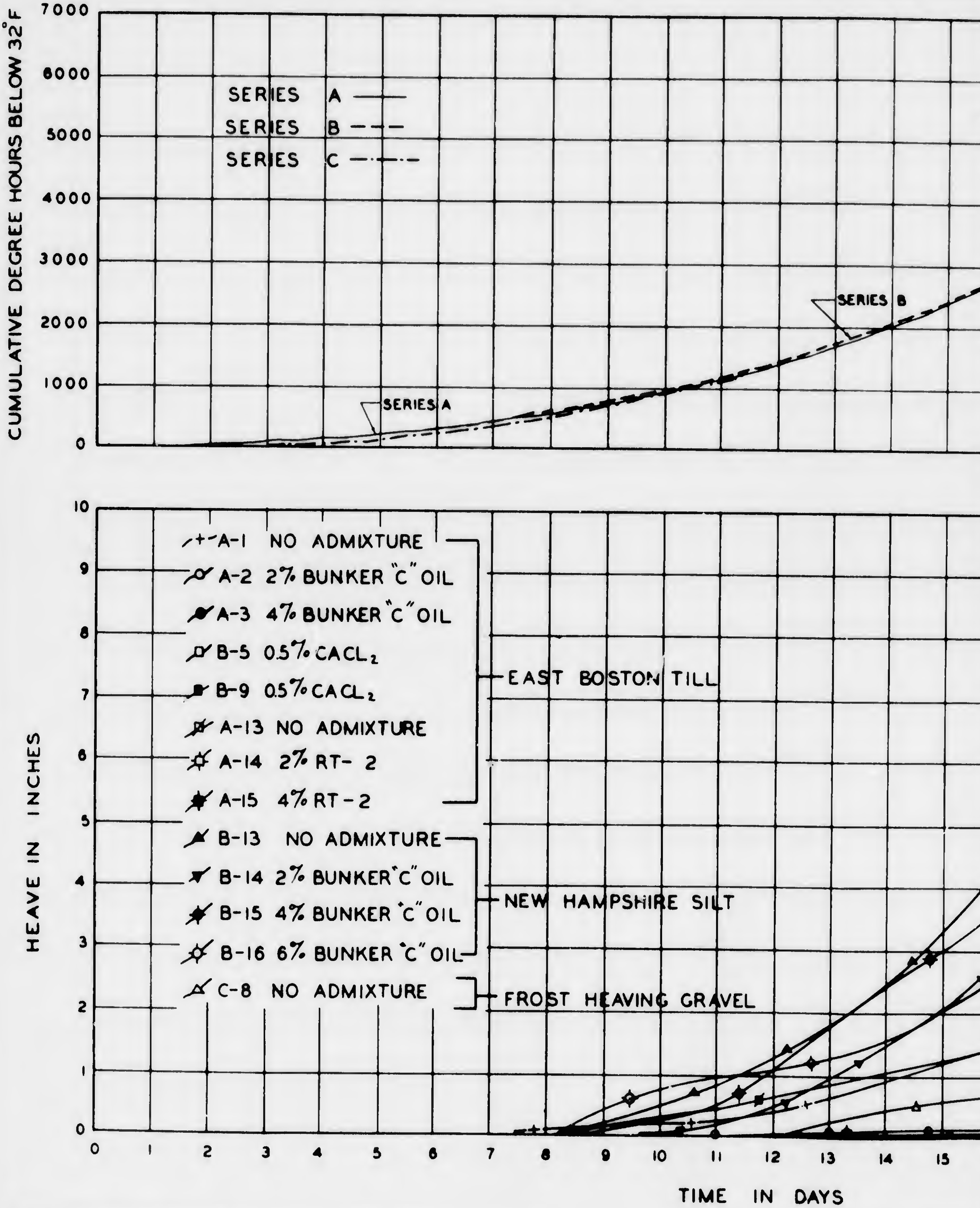
SUMMARY OF
SOIL TEST DATA

JUNE 1948
FROST EFFECTS LABORTORY, BOSTON, MASS.

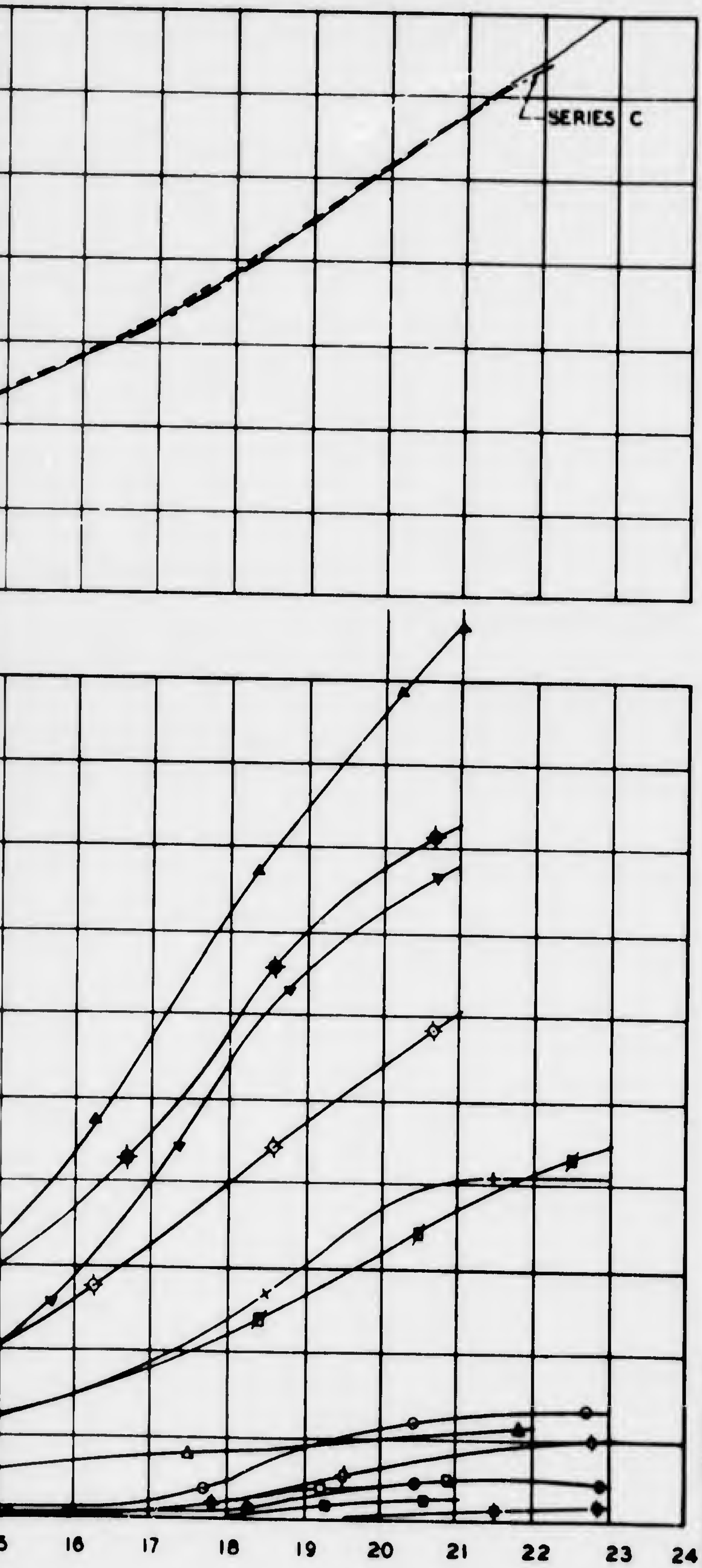
PLATE A-10



Sample Molding Equipment



CUMULATIVE DEGREE HOURS BELOW 32°F
7000
6000
5000
4000
3000
2000
1000
0
SERIES A
SERIES B
SERIES C
SERIES A
SERIES B
HEAVE IN INCHES
10
9
8
7
6
5
4
3
2
1
0
A-1 NO ADMIXTURE
A-2 2% BUNKER "C" OIL
A-3 4% BUNKER "C" OIL
B-5 0.5% CACL2
B-9 0.5% CACL2
A-13 NO ADMIXTURE
A-14 2% RT-2
A-15 4% RT-2
EAST BOSTON TILL
B-13 NO ADMIXTURE
B-14 2% BUNKER "C" OIL
B-15 4% BUNKER "C" OIL
B-16 6% BUNKER "C" OIL
NEW HAMPSHIRE SILT
C-8 NO ADMIXTURE
FROST HEAVING GRAVEL
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TIME IN DAYS



APPLIED TEMPERATURES

ELAPSED TIME (DAYS)	TEST SERIES A (°F)	TEST SERIES B (°F)	TEST SERIES C (°F)
-2	34	34	40
-1	35	34	35
0	32	32	32
1	32	31	31
2	31	31	31
3	30	30	55
4	29	29	30
5	29	29	27
6	28	28	27
7	27	27	26
8	26	26	26
9	25	25	25
10	24	24	24
11	23	23	23
12	22	22	22
13	20	20	20
14	18	18	18
15	16	16	14
16	14	14	14
17	12	12	13
18	10	10	11
19	5	5	5
20	5	5	5
21	5	5 *	5
22	5	-	5 *
23	5 *	-	-

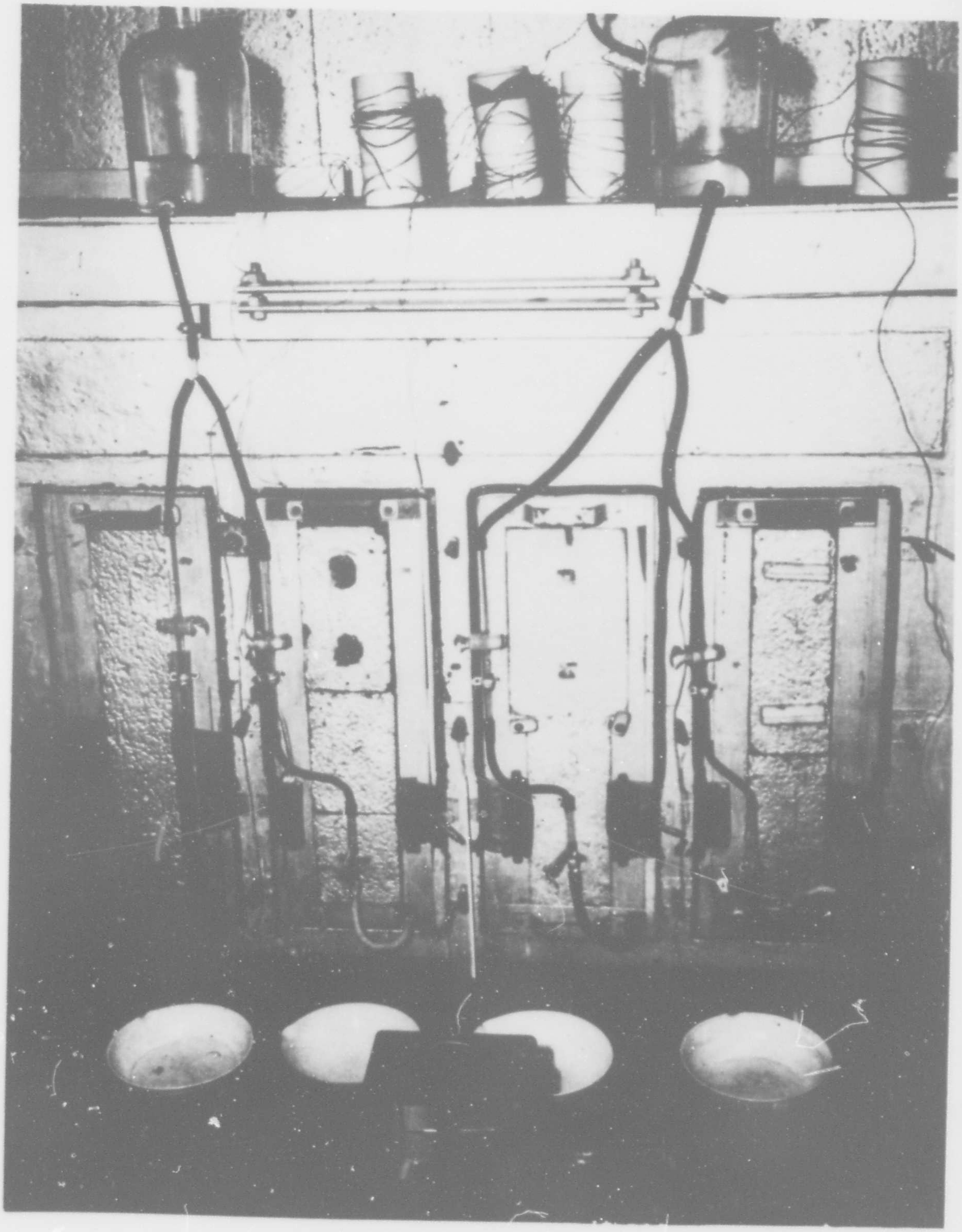
* FINAL DAY OF TEST

FROST INVESTIGATION
BASE COURSE TREATMENT
TO PREVENT FROST ACTION
1945 - 1946

HEAVE AND TEMPERATURE DATA

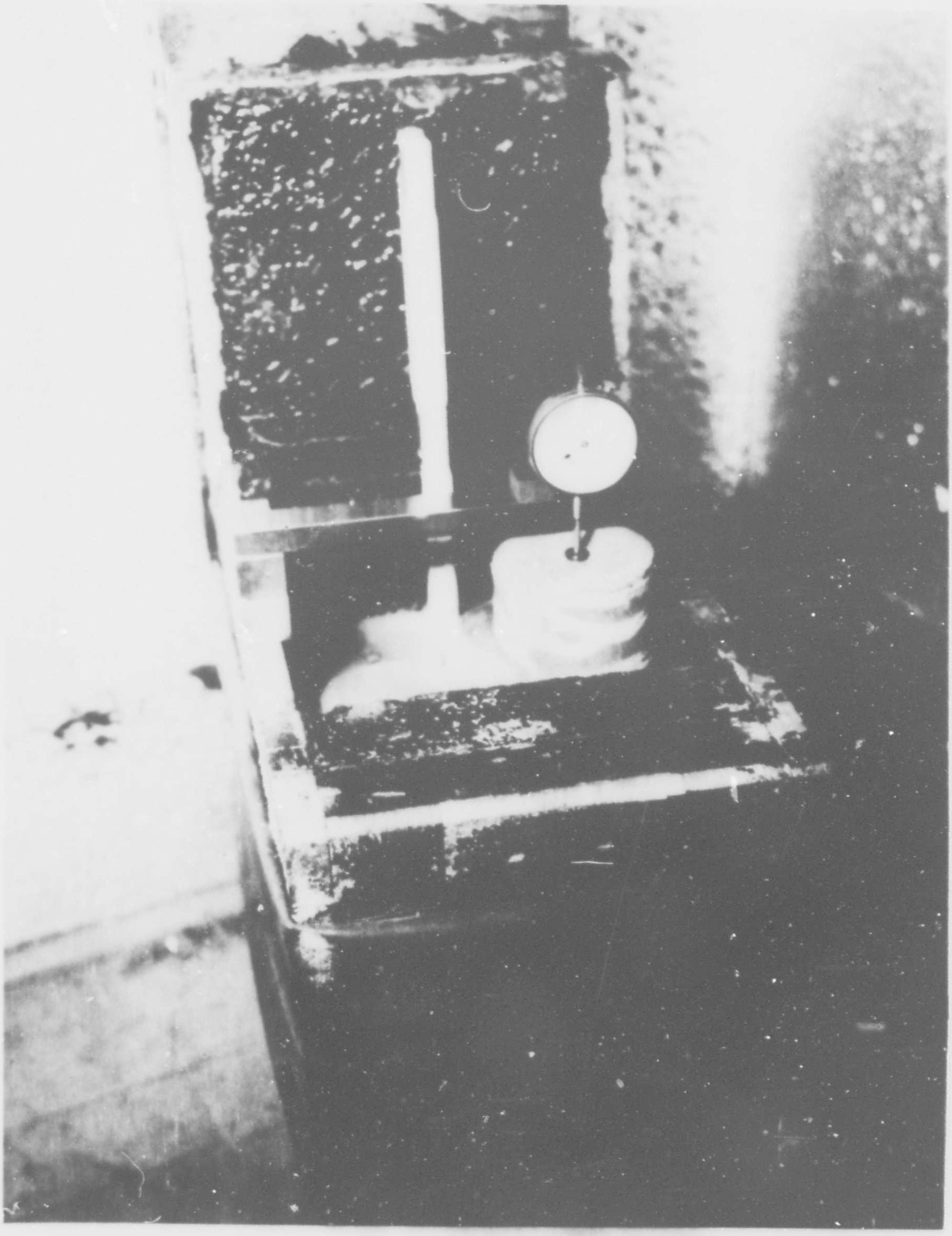
JUNE 1946
FROST EFFECTS LABORATORY, BOSTON, MASS.

PLATE A-12



Freezing cabinet showing Method used to supply water to the samples

PLATE A-13



Measuring Heave with 0.001 inch
Extensometer

PLATE A-14

SERIES AND SAMPLE NO.	SOIL TYPE	PER CENT AND TYPE OF ADMIXTURE			DENSITY		LENGTH OF TEST IN DAYS (a)	WATER CONTENT			SATURATION		VOID RATIO AT START e	WATER CONTENT OF BOTTOM INCH		[cut off]
		BUNKER "C"	RT-2	$CaCl_2$	WET WT. p.c.f. BEFORE TEST	DRY WT. p.c.f. BEFORE TEST		END OF TEST %	START OF TEST %	GAIN DURING TEST %	START OF TEST %	END OF TEST %		BEFORE TEST	AFTER TEST	
A-1	East Boston Till	-	-	-	139.1	127	26	46.4	9.7	36.7	77	100✓	.35	10	110	7
A-2		2	-	-	138.4	124		20.6	9.2	11.4	67	100✓	.37	9	79	
A-3		4	-	-	133.8	120		12.9	7.1	5.8	48	87	.42	7	41	
A-4		6	-	-	133.8	119		8.7	6.2	2.5	41	56	.44	6	13	
A-5		-	-	1	140.0	127		13.7	9.4	4.3	75	100✓	.35	9	13	
A-6		2	-	1	140.9	126		10.6	9.0	1.6	70	83	.36	9	12	
A-7		4	-	1	135.0	130		9.5	6.9	2.6	47	65	.42	7	11	
A-8		6	-	1	132.2	117		6.1	5.6	0.5	36	39	.46	6	9	
A-9		-	-	2	135.0	125		13.1	8.9	4.2	68	100	.37	9	12	
A-10		2	-	2	137.8	122		11.3	8.8	2.5	63	80	.40	9	14	
A-11		4	-	2	132.8	118		9.4	6.5	2.9	42	60	.45	6	11	
A-12		6	-	2	133.4	117		7.5	5.8	1.7	37	48	.46	6	9	
A-13		-	-	-	136.6	125		46.8	9.6	37.2	71	100✓	.37	10	21	
A-14		-	2	-	133.4	121		21.6	8.0	13.6	54	100✓	.41	8	24	
A-15		-	4	-	133.4	119		11.7	7.7	4.0	51	78	.43	8	15	
A-16		-	6	-	133.2	117		9.3	7.5	1.8	47	58	.47	7	11	
B-1		-	-	1	137.4	125	24	14.0	8.6	5.4	65	100✓	.37	9	15	5
B-2		-	1	1	139.0	125		12.4	9.0	3.4	68	100✓	.37	9	14	
B-3		-	2	1	138.2	124		10.8	8.5	2.3	62	79	.38	8	15	
B-4		-	4	1	140.0	122		10.0	9.4	0.6	67	72	.40	9	11	
B-5		-	-	0.5	138.5	126		17.7	9.2	8.5	71	100✓	.36	9	18	
B-6		-	1	0.5	138.4	125		13.6	9.0	4.6	68	100✓	.37	9	16	
B-7		-	2	0.5	136.7	122		12.4	8.4	4.0	60	89	.39	8	14	
B-8		-	4	0.5	137.2	127		9.1	7.7	1.4	55	64	.41	8	12	
B-9		-	-	0.5	139.8	127		16.4	9.2	7.2	72	100✓	.35	9	19	
B-10		1	-	0.5	138.7	126		12.1	8.6	3.5	66	93	.36	9	13	
B-11		2	-	0.5	138.0	124		11.4	8.1	3.3	61	86	.38	8	13	
B-12		4	-	0.5	134.4	121		8.1	6.6	1.5	45	55	.42	7	14	
B-13	New Hampshire Silt	-	-	-	114.6	101		102.5	13.4	89.1	55	100✓	.66	13	29	
B-14		2	-	-	117.6	101		82.5	13.9	68.6	53	100✓	.66	14	26	
B-15		4	-	-	122.3	103		82.7	14.9	67.8	65	100✓	.64	15	21	
B-16		6	-	-	121.0	101		63.1	13.0	50.1	56	100✓	.66	13	20	
C-20		-	-	3	107.6	87	25	26.2	20.3	5.9	60	78	.93	20	31	6
C-19		-	-	6	107.2	85		23.2	19.4	3.8	56	67	.98	19	27	
C-21		-	-	8	108.1	85		23.8	18.1	5.7	54	71	.98	18	32	
C-22		-	-	10	108.9	84		22.8	18.1	4.7	53	67	1.00	18	26	
C-8	Frost Heaving Gravel	-	-	-	139.4	132		11.2	5.7	5.5	57	100✓	.27	6	11	
C-17		-	-	1	140.6	131		10.0	6.0	4.0	59	99	.27	6	10	
C-6		-	-	2	142.9	132		9.1	6.4	3.7	65	92	.27	6	9	
C-7		-	-	3	142.6	130		8.1	6.7	1.4	64	77	.29	7	8	
C-9		-	-	2	128.8	117		9.7	8.3	1.4	52	61	.44	8	12	
C-10		-	-	3.5	128.2	114		9.0	8.6	0.4	51	54	.47	9	10	
C-11		-	-	4.5	128.6	114		8.9	8.0	0.9	48	53	.47	8	10	
C-12		-	-	5.5	130.8	115		8.5	7.9	0.6	49	53	.46	8	10	
C-13		1	-	2	143.7	131		8.0	6.4	1.6	64	80	.28	6	8	
C-14		2	-	2	143.3	129		7.6	6.5	1.1	62	73	.29	7	9	
C-15		3	-	2	143.3	128		7.4	6.4	1.0	59	69	.30	6	9	
C-16		4	-	2	143.0	127		7.1	6.6	0.5	58	63	.32	7	10	

(a) Length of test computed from time samples were placed in drawer until samples were removed.

WATER CONTENT			SATURATION		VOID RATIO AT START •	WATER CONTENT OF BOTTOM INCH		DEGREE HOURS IN TEST	DEGREE HOURS TO START OF HEAVE	HEAVE IN PER CENT	FROST ACTION	FROZEN ZONE
END OF TEST %	START OF TEST %	GAIN DURING TEST %	START OF TEST %	END OF TEST %		BEFORE TEST	AFTER TEST					
46.4	9.7	36.7	77	100✓	.35	10	110	7155	793	63.8	Severe	Entire
20.6	9.2	11.4	65	100✓	.37	9	79		1205	20.6	Severe	Entire
12.9	7.1	5.	48	87	.42	7	41		3932	6.7	Moderate	Bottom 1.3"
8.7	6.2	2.5	41	56	.44	6	13		-	0.0	None	Bottom 1"
13.7	9.4	4.3	75	100✓	.35	9	13		3931	0.3	Slight	None
10.6	9.0	1.6	70	83	.36	9	12		-	0.0	None	None
9.5	6.9	2.6	47	65	.42	7	11		-	0.0	None	None
6.1	5.6	0.5	36	39	.46	6	9		-	0.0	None	None
13.1	8.9	4.2	68	100	.37	9	12		-	0.0	None	None
11.3	8.8	2.5	63	80	.40	9	14		-	0.0	None	None
9.4	6.5	2.9	42	60	.45	6	11		-	0.0	None	None
7.5	5.8	1.7	37	48	.46	6	9		-	0.0	None	None
46.8	9.6	37.2	71	100✓	.37	10	21		639	69.9	Severe	Bottom 0.5" not frozen
21.6	8.0	13.6	54	100✓	.41	8	24		2912	16.3	Severe	Bottom 4.75" not frozen
11.7	7.7	4.0	52	78	.43	8	15		5871	3.5	Slight	Bottom 1" not frozen
9.3	7.5	1.8	47	58	.47	7	11		-	0.0	None	None
14.0	8.6	5.4	65	100✓	.37	9	15	5854	-	0.0	None	Top 3"
12.4	9.0	3.4	68	100✓	.37	9	14		-	0.0	None	None
10.8	8.5	2.3	62	79	.38	8	15		-	0.0	None	None
10.0	9.4	0.6	67	72	.40	9	11		-	0.0	None	None
17.7	9.2	8.5	71	100✓	.36	9	18		1735	9.2	Moderate	Bottom 0.5" not frozen
13.6	9.0	4.6	68	100✓	.37	9	16		3893	1.4	Slight	Frozen 1"-3.5" from bottom
12.4	8.4	4.0	60	89	.39	8	14		-	0.0	None	None
9.1	7.7	1.4	55	64	.41	8	12		-	0.0	None	None
16.4	9.2	7.2	72	100✓	.35	9	19		2455	5.4	Moderate	Bottom 0.5" not frozen
12.1	8.6	3.5	66	93	.36	9	13		-	0.0	None	None
11.4	8.1	3.3	61	86	.38	8	13		-	0.0	None	None
8.1	6.6	1.5	45	55	.42	7	14		-	0.0	None	None
102.5	13.4	89.1	55	100✓	.66	13	29		620	161.5	Severe	Bottom 2.8" not frozen
82.5	13.9	68.6	53	100✓	.66	14	26		620	115.5	Severe	Bottom 1.9" not frozen
82.7	14.9	67.8	65	100✓	.64	15	21		620	128.0	Severe	Bottom 1.9" not frozen
63.1	13.0	50.1	56	100✓	.66	13	20		620	91.0	Severe	Bottom 1.8" not frozen
26.2	20.3	5.9	60	78	.93	20	31	6393	-	0.0	None	None
23.2	19.4	3.8	56	67	.98	19	27		-	0.0	None	None
23.8	18.1	5.7	54	71	.98	18	32		-	0.0	None	None
22.8	18.1	4.7	53	67	1.00	18	26		-	0.0	None	None
11.2	5.7	5.5	57	100✓	.27	6	11		966	16.3	Severe	Entire
10.0	6.0	4.0	59	99	.27	6	10		-	0.0	None	None
9.1	6.4	3.7	65	92	.27	6	9		-	0.0	None	None
8.1	6.7	1.4	64	77	.29	7	8		-	0.0	None	None
9.7	8.3	1.4	52	61	.44	8	12		-	0.0	None	None
9.0	8.6	0.4	51	54	.47	9	10		-	0.0	None	None
8.9	8.0	0.9	48	53	.47	8	10		-	0.0	None	None
8.5	7.9	0.6	49	53	.46	8	10		-	0.0	None	None
8.0	6.4	1.6	64	80	.28	6	8		-	0.0	None	None
7.6	6.5	1.1	62	73	.29	7	9		-	0.0	None	None
7.4	6.4	1.0	59	69	.30	6	9		-	0.0	None	None
7.1	6.6	0.5	58	63	.32	7	10		-	0.0	None	None

gles were
re removed.

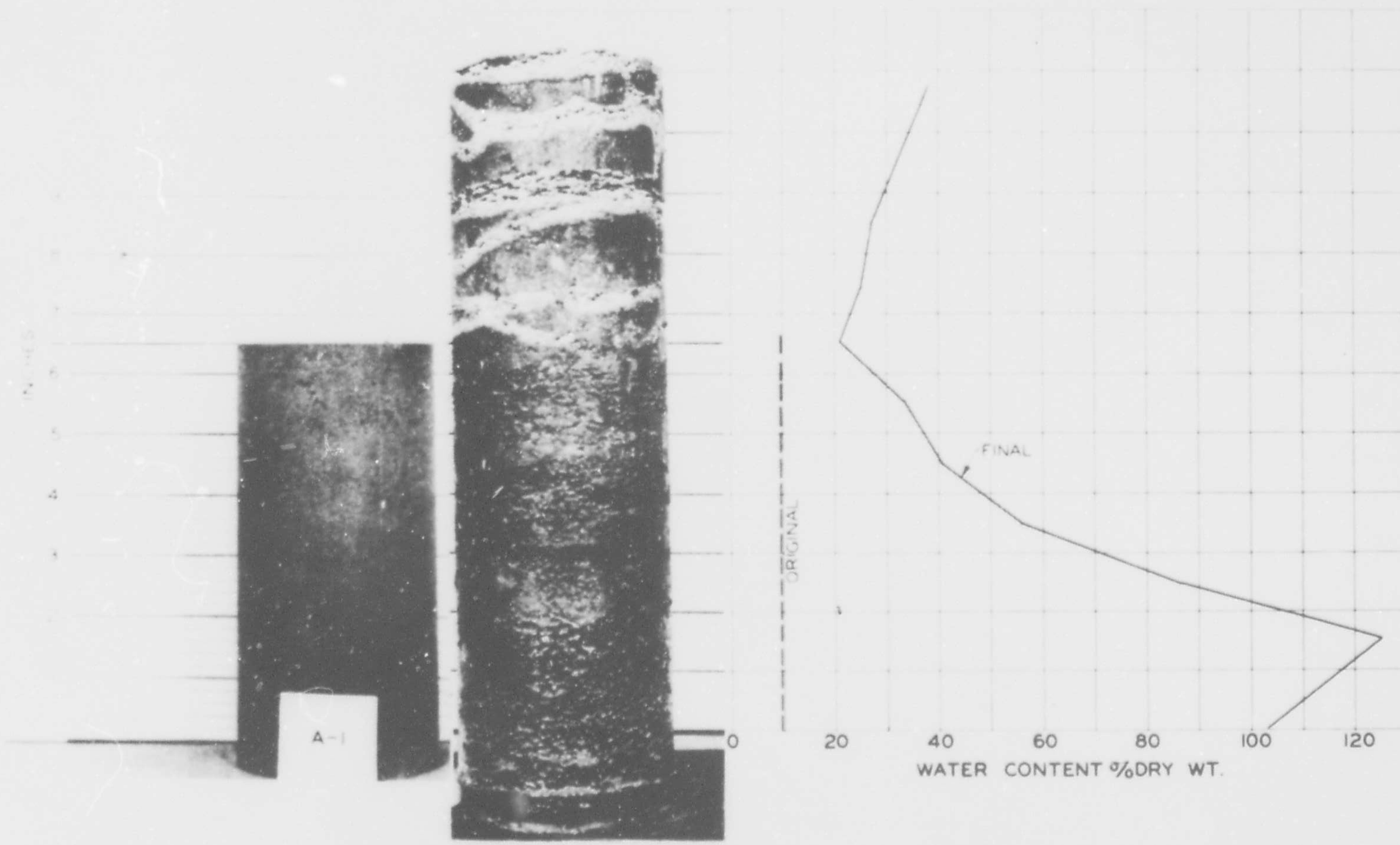
FROST INVESTIGATION
1945 - 1946

BASE COURSE TREATMENT
TO PREVENT FROST ACTION

SUMMARY OF FROST ACTION TEST DATA

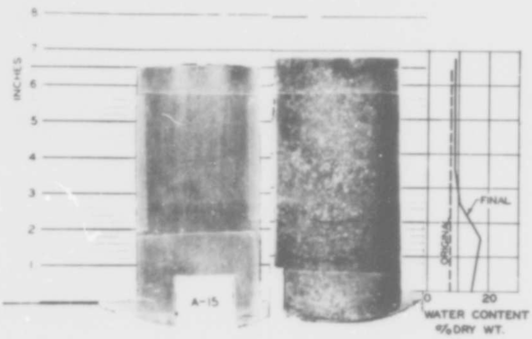
JUNE 1946
FROST EFFECTS LABORATORY, BOSTON, MASS.

PLATE A-15



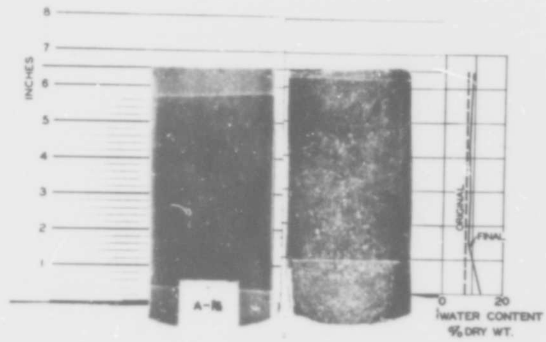
HEAVE AND WATER CONTENT DATA
SAMPLE A-1

EAST BOSTON TILL WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 127 PCF, WATER CONTENT 9.7 PER CENT AND 76 PER CENT SATURATION. FINAL WATER CONTENT 46.4 PER CENT.



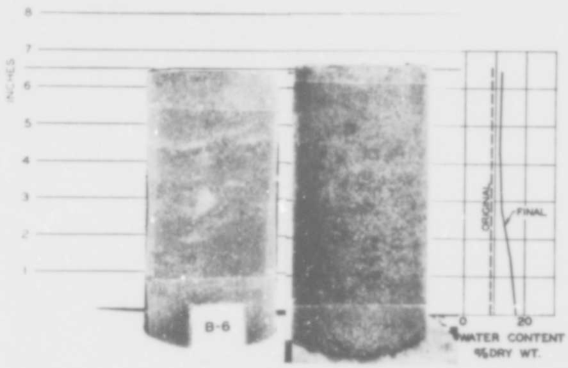
SAMPLE A-15

EAST BOSTON TILL WITH 4 PER CENT RT-2 ADMIXTURE. ORIGINAL DRY WEIGHT 124 pcf, WATER CONTENT 7.7 PER CENT AND 56 PER CENT SATURATION.



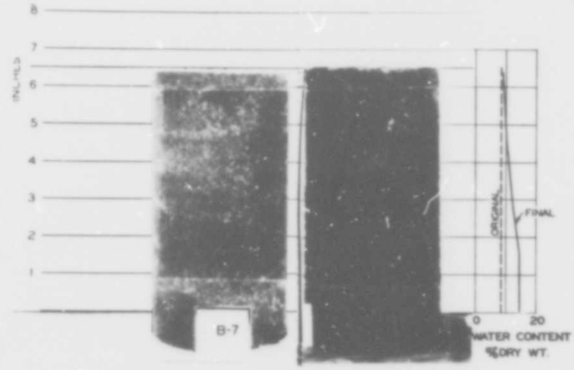
SAMPLE A-16

EAST BOSTON TILL WITH 6 PER CENT RT-2 ADMIXTURE. ORIGINAL DRY WEIGHT 124 pcf, WATER CONTENT 7.5 PER CENT AND 54 PER CENT SATURATION.



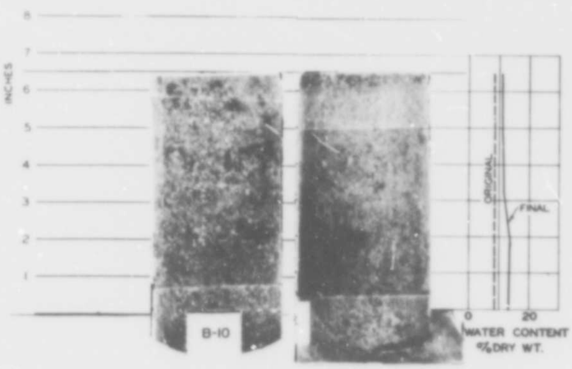
SAMPLE B-6

EAST BOSTON TILL WITH 1 PER CENT RT-2 AND 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURES. ORIGINAL DRY WEIGHT 127 pcf, WATER CONTENT 9.0 PER CENT AND 72 PER CENT SATURATION.



SAMPLE B-7

EAST BOSTON TILL WITH 2 PER CENT RT-2 AND 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURES. ORIGINAL DRY WEIGHT 126 pcf, WATER CONTENT 8.4 PER CENT AND 65 PER CENT SATURATION.

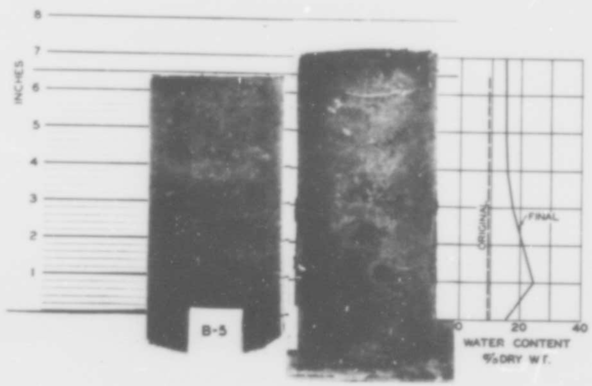


SAMPLE B-10

EAST BOSTON TILL WITH 1 PER CENT BUNKER "C" OIL AND 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURES. ORIGINAL DRY WEIGHT 128 pcf, WATER CONTENT 8.6 PER CENT AND 60 PER CENT SATURATION.

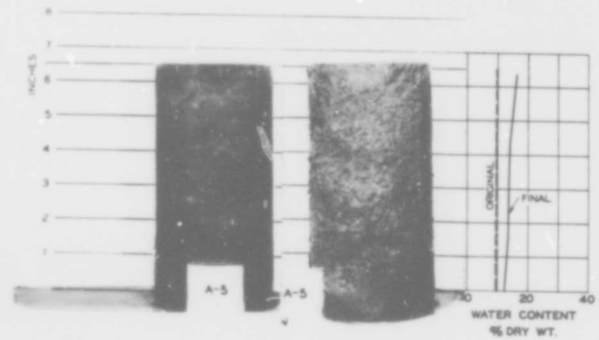
HEAVE AND WATER CONTENT DATA

PLATE A-17



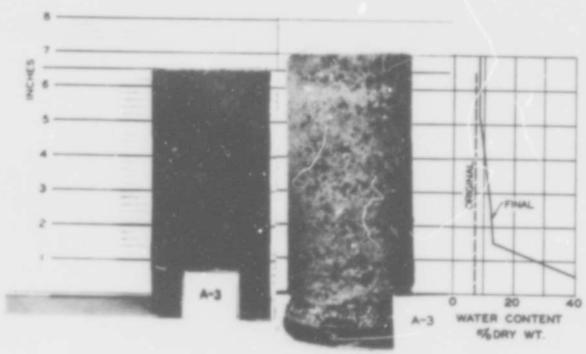
SAMPLE B-5

EAST BOSTON TILL WITH 0.5 PER CENT CALCIUM CHLORIDE ADMIXTURE ORIGINAL DRY WEIGHT 127 pcf, WATER CONTENT 9.2 PER CENT AND 72 PER CENT SATURATION.



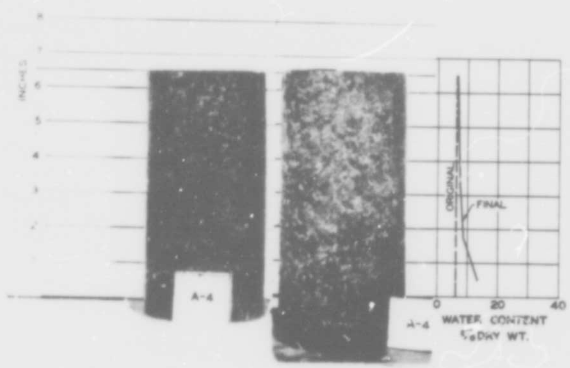
SAMPLE A-5

EAST BOSTON TILL WITH 1 PER CENT CALCIUM CHLORIDE ADMIXTURE. ORIGINAL DRY WEIGHT 128 pcf, WATER CONTENT 9.1 PER CENT AND 77 PER CENT SATURATION.



SAMPLE A-3

EAST BOSTON TILL WITH 1% BUNKER "C" OIL ADMIXTURE. ORIGINAL DRY WEIGHT 125 pcf, WATER CONTENT 7.1 PER CENT, AND 55 PER CENT SATURATION.

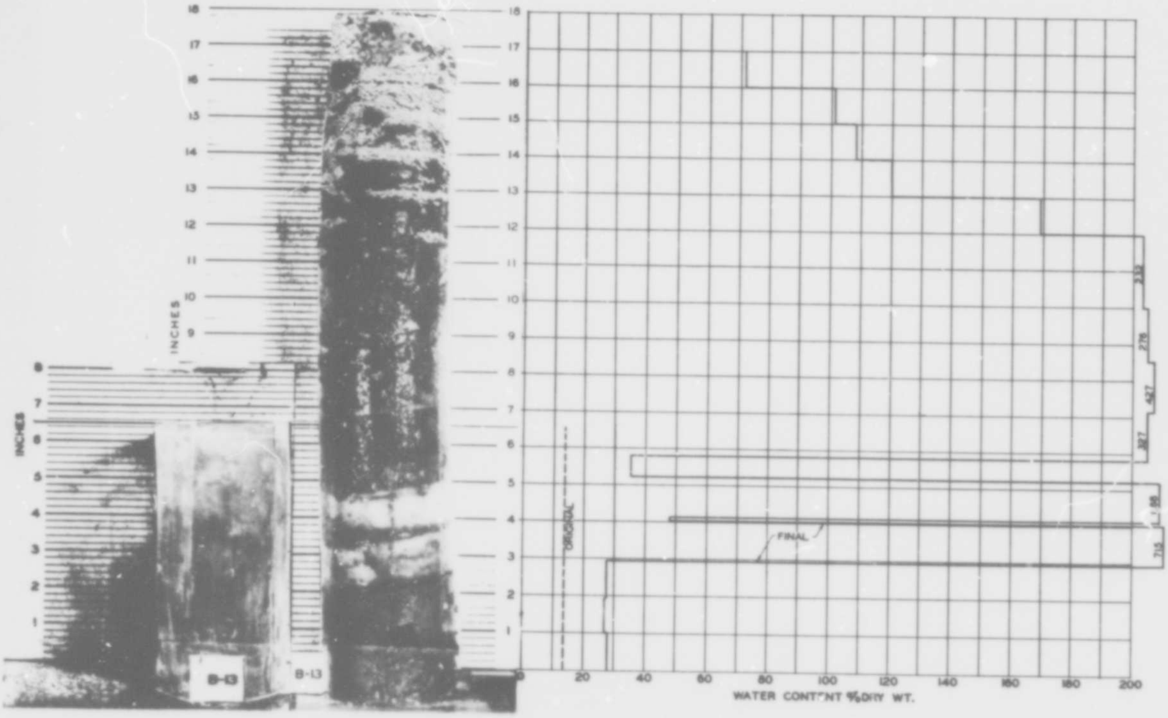


SAMPLE A-4

EAST BOSTON TILL WITH 4% BUNKER "C" OIL ADMIXTURE. ORIGINAL DRY WEIGHT 126 pcf, WATER CONTENT 6.2 PER CENT, 48 PER CENT SATURATION.

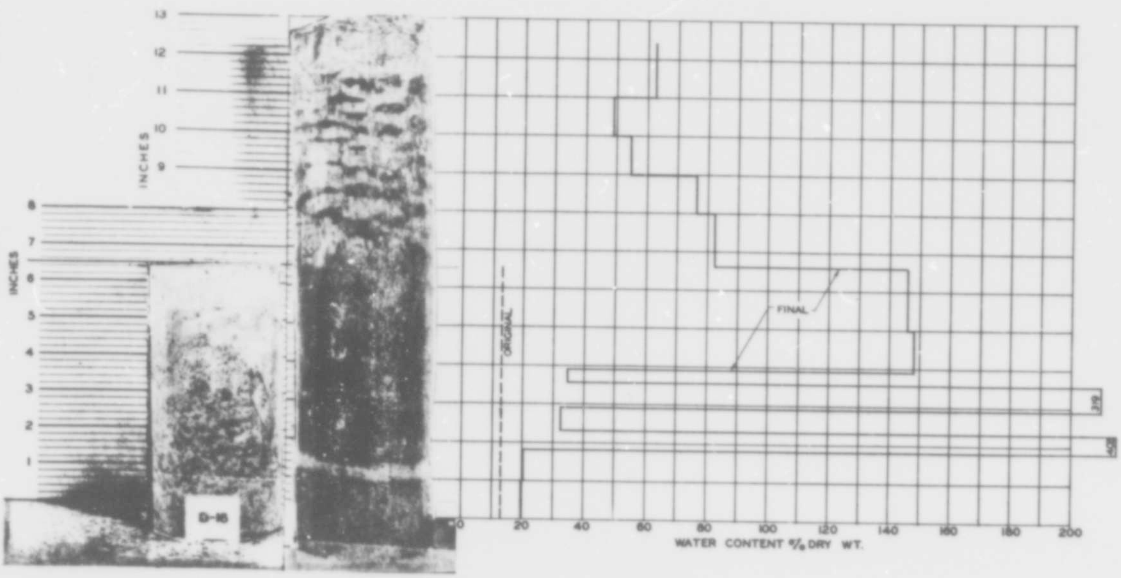
HEAVE AND WATER CONTENT DATA

PLATE A-18



SAMPLE B-13

NEW HAMPSHIRE SILT WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 101 pcf.
WATER CONTENT 13.4 PER CENT AND 55 PER CENT SATURATION.

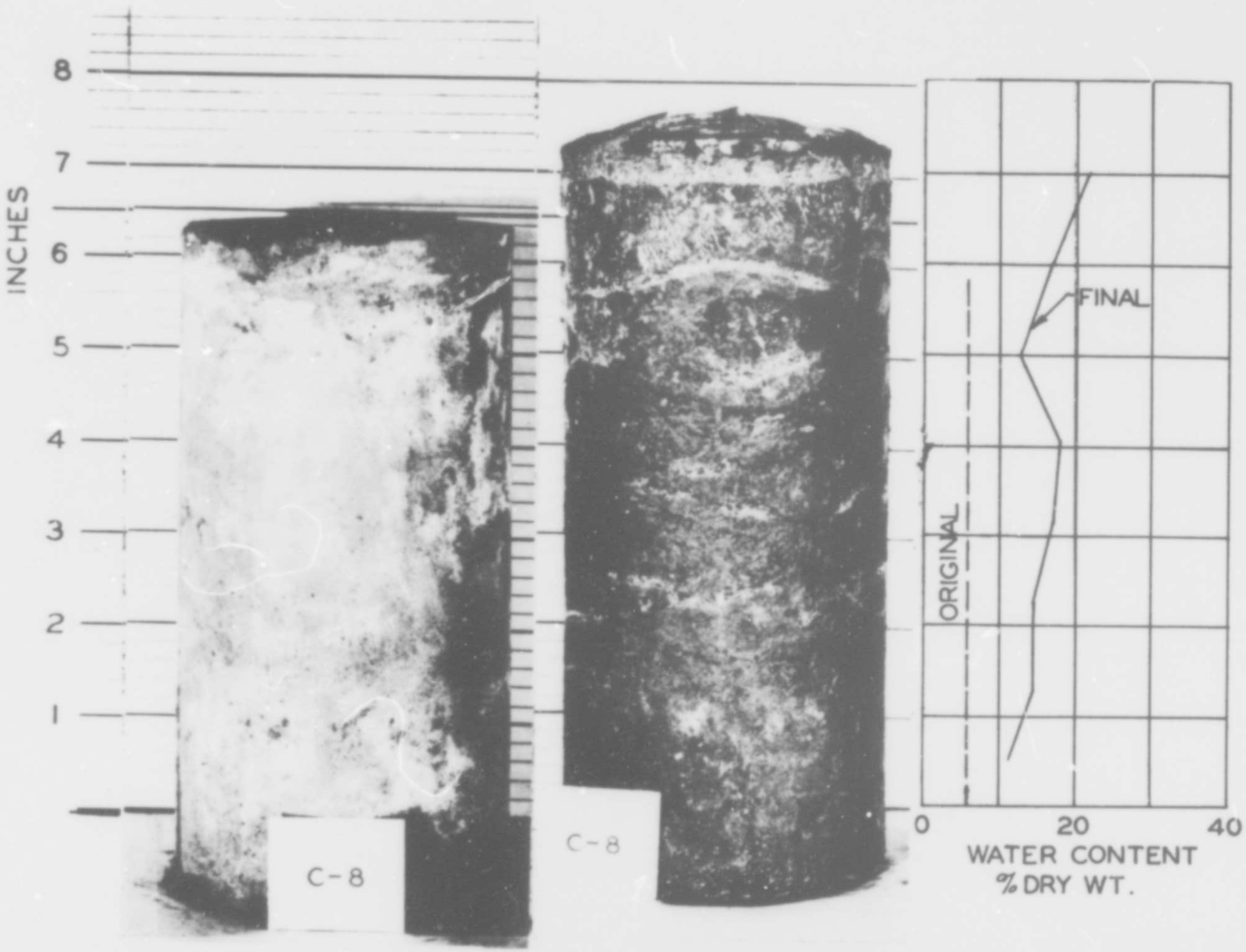


SAMPLE B-16

NEW HAMPSHIRE SILT WITH [illegible] BUNKER "C" OIL ADMIXTURE. ORIGINAL DRY WEIGHT
107 pcf, WATER CONTENT 13.0 PER CENT AND 62 PER CENT SATURATION.

HEAVE AND WATER CONTENT DATA

PLATE A-19



HEAVE AND WATER CONTENT DATA
SAMPLE C-8

FROST HEAVING GRAVEL WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 132 pcf, WATER CONTENT 5.7 PER CENT AND 58 PER CENT SATURATION.

FROST INVESTIGATION

SUMMARY OF LEACHING TEST DATA

BASE COURSE TREATMENT TO PREVENT FROST AC

Sample No.	Percent Calcium Chloride	Percent Bunker "C" Oil	Unit dry weight, pcf	Water Content		Vol. of Voids cc	Void Ratio e	Degree of Saturati %	
				Before Testing	After Testing			Before Testing	After Testing
1	2.0	0	123	8.8	14.6	81.9	0.382	61.6	100 +
2	2.0	2	124	8.7	13.1	80.5	0.381	62.6	[illegible]
2c	2.0	2	124	8.2	13.3	80.2	0.380	59.2	96.0
2c*	2.0	2	123	8.2	11.5	45.2	0.370	59.2	88.9
3	2.0	4	123	6.3	13.2	82.1	0.385	47.9	93.1
4a	2.0	1	126	8.6	12.8	76.8	0.357	70.0	100 +
4b	2.0	1	126	8.7	13.7	[illegible]	0.359	66.3	100 +
5	2.0	1.5	125	8.5	13.6	78.7	0.364	61.1	100 +
6	2.0	0.5	125	8.6	17.4	79.3	0.373	62.9	99.5
6b	2.0	0.5	125	5.3	13.7	73.0	0.368	61.3	99.1
1-0.5CA	0.5	-	127	8.7	13.2	65.6	0.349	68.0	100 +
2-1.0CA	1.0	-	125	9.5	13.0	77.7	0.374	70.0	95.0
3-1.5CA	1.5	-	127	9.8	13.5	59.4	0.348	73.4	100 +
4-2.0CA	2.0	-	123	8.8	14.6	81.9	0.382	61.6	100 +
1-0.5CB	0.5	-	113	7.4	16.3	99.1	0.510	37.5	87.7
2-1.0CB	1.0	-	113	7.2	17.2	94.7	0.520	[illegible]	91.0
3-1.5CB	1.5	-	113	9.8	16.4	[illegible]	0.500	[illegible]	98.4
4-2.0CB	2.0	-	114	8.2	15.8	63.2	0.505	[illegible]	92.4
1-0.5CC	0.5	-	99	5.3	18.2	41.1	0.721	31.6	69.3
2-1.0CC	1.0	-	102	6.8	16.2	82.3	0.677	[illegible]	65.7
3-1.5CC	1.5	-	103	12.4	17.6	[illegible]	[illegible]	[illegible]	72.1
4-2.0CC	2.0	-	98	[illegible]	17.4	82.3	0.740	30.6	64.1

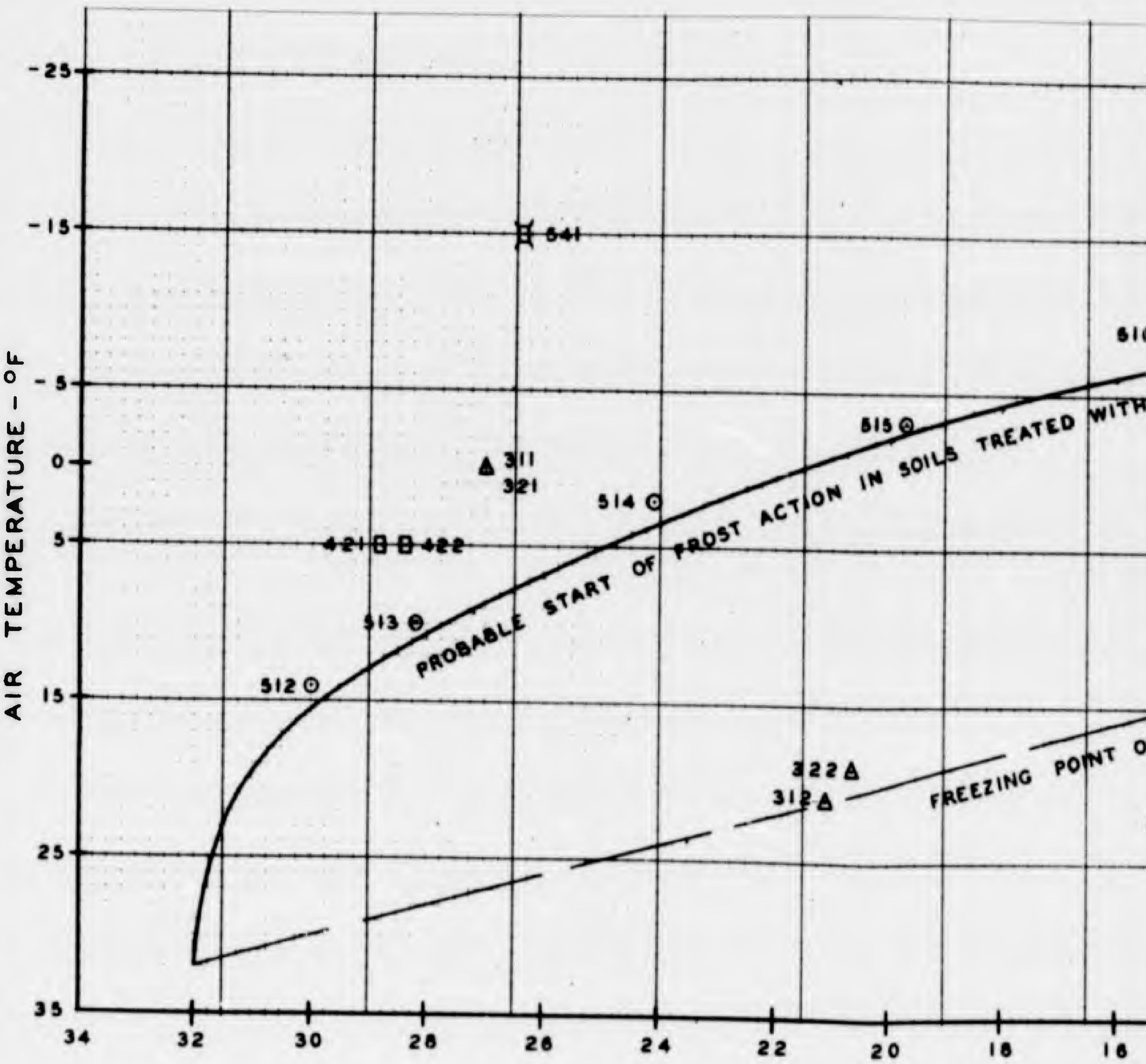
* Material and mix same as 2c. Test performed in Lucite Cylinder.
Note: Sample No. 1 same as sample No. 4 - 2.0CA

T INVESTIGATION

LEACHING TEST DATA

ENT TO PREVENT FROST ACTION

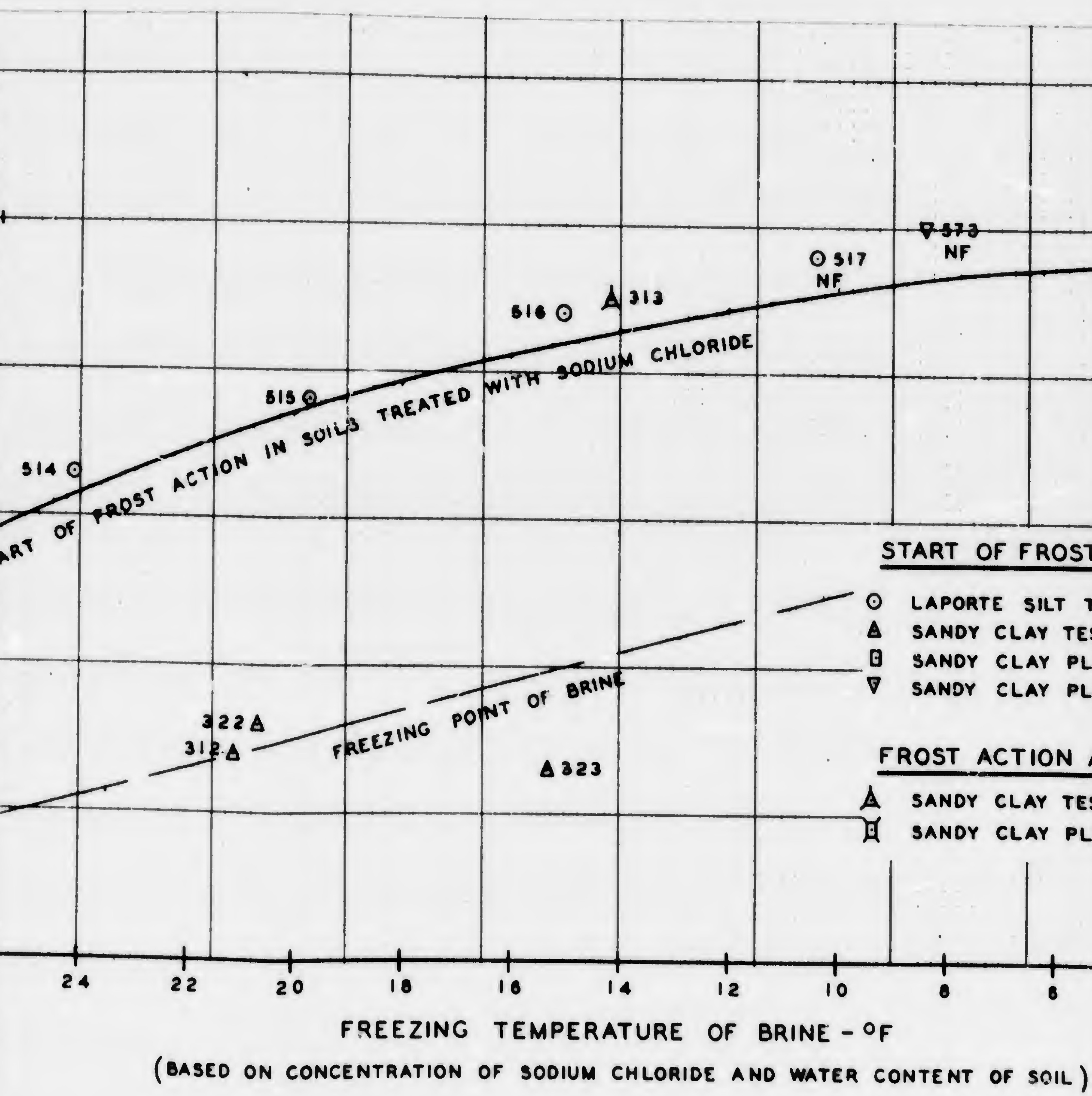
...d ...io	Degree of Saturation %		Coefficient of Permeability 10-4	Hydraulic Gradient	No. of Changes of Water in Sample to Leach Salt	Time Required to Leach Salt hours	Test Performed in
	Before Testing	After Testing					
[illegible]	61.6	100 +	0.006	133	21	26	Consolido-
1	62.6	[illegible].3	0.007	133	52	360	meter
0	[illegible]	96.0	0.007	133	28	247	"
0	[illegible]	98.9	0.007	145	44	230	Lucite Cyl.
[illegible]	47.9	93.1	0.00045	133	12	254	Consolido-
7	70.0	100 +	0.002	133	14	245	meter
[illegible]	66.3	100 +	0.0[illegible]	133	15	192	"
[illegible]	44.1	100 +	0.200	133	11	177	"
3	62.9	99.5	0.2[illegible]	133	48	365	"
3	61.3	99.1	0.230	133	20	129	"
[illegible]	68.0	100 +	-	87	13	136	Lucite Cyl.
[illegible]	70.0	95.0	-	87	9	130	"
[illegible]	77.4	100 +	-	95	54	[illegible]	"
[illegible]	61.6	100 +	-	133	21	26	Consolido-
[illegible]	[illegible]	87.7	-	133	16	72	meter
[illegible]	[illegible]	91.0	-	133	25	97	"
[illegible]	[illegible]	98.4	-	133	14	126	"
[illegible]	[illegible]	92.4	-	107	24	159	Lucite Cyl.
[illegible]	[illegible]	69.3	-	109	18	74	"
[illegible]	[illegible]	65.7	-	107	10	121	"
[illegible]	[illegible]	72.1	-	[illegible]	17	35	"
[illegible]	[illegible]	64.1	-	113	11	73	"



FREEZING TEM

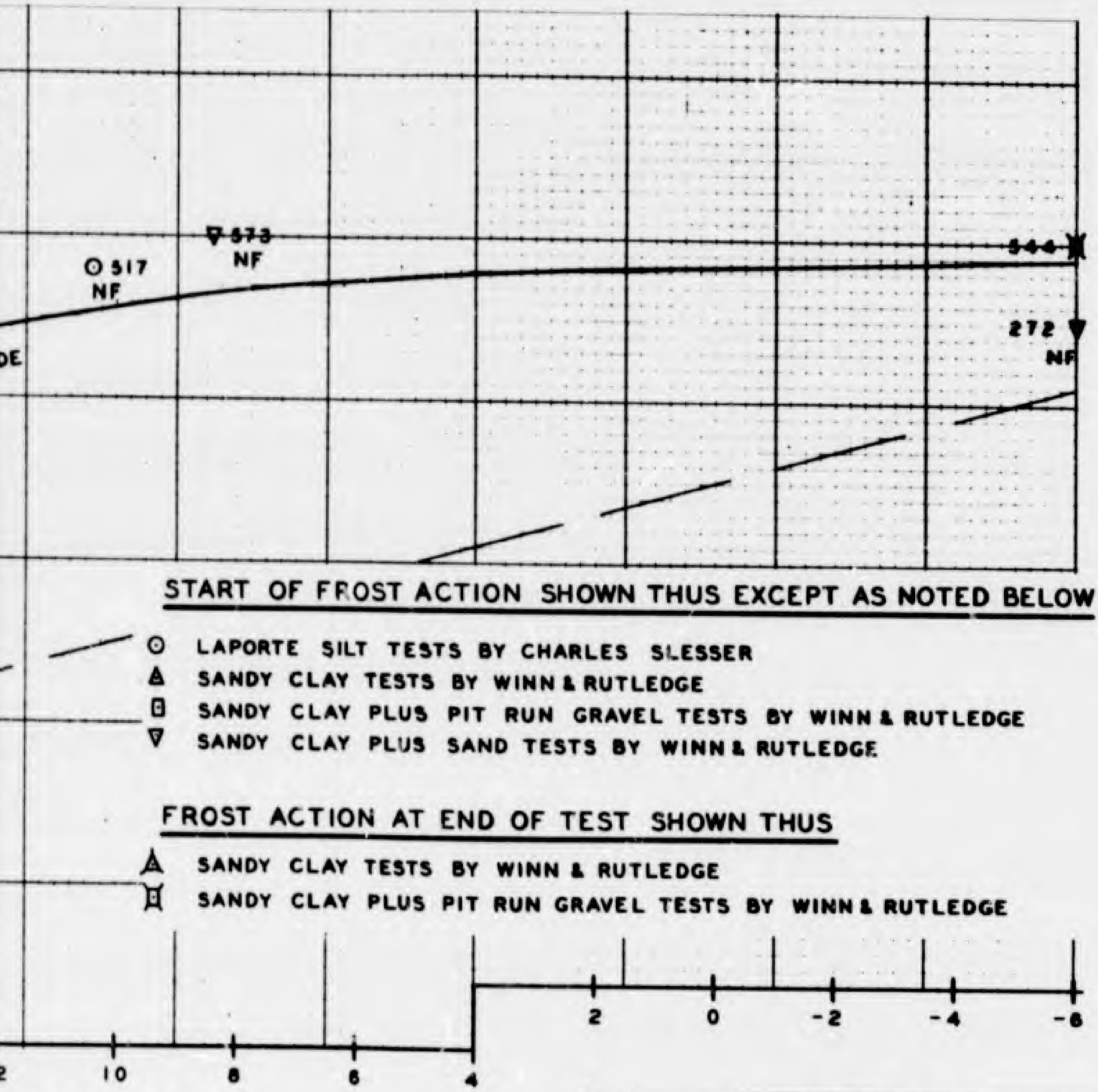
(BASED ON CONCENTRATION OF SO

NOTES:- FIGURES BESIDE PLOTTED POINTS ARE SPECIMEN NUMBERS ASSIG
THE LETTERS "NF" UNDER PLOTTED POINTS INDICATE THAT NO F
TEMPERATURE TESTED.



PLOTTED POINTS ARE SPECIMEN NUMBERS ASSIGNED IN THE ORIGINAL INVESTIGATION.
"UNDER PLOTTED POINTS INDICATE THAT NO FROST HEAVE OCCURED TO LOWEST
STED.

B



T BRINE - °F

AND WATER CONTENT OF SOIL)

GINAL INVESTIGATION.

URED TO LOWEST

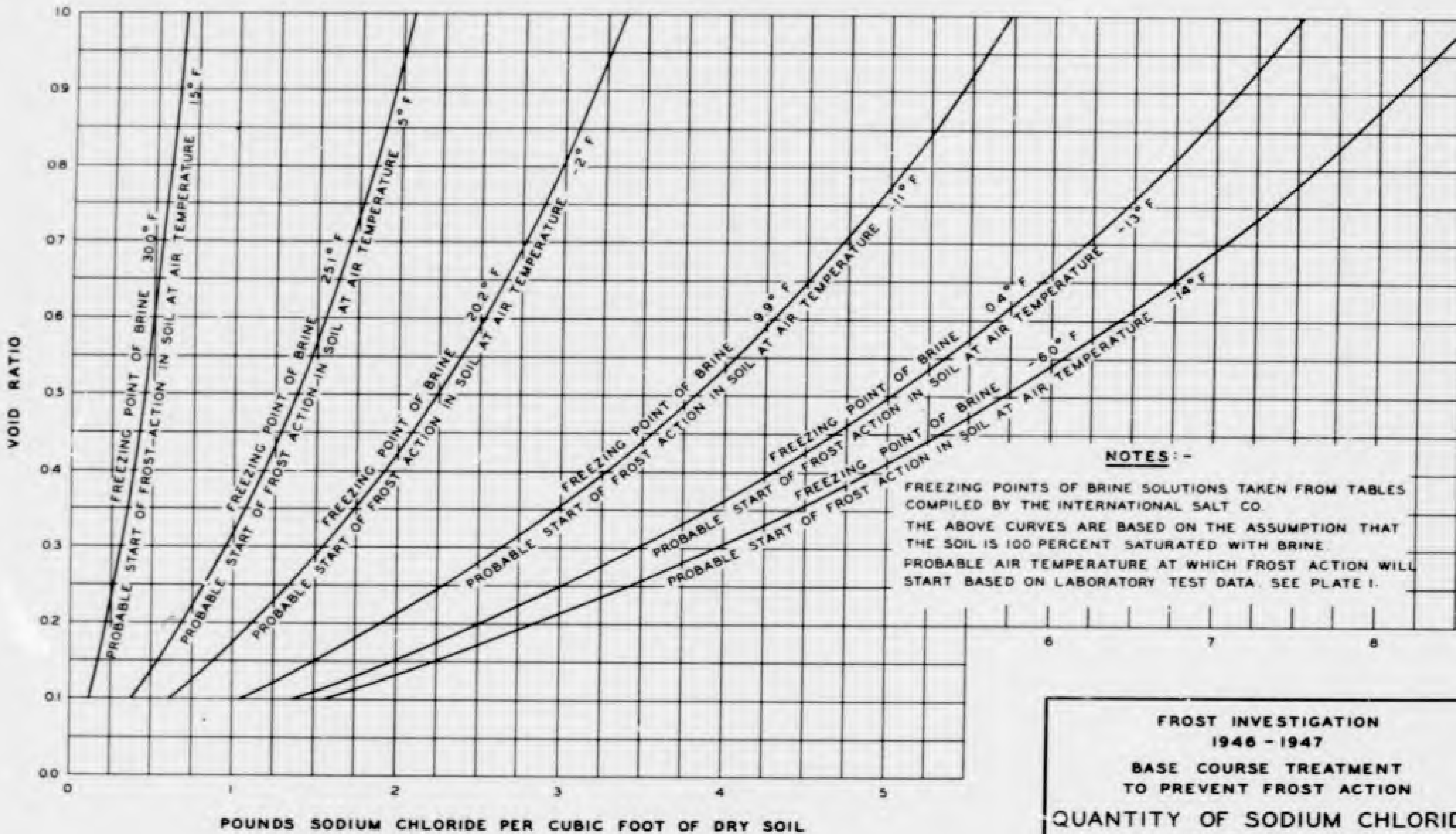
FROST INVESTIGATION
1946 - 1947
BASE COURSE TREATMENT
TO PREVENT FROST ACTION

PROBABLE START OF FROST ACTION
IN SOILS
TREATED WITH SODIUM CHLORIDE

SOILS LABORATORY
NEW ENGLAND DIVISION

JUNE 1947
BOSTON, MASS.

PLATE A-22



NOTES:-

FREEZING POINTS OF BRINE SOLUTIONS TAKEN FROM TABLES COMPILED BY THE INTERNATIONAL SALT CO.

THE ABOVE CURVES ARE BASED ON THE ASSUMPTION THAT THE SOIL IS 100 PERCENT SATURATED WITH BRINE.

PROBABLE AIR TEMPERATURE AT WHICH FROST ACTION WILL START BASED ON LABORATORY TEST DATA. SEE PLATE I.

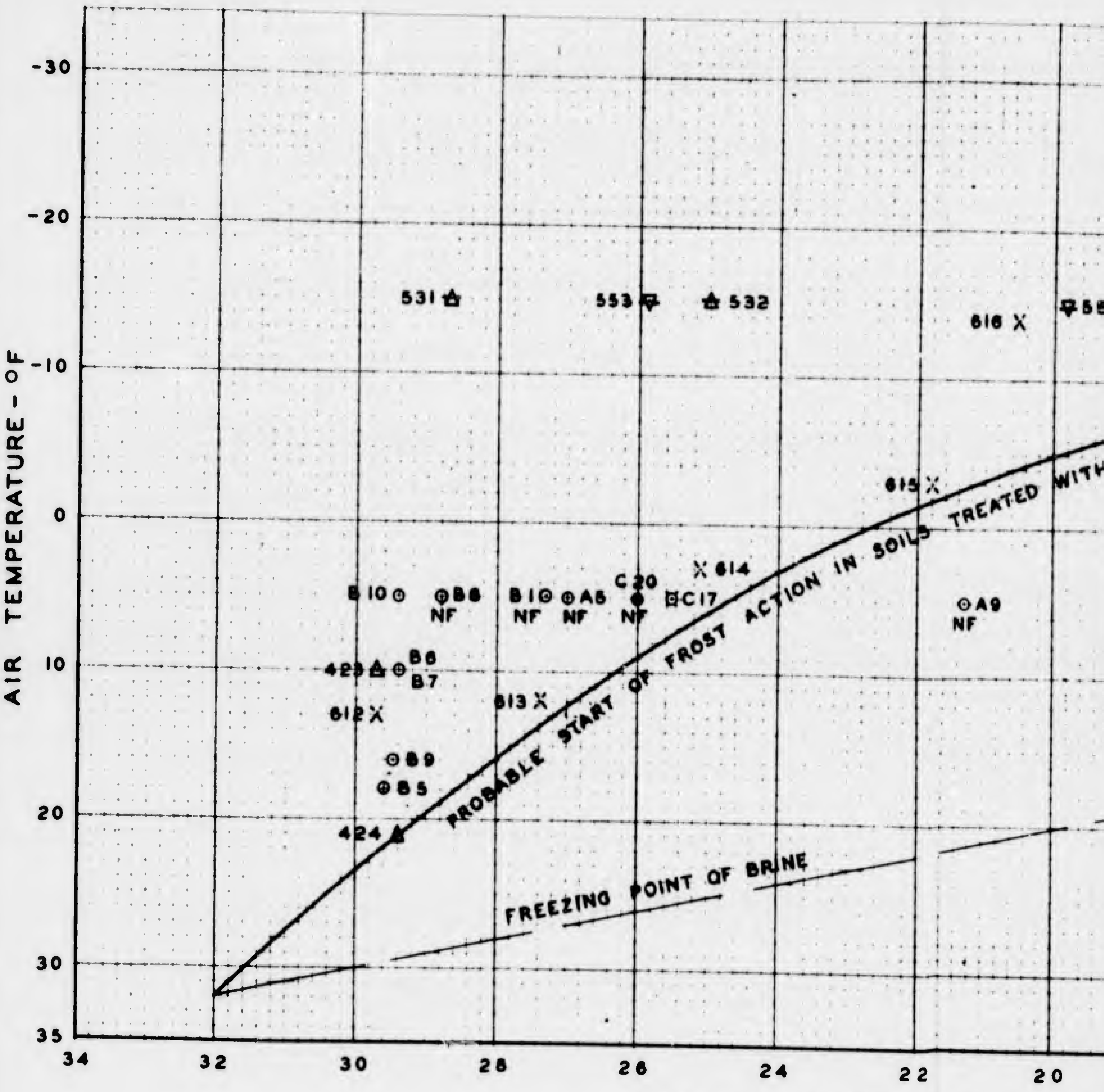
FROST INVESTIGATION
1946 - 1947

BASE COURSE TREATMENT
TO PREVENT FROST ACTION

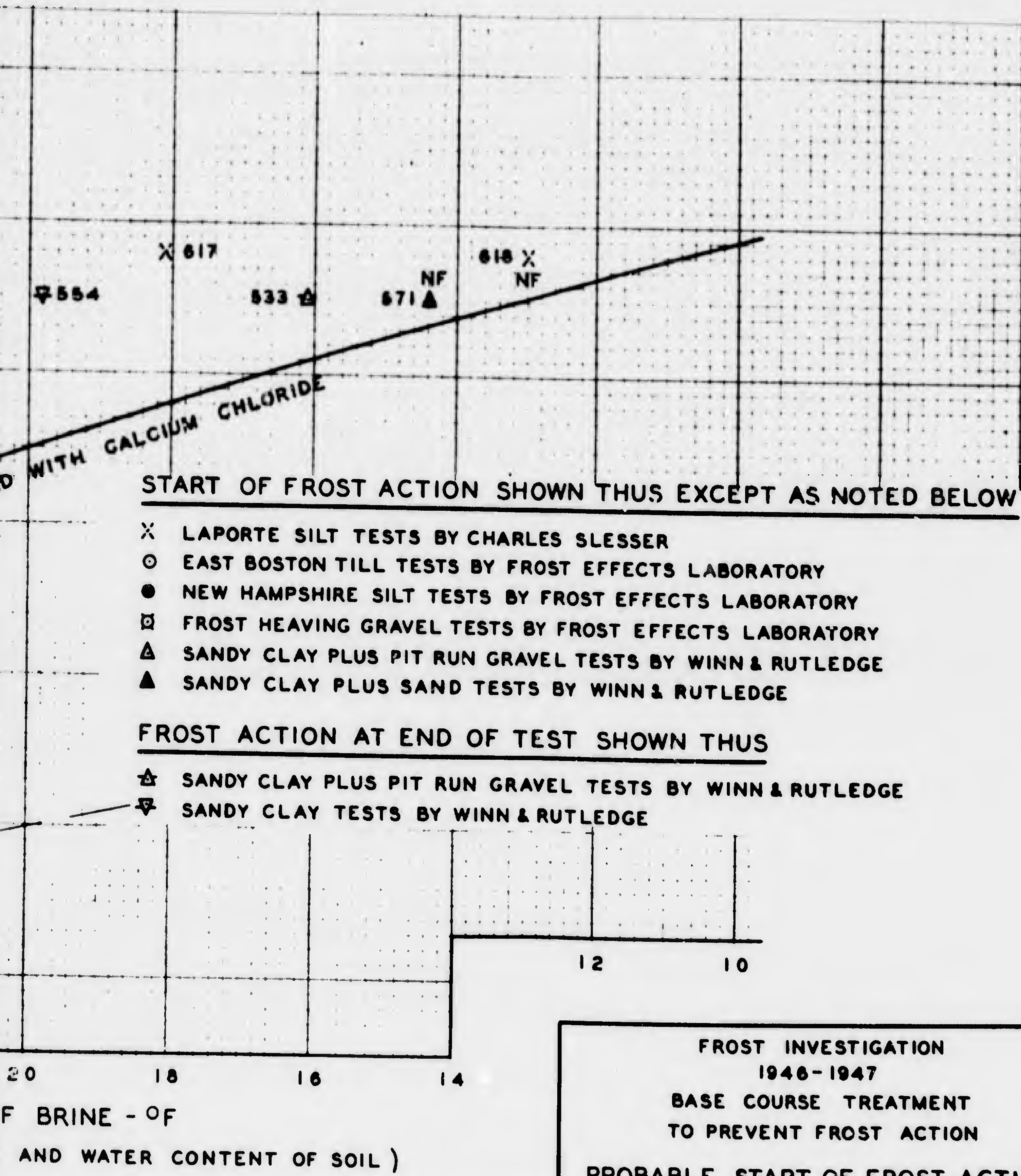
QUANTITY OF SODIUM CHLORIDE REQUIRED TO PREVENT FROST ACTION IN SOILS

SOILS LABORATORY
NEW ENGLAND DIVISION

BOSTON, MASS.
JUNE 1947



NOTES:- FIGURES BESIDE PLOTTED POINTS ARE SPECIMEN NUMBERS ASSIG
THE LETTERS "NF" UNDER PLOTTED POINTS INDICATE THAT NO FI
TEMPERATURE TESTED.



ASSIGNED IN THE ORIGINAL INVESTIGATION.

T NO FROST HEAVE OCCURED TO LOWEST

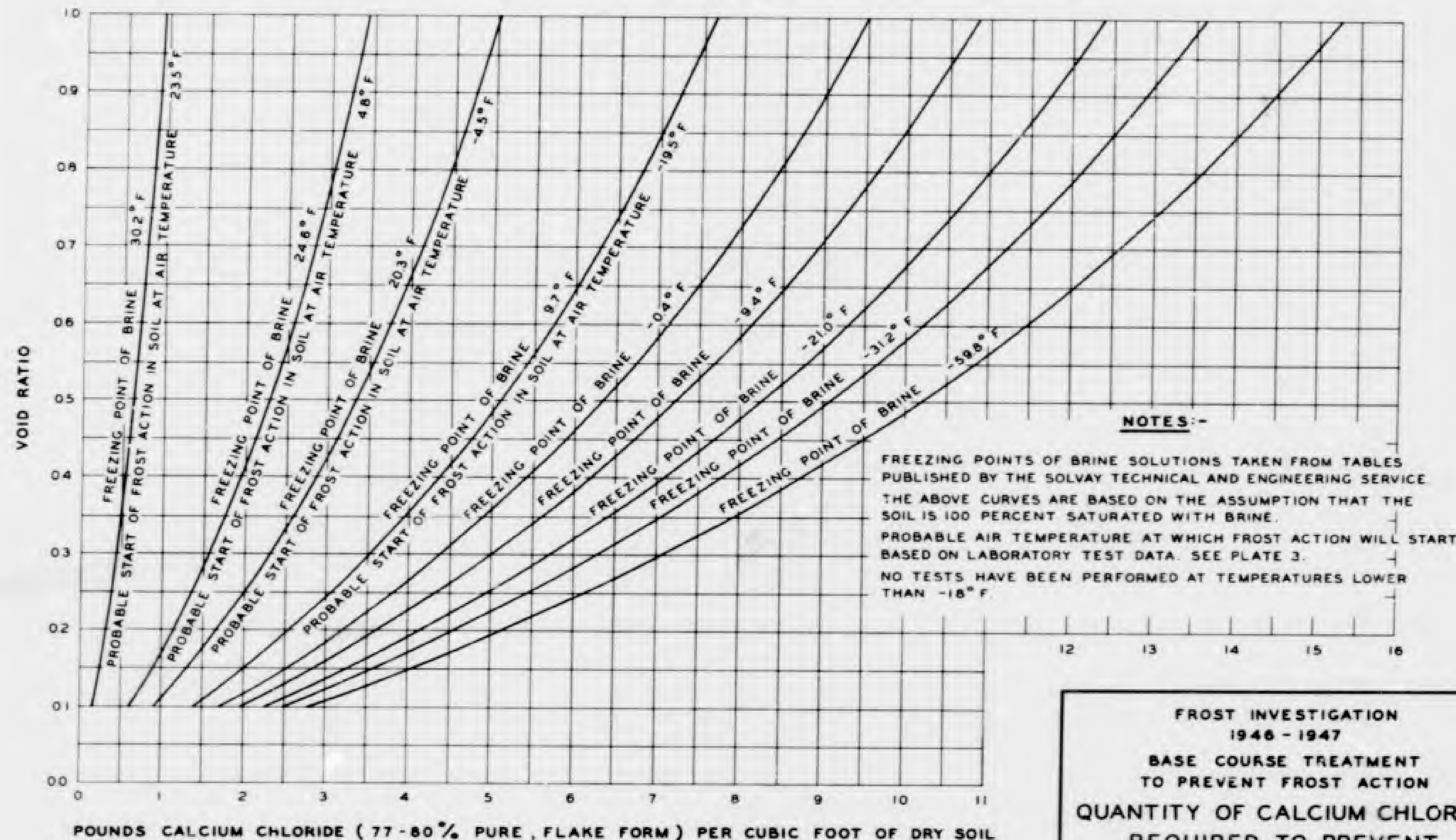
FROST INVESTIGATION
1946-1947
BASE COURSE TREATMENT
TO PREVENT FROST ACTION

PROBABLE START OF FROST ACTION
IN SOILS
TREATED WITH CALCIUM CHLORIDE

SOILS LABORATORY
NEW ENGLAND DIVISION

JUNE 1947
BOSTON, MASS.

PLATE A-24



NOTES:-

FREEZING POINTS OF BRINE SOLUTIONS TAKEN FROM TABLES PUBLISHED BY THE SOLVAY TECHNICAL AND ENGINEERING SERVICE.

THE ABOVE CURVES ARE BASED ON THE ASSUMPTION THAT THE SOIL IS 100 PERCENT SATURATED WITH BRINE.

PROBABLE AIR TEMPERATURE AT WHICH FROST ACTION WILL START BASED ON LABORATORY TEST DATA. SEE PLATE 3.

NO TESTS HAVE BEEN PERFORMED AT TEMPERATURES LOWER THAN -18° F.

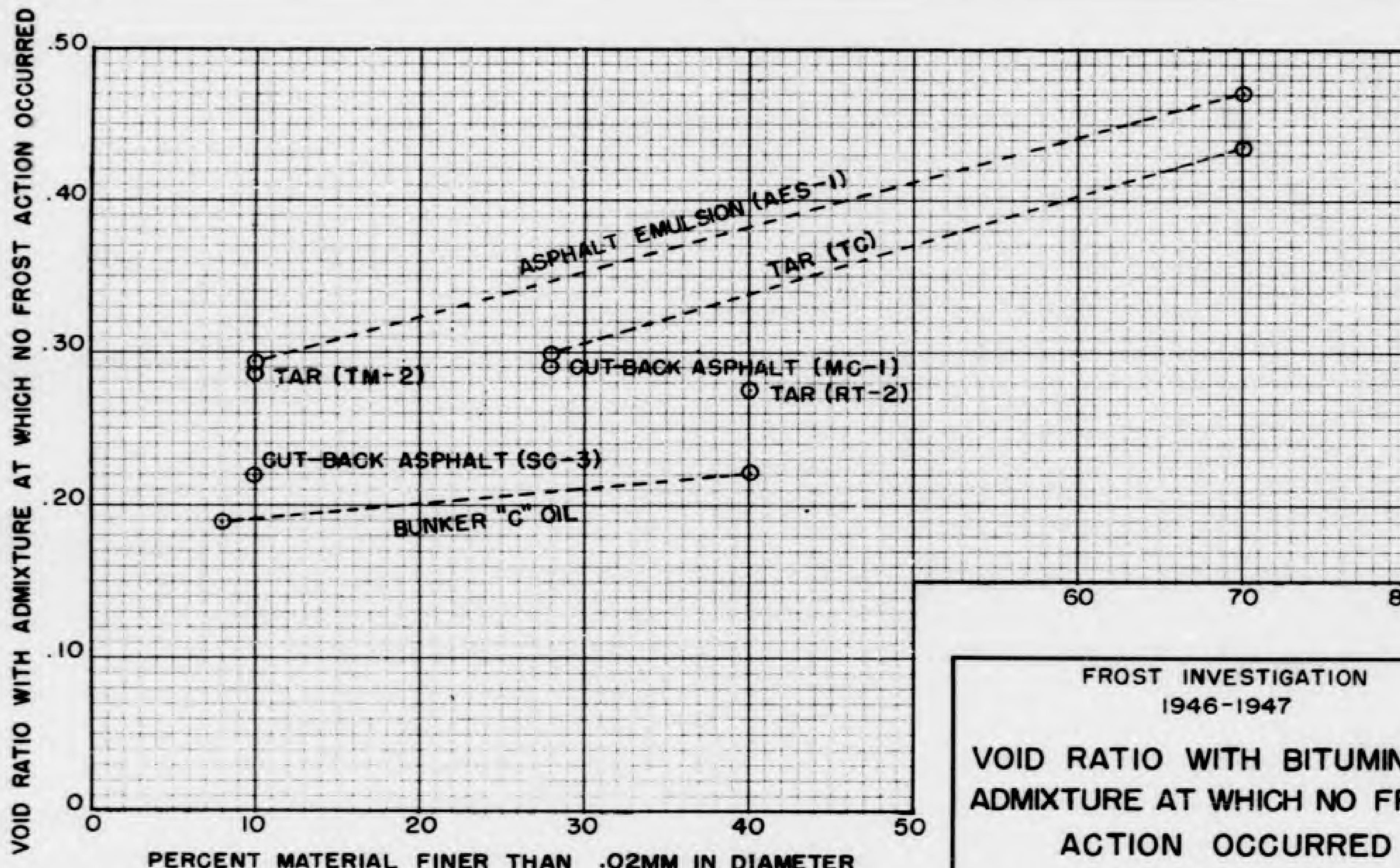
FROST INVESTIGATION
1946 - 1947

BASE COURSE TREATMENT
TO PREVENT FROST ACTION

QUANTITY OF CALCIUM CHLORIDE REQUIRED TO PREVENT FROST ACTION IN SOILS

SOILS LABORATORY
NEW ENGLAND DIVISION

BOSTON, MASS
JUNE 1947

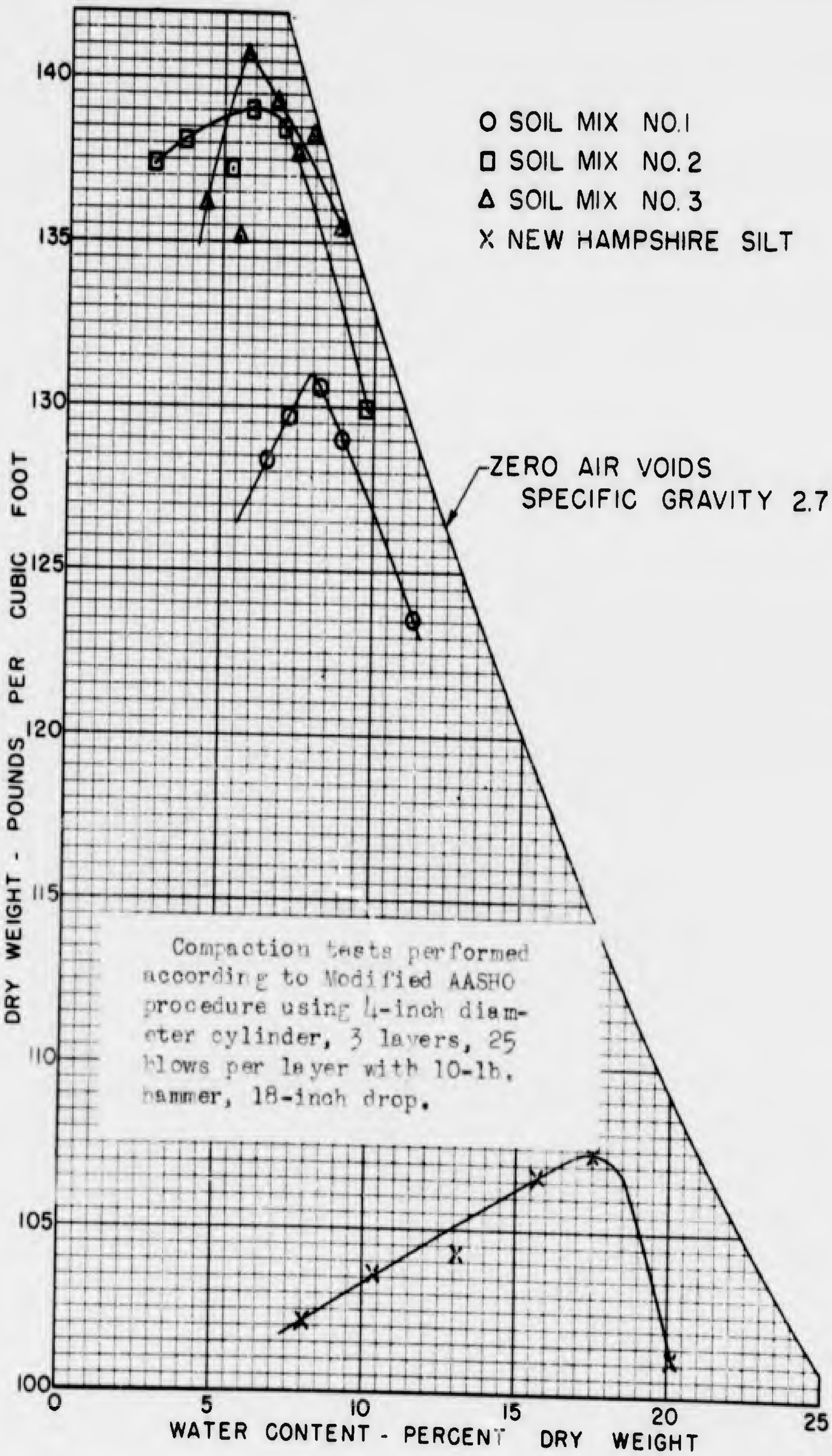


FROST INVESTIGATION
1946-1947

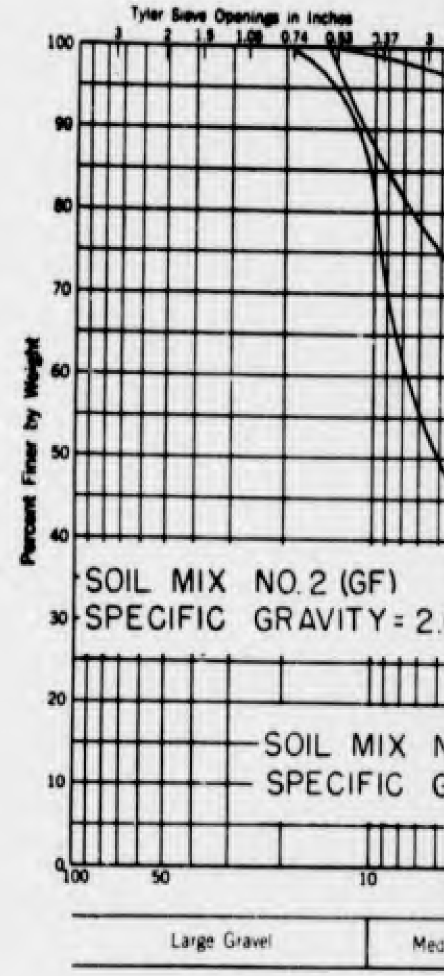
VOID RATIO WITH BITUMINOUS ADMIXTURE AT WHICH NO FROST ACTION OCCURRED

SOILS LABORATORY — JUNE, 1948
NEW ENGLAND DIVISION — BOSTON, MASS.

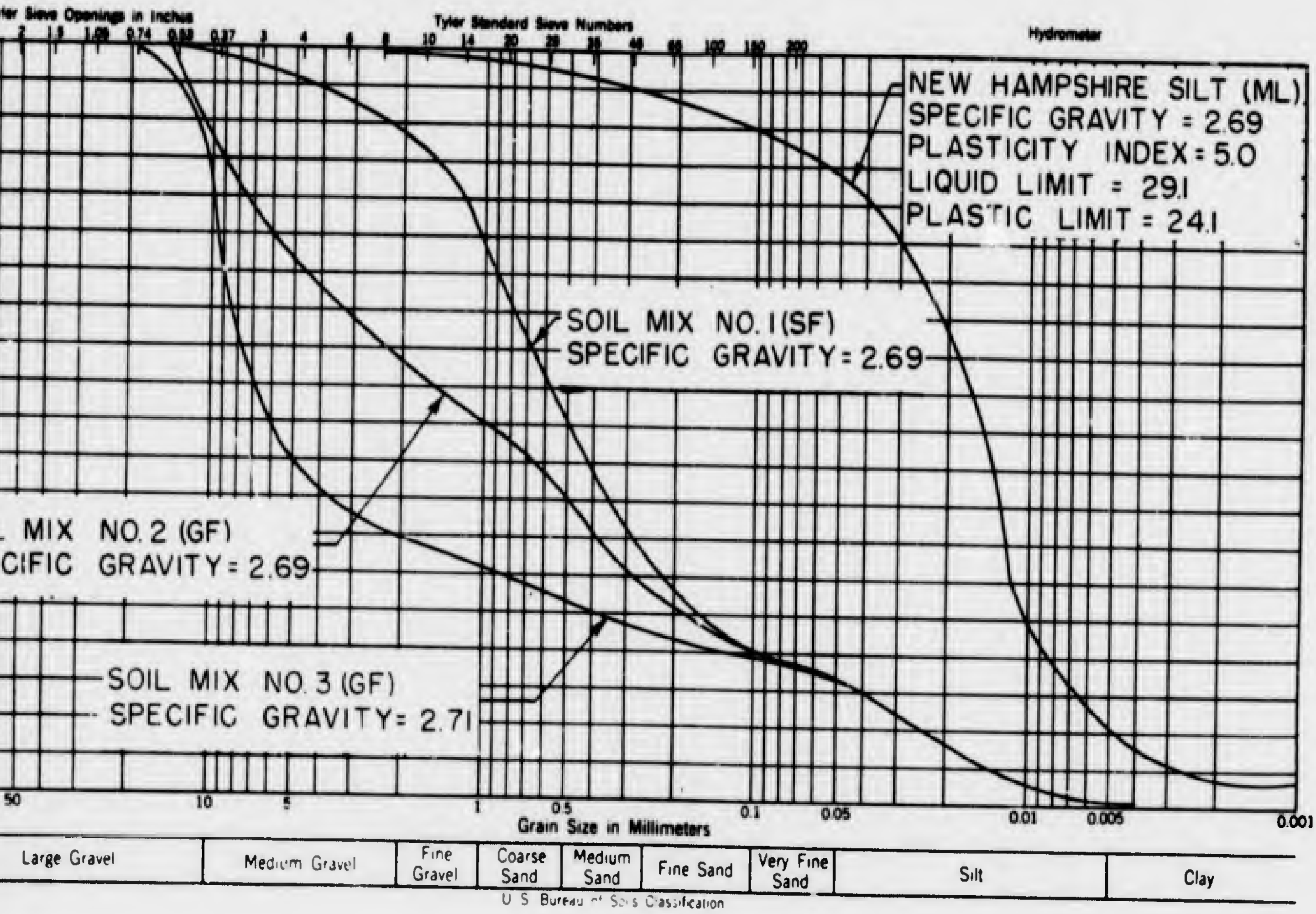
PLATE A-26



O SOIL MIX NO. 1
□ SOIL MIX NO. 2
Δ SOIL MIX NO. 3
X NEW HAMPSHIRE SILT
ZERO AIR VOIDS
SPECIFIC GRAVITY 2.7
Compaction tests performed according to Modified AASHO procedure using 4-inch diameter cylinder, 3 layers, 25 blows per layer with 10-lb. hammer, 18-inch drop.
DRY WEIGHT - POUNDS PER CUBIC FOOT
WATER CONTENT - PERCENT DRY WEIGHT
140
135
130
125
120
115
110
105
100
0
5
10
15
20
25



Tyler Sieve Openings in Inches
Percent Finer by Weight
SOIL MIX NO. 2 (GF)
SPECIFIC GRAVITY = 2.
SOIL MIX N
SPECIFIC G
Large Gravel
Med
100
90
80
70
60
50
40
30
20
10
0
100
50
10



FROST INVESTIGATION

1946-1947

BASE COURSE TREATMENT

TO PREVENT FROST ACTION

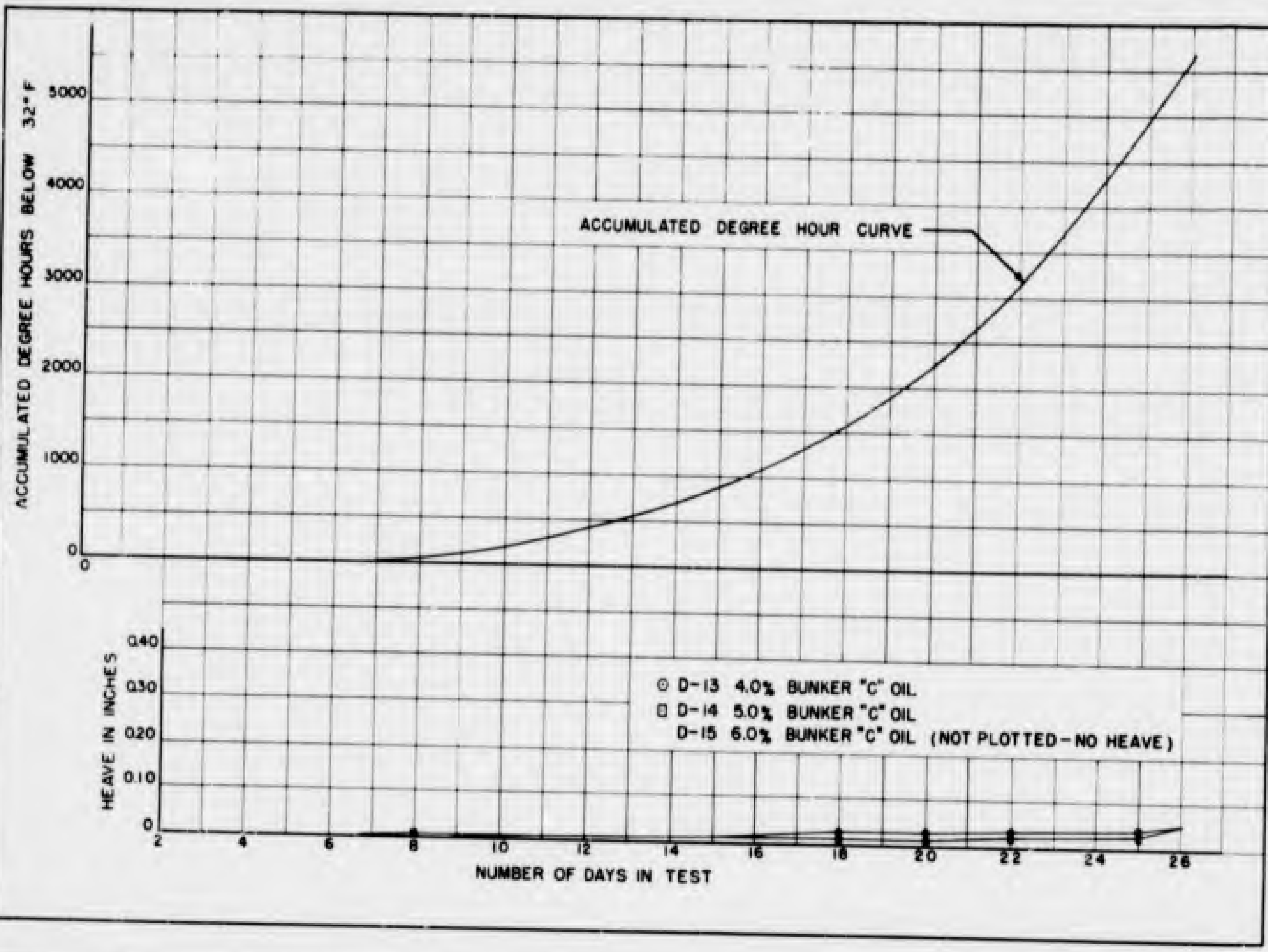
SUMMARY OF SOIL TEST DATA

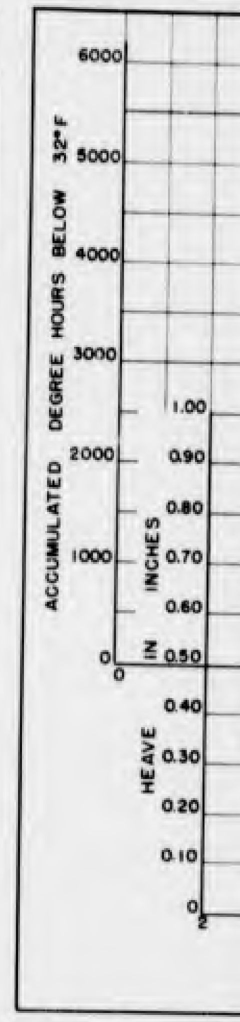
SOILS LABORATORY — JUNE 1947

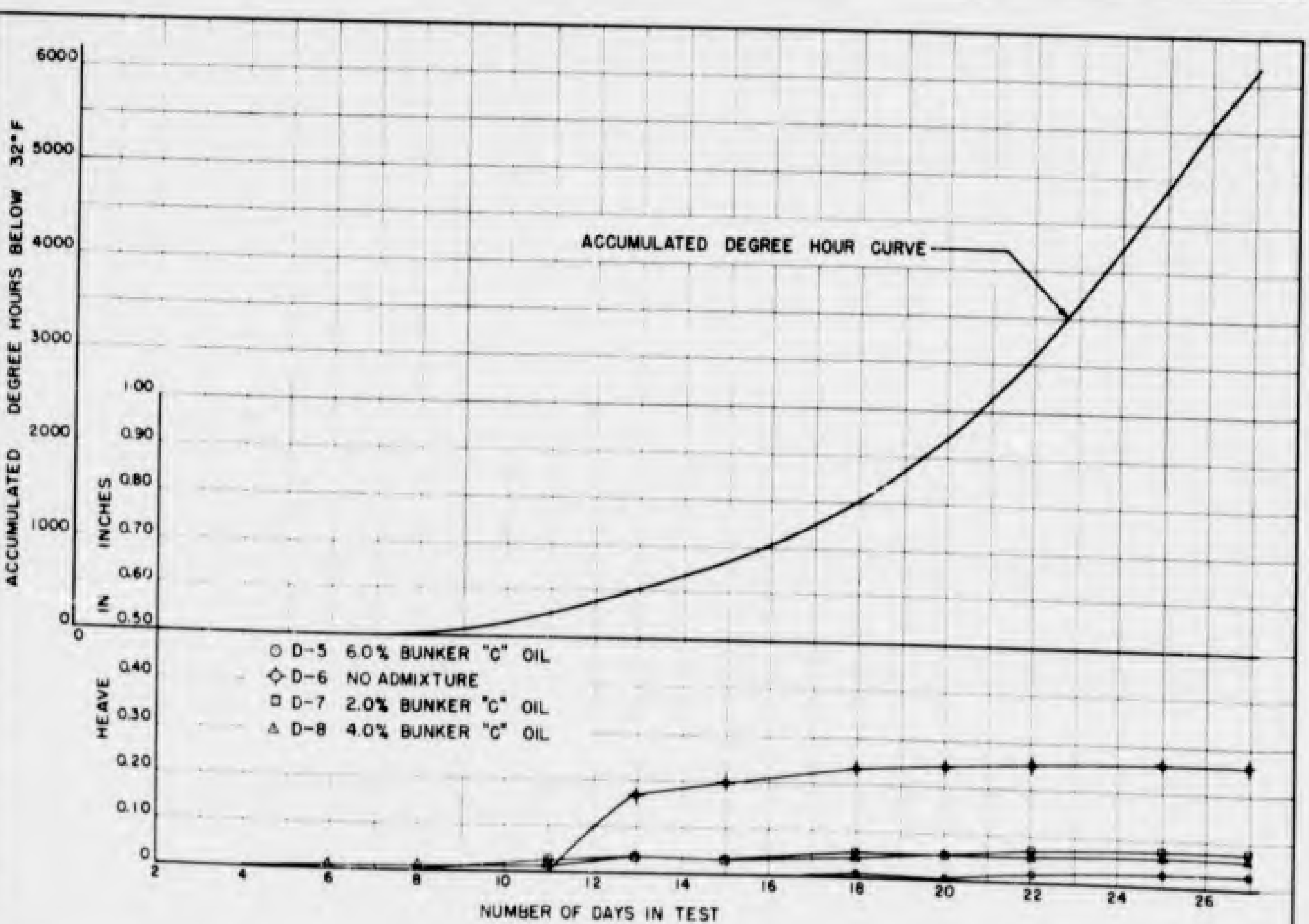
NEW ENGLAND DIVISION — BOSTON, MASS

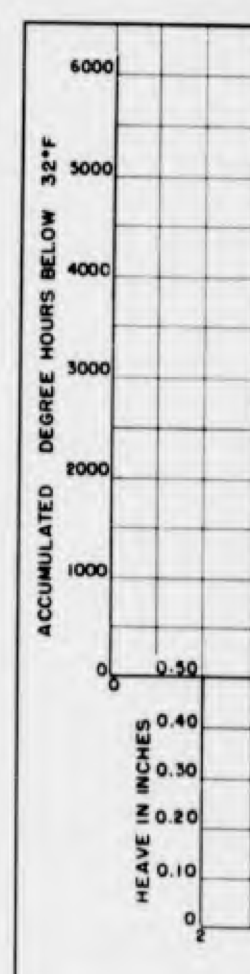
(3)

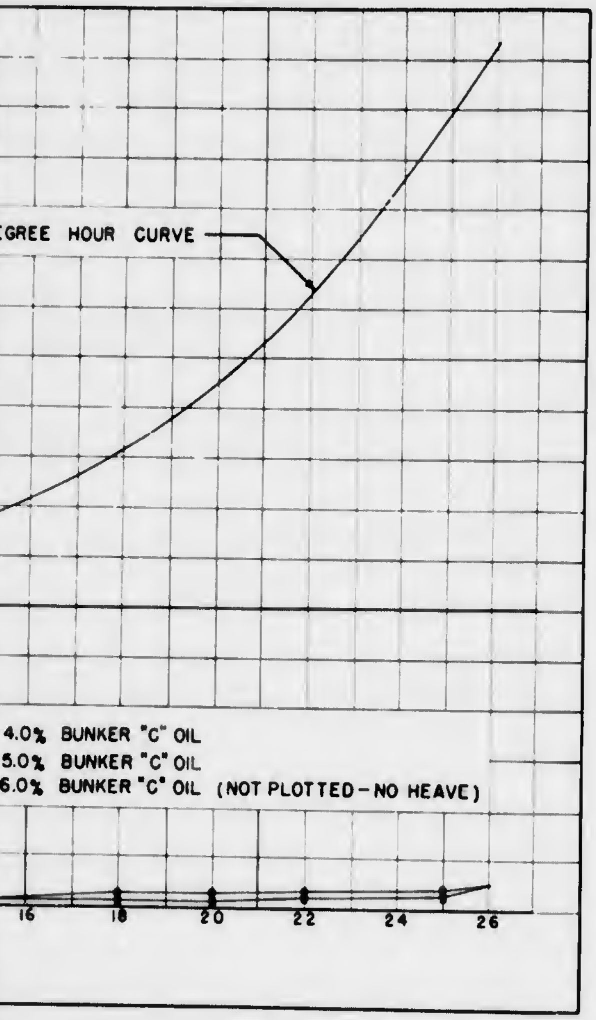
PLATE A-27


ACCUMULATED DEGREE HOURS BELOW 32° F
5000
4000
3000
2000
1000
0
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
0.40
0.30
0.20
0.10
0
D-13 4.0% BUNKER "C" OIL
D-14 5.0% BUNKER "C" OIL
D-15 6.0% BUNKER "C" OIL (NOT PLOTTED-NO HEAVE)
2
4
6
8
10
12
14
16
18
20
22
24
26
NUMBER OF DAYS IN TEST

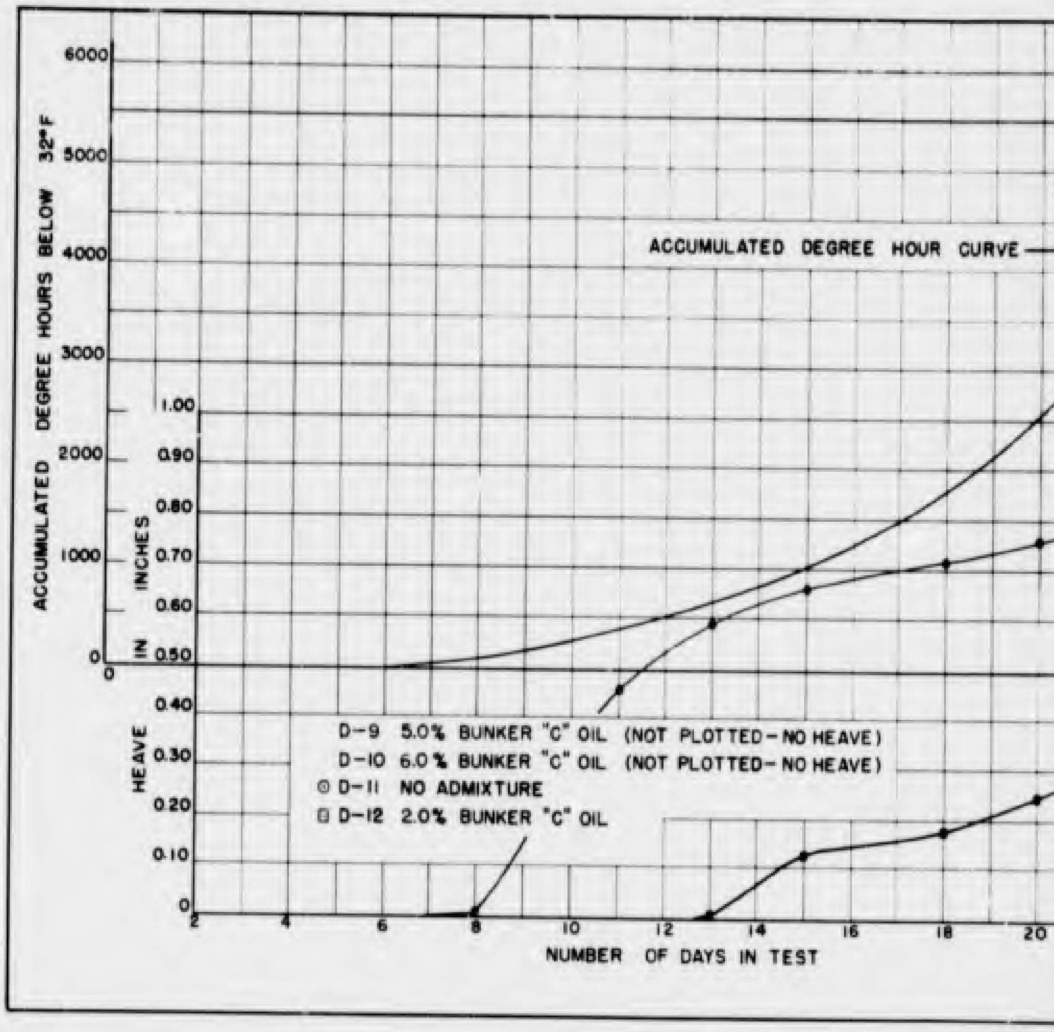

ACCUMULATED DEGREE HOURS BELOW 32°F
6000
5000
4000
3000
2000
1000
0
HEAVE IN INCHES
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
2


ACCUMULATED DEGREE HOURS BELOW 32° F
6000
5000
4000
3000
2000
1000
0
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
D-5 6.0% BUNKER "C" OIL
D-6 NO ADMIXTURE
D-7 2.0% BUNKER "C" OIL
D-8 4.0% BUNKER "C" OIL
2
4
6
8
10
12
14
16
18
20
22
24
26
NUMBER OF DAYS IN TEST

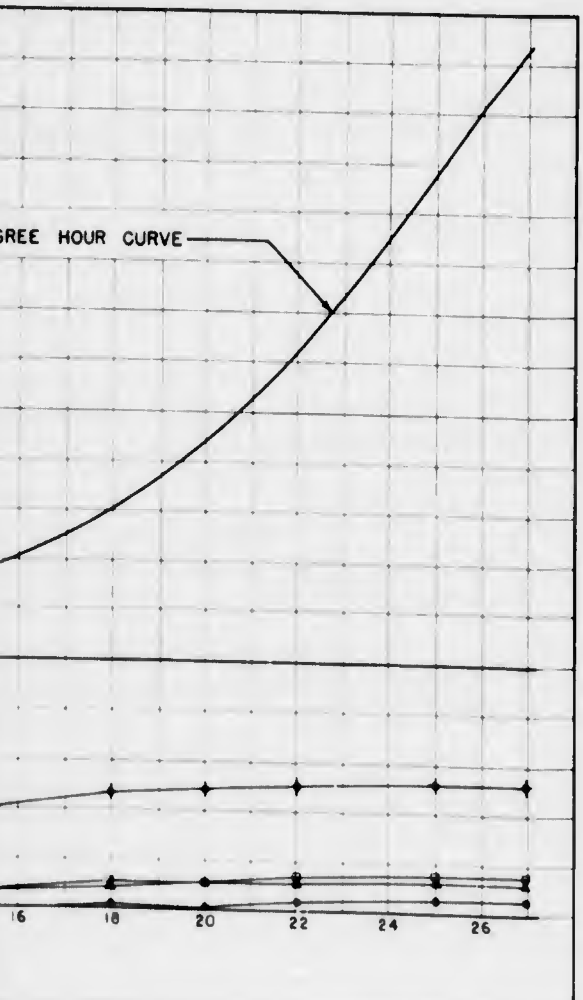

ACCUMULATED DEGREE HOURS BELOW 32°F
6000
5000
4000
3000
2000
1000
0
HEAVE IN INCHES
0.50
0.40
0.30
0.20
0.10
0
2



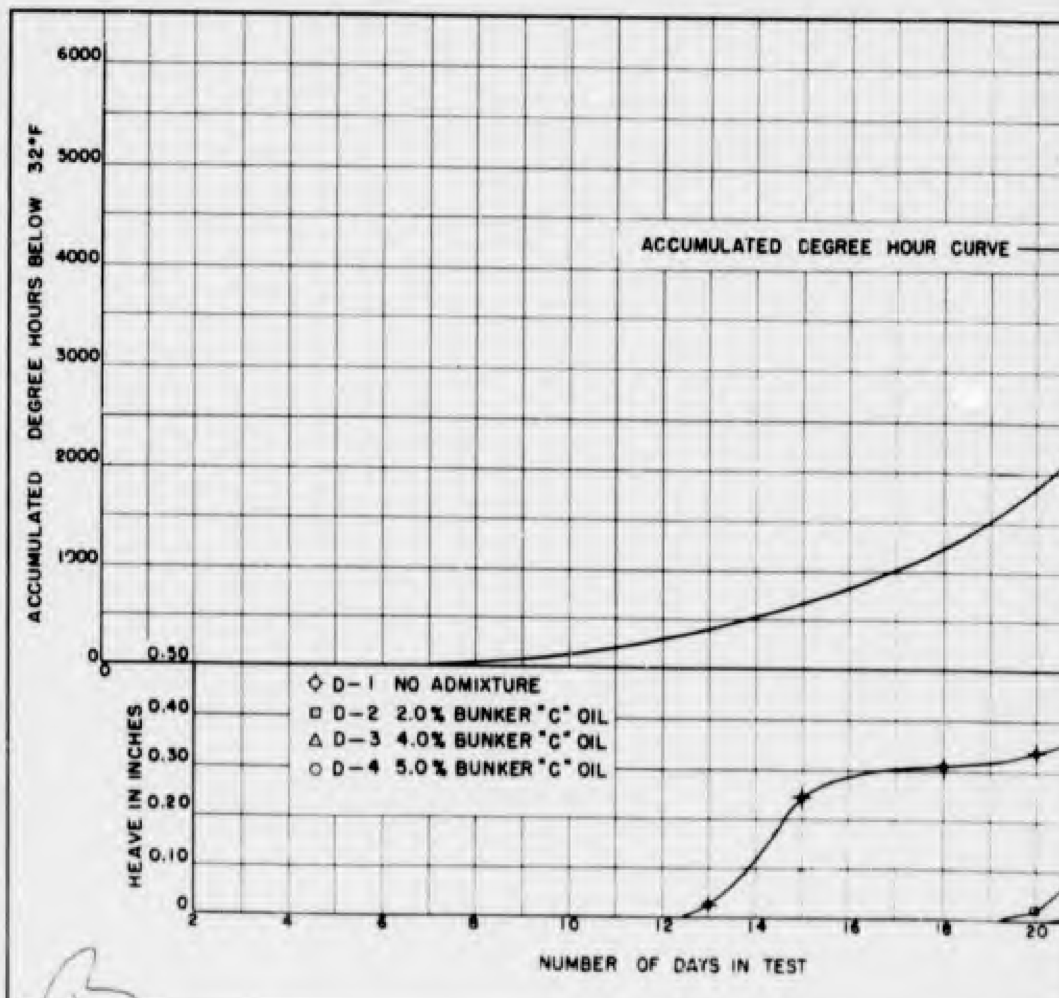
EGREE HOUR CURVE
4.0% BUNKER "C" OIL
5.0% BUNKER "C" OIL
6.0% BUNKER "C" OIL (NOT PLOTTED-NO HEAVE)
16
18
20
22
24
26



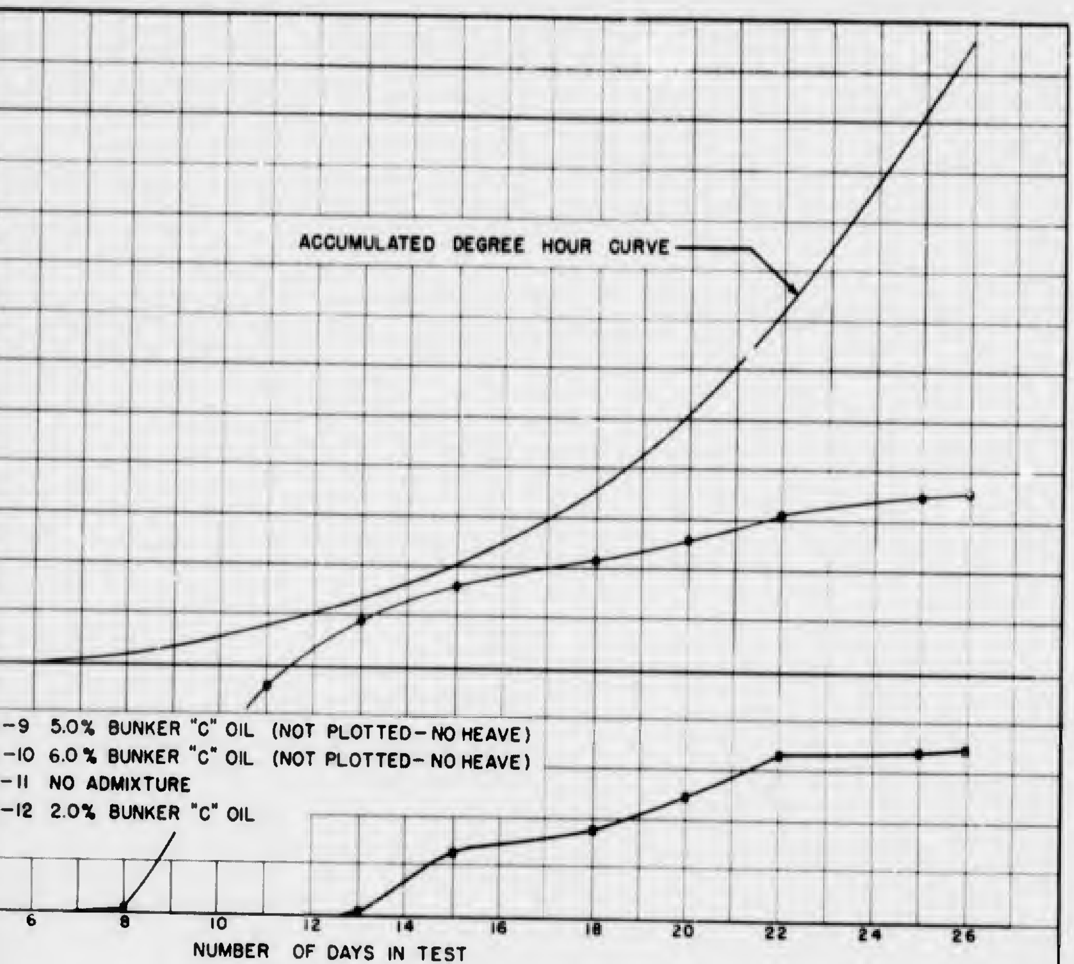
ACCUMULATED DEGREE HOURS BELOW 32°F
6000
5000
4000
3000
2000
1000
0
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
D-9 5.0% BUNKER "C" OIL (NOT PLOTTED-NO HEAVE)
D-10 6.0% BUNKER "C" OIL (NOT PLOTTED-NO HEAVE)
D-11 NO ADMIXTURE
D-12 2.0% BUNKER "C" OIL
2
4
6
8
10
12
14
16
18
20
NUMBER OF DAYS IN TEST

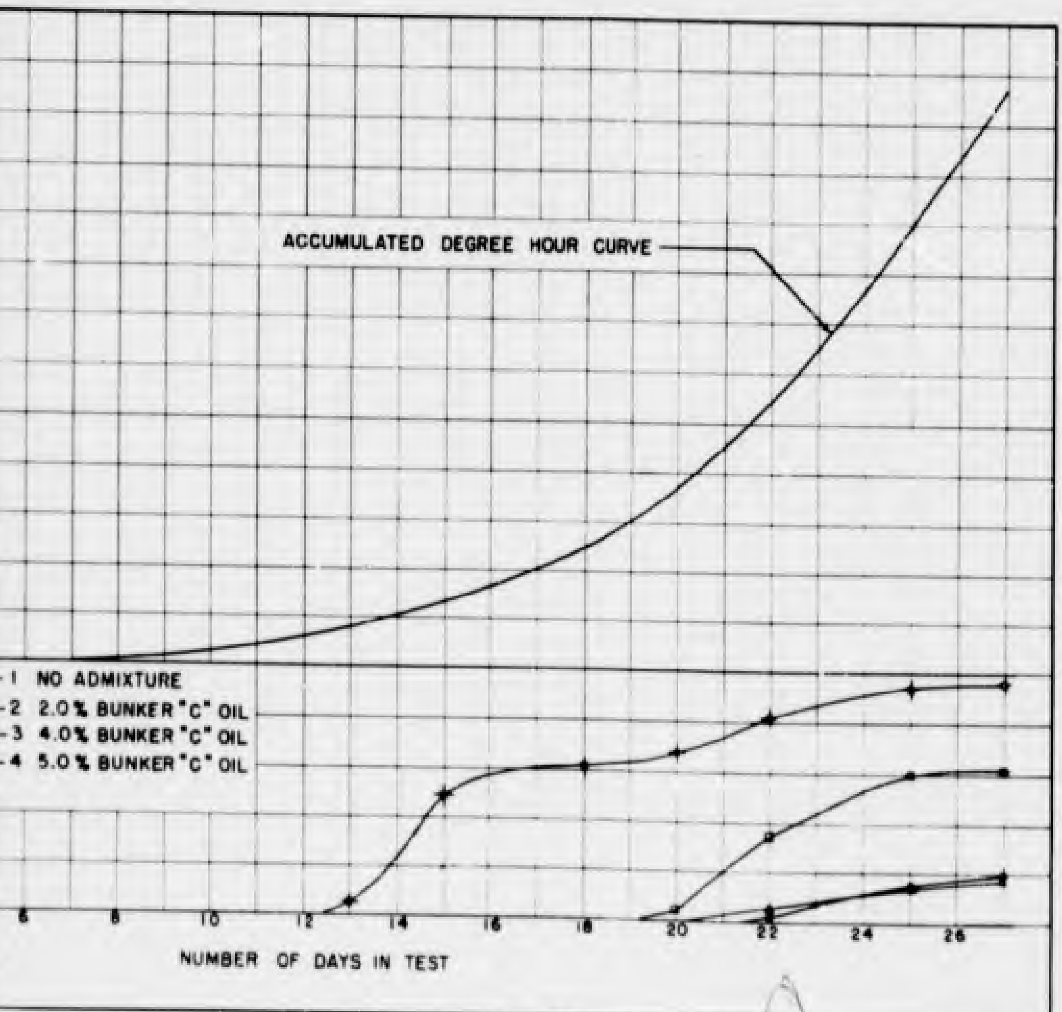


GREE HOUR CURVE
16
18
20
22
24
26



ACCUMULATED DEGREE HOURS BELOW 32°F
6000
5000
4000
3000
2000
1000
0
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
0.50
0.40
0.30
0.20
0.10
0
D-1 NO ADMIXTURE
D-2 2.0% BUNKER "C" OIL
D-3 4.0% BUNKER "C" OIL
D-4 5.0% BUNKER "C" OIL
2
4
6
8
10
12
14
16
18
20
NUMBER OF DAYS IN TEST





APPLIED TEMPERATURES				
ELAPSED TIME (DAYS)	TEST SAMPLES			
	D1 TO D4	D5 TO D8	D9 TO D12	D13 TO D16
1	38	37	37	37
2	38	37	37	37
3	38	37	37	37
4	38	37	37	37
5	33	33	32	32
6	34	33	31	33
7	32	33	31	32
8	31	30	29	30
9	31	30	29	30
10	29	29	28	28
11	29	28	27	28
12	28	28	27	28
13	27	26	26	26
14	27	26	25	25
15	26	25	23	25
16	25	24	23	24
17	25	23	22	23
18	23	22	21	21
19	20	19	17	19
20	18	16	14	16
21	15	14	12	14
22	13	12	9	12
23	10	10	7	10
24	7	6	3	6
25	5	4	1	5
26	5	5	1	4
27	4	4	-	-

Specimens D-1 through D-5 prepared with Soil Mix No. 1.
Specimens D-6 through D-10 prepared with Soil Mix No. 2.
Specimens D-11 through D-15 prepared with Soil Mix No. 3.

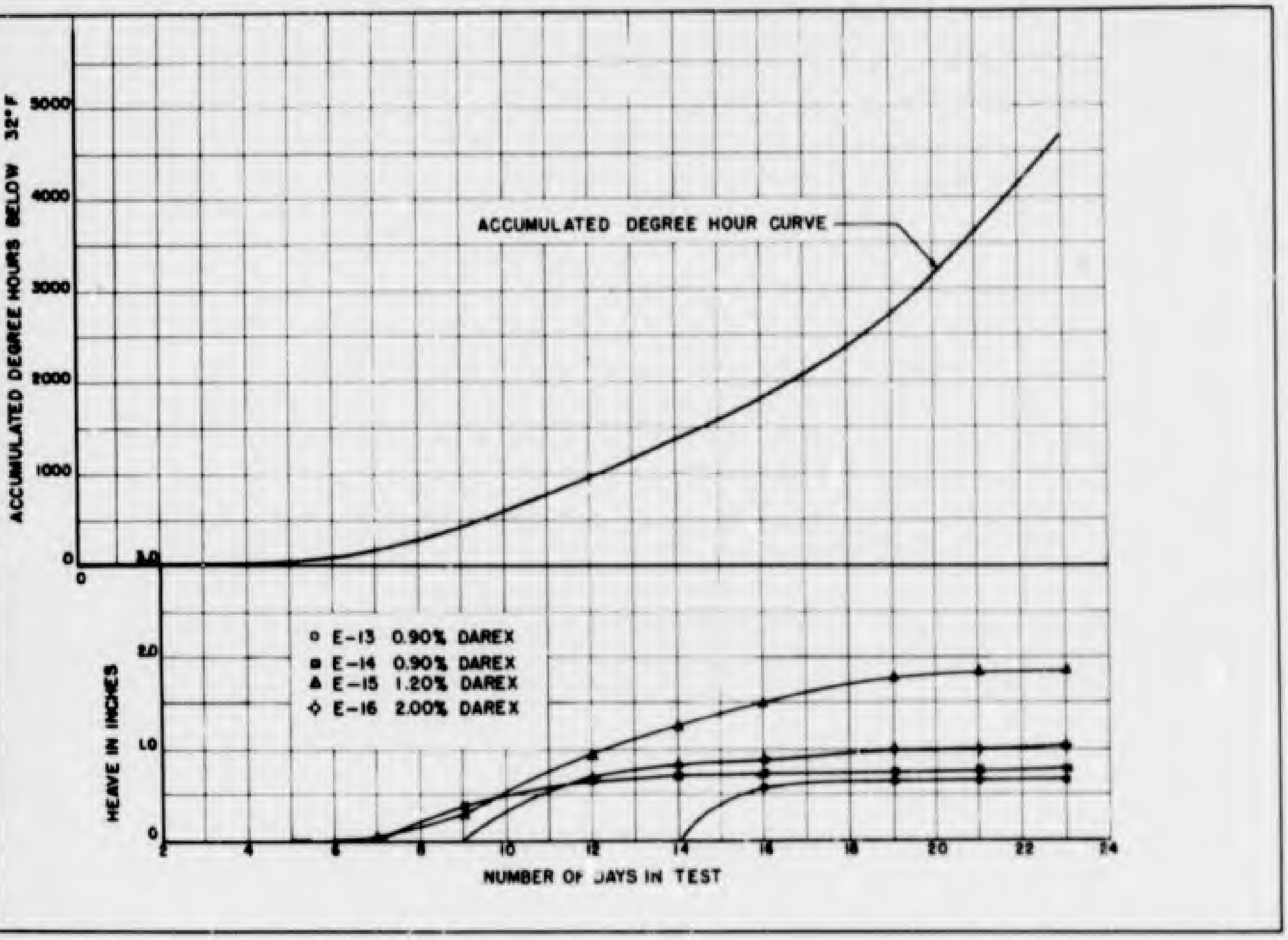
FROST INVESTIGATION
1946-1947

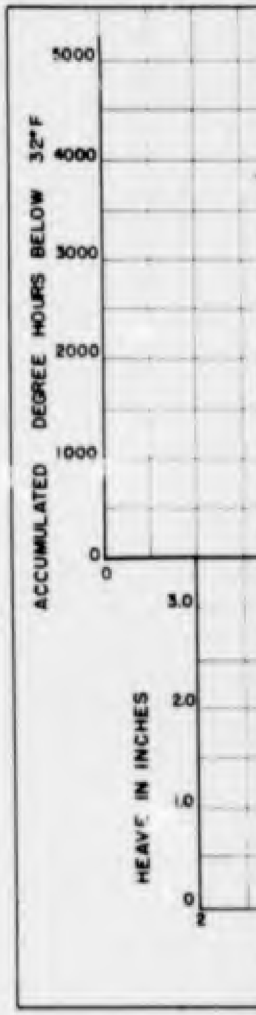
BASE COURSE TREATMENT
TO PREVENT FROST ACTION

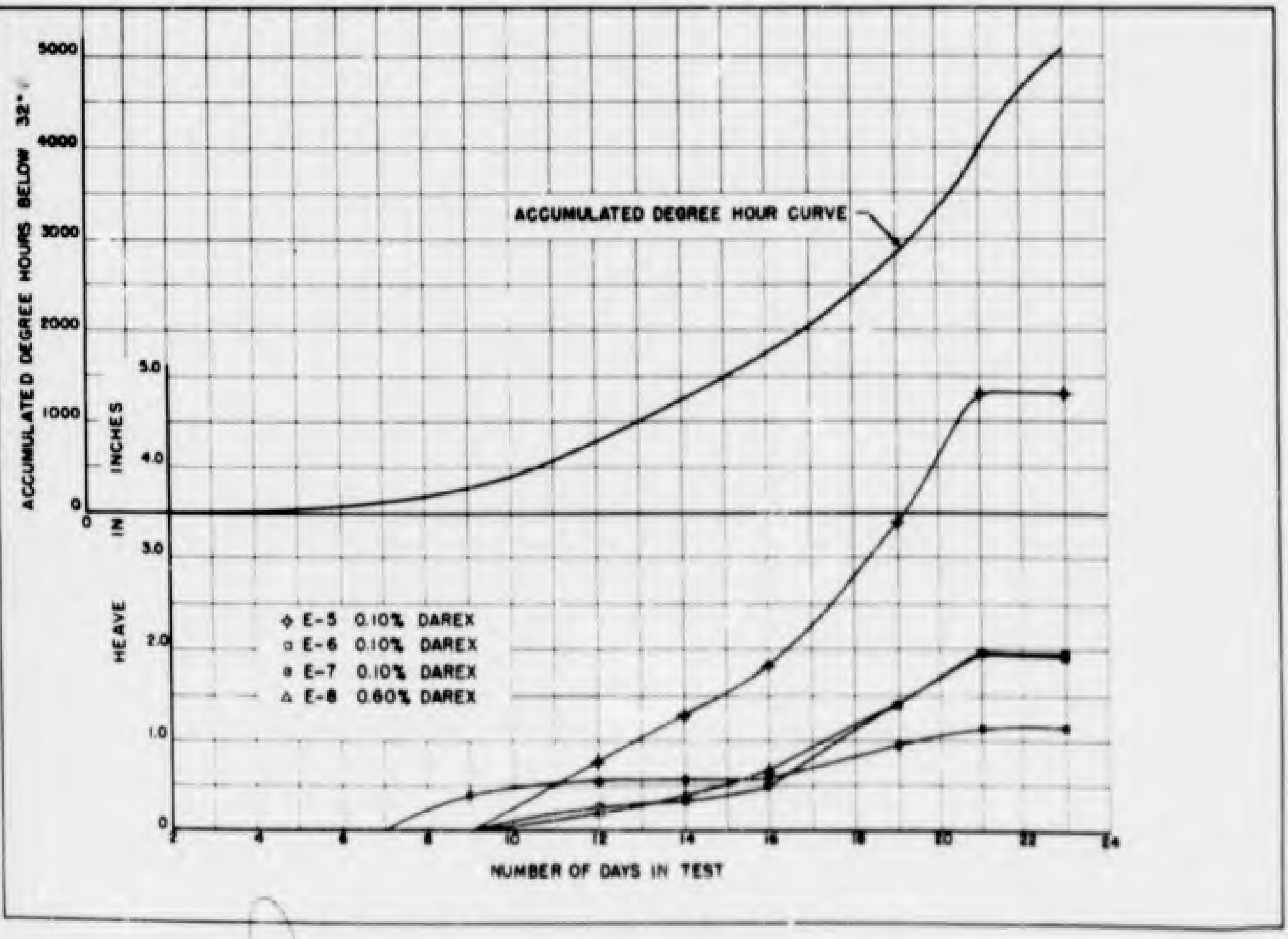
RATE OF HEAVE AND CUMULATIVE TEMPERATURE DIAGRAM SERIES D

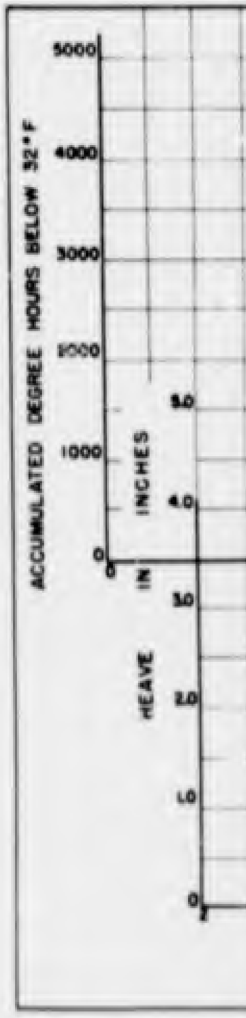
SOILS LABORATORY
NEW ENGLAND DIVISION

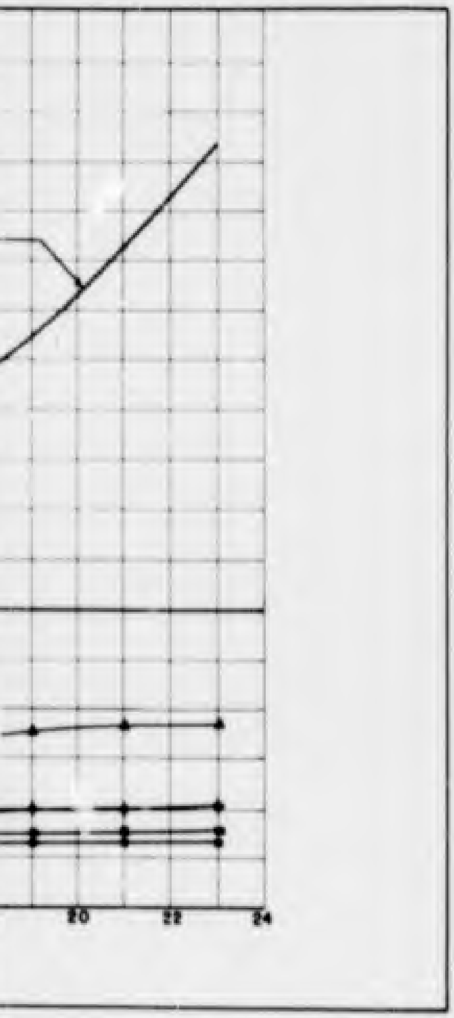
JUNE 1947
BOSTON, MASS.

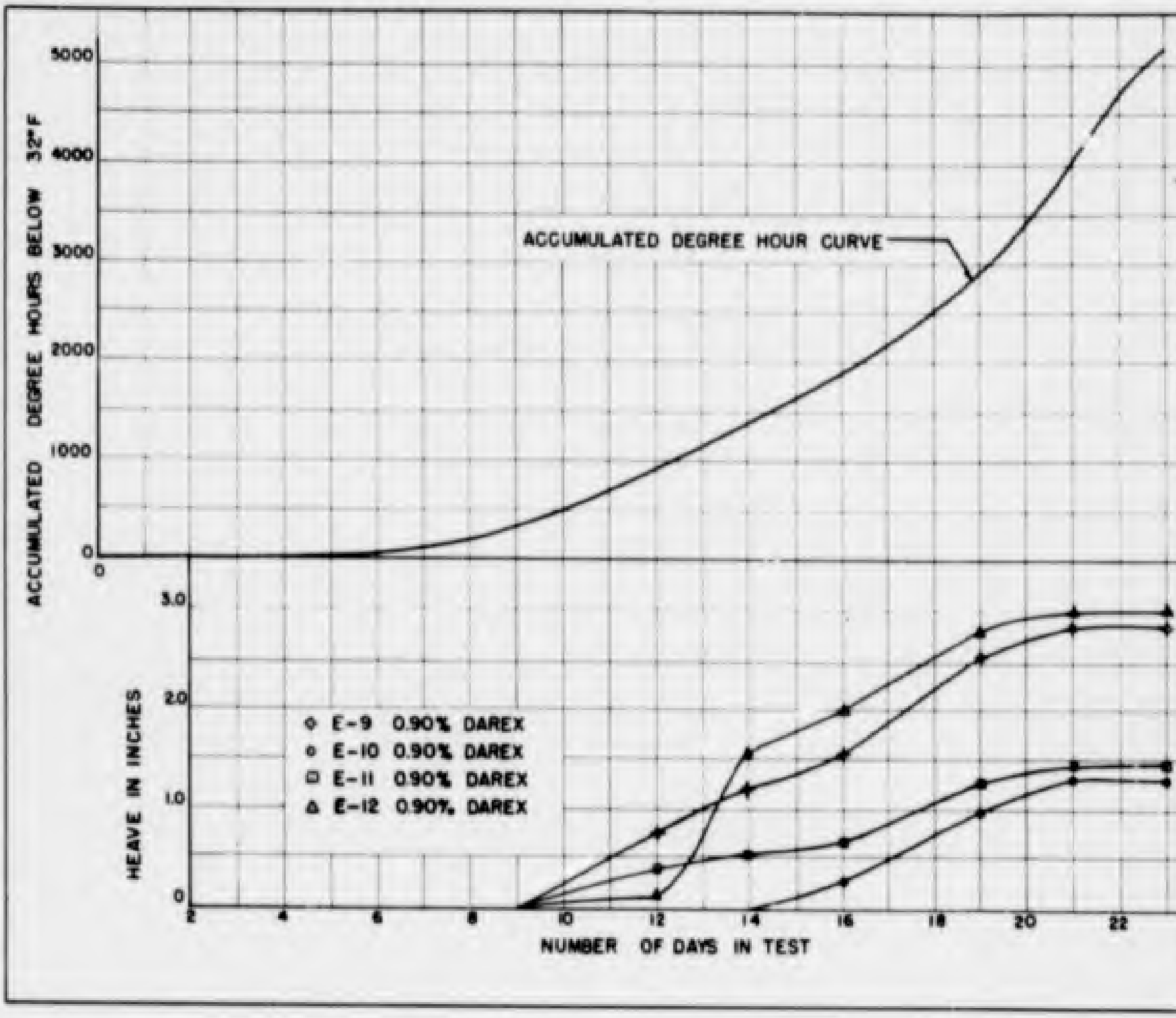

ACCUMULATED DEGREE HOURS BELOW 32°F
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
○ E-13 0.90% DAREX
■ E-14 0.90% DAREX
▲ E-15 1.20% DAREX
◇ E-16 2.00% DAREX
NUMBER OF DAYS IN TEST

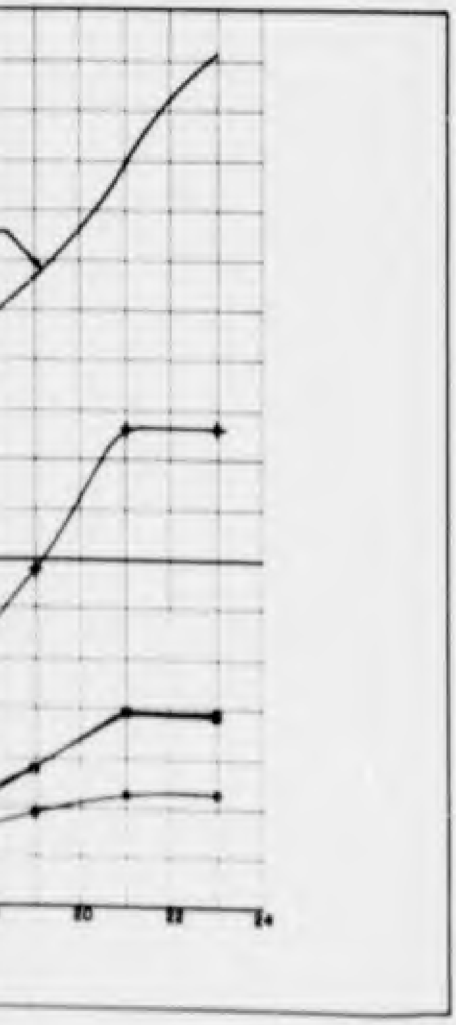

ACCUMULATED DEGREE HOURS BELOW 32°F
HEAVE IN INCHES

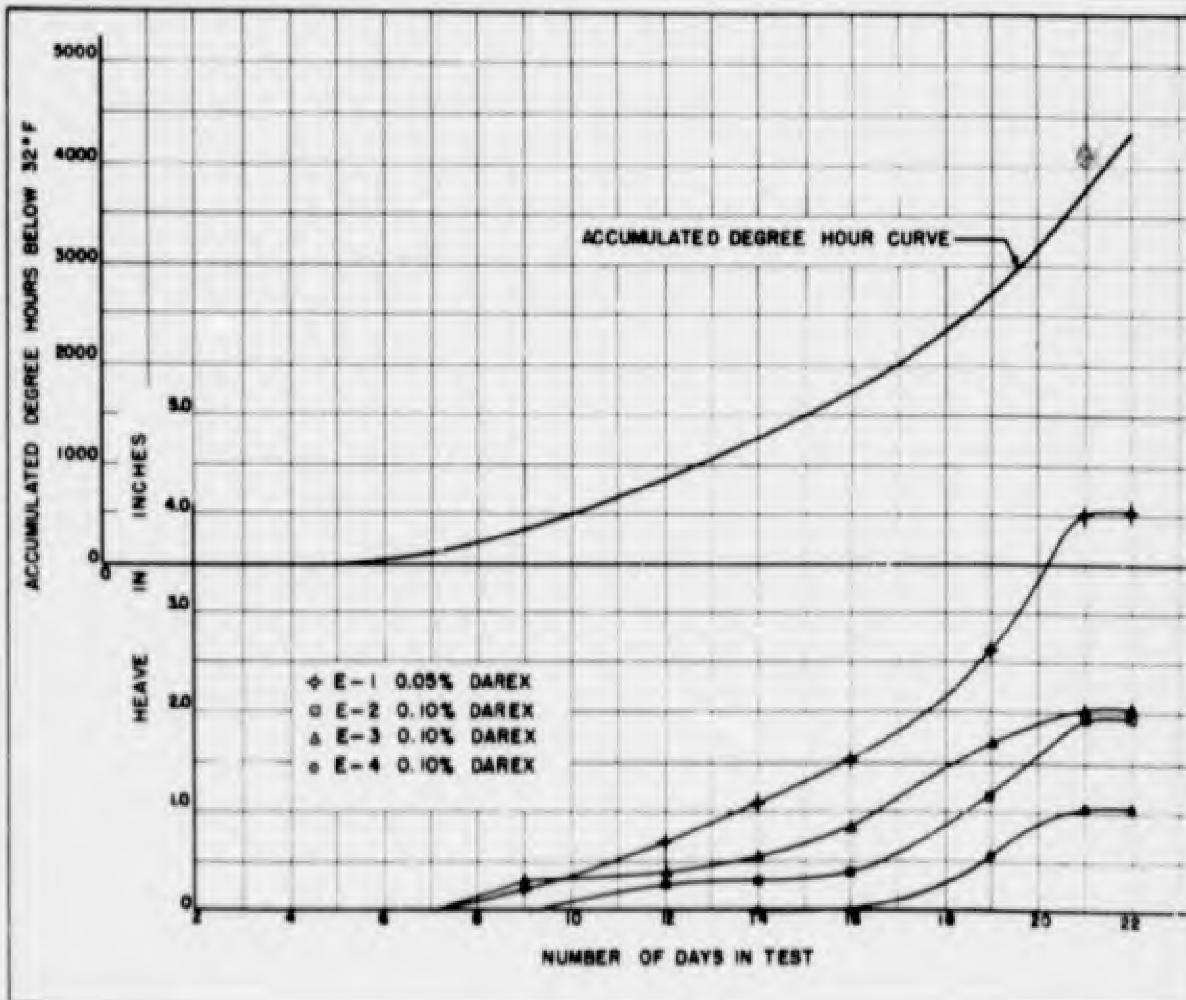

ACCUMULATED DEGREE HOURS BELOW 32°
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
◇ E-5 0.10% DAREX
□ E-6 0.10% DAREX
● E-7 0.10% DAREX
△ E-8 0.60% DAREX
NUMBER OF DAYS IN TEST

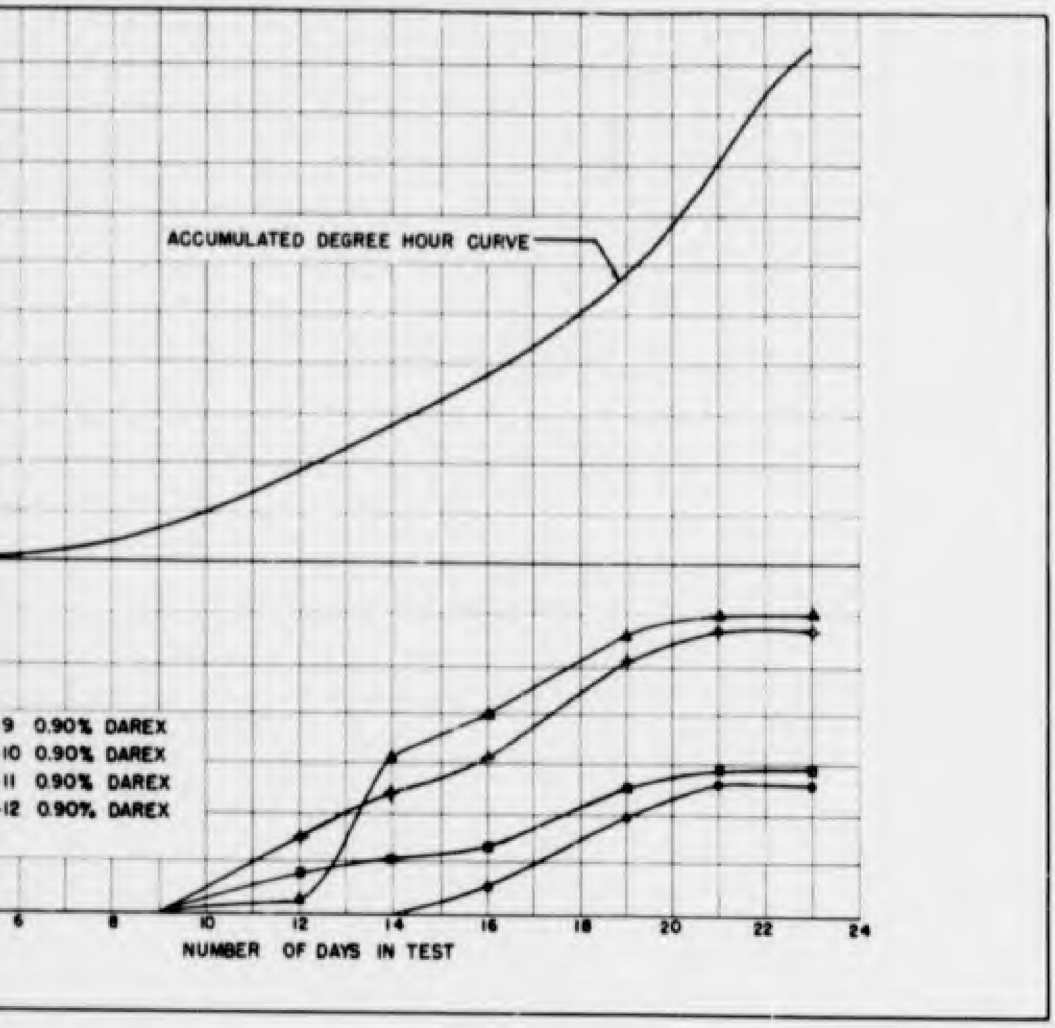

ACCUMULATED DEGREE HOURS BELOW 32°F
HEAVE IN INCHES

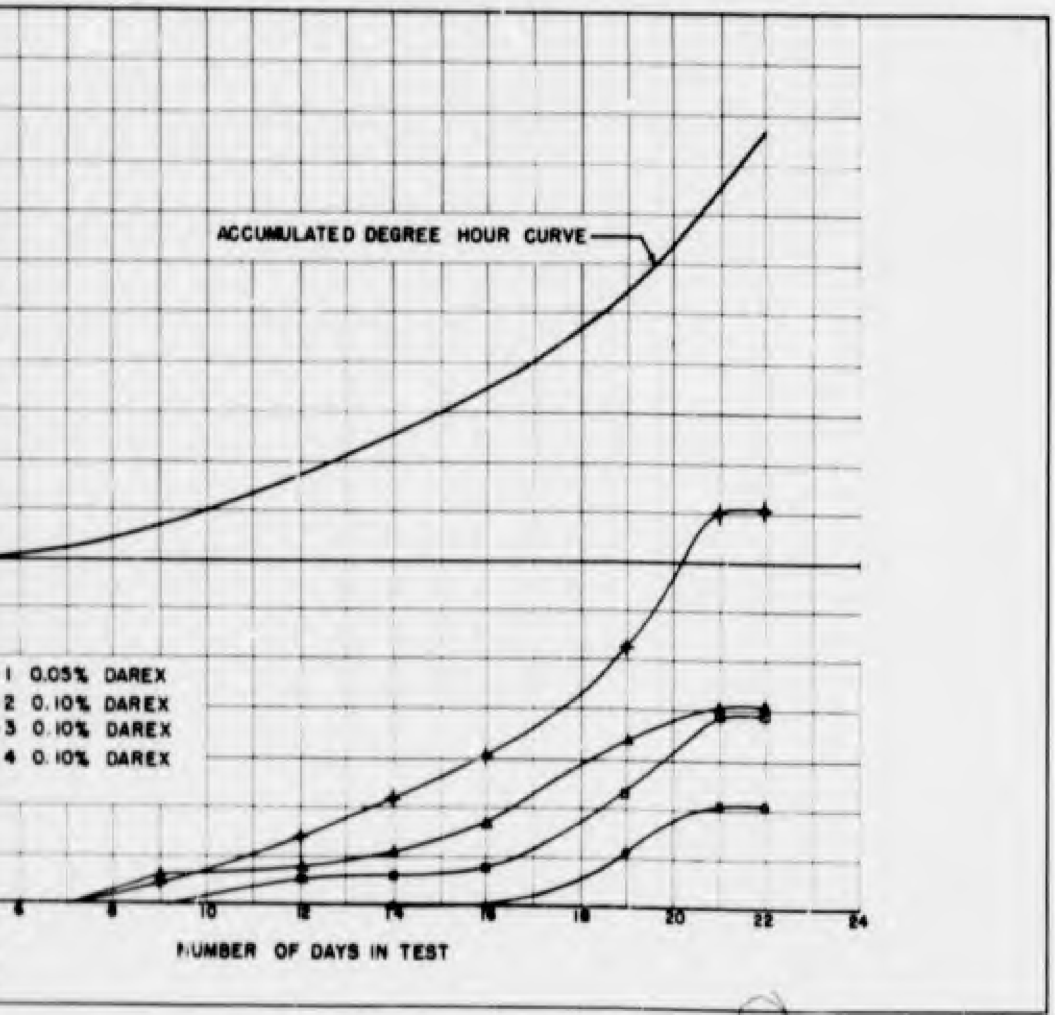

20
22
24


ACCUMULATED DEGREE HOURS BELOW 32°F
5000
4000
3000
2000
1000
0
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
3.0
2.0
1.0
0
◇ E-9 0.90% DAREX
○ E-10 0.90% DAREX
□ E-11 0.90% DAREX
△ E-12 0.90% DAREX
2
4
6
8
10
12
14
16
18
20
22
NUMBER OF DAYS IN TEST


20
22
24


ACCUMULATED DEGREE HOURS BELOW 32°F
5000
4000
3000
2000
1000
0
ACCUMULATED DEGREE HOUR CURVE
HEAVE IN INCHES
5.0
4.0
3.0
2.0
1.0
0
E-1 0.05% DAREX
E-2 0.10% DAREX
E-3 0.10% DAREX
E-4 0.10% DAREX
2
4
6
8
10
12
14
16
18
20
22
NUMBER OF DAYS IN TEST





APPLIED TEMPERATURES				
ELAPSED TIME (DAYS)	TEST SAMPLES			
	E1 TO E4	E5 TO E8	E9 TO E12	E13 TO E16
1	39	39	38	39
2	34	34	34	34
3	34	33	34	34
4	33	32	33	33
5	31	31	31	31
6	30	31	30	30
7	28	30	29	28
8	28	29	28	28
9	27	28	27	26
10	25	26	25	24
11	25	24	24	25
12	24	24	24	25
13	23	23	22	23
14	23	23	23	23
15	23	22	22	23
16	22	22	22	23
17	21	20	21	22
18	18	17	17	19
19	16	14	15	18
20	12	11	11	15
21	8	6	6	11
22	6	5	5	10
23	—	10	7	6

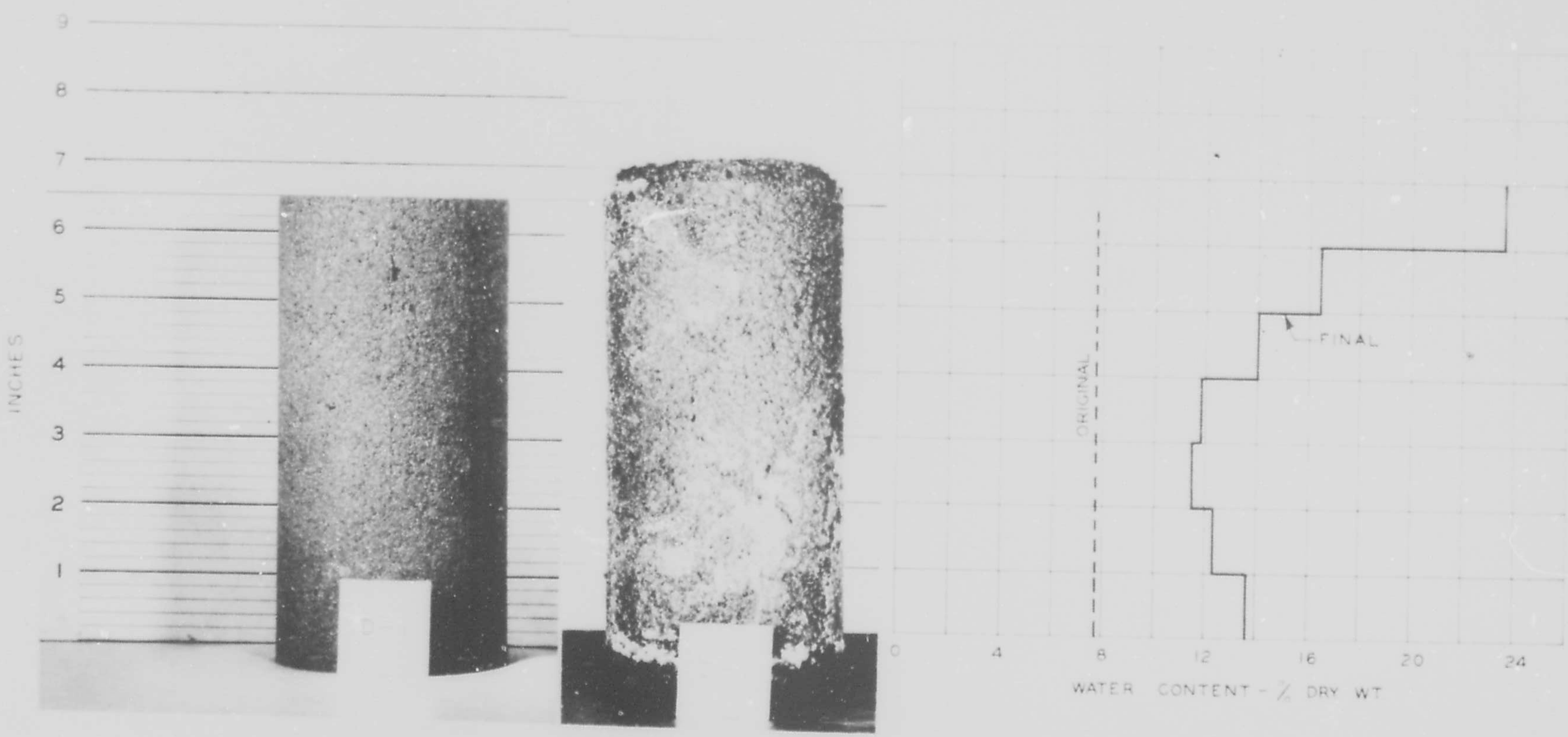
All specimens were prepared with New Hampshire Silt.

FROST INVESTIGATION
1946-1947

BASE COURSE TREATMENT
TO PREVENT FROST ACTION

RATE OF HEAVE AND CUMULATIVE TEMPERATURE DIAGRAM
SERIES E

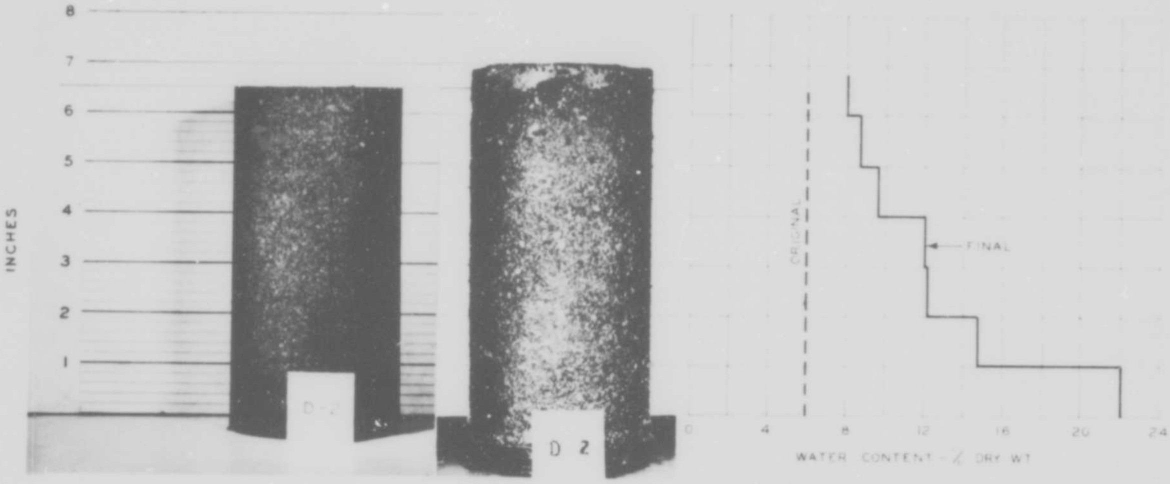
SOILS LABORATORY — JUNE 1947
NEW ENGLAND DIVISION — BOSTON, MASS.



HEAVE AND WATER CONTENT DATA

SAMPLE D-1

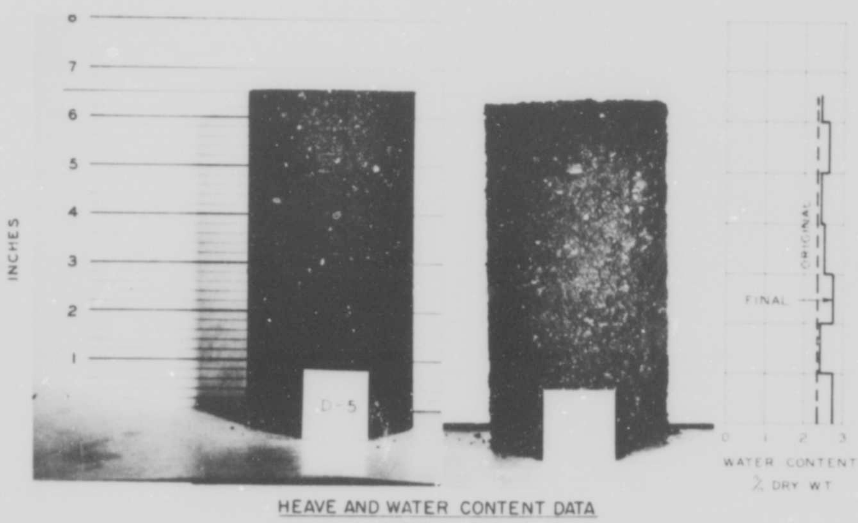
SOIL MIX NO. 1 WITH NO ADMIXTURE ORIGINAL DRY WEIGHT
122.9 P.C.F. WATER CONTENT START OF TEST 7.8 PER CENT
AND SATURATION 57 PER CENT



HEAVE AND WATER CONTENT DATA

SAMPLE D-2

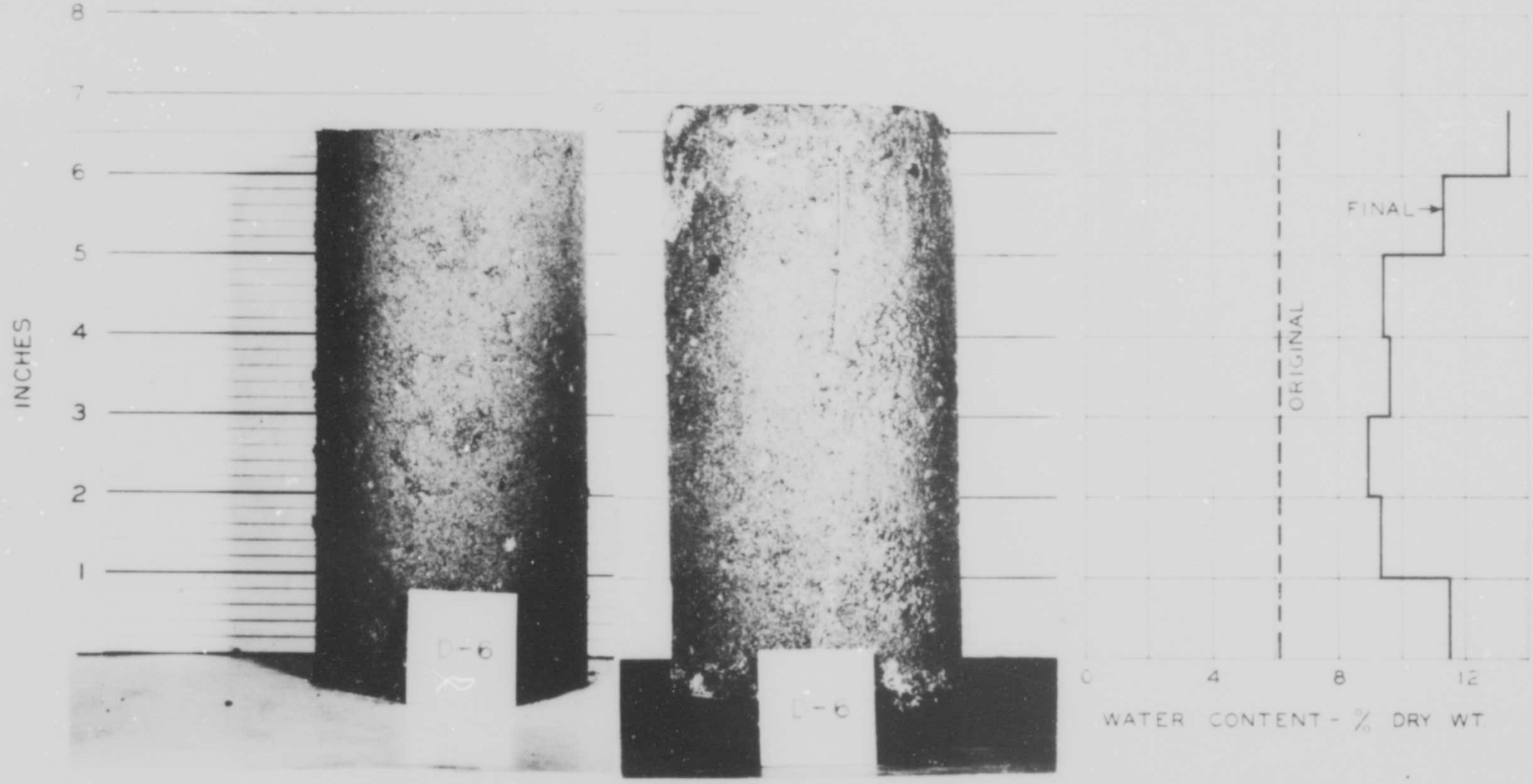
SOIL MIX NO.1 WITH 2.0 PER CENT BUNKER "C" OIL ORIGINAL DRY WEIGHT 121.3 P.C.F. WATER CONTENT START OF TEST 6.0 PER CENT AND SATURATION [illegible] PER CENT



HEAVE AND WATER CONTENT DATA

SAMPLE D-5

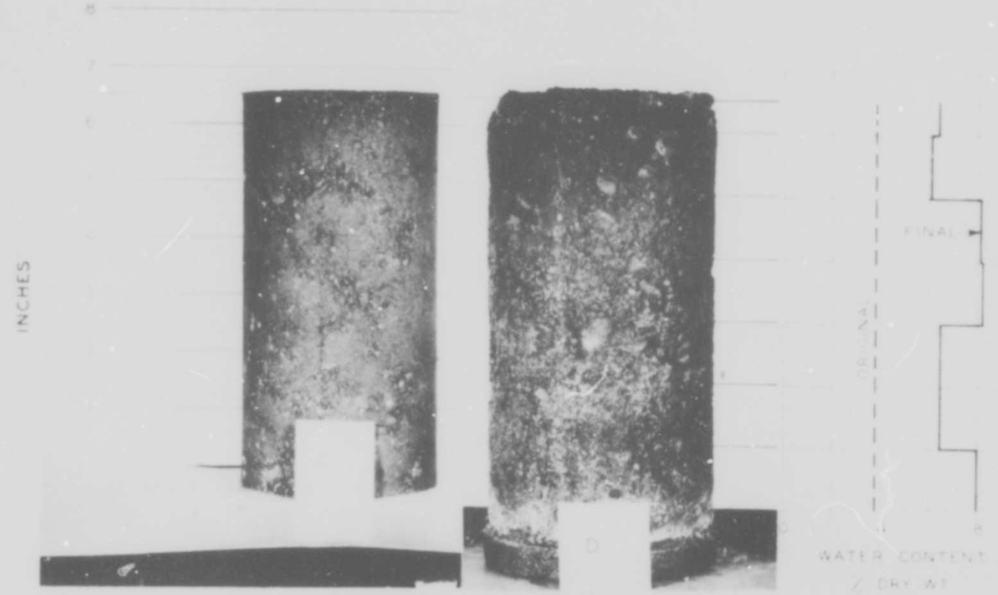
SOIL MIX NO.1 WITH 6.0 PER CENT BUNKER "C" OIL, ORIGINAL DRY WEIGHT 120.8 P.C.F. WATER CONTENT START OF TEST 2.3 PER CENT AND SATURATION 17 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE D-6

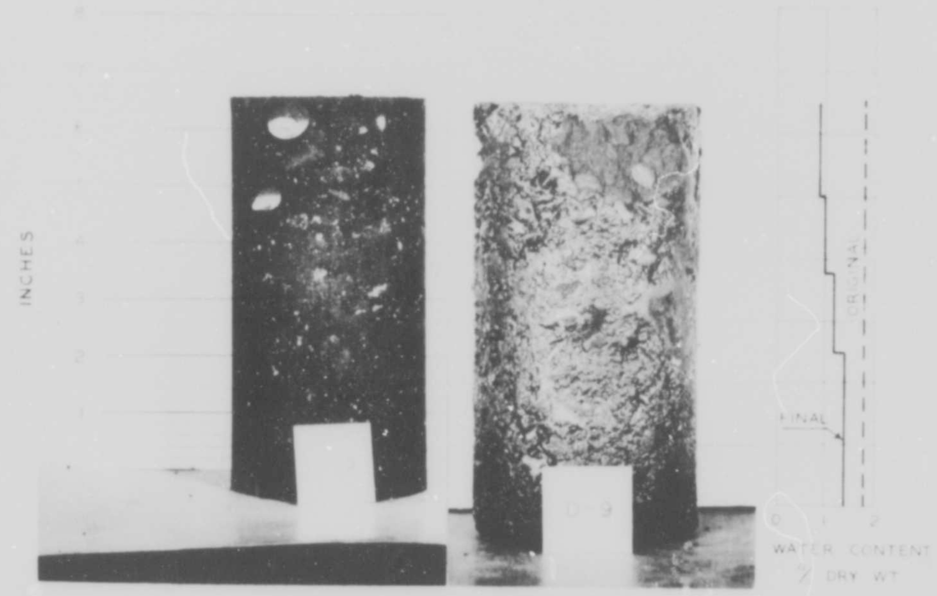
SOIL MIX NO. 2 WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 131.1 P.C.F. WATER CONTENT START OF TEST 6.1 PER CENT AND SATURATION 58 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE D-7

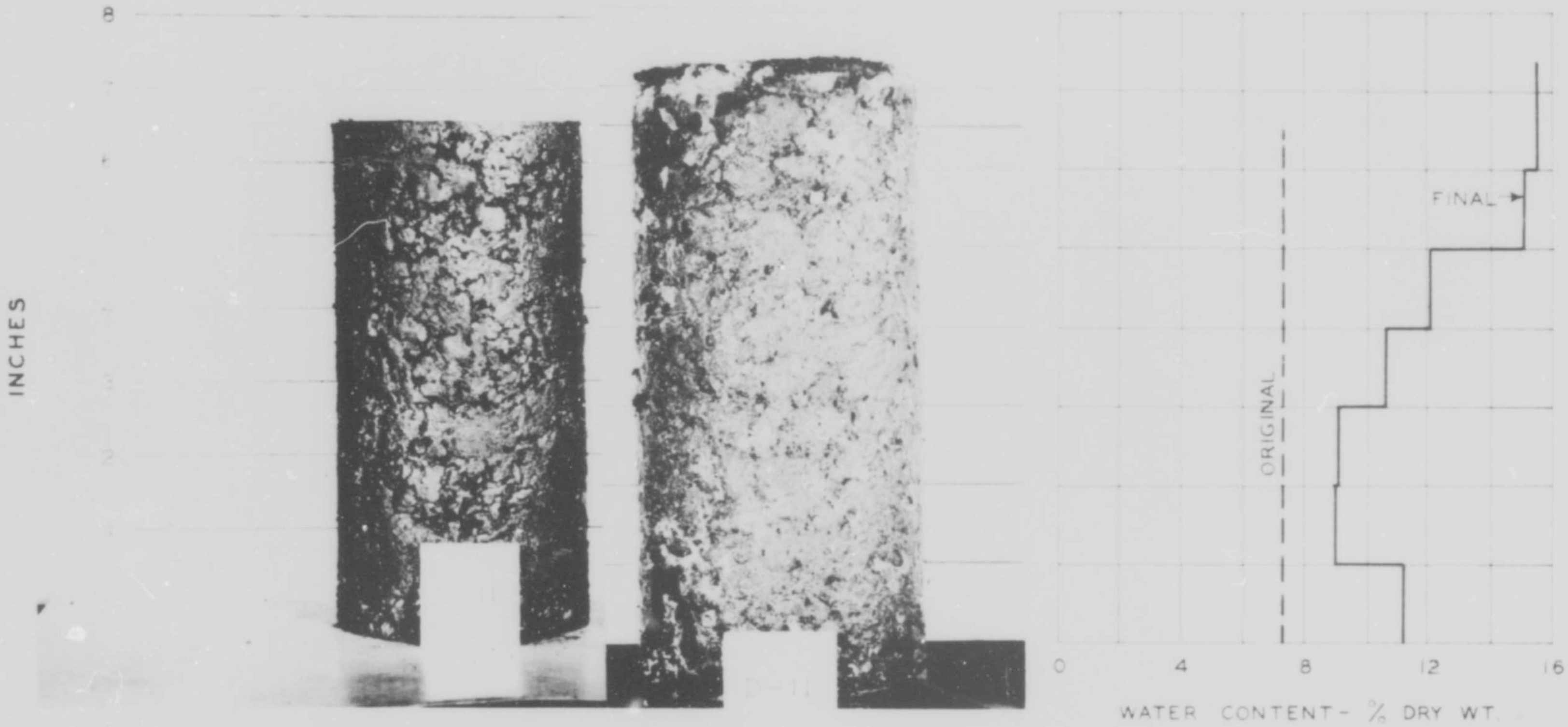
SOIL MIX NO 2 WITH 2.0 PER CENT BUNKER "C" OIL ORIGINAL DRY WEIGHT 126.7 P.C.F. WATER CONTENT START OF TEST 3.9 PER CENT AND SATURATION 33 PER CENT



HEAVE AND WATER CONTENT DATA

SAMPLE D-9

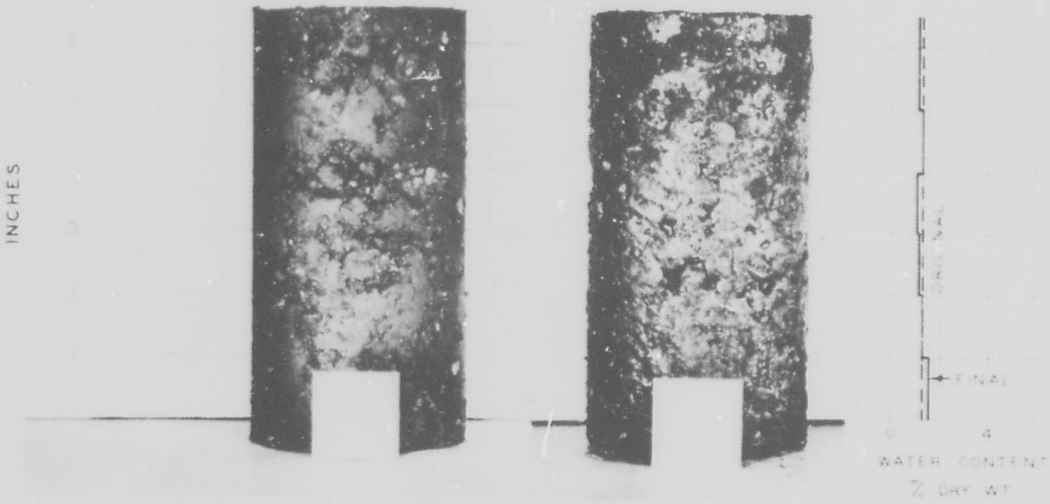
SOIL MIX NO.2 WITH 5.0 PER CENT BUNKER "C" OIL ORIGINAL DRY WEIGHT 126.6 P.C.F. WATER CONTENT START OF TEST 1.8 PER CENT AND SATURATION 16 PER CENT



HEAVE AND WATER CONTENT DATA

SAMPLE D-11

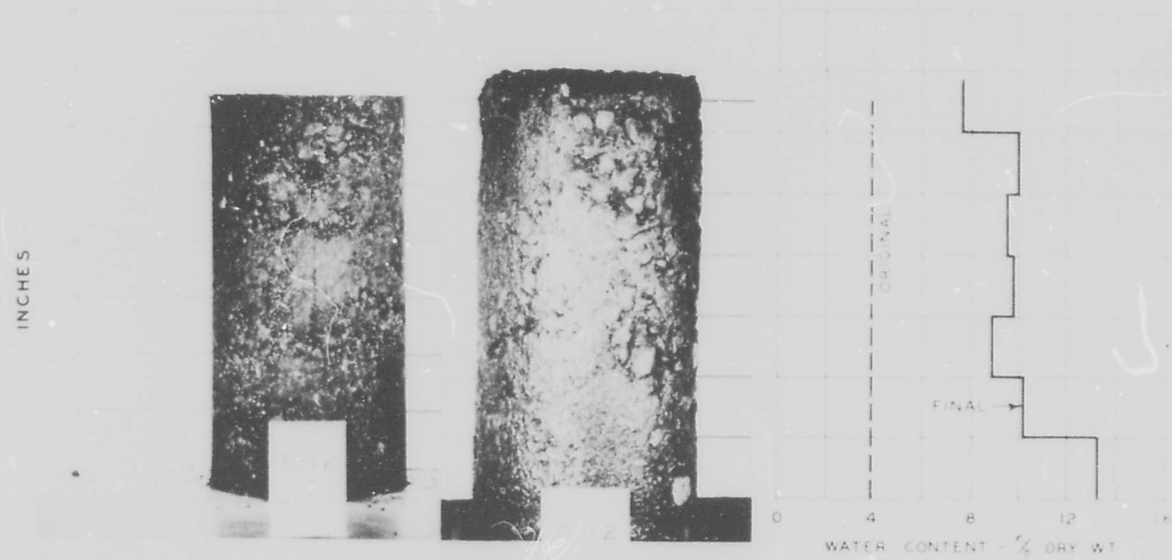
SOIL MIX NO.3 WITH NO ADMIXTURE. ORIGINAL DRY WEIGHT 134.8 P.C.F. WATER CONTENT START OF TEST 7.3 PER CENT AND SATURATION 77 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE D-15

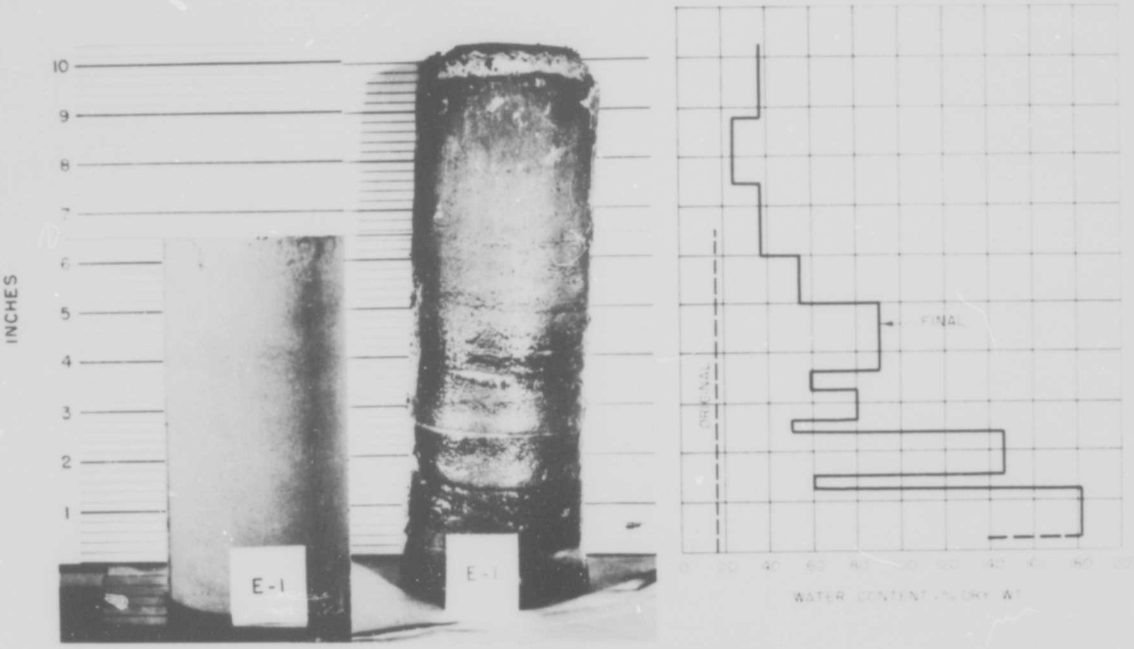
SOIL MIX NO. 3 WITH 6.0 PER CENT BUNKER "C" OIL ORIGINAL DRY WEIGHT 133.5 P.C.F. WATER CONTENT START OF TEST 1.3 PER CENT AND SATURATION 14 PER CENT



HEAVE AND WATER CONTENT DATA

SAMPLE D-12

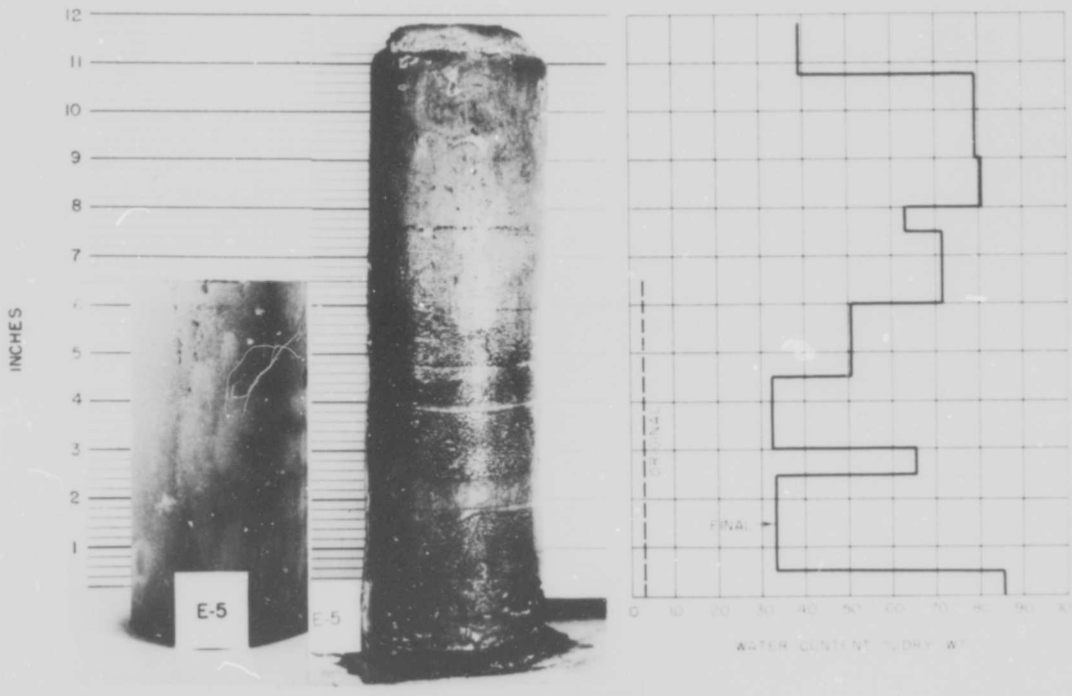
SOIL MIX NO. 3 WITH 2.0 PER CENT BUNKER "C" OIL ORIGINAL DRY WEIGHT 126.4 P.C.F. WATER CONTENT START OF TEST 4.0 PER CENT AND SATURATION 32 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE E-1

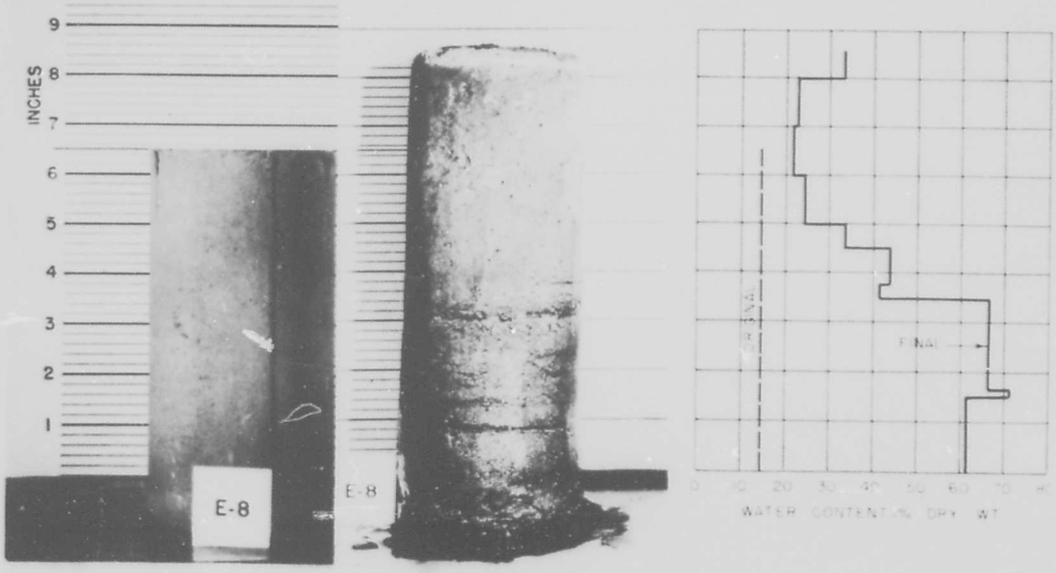
NEW HAMPSHIRE SILT WITH 0.05 PER CENT DAREX A.E.A. ORIGINAL DRY WEIGHT 104.3 P.C.F. WATER CONTENT START OF TEST 16.1 PER CENT AND SATURATION 71 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE E-5

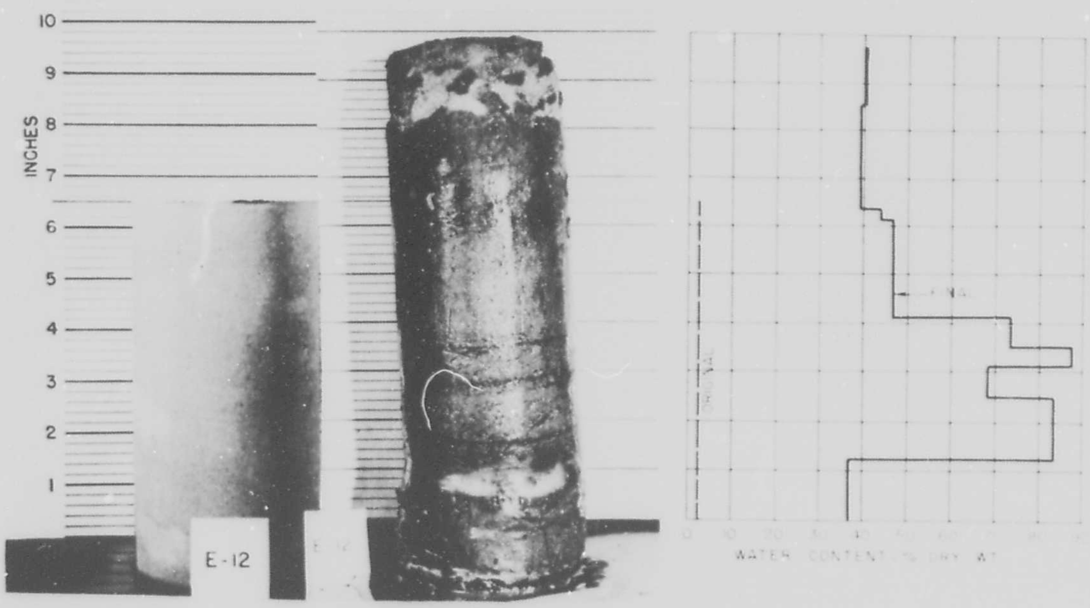
NEW HAMPSHIRE SILT WITH 0.10 PER CENT DAREX A.E.A. ORIGINAL DRY WEIGHT 103.0 P.C.F. WATER CONTENT START OF TEST 3.0 PER CENT AND SATURATION 13 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE E-8

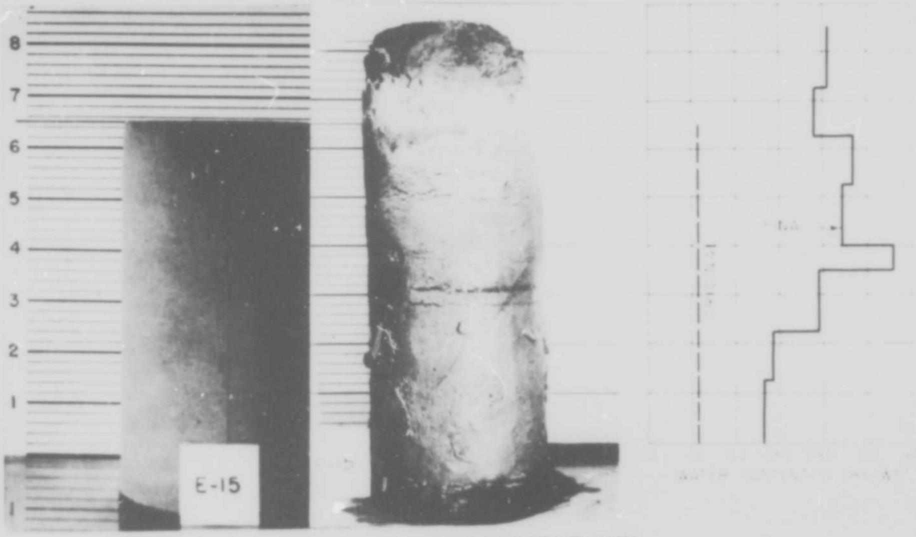
NEW HAMPSHIRE SILT WITH 0.60 PER CENT DAREX A.E.A. ORIGINAL DRY WEIGHT 102.5 P.C.F. WATER CONTENT START OF TEST 14.6 PER CENT AND SATURATION 62 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE E-12

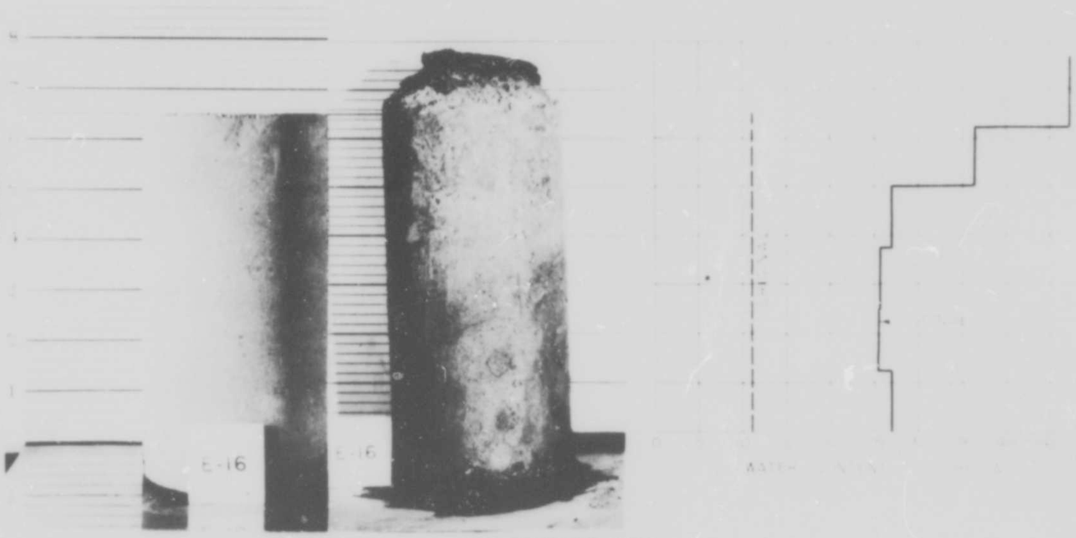
NEW HAMPSHIRE SILT WITH 0.90 PER CENT DAREX AEA. ORIGINAL DRY WEIGHT 101.0 P.C.F. WATER CONTENT START OF TEST 2.4 PER CENT AND SATURATION 10 PER CENT.



HEAVE AND WATER CONTENT DATA

SAMPLE E-15

NEW HAMPSHIRE SILT WITH 1.20 PER CENT DAREX A.E.A. ORIGINAL DRY WEIGHT 101.2 P.C.F. WATER CONTENT START OF TEST 11.6 PER CENT AND SATURATION 48 PER CENT



HEAVE AND WATER CONTENT DATA

SAMPLE E-16

NEW HAMPSHIRE SILT WITH 2.00 PER CENT DAREX A.E.A. ORIGINAL DRY WEIGHT 100.4 P.C.F. WATER CONTENT START OF TEST 11.1 PER CENT AND SATURATION 45 PER CENT

SUMMARY OF FROST ACTION TEST DATA. SERIES D.

SAMPLE NO.	SOIL TYPE	PERCENT FINER "C" CII	DENSITY WET BEFORE TEST LBS/CF	DENSITY DRY BEFORE TEST LBS/CF	LENGTH OF TEST IN DAYS (A)	WATER CONTENT END OF TEST %	WATER CONTENT START OF TEST %	WATER CONTENT GAIN DURING TEST %	SATURATION START OF TEST %	SATURATION END OF TEST %	VOID RATIO AT START TEST WITHOUT ADMIXTURE	VOID RATIO AT START TEST WITH ADMIXTURE	WATER CONTENT BOTTOM INCH BEFORE TEST %	WATER CONTENT BOTTOM INCH AFTER TEST %	DEGREE HOURS IN TEST*	DEGREE HOURS TO START OF HEAVE (APPROX)	HEAVE IN PERCENT	FROST ACTION	FROZEN ZONE
D-1	MIX 1*	0	130.5	122.0	27	14.8	7.8	7.0	57	100✓	.366	-	7.8	13.7	5870	300	7.4	Moderate	Entire
D-2	MIX 1	2	131.1	121.3	27	12.6	6.0	6.6	43	90	.384	.310	6.0	22.0	5870	1250	4.8	Slight	Entire
D-3	MIX 1	4	131.6	121.0	27	8.0	4.6	3.4	33	57	.387	.216	4.6	11.7	5870	1250	1.4	Slight	Entire
D-4	MIX 1	5	130.3	125.4	27	5.6	4.0	1.6	28	39	.406	.232	4.0	6.1	5870	1250	1.5	Slight	-
D-5	MIX 1	6	131.0	120.8	27	2.5	2.3	0.2	17	18	.390	.188	2.3	2.7	6190	2200	0.4	Slight	None
D-6	MIX 2*	0	139.0	131.1	27	10.4	6.1	4.3	58	99	.281	-	6.1	11.5	6190	400	4.0	Slight	Entire
D-7	MIX 2	2	134.2	126.7	27	7.2	3.9	3.3	33	60	.325	.254	3.9	8.0	6190	400	1.1	Slight	Entire
D-8	MIX 2	4	136.2	127.5	27	2.4	2.7	-0.3	24	21	.316	.182	2.7	3.1	6190	400	0.9	Slight	Entire
D-9	MIX 2	5	135.3	126.6	26	1.2	1.8	-0.6	16	10	.326	.162	1.8	1.4	6360	-	0.0	None	-
D-10	MIX 2	6	142.4	133.3	26	0.8	0.8	0.0	9	9	.259	.076	0.8	1.0	6360	-	0.0	None	-
D-11	MIX 3*	0	144.6	134.8	26	12.0	7.3	4.7	77	100✓	.255	-	7.3	11.2	6360	175	13.2	Severe	Entire
D-12	MIX 3	2	134.1	126.4	26	10.0	4.0	6.0	32	81	.338	.265	4.0	13.3	6360	400	5.4	Moderate	Entire
D-13	MIX 3	4	137.2	128.1	26	2.8	3.0	-0.2	26	24	.320	.185	3.0	4.1	5710	560	0.7	Slight	Top 2"
D-14	MIX 3	5	138.7	129.6	26	1.8	2.0	-0.2	18	16	.305	.142	2.0	1.9	5710	560	0.8	Slight	None
D-15	MIX 3	6	143.3	133.5	26	1.3	1.3	0.0	14	14	.267	.082	1.3	1.6	5710	-	0.0	None	None

(A) Length of test computed from time sample was placed in drawer until it was removed.

* Mix 1 consists of approximately 17% silt, 58% sand, 25% gravel (Bureau of Soils classification).
Mix 2 consists of approximately 17% silt, 33% sand, 50% gravel (" " " ").
Mix 3 consists of approximately 17% silt, 15% sand, 68% gravel (" " " ").

PLATE A-39

SUMMARY OF FROST ACTION TEST DATA. SERIES E.

TESTS USING DAREX AEA IN NEW HAMPSHIRE SILT.

SAMPLE NO.	PERCENT DAREX AEA	DENSITY		LENGTH OF TEST IN DAYS (A)	WATER CONTENT				NO. DAYS AIR DRIED	VOID RATIO AT START TEST	SATURATION		WATER CONTENT BOTTOM LAYER		DEGREE HOURS IN TEST	DEGREE HOURS TO START OF HEAVE (APPROX.)	HEAVE IN PERCENT	FROST ACTION	FROZEN ZONE
		WET BEFORE TEST LBS/CF	DRY BEFORE TEST LBS/CF		AS MOLDED %	START OF TEST %	END OF TEST* %	GAIN DURING TEST %			START OF TEST %	END OF TEST %	BEFORE TEST %	AFTER TEST* %					
E-1	.05	121.1	104.3	22	16.1	16.1	73.4	57.3	None	0.63	71	100✓	16.1	-	4412	150	62.4	Severe	Entire
E-2	.10	114.6	100.0	22	14.6	14.6	48.0	33.4	None	0.69	57	100✓	14.6	133.8	4412	350	30.5	"	"
E-3	.10	112.4	96.0	22	14.5	14.5	47.6	33.1	None	0.71	55	100✓	14.5	35.1	4412	150	31.7	"	"
E-4	.10	116.7	101.9	22	14.5	6.2	31.3	25.6	1	0.65	26	100✓	6.2	60.7	4412	1750	16.0	"	"
E-5	.10	118.3	103.0	23	14.7	3.0	57.2	54.2	2	0.63	13	100✓	3.0	85.6	5066	280	74.1	"	"
E-6	.10	118.0	103.0	23	14.5	1.6	42.0	40.4	3	0.63	7	100✓	1.6	65.3	5066	280	30.5	"	"
E-7	.10	113.9	99.4	23	14.6	0.5	30.1	29.6	4	0.6[illegible]	2	100✓	0.5	45.3	5066	170	17.6	"	"
E-8	.60	118.0	102.5	23	14.6	14.6	48.3	33.7	None	0.63	62	100✓	14.6	61.5	5066	280	26.8	"	"
E-9	.60	114.6	100.7	23	12.9	12.9	52.6	40.0	None	0.66	52	100✓	12.9	42.0	5177	350	43.4	"	"
E-10	.60	115.5	101.7	23	12.7	12.7	37.0	21.3	None	0.64	53	100✓	12.7	41.3	5177	1380	20.3	"	"
E-11	.60	114.9	100.7	23	13.2	6.1	38.5	32.4	1	0.66	25	100✓	6.1	30.4	5177	350	22.3	"	"
E-12	.90	115.5	101.5	23	13.5	2.4	45.8	43.4	2	0.65	10	100✓	2.4	36.8	5177	350	46.2	"	"
E-13	.90	114.9	101.4	23	12.4	1.1	27.7	26.6	3	0.65	4	100✓	1.1	26.1	4644	1370	13.5	"	"
E-14	.60	111.8	98.0	23	13.2	0.5	31.1	30.6	4	0.70	2	100✓	0.5	27.6	4644	180	14.0	"	"
E-15	1.20	114.2	101.2	23	11.6	11.6	38.6	27.0	None	0.65	48	100✓	11.6	26.2	4644	180	28.0	"	"
E-16	2.00	113.6	100.4	23	11.1	11.1	31.9	20.8	None	0.65	45	100✓	11.1	27.0	4644	420	35.6	"	"
E-13	None	114.6	101	23	13.4	13.4	102.5	89.1	None	0.66	55	100✓	13	29	5052	620	161.5	"	Bottom 2" unfrozen

(A) Length of test computed from time sample was placed in drawer until it was removed.

* As determined from oven dry weight. No correction applied for evaporation of Darex AEA.

PLATE A-40

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U. S. ARMY
BOSTON, MASSACHUSETTS

DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

APPENDIX B

REPORT ON LABORATORY TESTS ON FROST PENETRATION AND
THERMAL CONDUCTIVITY OF COHESIONLESS SOILS
1944 - 1946

FROST EFFECTS LABORATORY

JUNE 1949

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REPORT ON

LABORATORY TESTS ON FROST PENETRATION AND THERMAL CONDUCTIVITY OF COHESIONLESS SOILS

SYNOPSIS

The study of the effect of freezing temperatures on base and subgrade materials beneath pavements and the rate and depth of frost penetration must consider the thermal properties of frozen and unfrozen soils. The principal soil thermal properties influencing the rate of freezing are thermal conductivity, volumetric heat, latent heat of soil moisture, and freezing temperature of soil moisture. To supplement the extensive program of field investigations and theoretical and mathematical studies the laboratory study reported herein was initiated. Laboratory tests for frost penetration and thermal conductivity were conducted and previous investigations of thermal properties of soils were reviewed and summarized.

REPORT ON

LABORATORY TESTS OF FROST PENETRATION

AND THERMAL CONDUCTIVITY OF COHESIONLESS SOILS

I. INTRODUCTION

1-01. General. Presented herein are the results of laboratory frost penetration and thermal conductivity tests performed by the Frost Effects Laboratory and a review of tests conducted by other investigators dealing with the thermal properties of soils. These studies were part of the authorized Frost Investigation program for Fiscal Year 1944-1945 and Fiscal Year 1945-1946.

1-02. Purpose. The specific purposes of this investigation are as follows:

a. Determine the amount and rate of temperature changes within cylinderical laboratory specimens of sand due to a suddenly applied freezing air temperature at the top of the specimens.

b. Determine the thermal conductivity of several representative base course materials and one bituminous concrete mixture.

c. Review and summarize the results of previous investigations of the thermal properties of soil.

1-03. Scope. This report presents a summary of all the data obtained in the tests and investigations to accomplish the stated purpose. The laboratory tests were in a specially constructed cold room with controlled temperature conditions. The review of previous investigations consisted of library research.

1-04. Definitions.

a. Frost Action is the accumulation of water in the form of ice lenses in the soil or base materials under natural freezing conditions.

b. Non-Frost Susceptible Materials are crushed rock, sand, sand and gravel, gravel, slag, cinders or any other cohesionless material in which frost action is not possible.

c. Density is the unit dry weight in pounds per cubic foot.

d. Water Content is the ratio expressed as a percentage of the weight of water in a given soil to the weight of solid particles.

e. Specific Heat, c, of any substance is defined as the Btu's of heat required to raise one pound one degree Fahrenheit.

f. Volumetric Heat Capacity, C, of a soil is defined as the heat in Btu's required to raise one cubic foot of soil and moisture contained therein one degree Fahrenheit.

g. British Thermal Unit, Btu, is the heat required to raise the temperature of one pound of water one degree Fahrenheit at its maximum density. It is equal to 252 calories.

h. Latent Heat of Fusion, L, is the quantity of heat required to change a unit mass of ice to water with no temperature change.

i. Thermal Conductivity, k, is the quantity of heat that will pass through a unit area of unit thickness in unit time under a unit temperature gradient.

j. Degree of Saturation, G, is the ratio, expressed as a percentage, of the volume of water in a given soil mass to the total volume of voids.

k. Temperature Gradient, S, is the rate of change of temperature between two points.

1-05. Acknowledgement. The tests reported herein were conducted in the Soils Mechanics Laboratory, Harvard University. The use of the facilities of the Soil Mechanics Laboratory including the cold room was made available by Harvard University through the cooperation of Dr. Arthur Casagrande. Dr. Casagrande made frequent suggestions and assisted greatly in these tests by giving freely of his own time for consultation. In addition, members of the Staff of the Graduate School of Engineering furnished the temperature measuring equipment and valuable advice on its use. Personnel of the U. S. Engineer Office, Providence, R.I., assomplished, through a cooperative agreement, the theoretical mathematical studies utilized in the analysis of results and furnished valuable advice on test apparatus for determining the coefficient of thermal conductivity.

II. INVESTIGATION AND STUDIES

2-01. Description of Laboratory Cold Room and Equipment. The thermal conductivity and frost penetration investigations were carried out in the cold room laboratory, at Harvard University Graduate School of Engineering. General layout of the cold room and equipment is shown on Plate B-1.

a. Cold Room. The cold room is a walk-in refrigerator with inside dimensions 6 feet 9-1/2 inches long by 6 feet 9-1/2 inches wide and 6 feet 5 inches high. It is insulated on all 6 sides with 4 inches of cork. A pressure controlled unit cold blower and an externally located freon compressor cool the the room to any desired air temperature within a range of 30° to 50°F and to an accuracy of 1.0°F.

b. Freezing Cabinet. Within the cold room is a freezing cabinet located as shown on Plate B-1. A photograph of the freezing cabinet is shown on Plate B-2. This cabinet contains an air space at the top cooled by longitudinal coils, hung from the top of the cabinet, using a second compressor with sulphur dioxide refrigerant. Beneath this air space are 4 drawers arranged side by side as shown on photograph, Plate B-2. The temperature at the top of each drawer may be fixed at any desired temperature with an accuracy of 0.8°F and equal to or less than that in the cold room by adjustment of a bimetallic De-Khotinsky type temperature control located in the air space above the drawers. With the cold room at approximately 42°F, the top of the freezing cabinet can be lowered to a temperature of -10°F. A small fan in the air space at the top aids in maintaining a uniform temperature throughout the air space. The bottom of the drawers consist of a 24 gage galvanized iron sample tray and is set 15 inches above the floor of the cold room. Detail of the trays is shown on Plate B-1. The temperature of the bottom of the drawers is determined by the cold room temperature. Thus, test specimens may be placed in the drawers and subjected to any desired temperatures at the top and bottom within the temperature ranges of the two pieces of cooling equipment. Circulation of air between the air spaces at the top and bottom of drawers was prevented by inflating a tire inner tube installed in the air space between drawers until this space was sealed. Two of the drawers are equipped in such a manner that water may be supplied to the bottom of the test specimens.

c. Temperature Measurements. Temperature measurements in test specimens were made using 72 copper-constantan thermocouples and a Leeds and Northrop Potentiometer, type K. The thermocouples were arranged in groups of twelve. A switching arrangement permitted the rapid measurement of the temperature at individual thermocouples successively as desired. The constant temperature junction consisted of an ice water bath in a thermos bottle. The accuracy of a temperature determination was $\pm$ 0.1°F. Plate B-3 illustrates the switches and temperature indicating apparatus.

2-02. Experiments to Measure Temperature Changes in Test Specimens.

a. General. A series of tests were conducted, each series consisting of tests on 12 test specimens compacted at various densities and water contents.

b. Material Tested. The material tested consisted of a cohesionless, siliceous, medium sand obtained from a glacial outwash deposit at South Lowell, Mass. The grain size and specific gravity of the material (Lowell sand) as used for tests, after thorough mixing and removal of sizes larger than 2 mm and smaller than 0.07 mm, are shown on Figure 5, Plate B-4. This material is considered not susceptible to frost action and contains particle sizes that were very small in proportion to the size of test specimen.

c. Test Specimen. Each test specimen was a cylinder 3.36 inches in diameter and 6.5 inches high contained in a quart cardboard container. To measure temperature changes, several thermocouples were placed along the axis of the cylinder. Details of sample cylinder and location of thermocouples are shown on Plate B-1. From 2 to 4 specimens were placed in each drawer of the cold cabinet. The top of each specimen, except those which were saturated, was sealed with paraffin about 2 mm in thickness to prevent evaporation from the surface. The space between specimens and the sides of the drawer was filled from the bottom of the drawer to top of specimens with the same sand as the specimens, placed dry.

d. Test Conditions. Each test consisted in permitting the 12 specimens to reach cold room temperature of approximately 40°F and then suddenly applying at the top of the specimen a predetermined freezing temperature while maintaining the bottom of the specimen at cold room temperature and recording the temperature changes in the specimen vs. time until equilibrium was established.

e. Sample Preparation. The quart cardboard container, with top and bottom removed, forming the sides of a test specimen, was placed into a split forming jacket, illustrated on Plate B-5. The split forming jacket had holes through which thermocouples could be inserted into the center of the specimen during compaction. Placement and compaction of the material in a dense state was accomplished by using a device (shown on the left, Plate B-5) and procedure developed by Dr. Yen Chan in connection with his work on a thesis for the degree of Doctor of Engineering at Harvard University. For the dense state, material having the desired water content was placed in ten equal layers and each layer compacted by an increasing number of blows in a sequence which resulted in a uniform degree of compaction throughout the specimen. The compacting device consisted of an anvil and a falling hammer guided by a rod running through a hole in the center of the weight. The anvil was placed on the soil to be compacted and the hammer dropped on it from a predetermined height. Thermocouples were inserted at regular intervals along the longitudinal axis of the samples as the placement progressed. After removal from forming jacket the thermocouple lead wires were cemented with paraffin to the cardboard container. Loose samples were constructed by first cementing the thermocouples at the desired positions, then carefully placing material having the desired water content around the thermocouples. At the same time the side of the container was lightly tapped to obtain a small amount of compaction to minimize consolidation during handling and testing. To obtain saturated samples in either loose or dense state, the material was placed dry in containers which were equipped with screen bottoms. These specimens were then placed in the drawers, fitted with pans for water supply, and saturated by forcing water upward through the specimens until free water appeared on the surface.

f. Test Procedure. Four different tests were conducted with the same specimens, that is, the same specimens were tested under four different freezing temperatures, namely, approximately 30°F, 25°F, 20°F, and 10°F. In the application of the different freezing temperatures to the top of the test specimens, a time lag to reach the desired temperature was evident. The time lag for the 30°F, 25°F, and the 20°F tests was small. For the 30°F test the loaded drawers were left open until the compressor had cooled the coils of the freezing cabinet. The drawers were then closed and the time of closing was considered as the starting time of the test. The loaded drawers were closed and sealed in the 20°F and the 25°F tests and the freezing compressor was started and time vs. cabinet air temperature was observed until the test temperature was reached. For these tests the starting time was assumed to be the time at which the cabinet temperature had reached the average between the test temperature and the cold room temperature. Cork insulation was placed over the top of the samples in the 10°F test, the drawers closed and the cabinet temperature lowered to 10°F. The drawers were opened momentarily, the cork sheet was then removed, the drawers closed and the cabinet sealed. The starting time for the test was taken as the time of the final closing of the drawers.

g. Data Obtained. The data obtained from the four series of tests are summarized on Plate B-4. Table A summarizes the principal test conditions for each test performed. Figure 1 is a typical set of time vs. temperature curves for each of the thermocouples in a selected test. Figure 2 is a typical set of temperature gradients at selected times after suddenly applying a surface temperature. Figure 3 presents representative data showing the penetration of the 32°F temperature vs. time into test specimens at different water contents and unit dry weights and with two different, suddenly impressed, surface temperatures. For 4 tests, conditions were such that equilibrium was reached with the 32°F temperature approximately at the midpoint of the specimen, and equilibrium temperature gradients for both the frozen and the unfrozen portion of the samples for these 4 tests are shown in Figure 4, Plate B-4.

h. Analysis of Test Results. From the tests described it is possible to investigate the effect of the surface boundary upon temperature conditions in the test specimens. The temperature gradients at equilibrium were plotted for all tests, similar to the typical equilibrium temperature gradients shown on Figure 4, Plate B-4. These temperature gradients were then extrapolated to the top and bottom surface of the samples. The specimen temperatures at the top and bottom were then determined and are recorded on Table A, Plate B-4. The difference between the temperature of the specimen at the top or bottom and the air temperature at the top or bottom respectively is termed the "boundary temperature difference". The equilibrium temperature gradients of each specimen, expressed in degrees F per foot, have been computed and are recorded on Table A, Plate B-4. Plates B-6, B-7, and B-8 are plots of equilibrium temperature gradients vs. boundary temperature differences for the 3 different water contents tested. The scattering of the test data is rather wide, however, it will be noted that small increases in the equilibrium temperature gradient produce substantial increases in the boundary temperature difference for all water contents and in general, the greater the water content the greater the boundary temperature difference for a given temperature gradient. Field observations indicate that equilibrium temperature gradients at one foot depth below the ground surface as large as $6^{o}F$. per foot may be expected at Bedford, Massachusetts, and $10^{o}F$. per foot at Presque Isle, Maine. For gradients of these magnitudes, the boundary temperature difference is approximately $1^{o}F$. and $2^{o}F$. respectively as indicated by the test results on specimens at 2.8 per cent water content (Plate B-7). It is interesting to note on Plates B-6, B-7, and B-8 that the boundary temperature difference at the bottom of the specimens is approximately the same as the boundary temperature difference at top of the specimens even though the water content and the condition of the top and bottom of the specimens varied.

The importance of the evaluation of the boundary temperature difference lies in its relation to the prediction of frost penetration. Knowledge of the magnitude of the boundary temperature difference may permit refinements in theoretical methods for frost prediction and a more exact analysis of observed frost penetrations.

A study of Table A, Plate B-4 indicates that the time for temperature equilibrium to be reached within a given test specimen is dependent upon the magnitude of the temperature differential between top and bottom of the specimen and the density and water content of the specimen. This is as expected for the density and water content of the specimens influence the thermal properties of the material. Specimens at very low water content reached equilibrium temperature quickly because of the small latent heat of fusion and volumetric heat capacity. Saturated specimens reached equilibrium more slowly because of the greater latent heat of fusion and volumetric heat capacity. The same results are illustrated by Figure 3, Plate B-4 in which the rate of penetration of the 32°F temperature is a function of the magnitude of temperature difference between top and bottom of a specimen, and its density and water content.

From Figure 4, Plate B-4 the ratios of the thermal conductivity in the frozen to the unfrozen state can be determined. It may be shown that this ratio is equal to the ratio of the equilibrium temperature gradient in the unfrozen zone to that in the frozen zone since the quantity of heat passing through the sample at equilibrium is equal to $k_1 \times s_1$ and also equal to $k_2 \times s_2$. These ratios have been determined for the four tests plotted and at the density and water contents of the materials tested the coefficient of thermal conductivity in the unfrozen state varied from 52 to 85 per cent of that in the frozen state.

2-03. <u>Experiments to Measure Thermal Conductivity in Unfrozen and Frozen State.</u>

a. <u>General</u>. Five different base course materials were tested for thermal conductivity in the unfrozen state. Each material was tested at maximum density except one which was tested at several densities between maximum and minimum. Tests were performed on specimens at water contents ranging from almost dry to a saturated condition. The same materials were also tested for thermal conductivity in a frozen condition.

b. <u>Materials Tested</u>. Thermal conductivity tests were performed on the following materials:

(1) <u>Sand</u> (Lowell Sand) consisted of a cohesionless, siliceous sand from a glacial outwash deposit at South Lowell, Mass.

(2) <u>Crushed Rock</u> (Winchester Crushed Rock) consisted of a fine grained quartz diorite obtained from quarry at Winchester, Mass.

(3) <u>Slag</u> (Mystic Slag) consisted of basic residue from blast furnace located at Everett, Mass.

(4) Cinders (Somerville Cinders) consisted of commercial grade cinders obtained locally as a result of burning bituminous coal.

(5) Sand and Gravel (Bangor Sand and Gravel) consisted of a well graded sand and gravel of glacial origin obtained from Bangor, Maine.

(6) Blended Bituminous Concrete Aggregate consisted of locally processed aggregates of sand and partially crushed gravel obtained from bins of commercial plant at Cambridge, Mass.

(7) Asphaltic Bituminous Concrete consisted of the blended bituminous concrete aggregate and 4.5% bitumen.

c. Test Specimen. Each test specimen was of cylindrical shape, 5.36 inches in diameter and 10.67 inches in height, and was contained in a brass cylinder of 1/16 inch wall thickness. Brass was used because of its high thermal conductivity in comparison with soil. A thermocouple was placed at the exact midpoint of the cylinder as shown on Plate B-1. Cylinder ends were 1/16 inch brass and were sealed to prevent leakage and changes in water content of specimen during tests. Plate B-9 shows photograph of brass cylinder and cover.

d. Sample Preparation. The selected test material was placed in approximately five equal layers and compacted using the device and procedure described in paragraph 2-02 e. Care was taken not to injure or displace the thermocouple during compaction. A template was used to center the thermocouple accurately in the cylinder. After the cylinder was full the cover was put on and sealed first with glyptal, then paraffin.

e. Test Conditions.

(1) Unfrozen Specimens. Each test consisted of subjecting the cylindrical test specimen immersed in a bath, located outside the cold room, to a constant temperature of approximately 75°F. The specimen was then suddenly immersed in a second bath, located in the cold room, to a constant temperature of approximately 40°F. The resulting temperature changes were measured at the midpoint of the specimen. Baths consisted of circulating water maintained at constant temperature by addition of hot or cold water or ice as required. Plate B-1 shows details of constant temperature bath and Plate B-10 shows photograph of bath with test specimens immersed.

(2) Frozen Specimens. Each test consisted of subjecting the test cylinder to a constant freezing temperature of approximately minus 4 degrees F. inside the freezing cabinet until temperature equilibrium was reached and then immersing it into a brine bath in the cold room at a constant temperature of approximately 27 degrees F. The bath consisted of circulating brine maintained at constant temperature by the addition of either hot water or dry ice as required. The resulting temperature change was measured at the midpoint of the specimen until temperature equilibrium was reached.

f. Method of Computing Thermal Conductivity. The equation used for computing the thermal conductivity from the data obtained together with the nomenclature are contained on Plate B-11. The equation, designated (b) was derived for the following assumptions:

(1) The temperature of the exterior boundary of the soil is equal to the temperature of the liquid bath into which the container is immersed.

(2) The range of temperature change during any specific test was either above or below the freezing point of water, hence latent heat of fusion was not a factor.

g. Computation for Thermal Conductivity. From the test data the thermal conductivity, k, may be computed if the volumetric heat capacity is known. It may be assumed that the volumetric heat capacity can be computed for a given soil using equation (a), Plate B-11. This equation is based upon the assumption that the volumetric heat capacity is equal to the sum of the volumetric heat capacities of the dry soil and of the water present in the soil. The value for the specific heat, c, of dry soil is a variable depending upon the mineral and chemical constitutents of the soil. Reference to the tabulations of specific heat for various minerals, rocks, and dry soils based upon tests by various investigators will show that the specific heat of dry soil, minerals, and rocks varies within narrow limits and that a value of approximately 0.2 Btu/(lb) (degF) is a good average value. The value of the specific heat of water is 1 Btu/(lb)(degF) and of ice is 0.5 Btu/(lb)(degF). Hence, using equation (a), Plate B-11, the volumetric heat capacity of each test may be computed using the assumed value for specific heat of dry soil shown on Plate B-11 and the determined water content and density. By substituting the computed value for volumetric heat capacity, the thermal conductivity, k, may be computed using equation (b). An example for the determination the thermal conductivity, k, is presented on Plate B-12.

h. Test Data and Results. The data obtained from the thermal conductivity tests are summarized in tabular form on Plate B-12. Grain size curves of the materials tested are shown in Figures 4 and 5, Plate B-11. Figures 2 and 3 show typical curves of temperature changes at the thermocouple located at the midpoint of the specimen vs. time. Curves for determining the thermal conductivity from the measurements obtained, together with an example, are also contained on Plate B-11, Fig. 1. Plate B-13 contains a plot of the test results to illustrate, in general, the greater thermal conductivity of frozen material as the water content is increased. The results of tests on the blended bituminous concrete aggregate and asphalt bituminous concrete are tabulated on Plate B-11 but have not been plotted.

i. Tests by Other Investigators. A comprehensive investigation of the thermal conductivity of ten different soils was performed by Harrison E. Patten (1). The results of his investigations upon eight soils are presented on Plate B-14 in a form similar to tests conducted by Boston District as summarized on Plate B-12. Tests on the remaining two soils were incomplete and are not included. On Plate B-14, Table A, is a summary of test data, Figure 2 contains reported grain size curves, and Figure 1 is a summary plot of thermal conductivity vs. water content for the densities tested. It will be noted that densities of test specimen were very low and generally much less than that at which the soils would normally be found in their natural state.

The results of additional tests made by others are summarized on Plate B-15. It will be noted that the values of the unit dry weight of soil as tested were not determined by some of the investigators Shanklin states that in his tests, the soil was well tamped. Also, it is not certain whether the water content is expressed as a percentage of the dry or wet weight in these tests.

j. <u>Analysis of Test Results</u>. The tests performed by the Frost Effects Laboratory and summarized on Plate B-12 may be compared with those performed by H. E. Patten as summarized on Plate B-14. It will be noted that the sample of coarse quartz tested by Patten approaches in grain size distribution that of Lowell Sand, and further that the thermal conductivities of these two soils are approximately the same at equal water

(1) Patten, Harrison E. "Heat Transference in Soils", U. S. Dept. of Agriculture, Bulletin No. 59, September 1909.

contents. The test results on the Hudson River Sand are quite different from all other materials tested. The finer grained soils, Podunk fine sandy loam, Leonardtown silt loam, Hagerstown loam, Galveston clay and fine quartz flour all have approximately the same thermal conductivity at equal water contents. The thermal conductivity of the muck soil is much less than that of the Somerville cinders and Mystic slag tested.

The tests upon the Lowell sand indicate that the influence of water content upon thermal conductivity is much greater than density.

There is no apparent relation between grain size or other characteristics of the various soils tested which may be correlated with thermal conductivity. To satisfactorily determine the thermal conductivity of a given soil, tests are required at several different moisture contents. The test procedure herein described is considered a satisfactory method for the rapid determination of the coefficient of thermal conductivity.

Analyses of investigations made by others and of the controlled laboratory tests indicate that the thermal conductivity of frozen cohesionless soils is greater than unfrozen at high water contents and is approximately equal at low water contents and the thermal conductivity of most types of soils increases with increasing water content and increasing unit dry weight. A reasonable range of the thermal conductivity of most cohesionless soils frozen or unfrozen is from 0.6 to 1.5

Btu/ft. °F. Hr. This range does not include the organic soils such as peat, soils of volcanic origin, or cohesive soils which may be expected to differ in thermal properties.

2-04. Review of Studies of Latent Heat of Soil Moisture by Others.

The latent heat of soil moisture is directly determined from the quantity of water in the soil which freezes. Investigations reported by others* of the percentage of water which freezes were reviewed and are summarized in the following paragraphs.

a. Bureau of Public Roads Test. The Bureau of Public Roads tests were performed to determine the percentage of water in the soil which freezes, this percentage determining the latent heat. In performing the tests, the entire soils was subjected to below freezing temperature and water content of the soil maintained constant during the test. The materials tested were clean quartz sand (standard Ottawa sand), and soils containing silt and clay.

These tests indicated that, for the conditions tested, all water in a clean quartz sand froze at 0 degrees C (32 degrees F) and from 32 to 85 per cent of the water in the soils containing silt and clay froze at a temperature of minus 1.5 degrees C (29.3 degrees F), the percentage of water freezing

* "Percentage of Water Freezable in Soils" Bureau of Public Roads, Public Roads February 1925.

"Progress Report on an Investigation of Frost Action in Soils" by Mackintosh, Proceedings of International Conference on Soils Mechanics and Foundation Engineering. 1936.

depending approximately on the amount of fines.

b. Harvard University Tests. The tests reported by Mackintosh were performed at Harvard University on a plastic clay, and indicated that for the conditions tested, about 33 per cent of the original water in the clay froze at a temperature between minus 1.0 deg. C and minus 2.0 deg. C (30.2 deg. F and 28.4 deg. F).

The latent heat of soil moisture is a direct function of the percentage of its water content that freezes. The percentage of water which will freeze in a soil is primarily dependent on the void size, the degree of saturation, the presence of soluble salts, the temperature of the soil, and the molecular attraction between ice and water. For all practicable purposes, all the water in clean cohesionless soils or the GW, GP, SW, and SP classifications will freeze at 32°F. In silt soils of the ML classification, most of the water may be expected to freeze at 32°F. In the remaining soils of the GC, GF, SC, SF, CL, OL, MH, CH, and OH classifications, a lesser percentage of the water contained in the voids will freeze and will depend on the factors listed above. The range of values of the percentage of water frozen, for the usual conditions encountered in plastic soils, may vary from 35 to 80. Figure 1, Plate 3-10 shows the relationship between density in pounds per cubic foot and latent heat of fusion in Btu per cubic foot for various water contents assuming that all the water freezes. This figure is a nomographic presentation of the graph shown on Figure 3. The average latent heat, where there are several soil layers at different water contents, may be determined using the following equation:

$$L = \frac{L_1 d_1 + L_2 d_2 + L_3 d_3 + \dots + L_n d_n}{d_1 + d_2 + d_3 + \dots + d_n}$$

where:

L is average latent heat of soil moisture

L_1, L_2, L_3, are latent heats of soil moisture in layers 1, 2, 3, etc.

d_1, d_2, d_3, etc. are the thicknesses of layers 1, 2, 3, etc. (note that $d_1 + d_2 + d_3 + \dots d_n$ equal depth of freezing)

2-05. Review of Studies of Volumetric Heat of Soil by Others. Studies by various investigators, as summarized by H. E. Patten in "Heat Transference in Soils," demonstrated that the total volumetric heat of a given volume of soil is the sum of the volumetric heats of the individual components of the soil, i.e., dry soil and water or ice. Figure 2, Plate B-16 shows the relationship between unit dry weight, water content, and volumetric heat for average values of the specific heats of soil, water and ice.

There are tabulated below a number of values for specific heats for various soils, rocks, and minerals. These values were obtained from "Handbook of Chemistry and Physics" 1945 Edition, and "Mechanical Engineer's Handbook" by Marks, 1941. Most determinations were made at about room temperature.

MATERIAL	SPECIFIC HEAT BTU/(Lb)(°F)	MATERIAL	SPECIFIC HEAT BTU/(Lb)(°F)
Asbestos	0.195	Humus	0.44
Basalt	0.20	Kaolin	0.224
Calcspar	0.20	Marble	0.21
Cement	0.20	Mica	0.206
Chalk	0.214	Quartz	0.188
Clay, dry	0.22	Salt, Rock	0.21
Cinders	0.18	Sand	0.195
Dolomite	0.222	Sandstone	0.22
Gneiss	0.18	Serpentine	0.25
Granite	0.192	Talc	0.209
Hornblende	0.195		

Based on the specific heats of the various soils, rocks, and mineral an average value of 0.2 Btu/(lb)(°F) has been used for the specific heat of soil and values at 1.0 and 0.5 Btu/(lb)(°F) for water and ice, in all calculations involving the prediction of the depth of frost penetration. Figure 2, Plate B-16 shows the relationship between density in pounds per cubic foot and volumetric heat in BTU per cubic foot per degree F for various water contents for both frozen and nonfrozen states. Where the soil is fully saturated, the volumetric heat of the nonfrozen soil is nearly constant, varying from 40 to 45 Btu/(cu.ft.)(°F) within reasonable limits of unit dry weight and for frozen soil it may be considered constant at approximately 32 Btu/(cu.ft.)(°F). Where there are several layers at different unit dry weights and water contents, the following equation may be used to determine an average value for volumetric heat:

$$C = \frac{C_1d_1 + C_2d_2 + C_3d_3 + \cdots + C_nd_n}{d_1 + d_2 + d_3 + d_n}$$

where:

C is the average volumetric heat

C_1, C_2, C_3, etc. are volumetric heats in frozen or unfrozen states for layers 1, 2, 3, etc.

d_1, d_2, d_3, etc. are thickness of layer 1, 2, 3, etc.

From the data as presented on Plate B-17 the freezing temperature of soil moisture is considered as 32°F.

2-06. Studies of the Temperature Required to Freeze Soil Moisture.

The determination of the temperature at which soil moisture freezes was made from field investigations, and from a study of investigations performed by others* and are summarized below.

a. Supercooling. Studies by Bouyoucos involved tests in cooling cohesionless and cohesive soils with and without agitation. The tests indicate that cohesionless soils could be supercooled without agitation to a temperature of 24.4 deg. F. and

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* "Degree of Temperature to which Soils can be Cooled Without Freezing," by G. Bouyoucos - Journal of Agricultural Research, November 1920.

"Ice Pressure Determination in Clay Soils," Engineering News Record, 25 July 1935.

"A Progress Report on an Investigation of Frost Action in Soils," by Mackintosh - Proceedings of the International Conference on Soil Mechanics and Foundation Engineering, 1936.

"Studies of Frost Penetration," by H. U. Fuller - Journal N.E. Water Works Association, September 1940.

cohesive soils to 23 deg. F before they froze. Distilled water can be supercooled to 21.2 deg. F before it freezes. With constant agitation, it can be cooled to about 30.2 degrees F before it freezes.

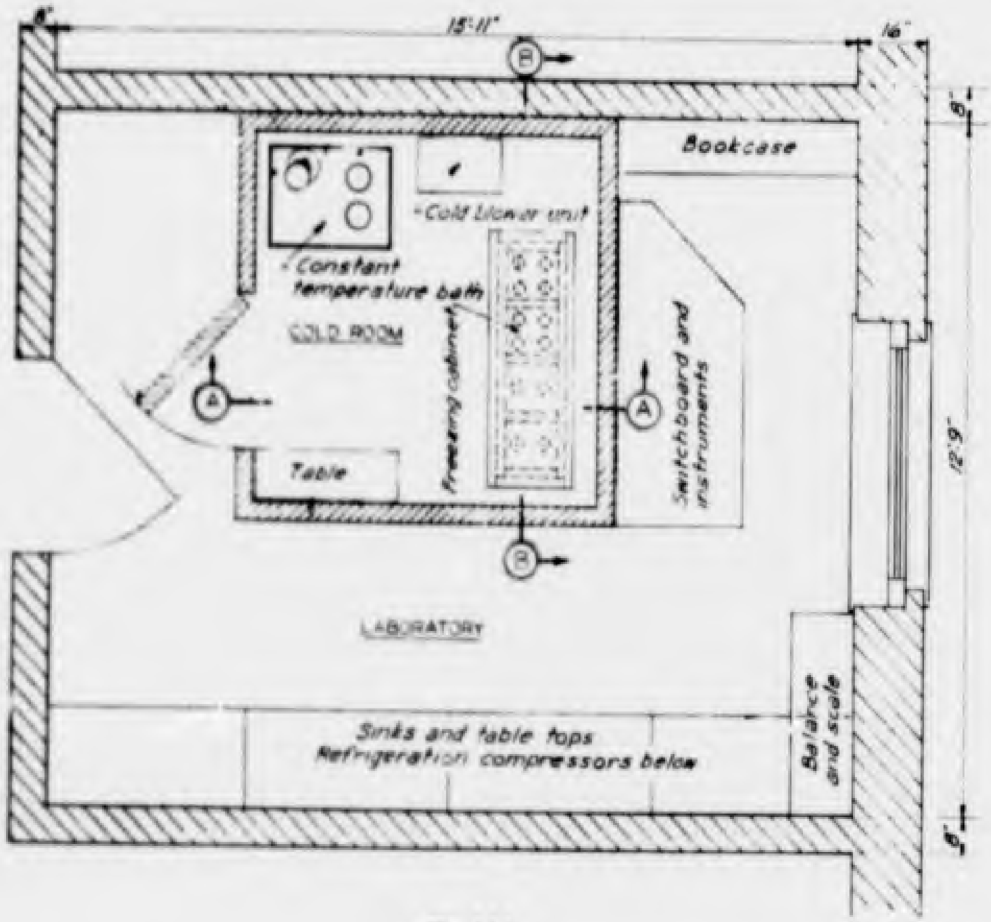
b. Bureau of Public Roads Tests. Tests performed by the Bureau of Public Roads on clean quartz and soils containing silt and clay, indicated that the freezing temperature was below 32°F, in some cases being as low as 29.3°F.

c. Harvard University Tests. Two sets of tests were performed independently at Harvard University, both on soft clay. In the first series of tests, the temperature at the bottom of the zone of ice lenses ranged from minus 1.0°C to minus 2.0°C (30.2°F to 28.4°F) and in the second series of tests, the boundary temperature between ice lenses and the unfrozen clay ranged from minus 0.5°C to minus 0.7°C (31.1°F to 30.7°F).

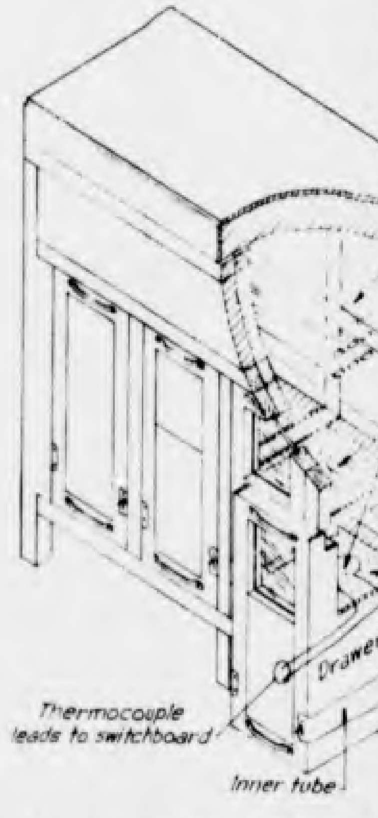
d. Observations by Fuller. Observations were made by Fuller on a gravel soil and on a clay soil at Portland, Maine, by reading thermometers installed at 6-inch intervals of depth and observing the frost penetration. These observations indicated that the temperature at the bottom of the frozen layer was 32.5°F, for both types of soil.

e. Field Observations by Frost Effects Laboratory. The depth of frost penetration as observed in test pits compared with the temperature of the soil at that depth in adjacent subsurface temperature installations are shown on Plate B-17 for 145 locations during 1944-1947 indicated a temperature range of

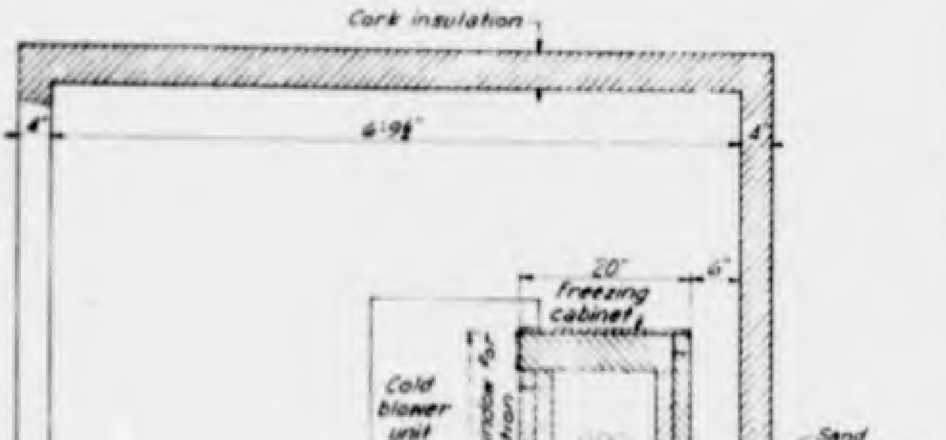
25°F to 40°F. Discounting the three values below 30°F and approximately 35 values above 34°F the average temperature at the maximum depth of frost penetration was 32°F.



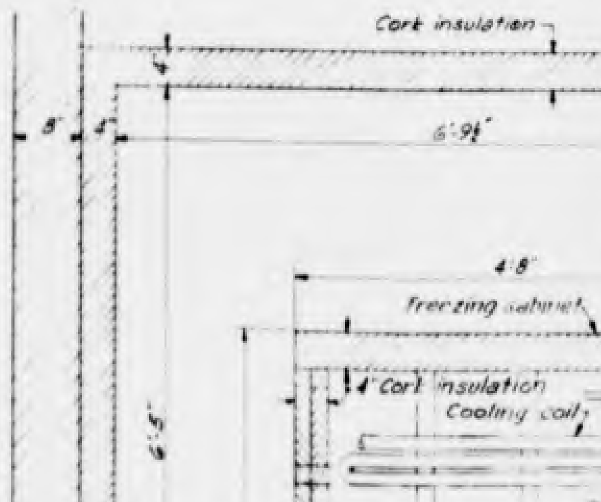
PLAN



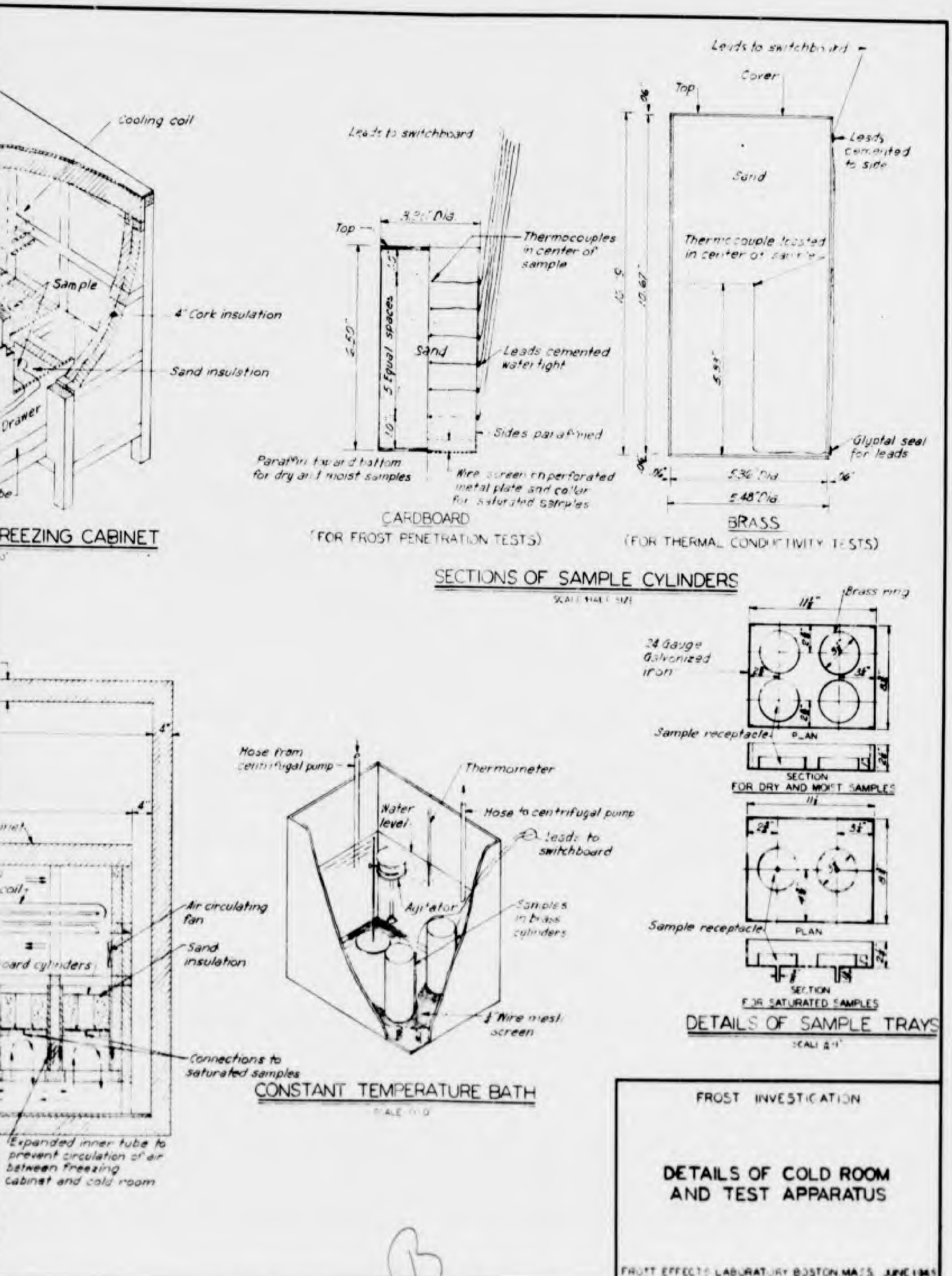
ISOMETRIC VIEW OF FREEZ



SECTION A-A

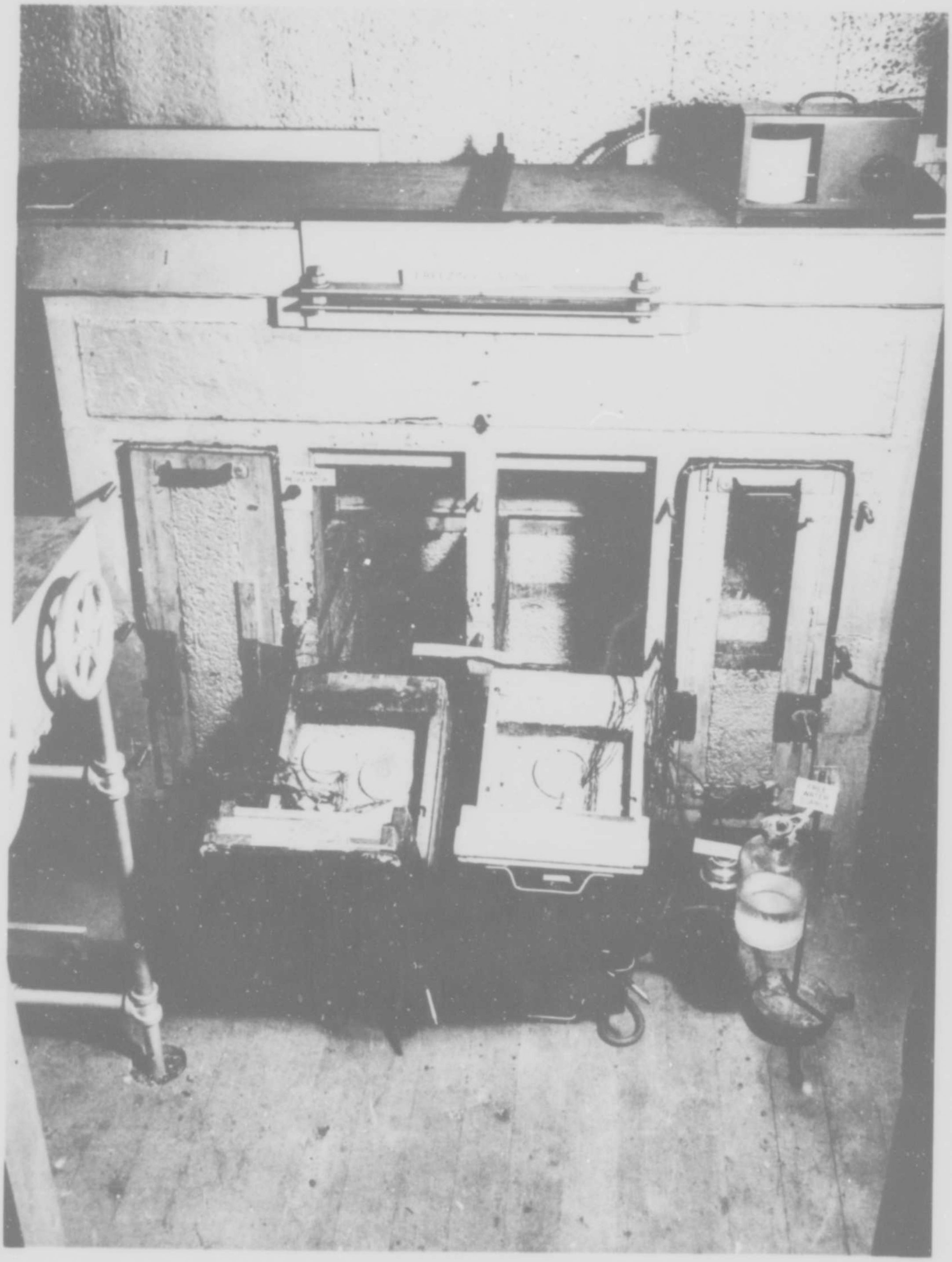


SECTION B-B



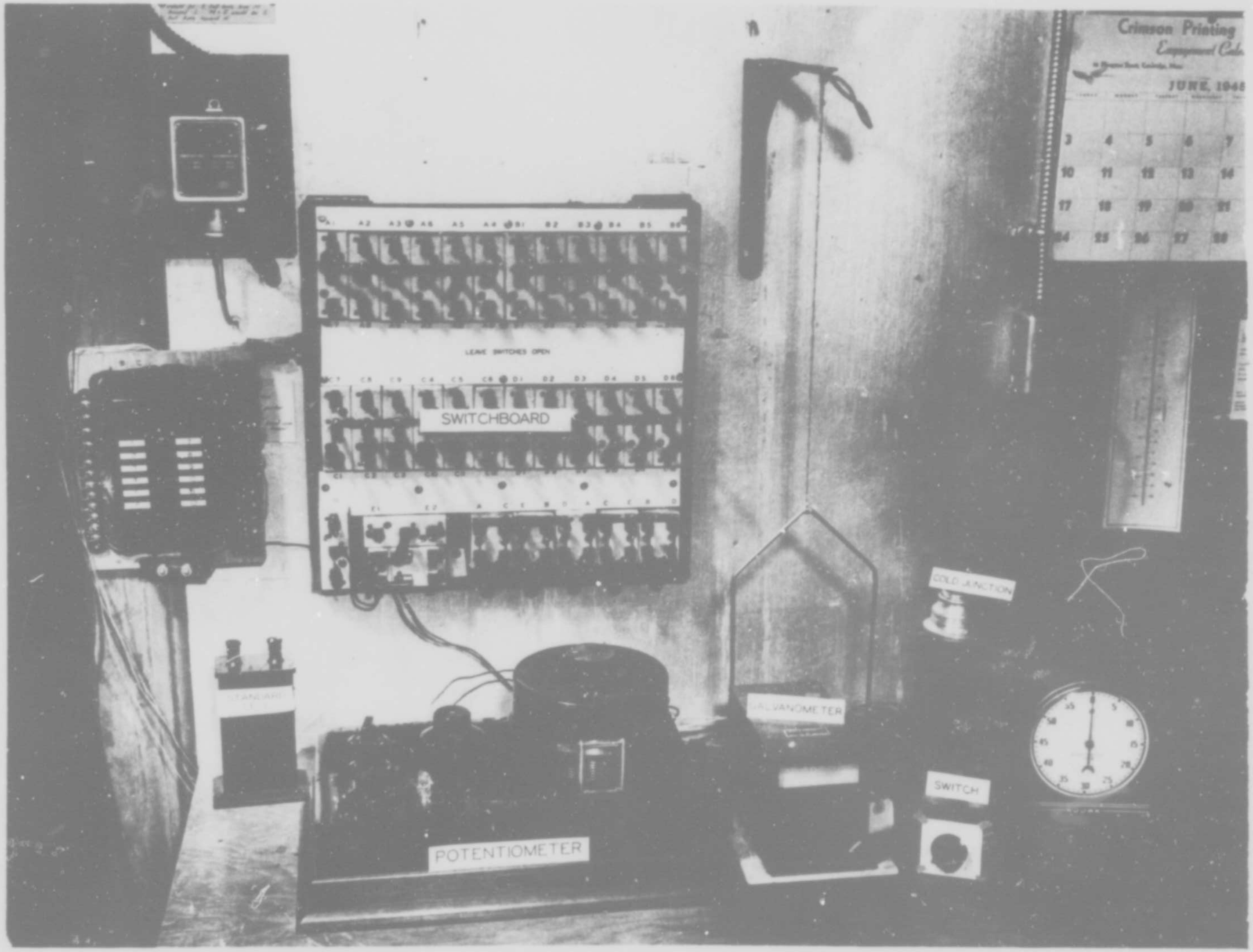
Cooling coil
Sample
4" Cork insulation
Sand insulation
Drawer
FREEZING CABINET
Leads to switchboard
Top
Thermocouples in center of sample
5 Equal spaces
Sand
Leads cemented water tight
Sides paraffined
Paraffin toward bottom for dry and moist samples
Wire screen on perforated metal plate and collar for saturated samples
CARDBOARD
(FOR FROST PENETRATION TESTS)
Cover
Leads cemented to side
Thermocouple located in center of sample
Glyptal seal for leads
5.36" Dia
5.48" Dia
BRASS
(FOR THERMAL CONDUCTIVITY TESTS)
SECTIONS OF SAMPLE CYLINDERS
SCALE HALF SIZE
Brass ring
24 Gauge Galvanized iron
Sample receptacle
PLAN
SECTION
FOR DRY AND MOIST SAMPLES
FOR SATURATED SAMPLES
DETAILS OF SAMPLE TRAYS
Hose from centrifugal pump
Thermometer
Water level
Hose to centrifugal pump
Leads to switchboard
Agitator
Samples in brass cylinders
Wire mesh screen
CONSTANT TEMPERATURE BATH
Air circulating fan
Sand insulation
Connections to saturated samples
Expanded inner tube to prevent circulation of air between freezing cabinet and cold room
FROST INVESTIGATION
DETAILS OF COLD ROOM AND TEST APPARATUS
FROST EFFECTS LABORATORY BOSTON MASS. JUNE 1945

PLATE B-1



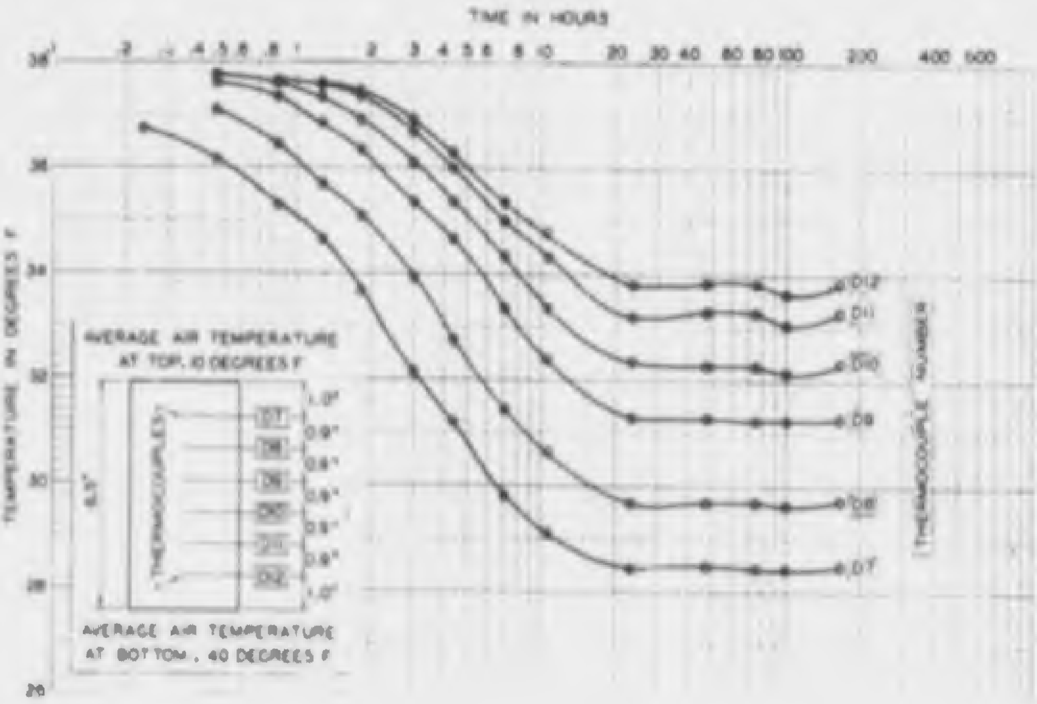
View of Freezing Cabinet

PLATE B-2



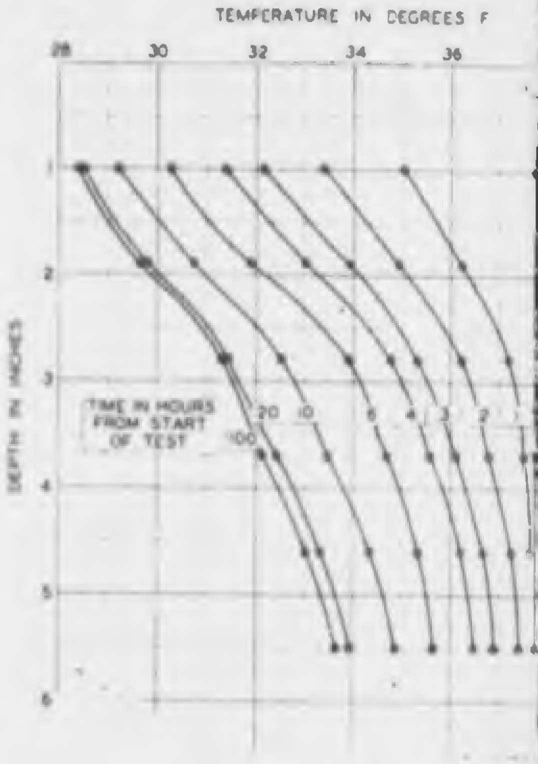
Temperature Indicating Apparatus

PLATE B-3



TYPICAL SET OF TIME TEMPERATURE CURVES

FIG. 1



TYPICAL SET OF TEMPERATURE G

FIG. 2

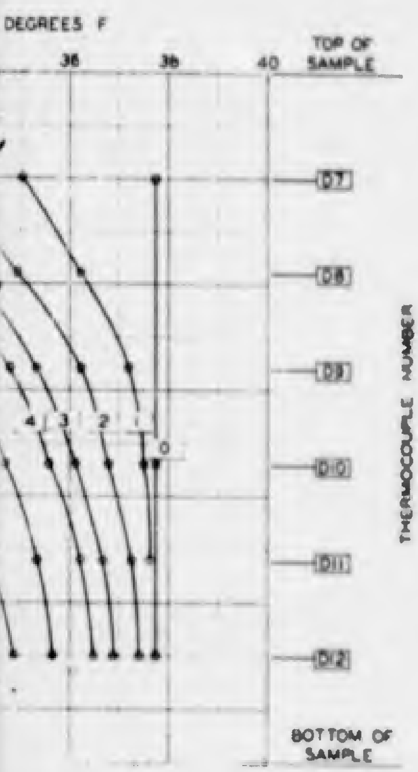
DEPTH IN INCHES

SAMPLE NO.	TEST DRY WEIGHT (lb/ft³)	WATER CONTENT (%)	RUN A: AVERAGE AIR TEMPERATURE, TOP OF SPECIMEN A	RUN A: AVERAGE AIR TEMPERATURE, BOTTOM OF SPECIMEN B	RUN A: TIME FOR EQUILIBRIUM CONDITIONS TO BE REACHED, HOURS	RUN A: EXTRAPOLATED SAMPLE TEMPERATURE, TOP C	RUN A: EXTRAPOLATED SAMPLE TEMPERATURE, BOTTOM D	RUN A: EQUILIBRIUM TEMPERATURE GRADIENT IN SPECIMEN °F/FT.	RUN A: C - A	RUN A: D - B	RUN B: AVERAGE AIR TEMPERATURE, TOP OF SPECIMEN A	RUN B: AVERAGE AIR TEMPERATURE, BOTTOM OF SPECIMEN B	RUN B: TIME FOR EQUILIBRIUM CONDITIONS TO BE REACHED, HOURS	RUN B: EXTRAPOLATED SAMPLE TEMPERATURE, TOP C	RUN B: EXTRAPOLATED SAMPLE TEMPERATURE, BOTTOM D	RUN B: EQUILIBRIUM TEMPERATURE GRADIENT IN SPECIMEN °F/FT.	RUN B: C - A	RUN B: D - B
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SAMPLE NO.	TEST DRY WEIGHT (lb/ft³)	WATER CONTENT (%)	RUN C: TOP OF SPECIMEN A	RUN C: BOTTOM OF SPECIMEN B	RUN C: TIME, HOURS	RUN C: TOP C	RUN C: BOTTOM D	RUN C: GRADIENT °F/FT.	RUN C: C - A	RUN C: D - B	RUN D: TOP OF SPECIMEN A	RUN D: BOTTOM OF SPECIMEN B	RUN D: TIME, HOURS	RUN D: TOP C	RUN D: BOTTOM D	RUN D: GRADIENT °F/FT.	RUN D: C - A	RUN D: D - B
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SUMMARY OF TEST CONDITIONS

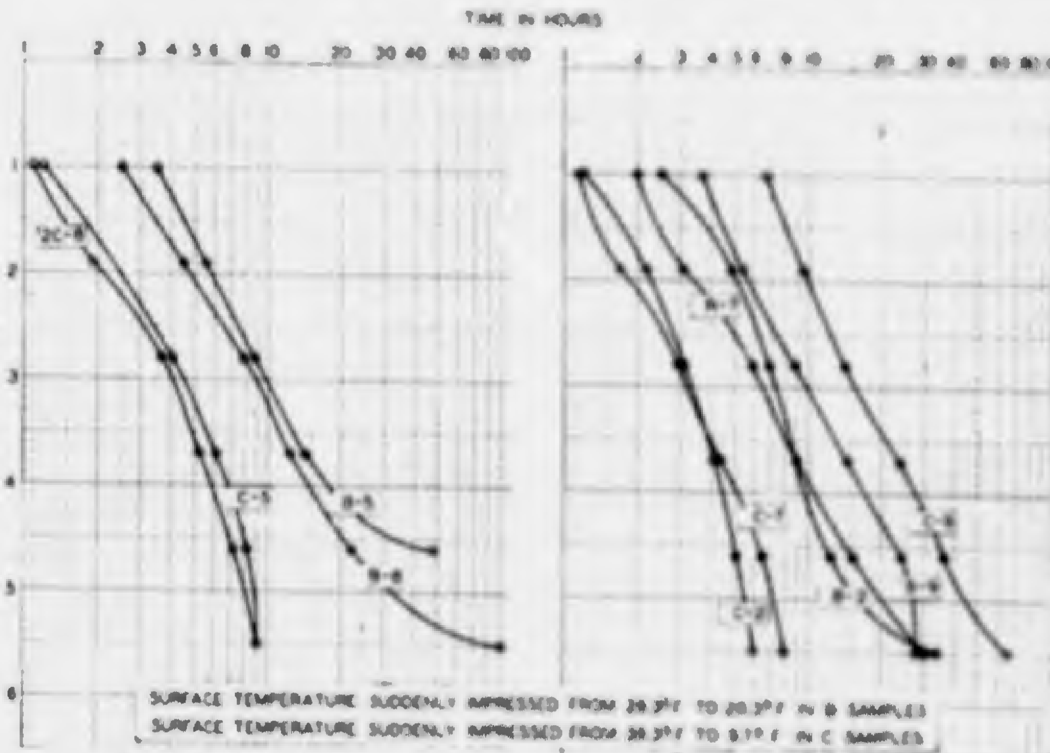
TABLE A



C-8

RATURE GRADIENTS

b-d
5.0
5.0
4.8
4.4
3.6
4.2
4.1
4.6
4.8
6.0
8.2
7.4
3.7
3.2
2.7
2.6
3.8
3.0
2.5
2.7
3.6
4.0
5.8
5.6



SAMPLE NO	w	f
B-5, C-5	2.8	81.6
B-8, C-8	2.7	103.6

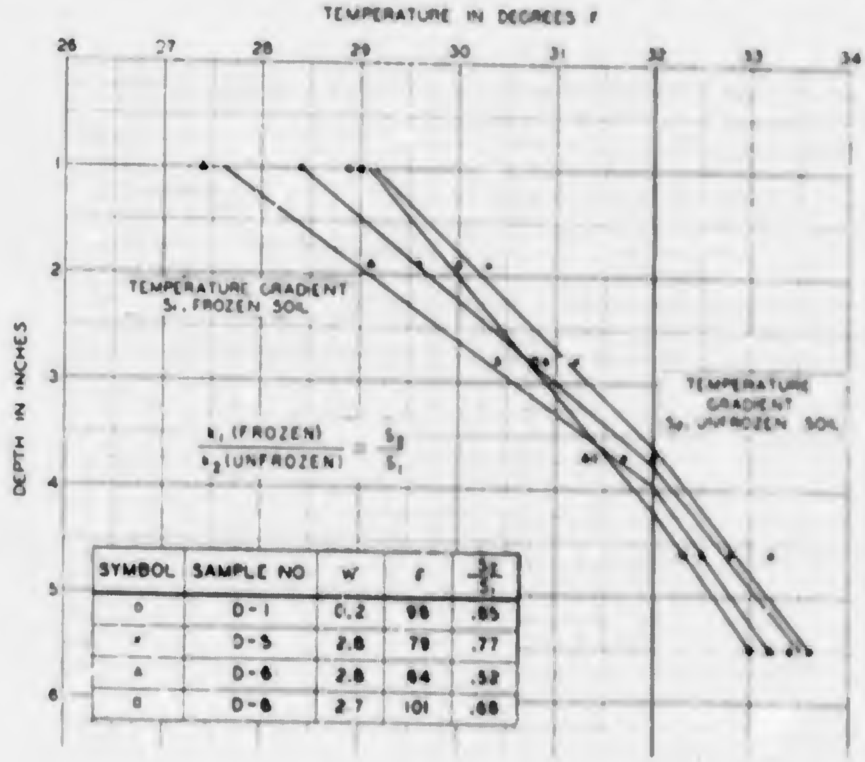
FIG. 3a

SAMPLE NO	w	f
B-2, C-2	0.2	99.3
B-7, C-7	2.8	102.4
B-9, C-9	23.8	101.0

FIG. 3b

PENETRATION OF 32 DEGREES F TEMPERATURE VS TIME

FIG. 3

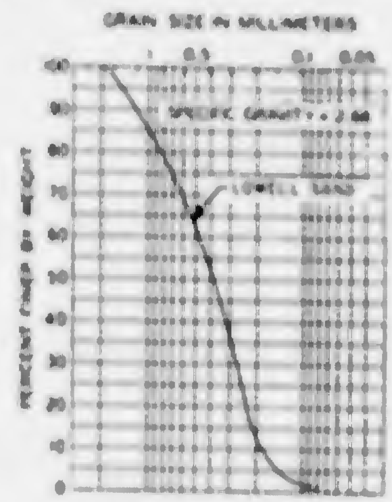


SYMBOL	SAMPLE NO	w	f	$\frac{S_2}{S_1}$
o	D-1	0.2	98	.85
•	D-5	2.8	79	.77
Δ	D-6	2.8	64	.52
□	D-8	2.7	101	.88

SAMPLES D-1, D-5, D-6, D-8

EQUILIBRIUM TEMPERATURE GRADIENTS

FIG. 4



GRAIN SIZE GRADATION CURVE

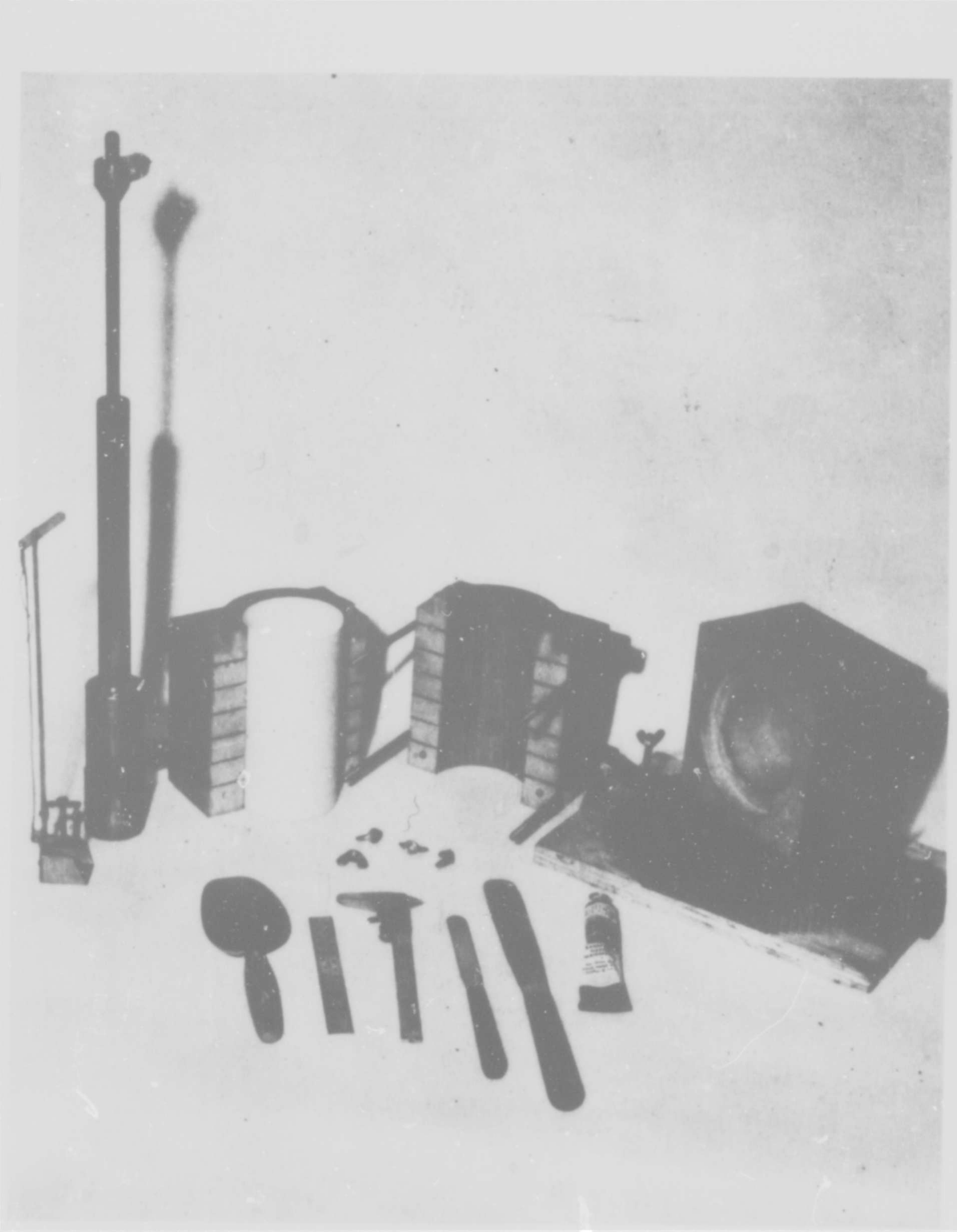
FIG. 5

FROST INVESTIGATION

INVESTIGATION OF TEMPERATURE CONDITIONS IN LABORATORY SPECIMENS

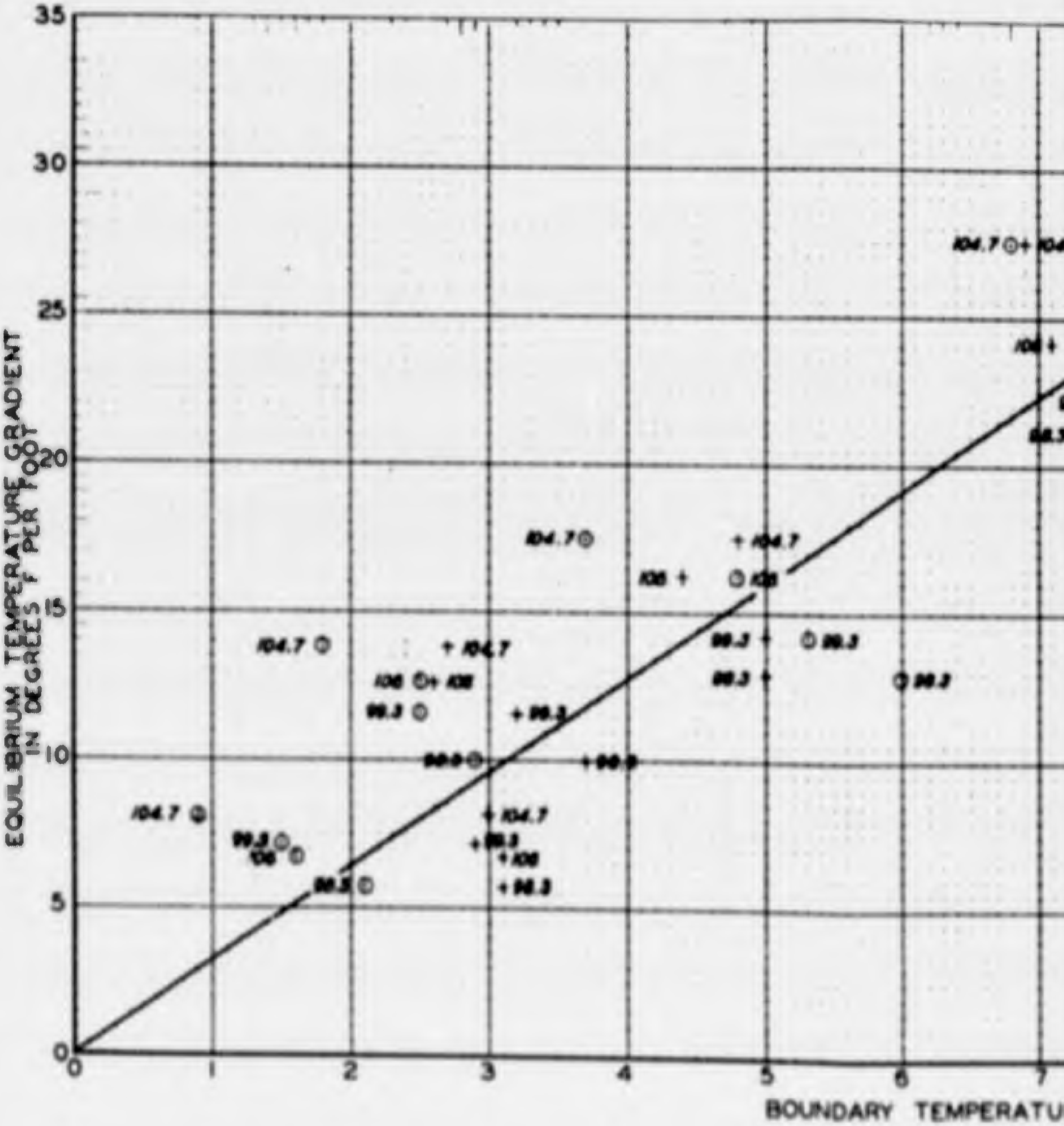
FROST EFFECTS LABORATORY BOSTON MASS JUNE 1945

REVISED FEBRUARY, 1947



Laboratory equipment for compacting samples
in cardboard cylinders

PLATE B-5

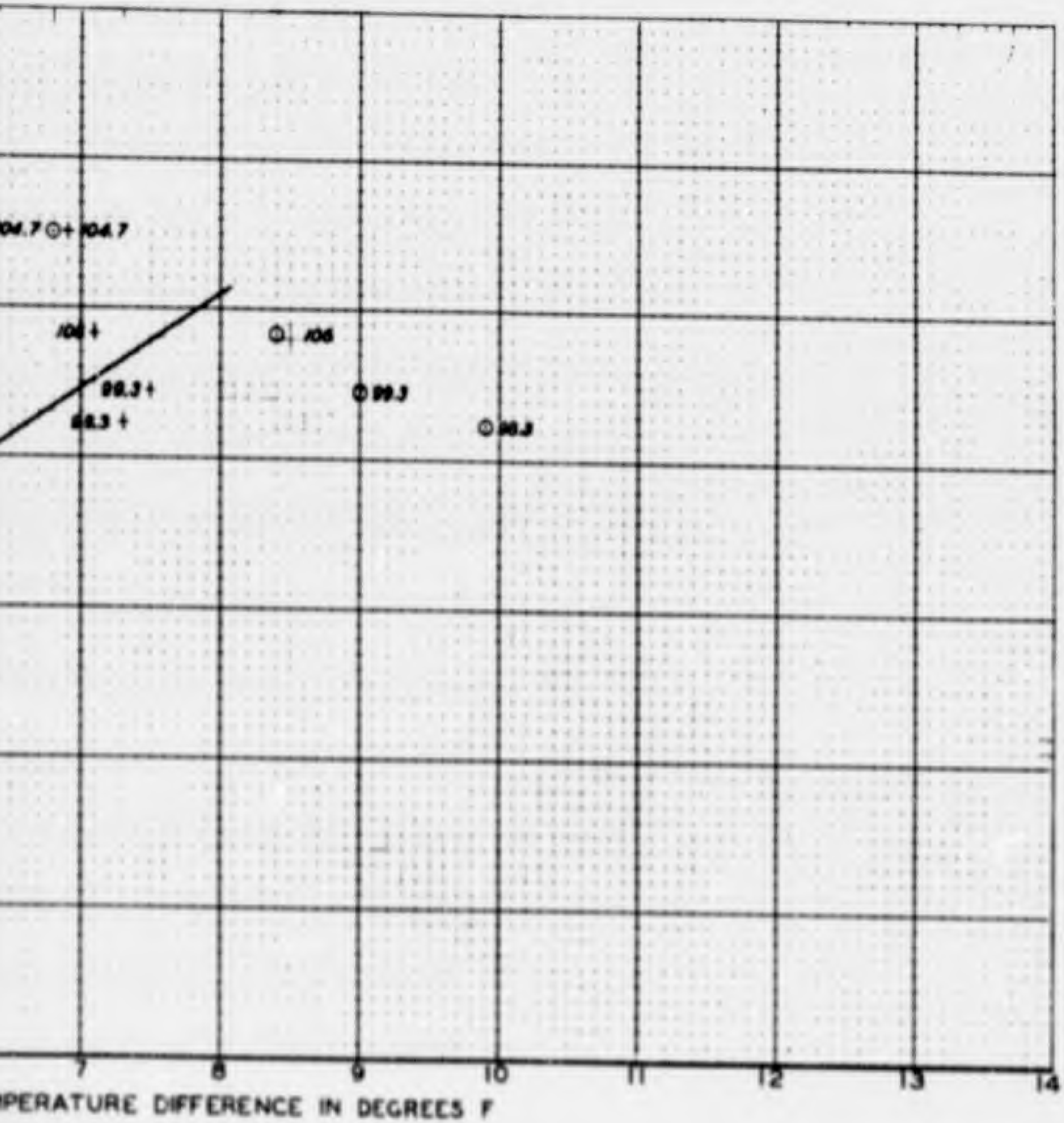


<u>LEGEND</u>

◎ TOP - SPECIMEN WITH THIN PARAFFIN LAYER

\+ BOTTOM - SPECIMEN IN CONTACT WITH SHEET METAL

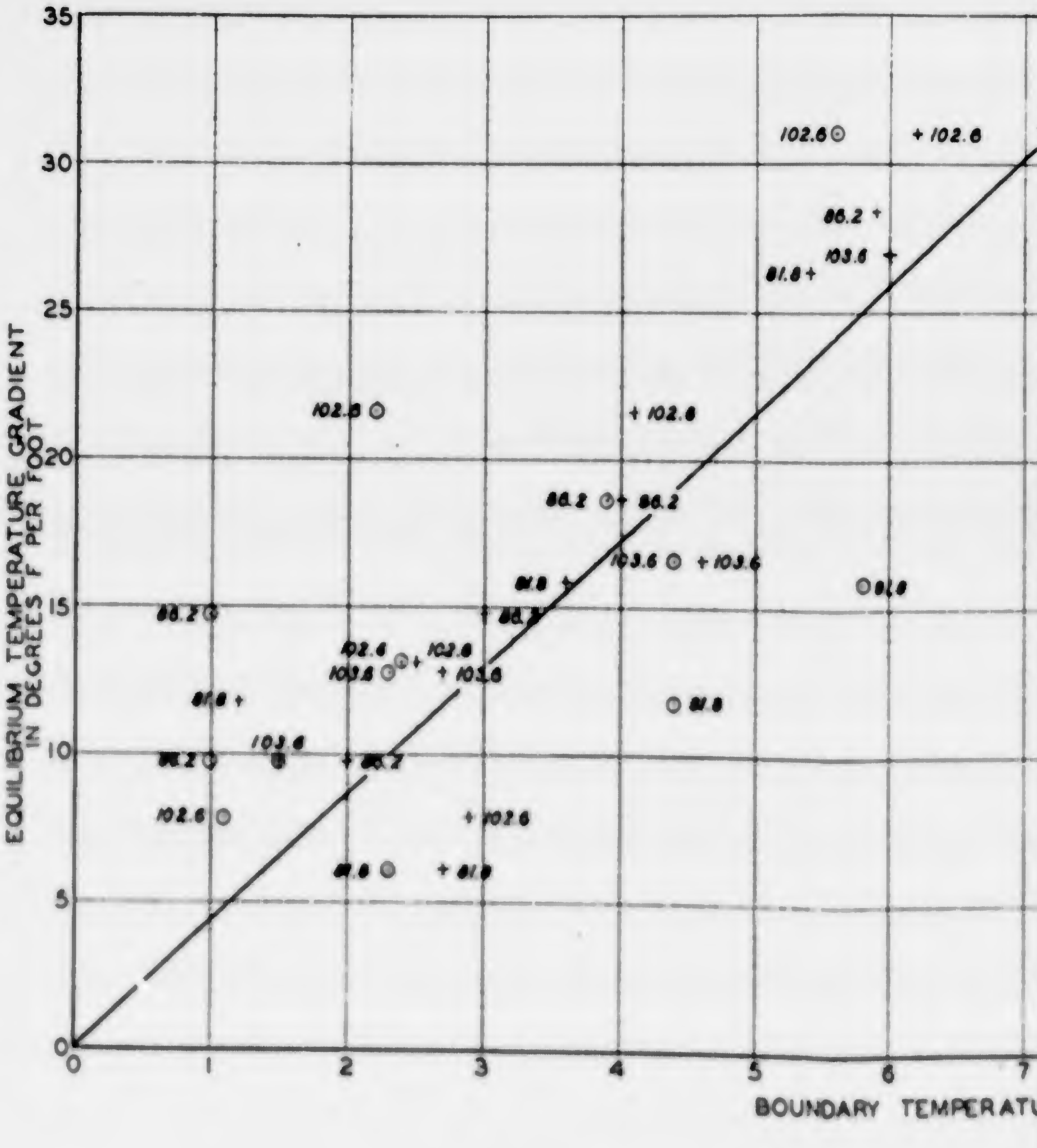
101 NUMBERS BESIDE PLOTTED POINTS INDICATE UNIT DRY WEIGHT IN LBS. PER CU. FT.



FROST INVESTIGATION

BOUNDARY TEMPERATURE DIFFERENCE
0.2 PERCENT WATER CONTENT

JUNE 1945
FROST EFFECTS LABORATORY BOSTON, MASS.

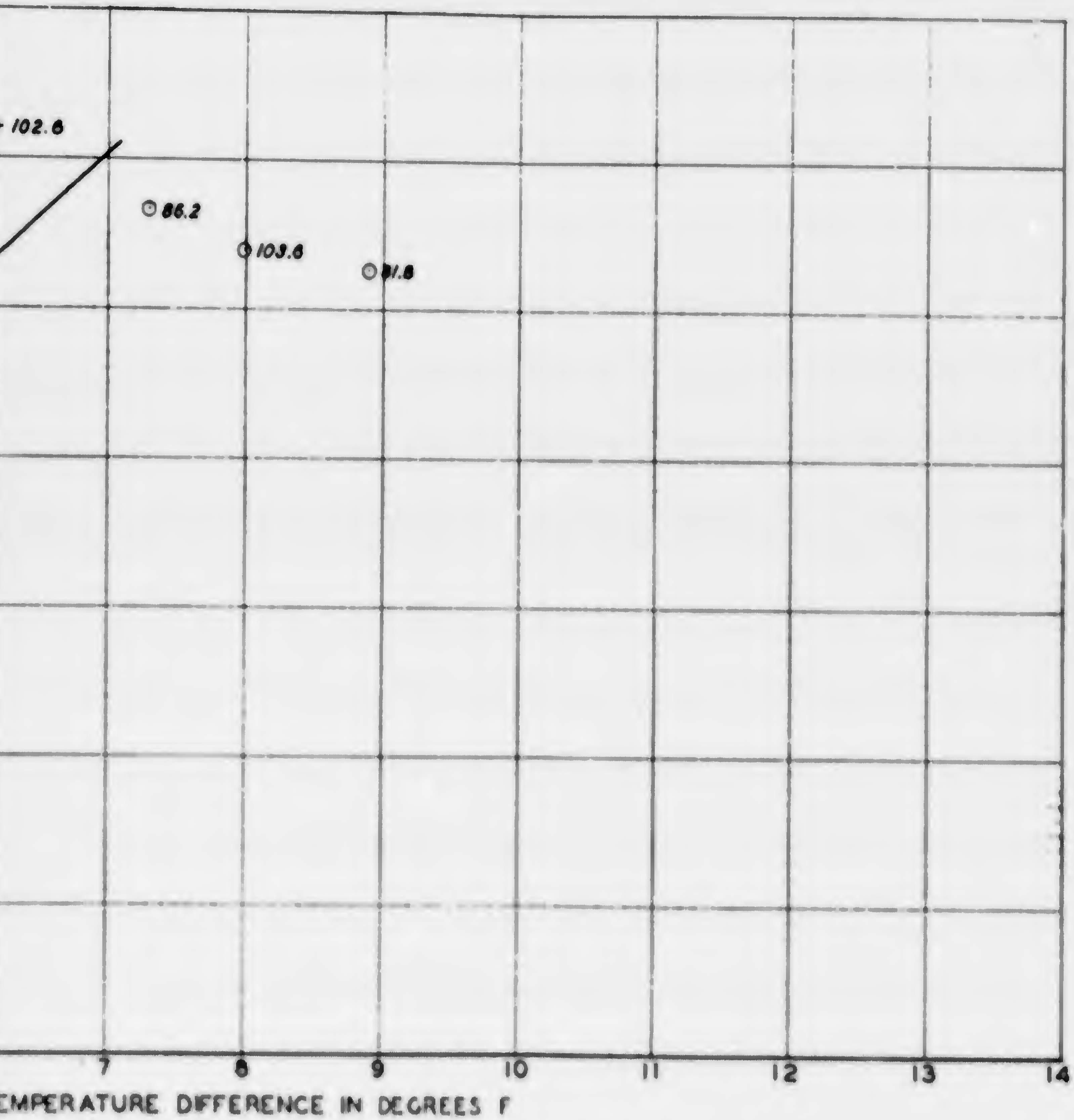


LEGEND

○ TOP - SPECIMEN WITH THIN PARAFFIN LAYER

\+ BOTTOM - SPECIMEN IN CONTACT WITH SHEET METAL

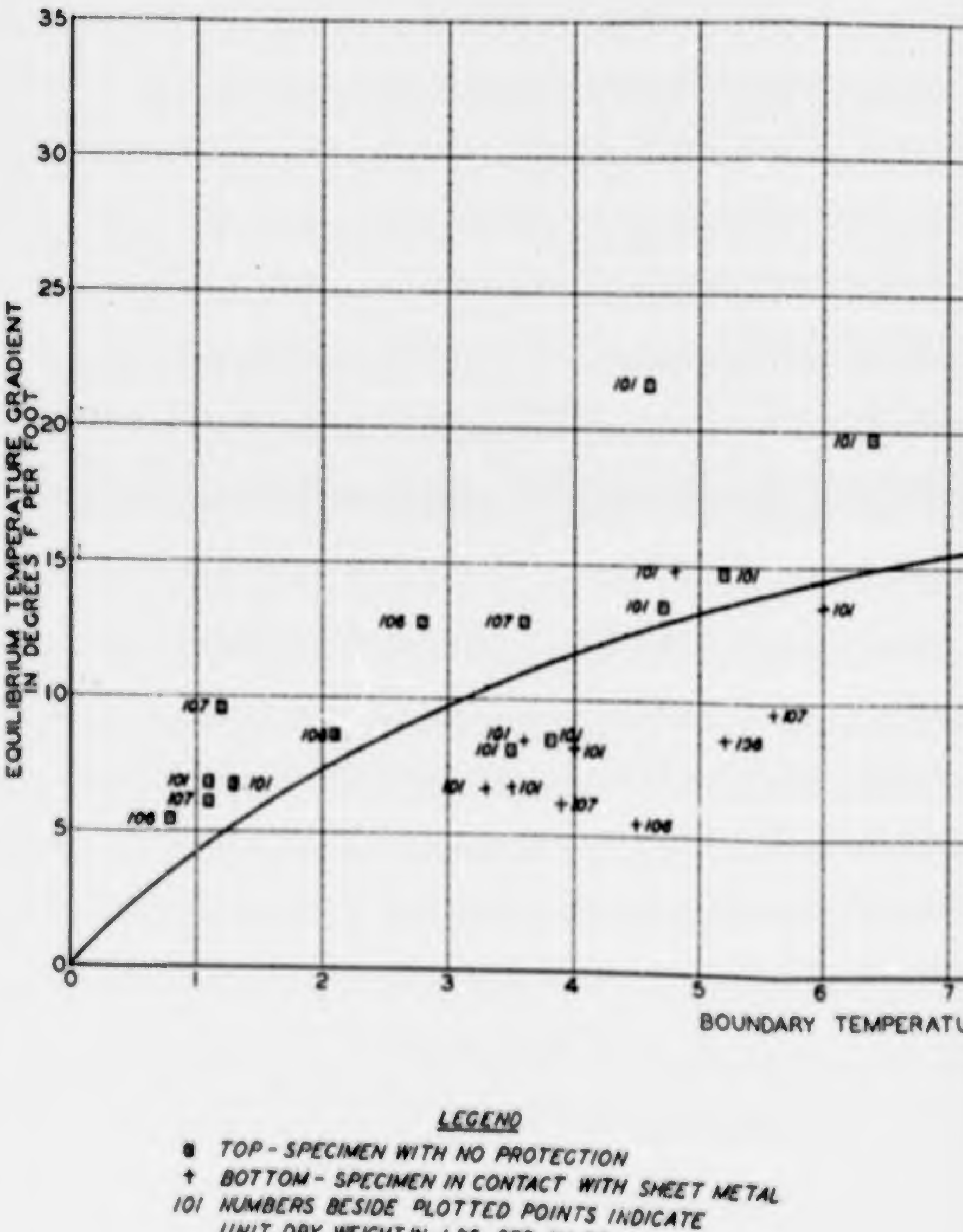
101 NUMBERS BESIDE PLOTTED POINTS INDICATE UNIT DRY WEIGHT IN LBS. PER CU. FT.

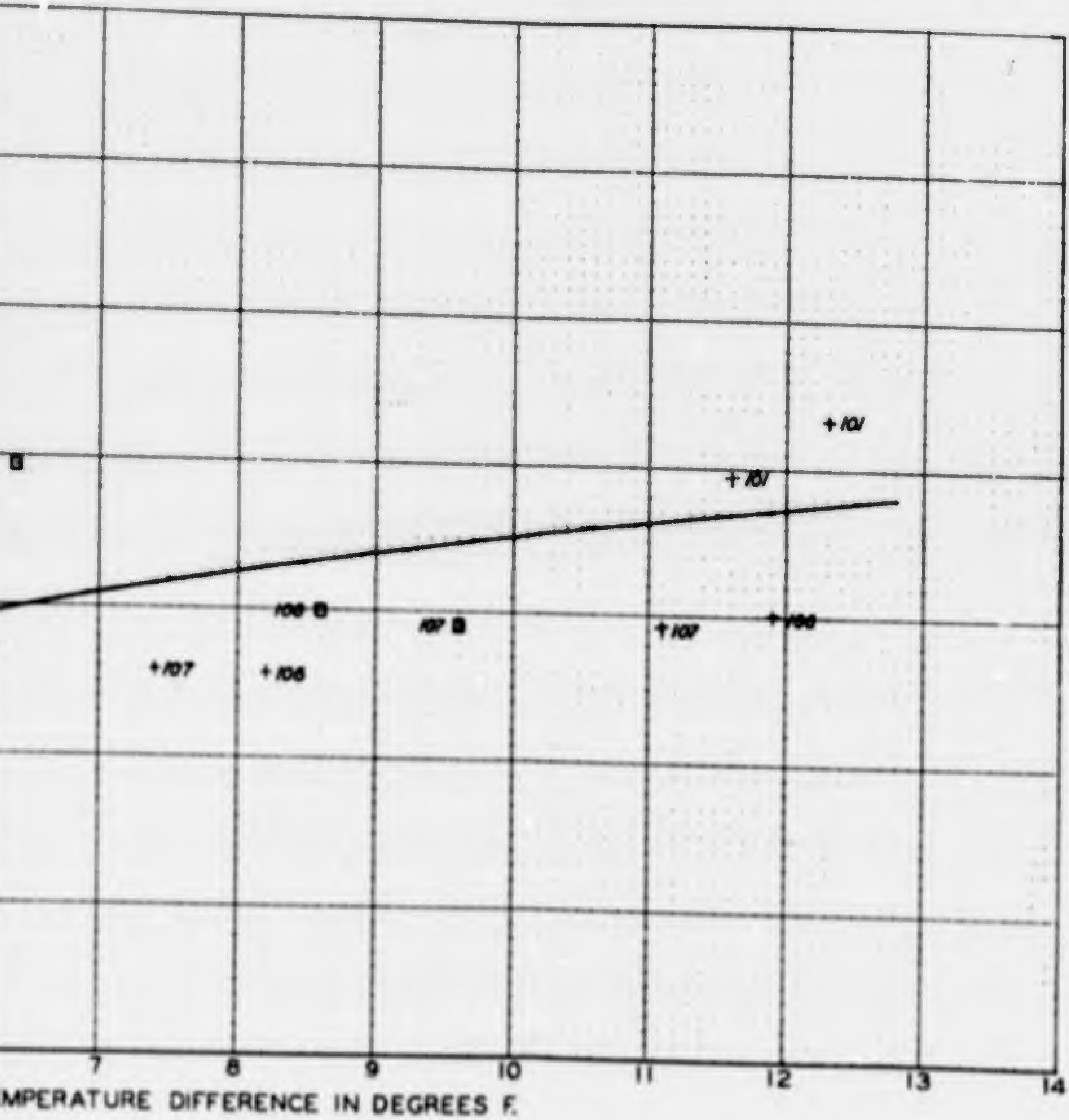


FROST INVESTIGATION

BOUNDARY TEMPERATURE DIFFERENCE
2.8 PERCENT WATER CONTENT

JUNE 1943
FROST EFFECTS LABORATORY BOSTON, MASS.


EQUILIBRIUM TEMPERATURE GRADIENT IN DEGREES F PER FOOT
BOUNDARY TEMPERATU
0
5
10
15
20
25
30
35
1
2
3
4
5
6
7
LEGEND
TOP - SPECIMEN WITH NO PROTECTION
BOTTOM - SPECIMEN IN CONTACT WITH SHEET METAL
101 NUMBERS BESIDE PLOTTED POINTS INDICATE UNIT DRY WEIGHT IN LBS. PER CU. FT.

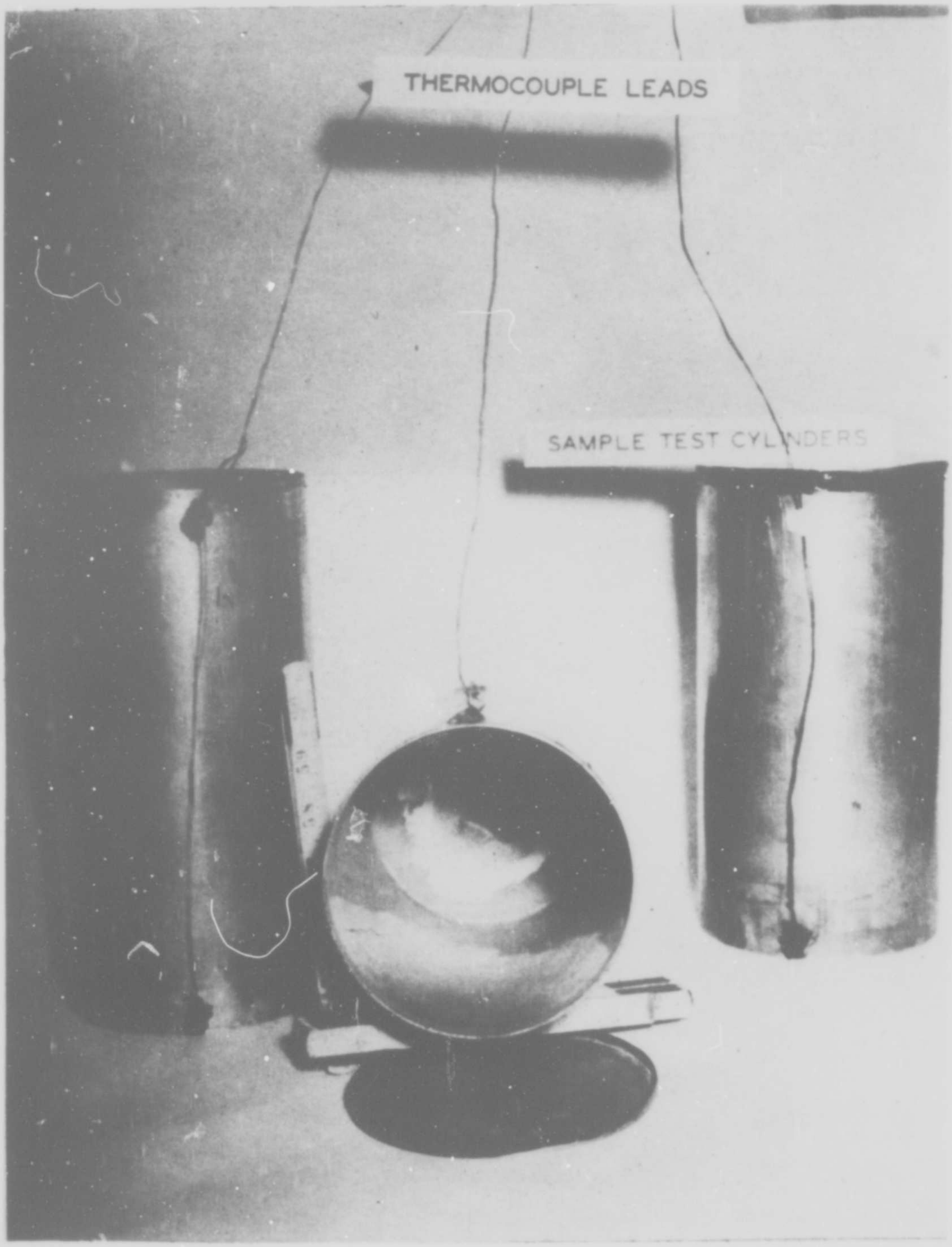


FROST INVESTIGATION

BOUNDARY TEMPERATURE DIFFERENCE
20 TO 23 PERCENT WATER CONTENT

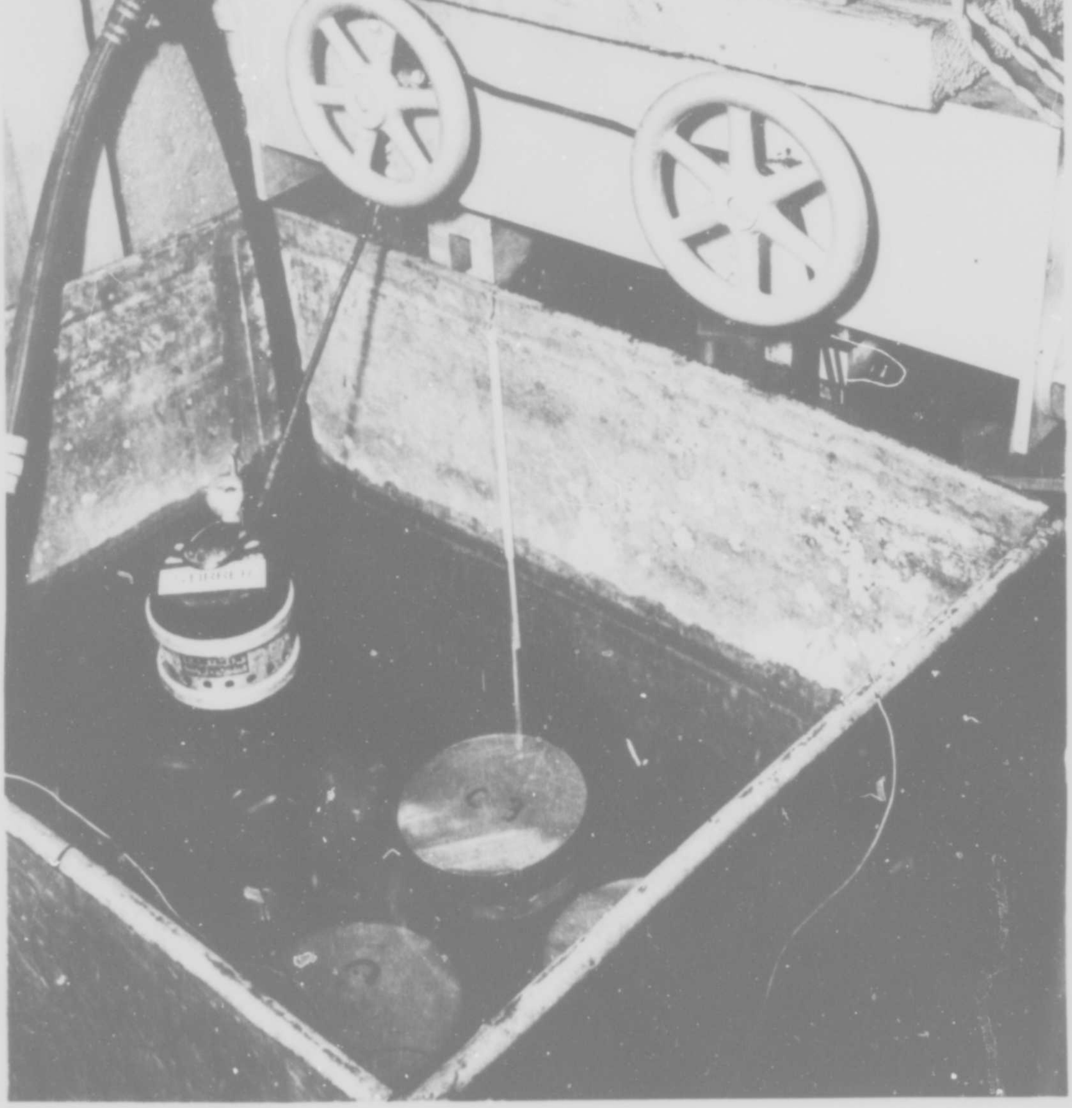
JUNE 1945

FROST EFFECTS LABORATORY BOSTON, MASS



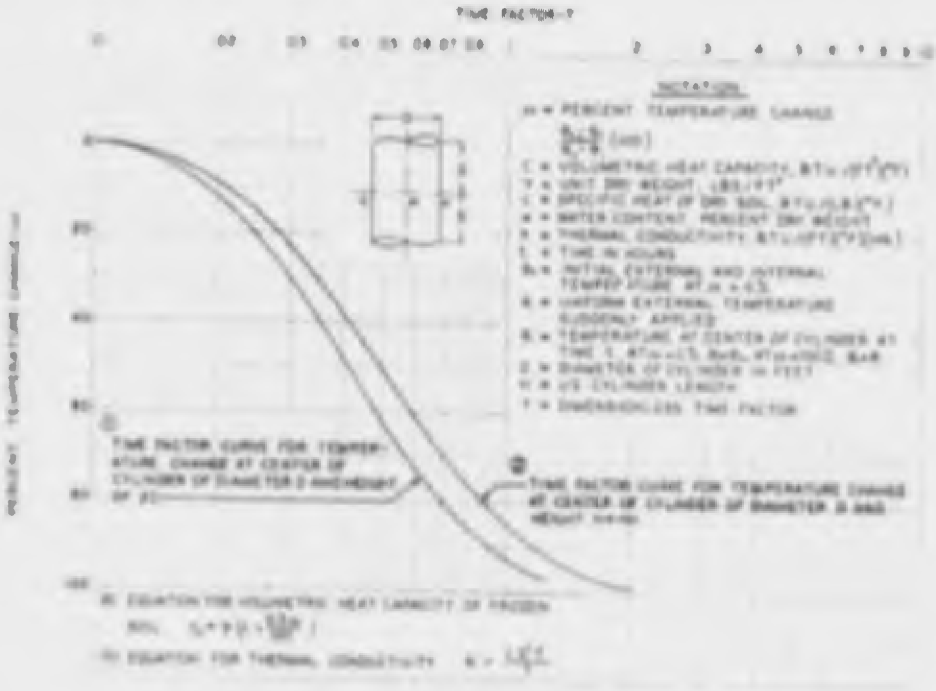
Cylinders used for thermo-conductivity tests

PLATE B-9

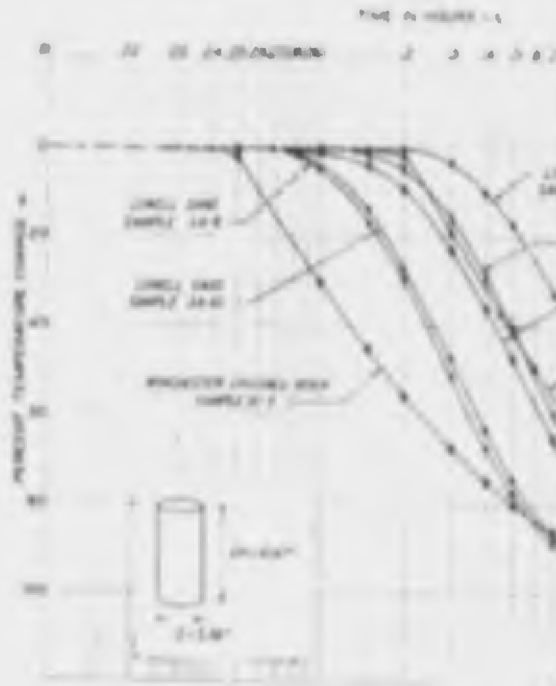


Constant Temperature Bath with Test Specimens Immersed

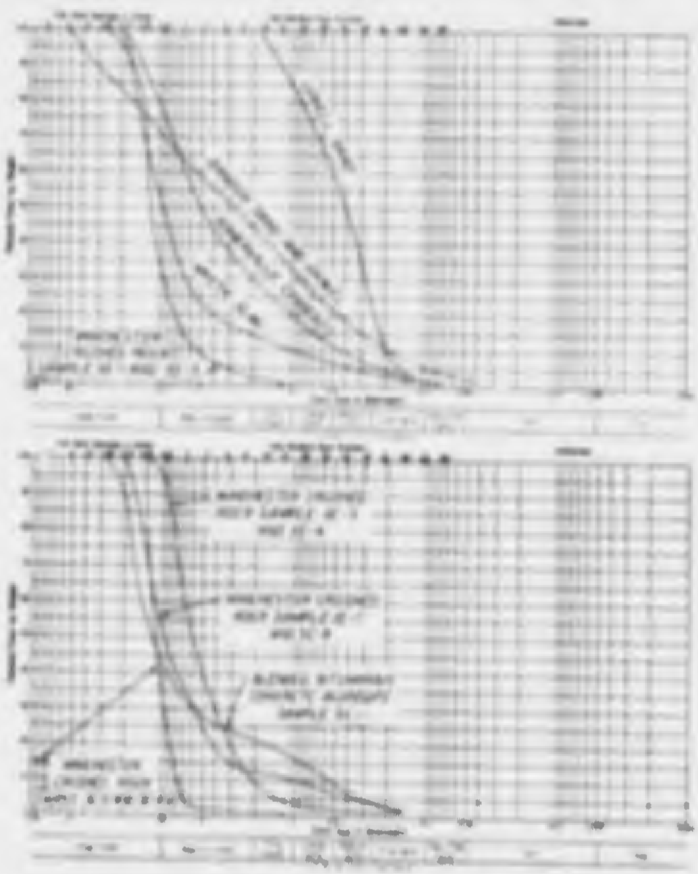
PLATE B-10



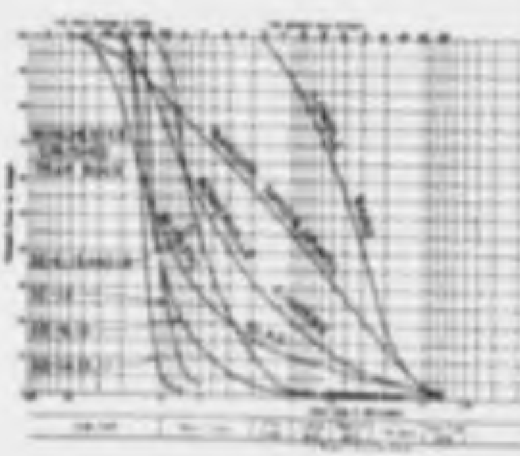
TIME FACTOR CURVES
FOR TEMPERATURE CHANGE
AT CENTER OF CYLINDER
FIG. 1



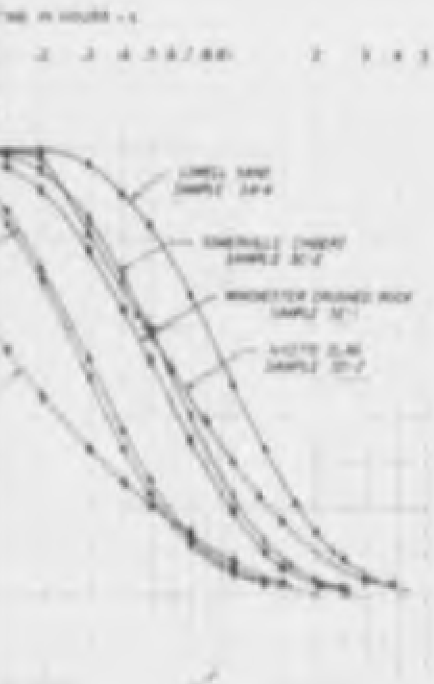
TYPICAL TIME CURV
THERMAL CONDUCTIVITY DET
UNFROZEN MATERI
FIG. 2



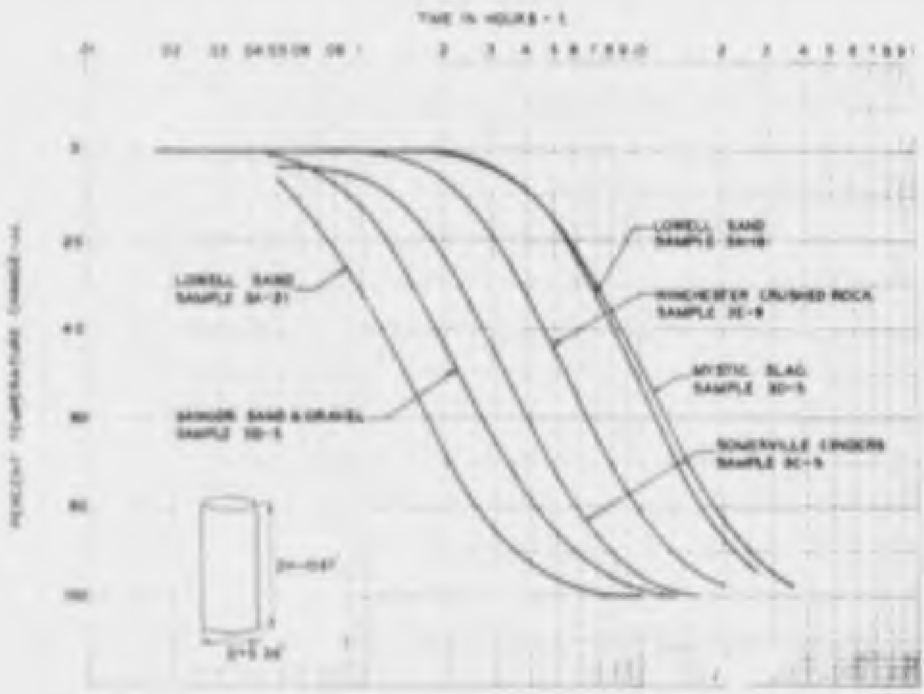
GRADATION OF MATERIALS
TESTED IN UNFROZEN STATE
FIG. 4



GRADATION OF MATER
TESTED IN FROZEN S
FIG. 5



TIME CURVES
...IVITY DETERMINATIONS
...EN MATERIAL
FIG. 2



TYPICAL TIME CURVES
THERMAL CONDUCTIVITY DETERMINATIONS
FROZEN MATERIAL
FIG. 3

EXAMPLE FOR DETERMINATION OF THERMAL CONDUCTIVITY

GIVEN: [illegible]

TEST DATA FOR SAMPLE NO. [illegible], PLATE [illegible], AS FOLLOWS

[illegible]

EQUATIONS:

(a) [illegible]

(b) [illegible]

SUBSTITUTING IN (a):

[illegible]

FROM FIG. 2

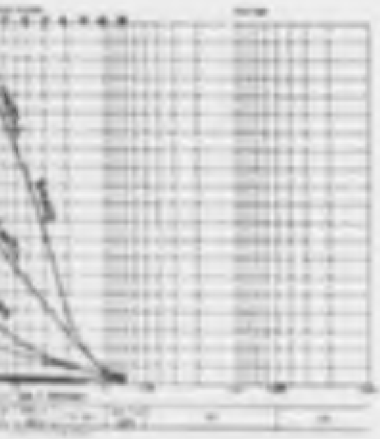
[illegible]

FROM FIG. 1, CURVE 1

[illegible]

SUBSTITUTING IN (b):

[illegible]



... OF MATERIALS
... FROZEN STATE
FIG. 5

FROST INVESTIGATION
1944-1946

THERMAL CONDUCTIVITY
DETERMINATIONS
FROZEN AND UNFROZEN
BASE MATERIALS

FROST EFFECTS LABORATORY, BOSTON, MASS.

PLATE B-11

SERIES NO.	MATERIAL	SPECIFIC GRAVITY g	SPECIFIC HEAT (1) DRY SOIL BTU./(LB)(DEG.F) c	NONFROZEN			
				LABORATORY SAMPLE NO.	UNIT DRY WEIGHT LBS./CU.FT. γ	WATER CONTENT PER CENT DRY WEIGHT w	VOLUMETRIC HEAT CAPACITY TOTAL SAMPLE BTU/(FT^3)(DEG.F) c_u
3A	LOWELL SAND (Well graded medium to coarse sand (2)	2.66	0.20	3A-4	105.0	0.2	21.2
		2.66	0.20	3A-4a	105.0	0.2	21.2
		2.66	0.20	3A-5(3)	101.0	0.2	20.4
		2.66	0.20	3A-6c	106.5	16.4	38.8
		2.66	0.20	3A-7	101.0	20.9	41.3
		2.66	0.20	3A-8	103.0	4.5	25.3
		2.66	0.20	3A-9	83.5	4.9	20.8
		2.66	0.20	3A-10(3)	84.5	2.3	18.8
		2.66	0.20	3A-11(3)	91.1	1.9	19.9
		2.66	0.20	3A 12	109.0	2.2	24.3
		2.66	0.20	3A-13	103.0	2.0	22.7
		2.66	0.20	3A-15	89.3	2.1	19.7
		2.66	0.20	3A-16	105.0	5.1	26.4
		2.66	0.20	3A-17	90.8	2.1	20.1
3B	BANGOR SAND & GRAVEL (Well graded - 1½" maximum)	2.70	0.20	3B-1	127.0	3.4	29.8
		2.70	0.20	3B-2	131.5	1.1	27.7
		2.70	0.20	3B-3	127.0	9.3	36.3
		2.70	0.20	3B-11	133.3	0.32	27.1
		2.70	0.20				
		2.70	0.20				
		2.70	0.20				
3C	SOMERVILLE CINDERS (Well graded - 1" maximum)	2.27	0.18	3C-1	60.9	20.7(5)	23.6
		2.27	0.18	3C-2	60.0	36.6	32.8
		2.27	0.18	3C-3	60.8	21.2(6)	23.9
		2.27	0.18	3C-4	61.7	11.3	18.1
		2.27	0.18	3C-8	61.9	1.1	11.9
3D	MYSTIC SLAG (1½"maximum)	2.45	0.17	3D-1	79.1	9.1	17.5
		2.45	0.17	3D-2(7)	81.2	33.5	40.9
		2.45	0.17	3D-6	92.3	0.6	16.3
3E	WINCHESTER CRUSHED TRAP ROCK (2"maximum)	2.91	0.20	3E-1	99.2	1.9	21.7
		2.91	0.20	3E-2	100.0	2.1	22.1
		2.91	0.20	3E-3	98.5	4.4	23.6
		2.91	0.20	3E-4	98.5	27.2	46.5
		2.91	0.20	3E-5(7)	99.3	28.4	48.0
		2.91	0.20	3E-6a(7)	100.0	27.7	47.7
		2.91	0.20	3E-7	102.0	2.5	23.0
		2.91	0.20	3E-8	102.0	26.7	47.7
		2.91	0.20	3E-21	112.4	0.21	22.7

Results of test on a sample of bituminous concrete and on the aggregate will be added to this table.

NOTES

(1) Assumed

(2) Minimum dry density 92.9 lbs/cu.ft.
Maximum dry density 110.9 lbs/cu.ft.

(3) Sample not properly sealed; some water leaked into sample during test.

(4) Slight leaking into cylinder during test.

(5) Average - w =
w =

(6) Non-uniform wa

(7) Test results a
results c

(8) Cover lifted c
heaving.
fected by
specimen

(9) Average heave

THERMAL CONDUC[illegible]IVITY [illegible]U/(FT)(DEG.F)(HR) k	FROZEN LABORATORY SAMPLE NO.	UNIT DRY WEIGHT LBS/CU.FT. γ	VOID RATIO e	WATER CONTENT PER CENT DRY WEIGHT w	PER CENT SATURATION G	VOLUMETRIC HEAT CAPACITY TOTAL SAMPLE BTU/(FT^3)(DEG.F) C_f	THERMAL CONDUCTIVITY BTU/(FT)(DEG F)(HR) k
0.188	3A-18	106.2	0.563	0.165	0.780	21.3	0.185
0.188	3A-19	102.9	0.612	0.165	0.717	20.7	0.164
0.169	3A-20	102.5	0.620	5.4	23.2	23.3	0.885
1.025	3A-21	106.2	0.563	16.5	77.7	30.0	1.755
1.000	3A-22	102.6	0.618	18.5	79.6	30.0	1.540
0.718	3A-23	102.5	0.620	20.5	88.2	31.0	1.610
0.469	3A-24	105.0	0.581	2.2	10.1	22.2	0.460
0.335	3A-25	106.0	0.565	4.2	19.8	23.4	0.912
0.352	3A-26(4)	111.8	0.475	0.66	3.7	22.4	0.265
0.582	3A-27(4)	111.1	0.496	0.98	5.25	22.8	0.314
0.476							
0.463							
0.777							
0.437							
0.890	3B-4(4)	130.8	0.289	2.1	19.6	27.5	0.725
0.673	3B-5	127.1	0.328	3.6	30.2	27.7	1.038
1.125	3B-6	130.8	0.289	9.9	90.0	32.8	1.528
0.472	3B-7	127.1	0.328	10.6	87.8	32.2	1.489
	3B-8	130.2	0.295	1.8	16.5	27.2	0.665
	3B-9	130.2	0.295	10.3	94.3	32.8	1.475
	3B-10	132.9	0.267	0.23	2.3	26.7	0.465
0.353	3C-5	60.8	1.327	11.7	20.0	14.5	0.372
0.462	3C-6	60.8	1.327	35.5	60.7	21.7	0.700
0.354	3C-7	63.4	1.233	0.09	0.03	11.4	0.152
0.297							
0.173							
0.188	3D-3	87.2	0.750	5.5	18.9	17.2	0.245
0.553	3D-4	87.2	0.750	27.7	90.6	26.9	0.673
0.146	3D-5	89.3	0.710	0.21	0.73	15.3	0.122
0.350	3E-9	102.8	0.767	1.5	5.7	21.3	0.328
0.371	3E-10(8)	102.8	0.767	25.8	97.9	33.8	1.189
0.403	3E-11	106.5	0.706	2.2	9.1	22.5	0.417
0.849	3E-12	103.6	0.754	1.2	4.6	21.3	0.334
2.320	3E-13(9)	106.5	0.706	28.1	91.1	33.1	0.989
1.850	3E-14(9)	103.5	0.754	25.0	96.5	33.6	1.080
0.371	3E-15	104.7	0.734	2.0	7.9	22.0	0.375
1.479	3E-17	102.5	0.772	0.21	0.784	20.6	0.157
0.196	3E-18	111.3	0.631	0.12	0.553	22.3	0.196

2% - top of sample
3% - bottom of sample
content.
not consistent with
other tests.
cylinder due to
esults slightly af-
aking of brine into
ing test.
8". Slight leaking.

RANGE OF STONE SIZES - SERIES 3E

3E-1 & 3E-9		(1/2" - 3/4")
3E-2 & 3E-10		(1/2" - 3/4")
3E-3 & 3E-11		(1/8" - 3/8")
3E-4 & 3E-12		(3/8" - 1/2")
3E-5 & 3E-13		(1/8" - 3/8")
3E-6a & 3E-14		(3/8" - 1/2")
3E-7 & 3E-15	50%	(1/2" - 3/4")
	25%	(3/8" - 1/2")
	25%	(1/8" - 3/8")
3E-8 & 3E-17		(1/2" - 3/4")
3E-21 & 3E-18		(1/8" - 3/8")

FROST INVESTIGATION
1945-1946

THERMAL PROPERTIES OF SOILS
SUMMARY OF TEST DATA

FROST EFFECTS LABORATORY
BOSTON, MASS. JUNE 1946

PLATE B-12

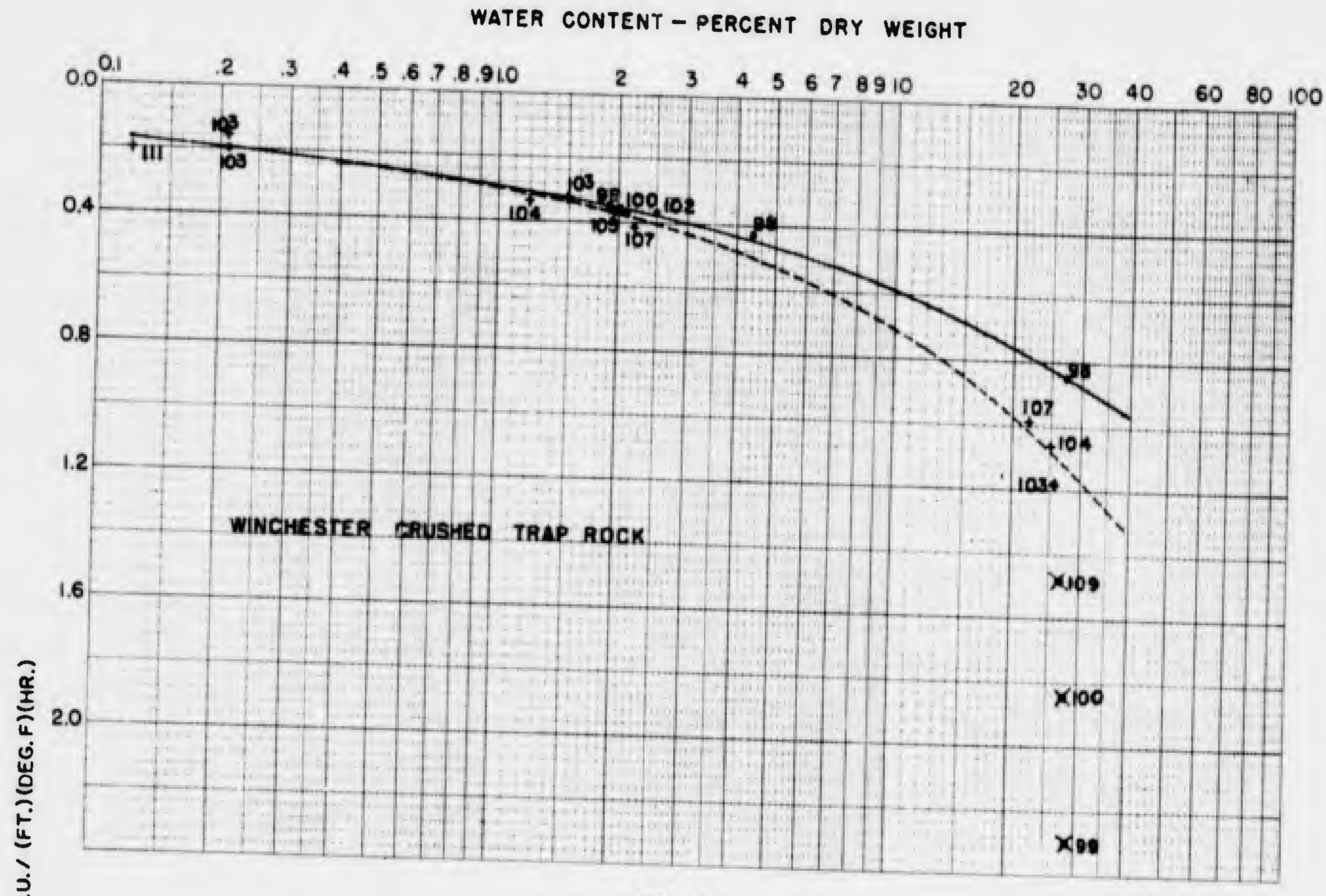


FIG. 1

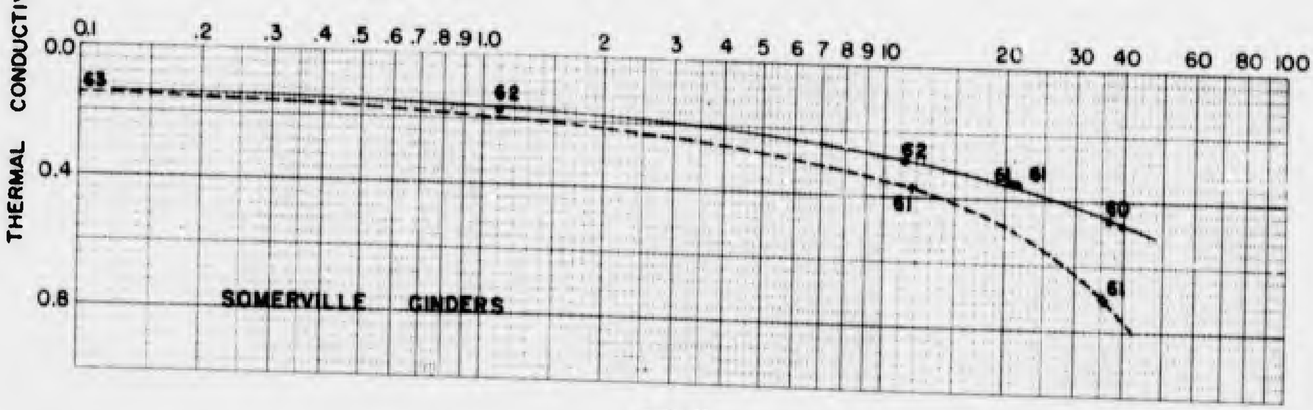


FIG. 2

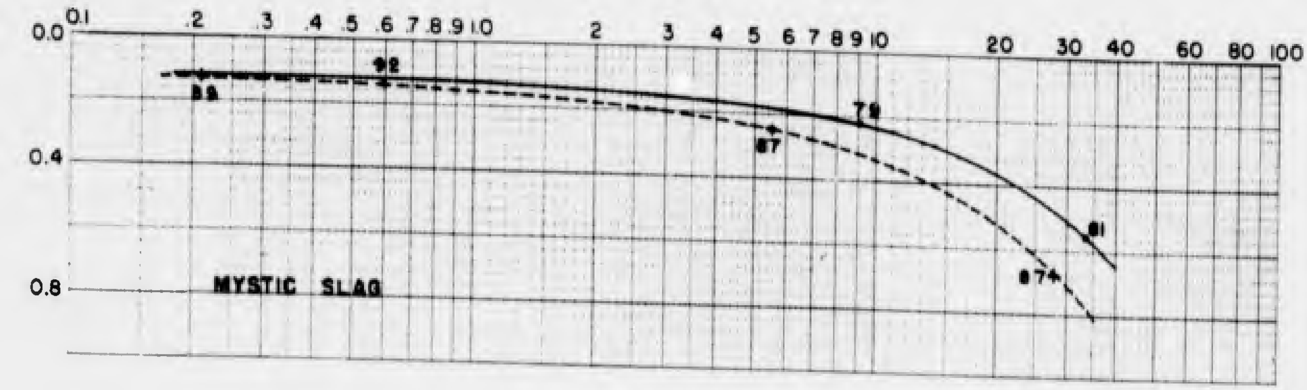
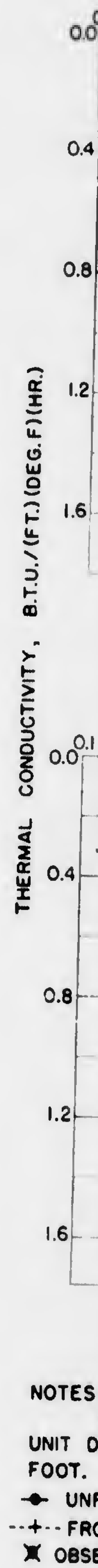


FIG. 3



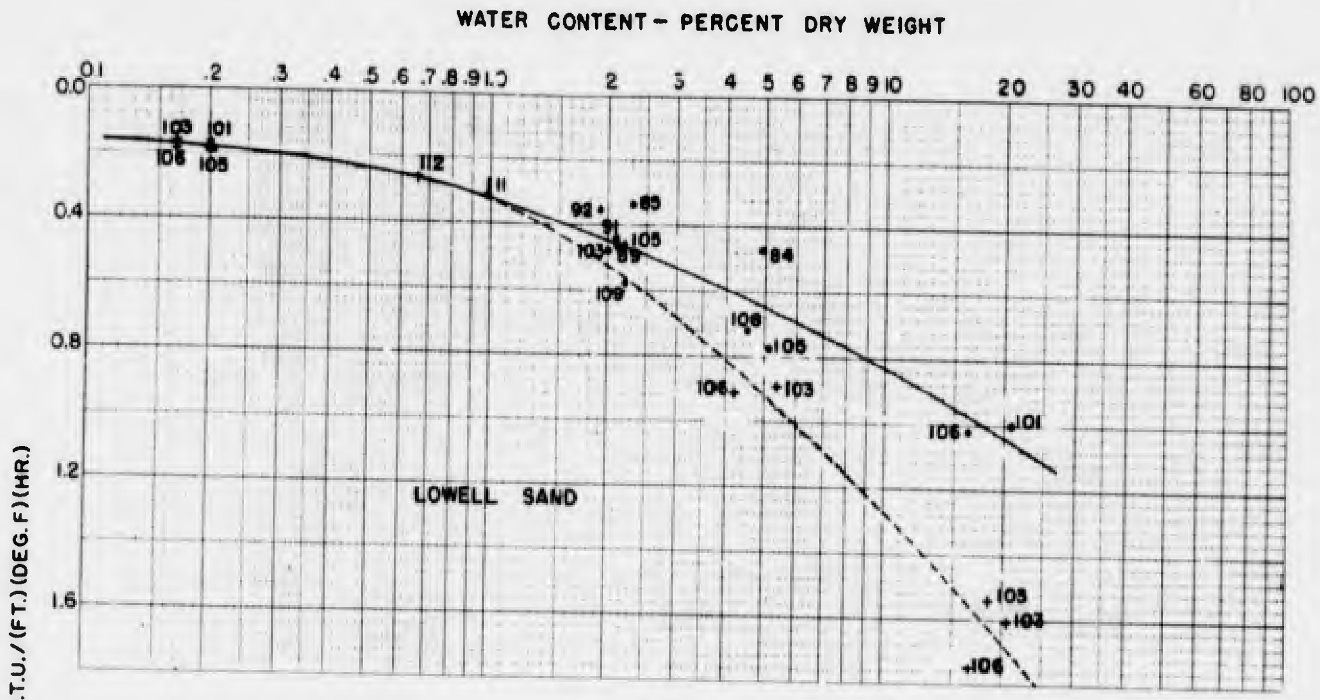


FIG. 4

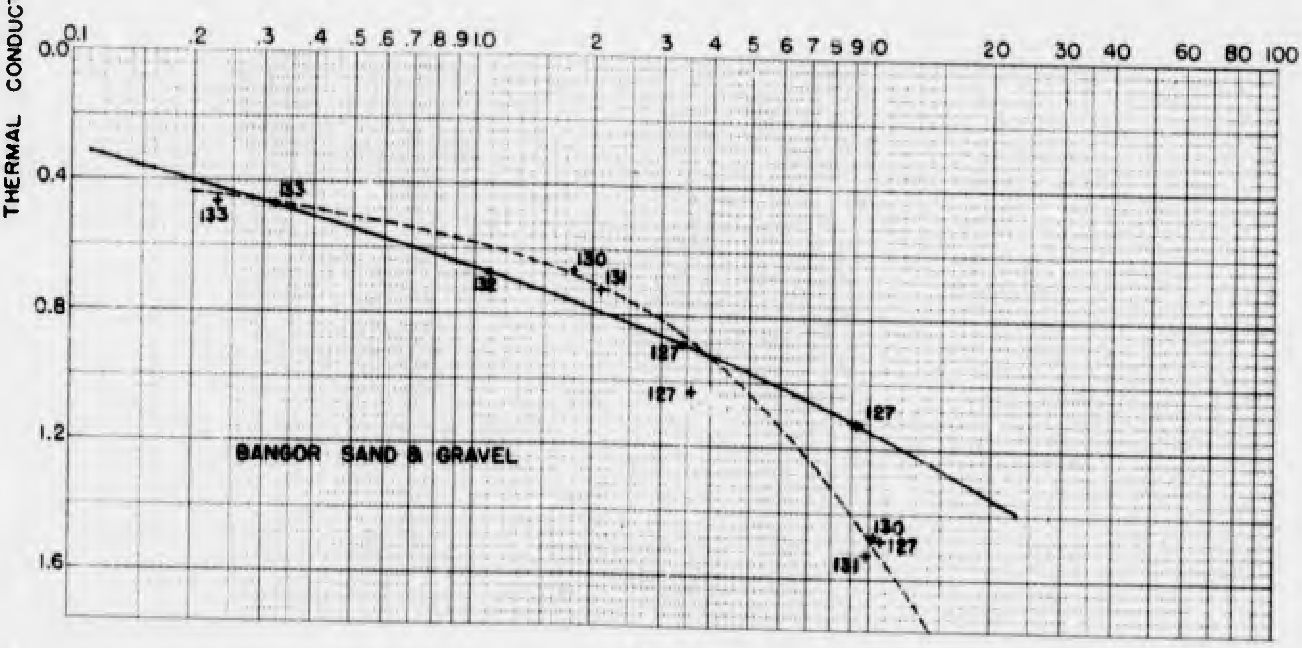


FIG. 5

NOTES:

NUMBERS BESIDE PLOTTED POINTS INDICATE UNIT DRY WEIGHT OF SAMPLE IN POUNDS PER CUBIC FOOT.

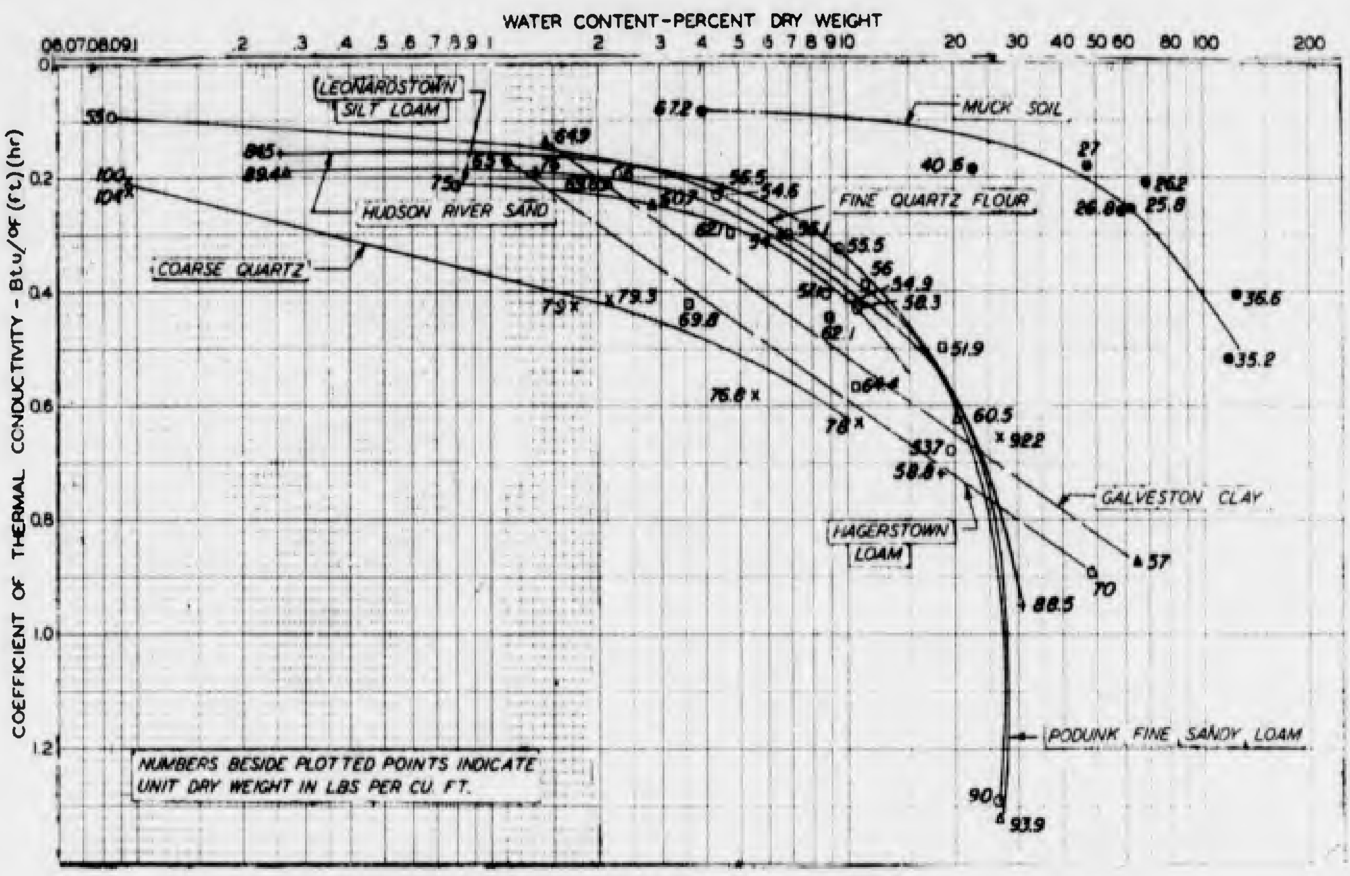
- —●— UNFROZEN MATERIAL
- --+-- FROZEN MATERIAL
- ✕ OBSERVATION IN ERROR

FROST INVESTIGATION
1945-1946

THERMAL CONDUCTIVITY VS. WATER CONTENT OF BASE MATERIALS

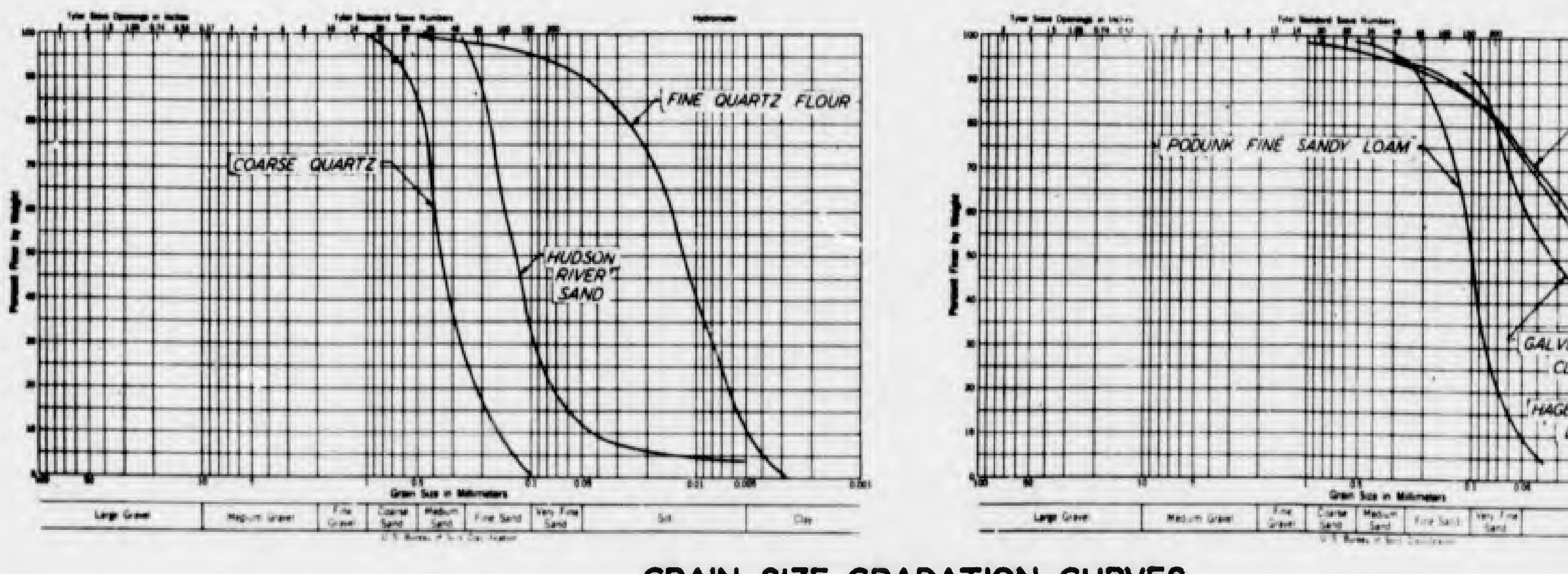
FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1946

PLATE B-13



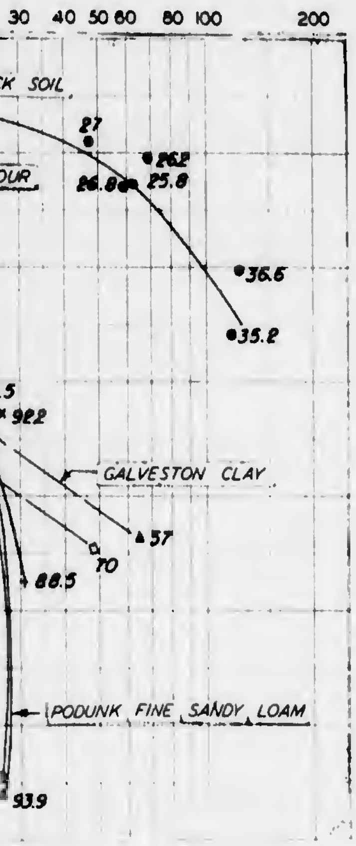
THERMAL CONDUCTIVITY VS WATER CONTENT

FIG. 1



GRAIN SIZE GRADATION CURVES

FIG. 2

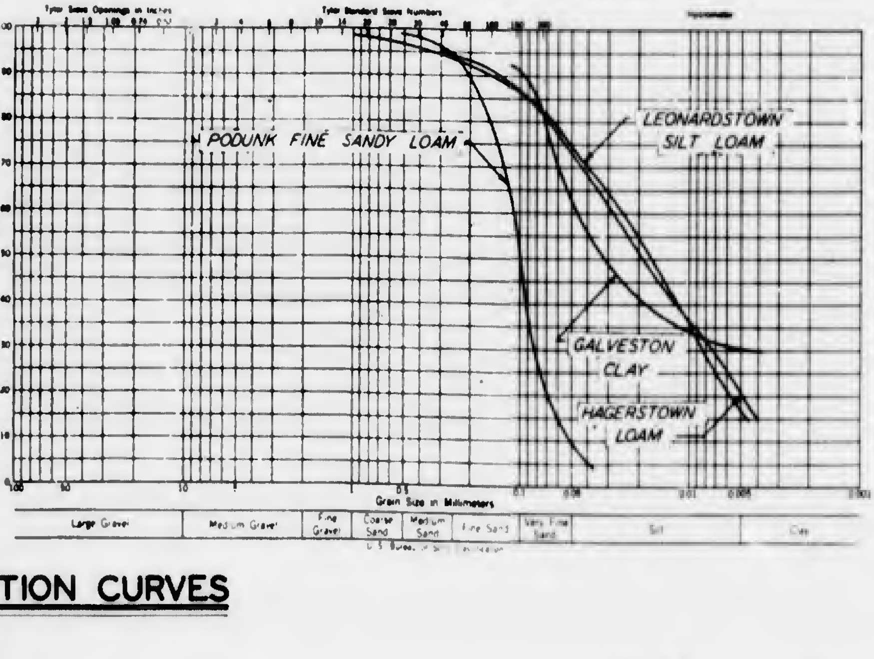


ONTENT

Material	Unit Dry Weight	Water Content	Specific Heat	Volumetric Heat Capacity	Thermal Conductivity
	lbs/c.f.	% Dry Wt.		Btu/(°F)(cf)	Btu/°F (ft)(hr)
COARSE QUARTZ	104	0.095	0.1900	19.[illegible]	0.221
	100	0.095	0.1900	[illegible].1	0.206
	79	1.710	0.1900	16.3	0.423
	79.3	2.160	0.1900	16.7	0.415
	76.8	5.520	0.1900	18.[illegible]	0.581
	78.0	10.910	0.1900	23.3	0.630
	92.2	26.700	0.1900	42.1	0.653
FINE QUARTZ FLOUR	55	0.0833	0.1900	10.[illegible]	0.0981
	54.6	4.280	0.1900	12.7	0.232
	56.1	6.930	0.1900	11.5	[illegible].300
	57.1	8.720	0.1900	1[illegible]	0.403
	55.5	9.530	0.1900	15.[illegible]	0.323
	58.3	10.9[illegible]	0.1900	17.4	0.427
	53.7	19.670	0.1900	20.7	0.680
	90.0	26.650	0.1900	41.[illegible]	1.290
HUDSON RIVER SAND	84.5	0.257	0.1900	16.2	0.1575
	56.5	4.500	0.1900	13.3	[illegible]
	58.8	13.120	0.1900	21.	0.72[illegible]
	88.5	30.760	0.1900	43.	0.953
PODUNK FINE SANDY LOAM	89.4	0.268	0.1900	17.2	0.191
	76.0	1.330	0.1900	15.5	0.191
	66.0	2.140	0.1900	13.[illegible]	0.209
	[illegible].7	2.830	0.1900	13.2	0.244
	54.0	6.601	0.1900	13.[illegible]	0.302
	54.9	10.080	0.1900	16.0	0.418
	60.5	20.250	0.1900	23.7	0.623
	93.9	26.930	0.1900	43.0	1.32
LEONARDSTOWN SILT LOAM	75.0	0.806	0.1900	14.[illegible]	0.214
	69.6	2.127	0.1900	14.7	0.210
	69.8	3.580	0.1900	15.7	0.422
	62.1	4.690	0.1900	14.7	0.299
	62.1	8.980	0.1900	17.3	0.443
	64.4	10.650	0.1900	1[illegible].0	0.562
	56.0	11.570	0.1900	17.1	0.388
	51.9	18.350	0.1900	1[illegible]	0.500
HAGERSTOWN LOAM	65.0	1.12	0.1914	13.2	0.1686
	70.0	48.06	0.1914	47.0	0.893
GALVESTON CLAY	64.9	1.41	0.2097	14.[illegible]	0.139
	57.0	67.55	0.2097	5[illegible].4	0.868
MUCK SOIL	67.2	3.93	0.1900	15.4	0.0842
	40.6	22.95	0.1900	17.[illegible]	0.184
	27.0	47.06	0.1900	17.[illegible]	0.190
	26.8	58.98	0.1900	2[illegible]	0.260
	25.8	62.33	0.1900	21.1	0.257
	26.2	69.42	0.1900	23.1	0.208
	35.2	119.20	0.1900	49.[illegible]	0.519
	36.6	123.00	0.1900	51.9	0.402

DATA SUMMARY TABULATION

TABLE A



TION CURVES

NOTE

(1) H. E. PATTEN "HEAT TRANSFERENCE IN SOILS" U.S. DEPARTMENT OF AGRICULTURE BULLETIN NO. 59 SEPTEMBER 1909.

REVISED JULY, 1947

FROST INVESTIGATION

SUMMARY OF THERMAL CONDUCTIVITY TESTS BY H. E. PATTEN (1)

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

PLATE B-14

INVESTIGATOR	SOIL TESTED	WATER CONTENT %	THERMAL CONDUCTIVITY		UNIT DRY WEIGHT LBS/CU.FT.
			WATTS / CM/°C	BTU / FT/°F/HR	
Shanklin	Clean yellow builders sand	0.15	0.003	0.174	
		1.6	0.0035	0.202	
		4.2	0.0048	0.278	
		9.0	0.013	0.752	
	Yellow sandy clay	0.89	0.0025	0.145	
		3.87	0.0029	0.168	
		8.5	0.0032	0.185	
		25.0	0.014	0.810	
Kennelly (a)	Fine white quartz sand (b)	0.2	0.0025	0.145	
		7.0	0.0044	0.255	
		13.8	0.0062	0.359	
	Fine sandy soil	0.2	0.0021	0.121	
		4.0	0.0023	0.133	
		8.0	0.0024	0.139	
		15.0	0.0028	0.162	
Teichmuller	Clean yellow sand	0.2	0.0031	0.179	
		4.1	0.0125	0.729(c)	
		9.8	0.0161	0.932	
	Average sandy soil	12.0	0.0085	0.492	
Ingersoll and Koepp	Quartz	0.0		0.42	103
	Medium fine sand	8.3		0.94	109
	Sandy clay	15.0		1.47	111
	Calcareous earth	43.0		1.14	104
Berggren	Dry soil	0.0		0.19	
	Moist soil (frozen)			0.68	
	Moist soil (unfrozen)			0.48	
	Wet soil (frozen)			1.21	
	Wet soil (unfrozen)			0.97	

(a) Test equipment considered unsatisfactory by Shanklin.
(b) Passing 0.25 mm mesh.
(c) Shanklin believes water content for this value should be about nine per cent.

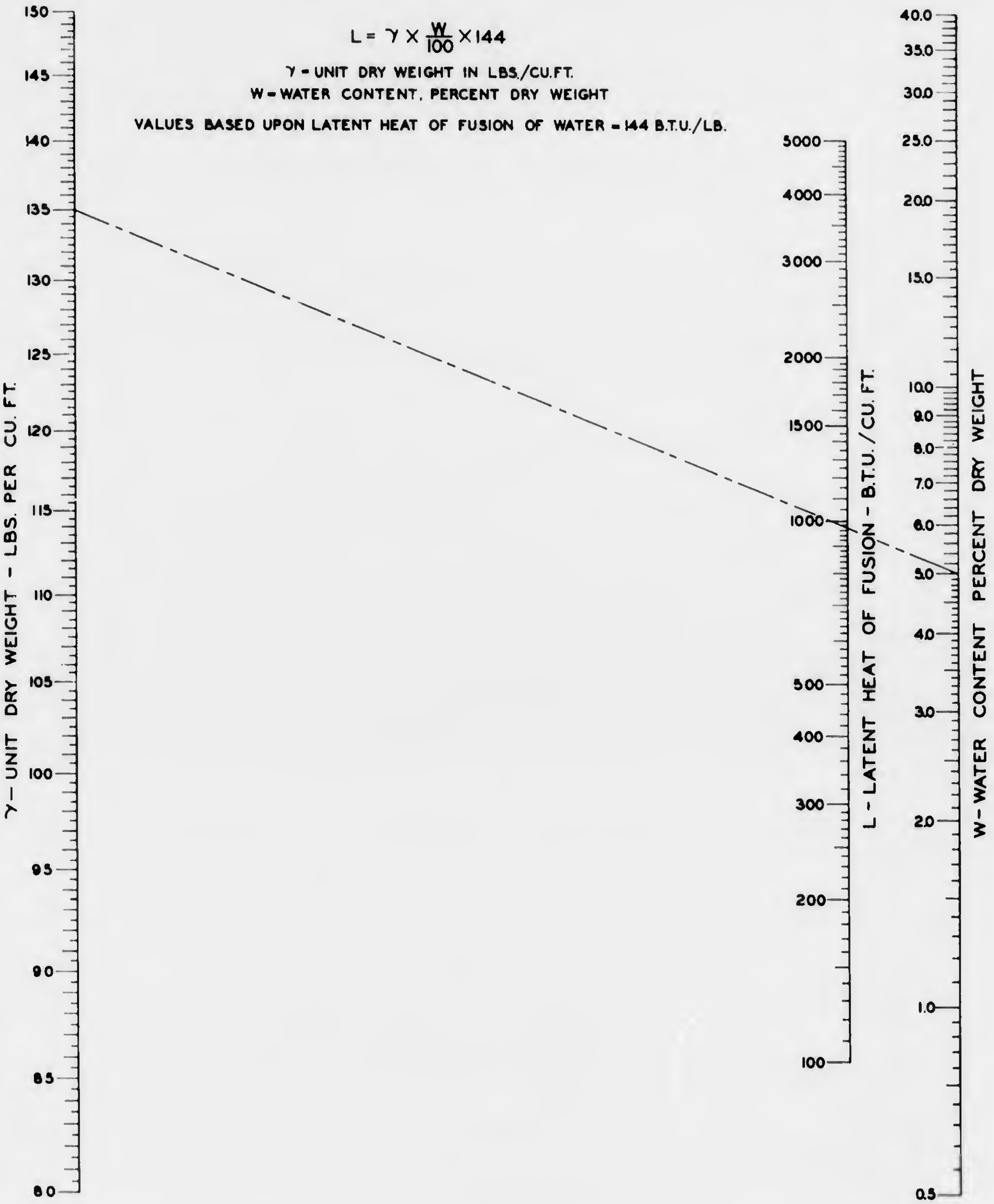
FROST INVESTIGATION
1945 - 1946

THERMAL CONDUCTIVITY TESTS

BY OTHER INVESTIGATORS

BOSTON, MASS.
FROST EFFECTS LABORATORY, JUNE 1946

PLATE B-15



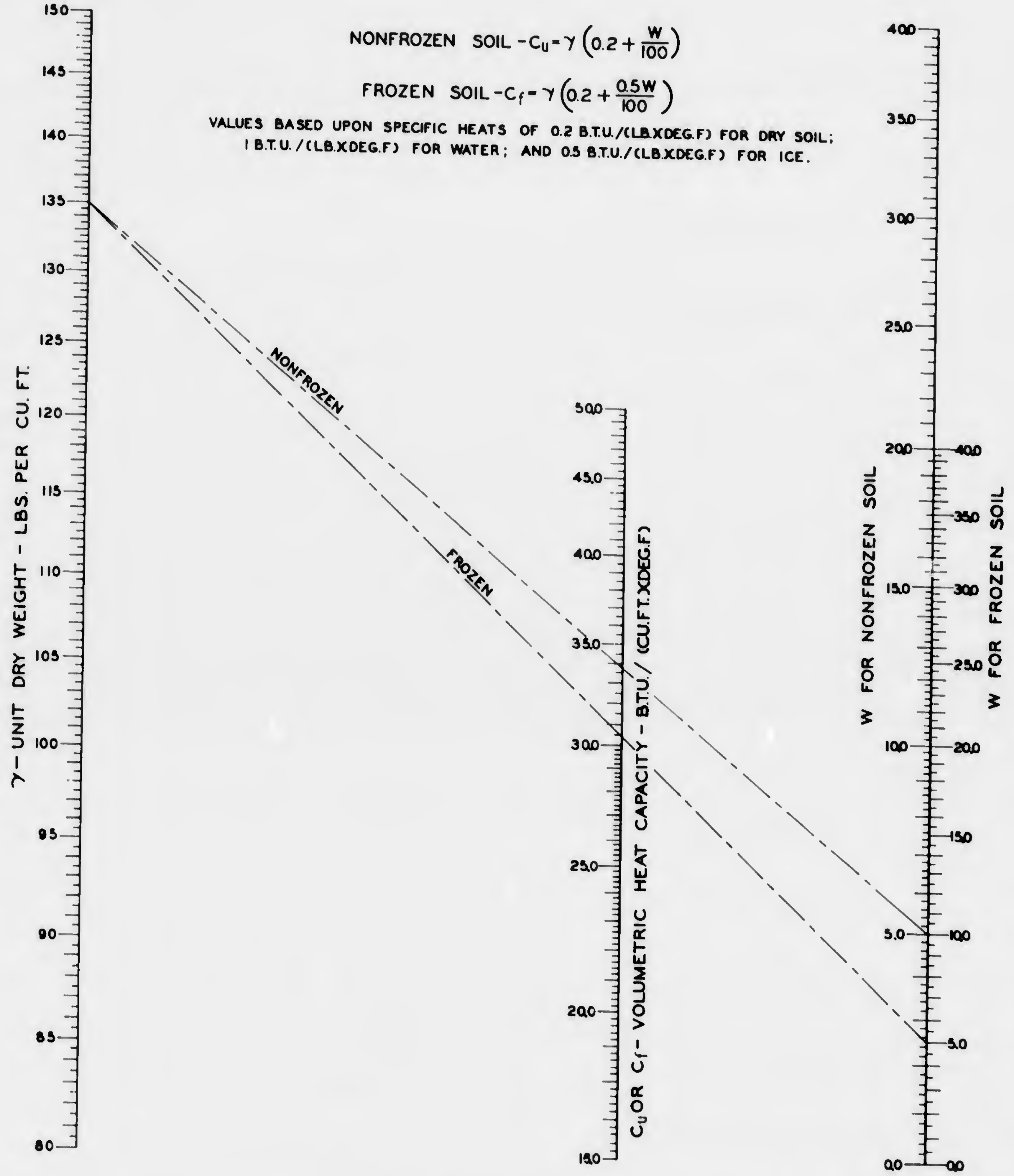
LATENT HEAT DETERMINATION

FIG. 1

$$\text{NONFROZEN SOIL} - C_u = \gamma\left(0.2 + \frac{W}{100}\right)$$

$$\text{FROZEN SOIL} - C_f = \gamma\left(0.2 + \frac{0.5W}{100}\right)$$

VALUES BASED UPON SPECIFIC HEATS OF 0.2 B.T.U./(LB.XDEG.F) FOR DRY SOIL; 1 B.T.U./(LB.XDEG.F) FOR WATER; AND 0.5 B.T.U./(LB.XDEG.F) FOR ICE.



VOLUMETRIC HEAT CAPACITY DETERMINATION

FIG. 2

FROST INVESTIGATION
1945-1946

DETERMINATION OF LATENT HEAT OF FUSION AND VOLUMETRIC HEAT CAPACITY

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1946

OBSERVED TEMPERATURES AT DEPTHS OF FRO

AIRFIELD	YEAR	TEST AREA	TYPE OF TEMPERATURE MEASURING INSTALLATION	THICKNESS OF PAVEMENT AND BASE (INCHES)		CLASS OF FROZEN SUBGRADE SOIL	MEASURED DEPTH OF FROST PENETRATION (INCHES)	TEMPERATURE AT DEPTH OF FROST PENETRATION (°F)	DISTANCE BETWEEN NEAREST TEMPERATURE INSTALLATION AND TEST PIT (FEET)
				AT TEMPERATURE INSTALLATION	AT TEST PIT				
Presque Isle	1944-45	A	Thermocouple	31	37	GC	64	32.1	47
					40	GC	56	33.0	51
					41	GC	70	34.2	33
					31	GC	65	33.5	320
		B	Thermocouple	30	30	GC	68	33.0	40
					31	GC	48	31.6	45
					30	GC	64	32.5	552
					24	GW	24	32.1	1118
					31	GC	71	32.7	37
					31	GC	68	32.6	277
					31	GC	70	32.6	655
					31	GC	70	32.1	1062
	1945-46	A	Thermocouple	31	42	GC	48	33.4	25
					42	GC	52	32.2	15
					41	GC	78	34.4	30
					31	GC	32	32.7	47
					31	GC	68	33.2	47
					38	GC	40	37.2	8
					38	GC	46	35.0	8
		C	Thermocouple	30	31	GC	42	32.9	12
					35	GC	50	31.5	15
					46	GC	62	31.6	20
					30	GC	68	31.7	35
					29	GC	65	31.9	48
		Turf	Thermocouple	-	5(TS)	GC	18	32.1	25
					2(TS)	GC	36	30.7	10
					4(TS)	GC	32	29.8	50
					2(TS)	GC	50	31.6	173
Dow	1944-45	A	Thermocouple	20	19	CL	47	35.1	39
					24	CL	54	34.9	182
					22	CL	52	35.6	163
					24	CL	53	35.8	144
					20	CL	44	34.9	45
					24	CL	47	34.0	124
					22	CL	46	35.6	56
					24	CL	44	35.8	148
					24	CL	43	40.6	43
		B	Thermocouple	30	32	CL	46	34.3	50
					24	CL	41	33.2	92
					40	CL	52	35.0	166
					37	CL	48	34.7	198
					29	CL	46	34.6	80
					38	CL	48	34.7	142
					37	CL	47	35.2	122
					29	CL	49	35.5	140
					26	CL	47	34.9	72
					29	CL	44	34.2	56
					26	CL	38	35.4	80
					32	CL	52	35.5	156
		C	Thermocouple	41	49	CL	60	33.0	38
					66	GW	48	35.2	280
					60	CL	62	35.8	294
					49	GW	44	34.1	62
					48	CL	55	34.9	218
					30	CL	48	33.6	-
		Turf	Thermocouple	-	2(TS)	CL	13	31.8	124
					0	CL	20	32.6	46
					7(TS)	CL	24	34.0	14
	1945-46	D	Thermometer	42	41	CL	50	33.1	28
		E	Thermocouple	38	37	GW	31	32.4	38
					36	GW	36	32.5	28
					42	CL	44	32.5	32
					37	CL	19	31.4	22
					37	CL	48	32.0	22
		F	Thermocouple	20	28	CL	36	32.7	117
					28	CL	54	35.6	131
					29	CL	53	33.1	116
					26	CL	26	35.1	100
					26	CL	52	35.3	100
		Turf	Thermocouple	-	2(TS)	CL	15	33.0	70
					2(TS)	CL	24	33.3	14
					2(TS)	CL	24	32.9	14
					1(TS)	CL	26	33.4	130

AIRFIELD
Dow
Sioux Falls
Pierre
Great Bend
Fargo
Watertown
Truax
Bedford
Selfridge

NOTE

(TS) Indic

URES AT DEPTHS OF FROST PENETRATION

DISTANCE BETWEEN NEAREST TEMPERATURE INSTALLATION AND TEST PIT (FEET)
47
51
33
320
40
45
552
1118
37
277
655
1062
25
15
30
47
47
8
8
12
15
20
35
48
25
10
50
173
39
182
163
144
45
124
56
148
43
50
92
166
198
80
142
122
140
72
56
80
156
38
280
294
62
218
-
124
46
14
28
38
28
32
22
22
117
131
116
100
100
70
14
14
130

AIRFIELD	YEAR	TEST AREA	TYPE OF TEMPERATURE MEASURING INSTALLATION	THICKNESS OF PAVEMENT AND BASE (INCHES)		CLASS OF FROZEN SUBGRADE SOIL	MEASURED DEPTH OF FROST PENETRATION (INCHES)	TEMPERATURE AT DEPTH OF FROST PENETRATION (°F)	DISTANCE BETWEEN NEAREST TEMPERATURE INSTALLATION AND TEST PIT (FEET)
				AT TEMPERATURE INSTALLATION	AT TEST PIT				
[illegible]	1946-47	B	Thermometer	40	41	CL	[illegible]	[illegible]	[illegible]
					43	-	43	[illegible]	[illegible]
					42	[illegible]	19	[illegible]	[illegible]
					44	CL	[illegible]	[illegible]	[illegible]
		[illegible]	Thermometer	30	[illegible]	-	[illegible]	[illegible]	37
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					[illegible]		[illegible]	32.1	[illegible]
					[illegible]	-	[illegible]	[illegible]	[illegible]
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	Thermometer	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					[illegible]	CL	[illegible]	[illegible]	[illegible]
					[illegible]	-	[illegible]	[illegible]	[illegible]
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					[illegible]	-	[illegible]	[illegible]	[illegible]
					19	[illegible]	31	[illegible]	[illegible]
		Turf	Thermometer	-	-(TS)	[illegible]	[illegible]	[illegible]	[illegible]
					-([illegible])	[illegible]	[illegible]	[illegible]	[illegible]
					-([illegible])	[illegible]	[illegible]	[illegible]	[illegible]
					-([illegible])	[illegible]	[illegible]	[illegible]	[illegible]
					-([illegible])	[illegible]	[illegible]	[illegible]	[illegible]
					-([illegible])	[illegible]	[illegible]	[illegible]	[illegible]
					-([illegible])	[illegible]	[illegible]	[illegible]	[illegible]
Sioux Falls	1944-45	[illegible]	Thermocouple	12	12	[illegible]	[illegible]	[illegible]	[illegible]
				12	12	[illegible]	[illegible]	[illegible]	110
	1945-46	[illegible]	Thermocouple	12	10	[illegible]	[illegible]	[illegible]	[illegible]
					10	[illegible]	[illegible]	[illegible]	[illegible]
					12	[illegible]	31	[illegible]	[illegible]
					12	[illegible]	[illegible]	[illegible]	[illegible]
		B	Thermometer	6	6	[illegible]	[illegible]	[illegible]	[illegible]
					6	[illegible]	[illegible]	[illegible]	[illegible]
	1946-47	A	Thermometer	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		B	Thermometer	6	6	[illegible]	[illegible]	[illegible]	[illegible]
Pierre	1944-45	A	Thermocouple	14	14	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	Thermocouple	[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]
	1945-46	A	Thermocouple	14	12	[illegible]	[illegible]	33.1	[illegible]
					[illegible]	[illegible]	14	[illegible]	65
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Great Bend	1944-45	A	Thermometer	12	13	[illegible]	13	[illegible]	37
Fargo	1945-46	A	Thermometer	[illegible]	7	[illegible]	[illegible]	[illegible]	15
Watertown	1944-45	A	Thermocouple	10	10	[illegible]	[illegible]	[illegible]	[illegible]
					10	[illegible]	[illegible]	[illegible]	60
		Turf	Thermocouple	-	-(TS)	[illegible]	42	[illegible]	[illegible]
Truax	1945-46	[illegible]	Thermometer	42	43	[illegible]	41	31.5	16
					42	[illegible]	[illegible]	[illegible]	[illegible]
		D	Thermometer	23	22	[illegible]	[illegible]	[illegible]	14
Bedford	1945-46	A	Thermocouple	[illegible]	24	[illegible]	[illegible]	32.1	21
					24	[illegible]	24	32.2	17
					24	[illegible]	[illegible]	[illegible]	33
					25	[illegible]	[illegible]	[illegible]	33
		B	Thermometer	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]
					[illegible]	SW	[illegible]	[illegible]	[illegible]
					24	[illegible]	[illegible]	[illegible]	[illegible]
					[illegible]	[illegible]	[illegible]	32.1	[illegible]
Selfridge	1945-46	A	Thermometer	26	21	[illegible]	24	[illegible]	210
					21	[illegible]	34	31.5	260
					24	[illegible]	35	[illegible]	[illegible]
					[illegible]	[illegible]	31	[illegible]	[illegible]
					22	[illegible]	[illegible]	[illegible]	[illegible]
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1946-47	[illegible]	Thermometer	26	[illegible]	[illegible]	[illegible]	31.1	[illegible]

NOTE

(TS) Indicates Topsoil.

OBSERVED TEMPERATURES

AT DEPTHS OF FROST PENETRATION

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U. S. ARMY
BOSTON, MASSACHUSETTS

DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

APPENDIX C

REPORT ON MATHEMATICAL STUDIES OF THERMAL CHANGES IN A SOIL MASS
1945 - 1946

FROST EFFECTS LABORATORY
JUNE 1949

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LIST OF PLATES

REPORT ON
MATHEMATICAL STUDIES OF THERMAL CHANGES IN A SOIL MASS.

SYNOPSIS

A comprehensive, mathematical study of the thermal conditions induced in a semi-infinite, homogeneous, isotropic, soil mass by variations of the surface air temperature is presented in this report. The studies are presented in the form of 17 problems. The problems deal with the determination of the thermal diffusivity, depths of frost and melt penetration, effect of radiation and surface film and the effect of an insulating layer. A series of formulae were developed to predict the depth of frost penetration and several of these were selected to predict the depth of frost penetration for comparison with actual field measurements. The theoretical depths of frost penetration obtained using the developed formulae compare reasonable well with observed depths from field investigations.

MATHEMATICAL STUDIES OF THERMAL CHANGES IN A SOIL MASS.

I. INTRODUCTION

1-01. Authorization. The frost investigation program was authorized by the Chief of Engineers by letter to the Division Engineer, New England Division, dated 4 August 1945, Subject: "Frost Investigation, Fiscal Year 1945 - 1946." The mathematical studies reported herein are a part of this program.

1-02. Purpose. The purpose of these studies was to develop mathematical solutions for problems of heat transfer through soils so that these solutions could be used to supplement and analyze data from field and laboratory frost investigations.

1-03. Scope. This report presents the solution of 17 problems in a condensed form with examples. A detailed development of each equation is on file in the New England Division Office.

1-04. Acknowledgement. These studies were principally performed by Dr. L. A. Pipes, Harvard University.

II. MATHEMATICAL STUDIES

2-01. General. The depth to which a pavement, base, and subgrade will be frozen during a winter will depend principally upon the magnitude and duration of freezing air temperature, the thermal properties of the materials and the subsurface temperature conditions at the start of freezing. All these factors have been used in this study. Methods of predicting the depth of frost penetration are presented which give results reasonably close to the measured values at the various test areas.

Observations of depths of freezing have been made over a period of one to three years at 17 airfields. The results of these observations together with pertinent data influencing freezing are summarized on Plate C-1. In addition, there are also tabulated the values for predicted depth of freezing based upon equations (83), (93), (154), (158), developed in Supplement A and from the design curve which is based on the correlation of the Freezing Index and measured depth of frost penetration at several airfields. This correlation is shown on Plate C-2 for both portland cement and bituminous concrete pavements. The equations selected from the mathematical problems presented in Supplement A of this appendix were considered to represent the principal variations of assumptions in the most usable form.

2-02. Values of Thermal Properties Used in Equations. The thermal properties used in calculating the depth of frost penetration were determined in the following manner:

a. Thermal Conductivity, k. The thermal conductivity used for computations of depth of freezing is for all cases 1.3 Btu/(ft)(Hr.)(^{o}F). Based upon tested values for thermal conductivity, as discussed in paragraph 2-03 j Appendix B this value may be somewhat high as an average value for all soils to a depth of 16 feet; however, it is believed to be a reasonable value for the pavement, based, and subgrade soils which are frozen or unfrozen.

b. Mean Soil Temperature, Vo. The mean soil temperature is equal to the mean annual air temperature at the particular location. At a depth of about 16 feet below ground surface the amplitude of soil temperature change approaches zero. Values for the mean air temperature in the United States are given in Figure 1, Plate 3, of Volume I.

c. <u>Latent Heat, L.</u> In cohesionless soils, all water in the voids will be frozen and thus the latent heat may be determined from the water content using graph shown in Fig. 1, Plate B-16, Appendix B. For cohesive soils, there will be a portion of the measured water content (in percentage of dry weight of soil) which will not freeze at 32°F as discussed in paragraph 2-04, Appendix B. Thus, for some soils, not all the water content contributes latent heat. On Plate C-1 it is considered that all of the water freezes, the value of latent heat as tabulated being determined from Figure 1, Plate B-16, Appendix B.

d. <u>Volumetric Heat, C.</u> The average volumetric heat at each location was determined using the equation given in paragraph 2-05, Appendix B. Values for the volumetric heat for each different soil were determined using the average water content and unit dry weight as tabulated on Plate C-1 and Figure 2, Plate B-16 of Appendix B. Soils within the depth of freezing were considered to be totally frozen in determining the average volumetric heat.

2-03. <u>Analyses of Problems.</u> Problems 1 to 5 inclusive, Supplement A to this appendix, are presented in a form convenient for computing values of thermal conductivity or thermal diffusivity and apply only to cases where temperatures are above freezing or where no latent heat is involved. The accuracy of determinations of the values of thermal diffusivity "a", in the manner outlined is dependent on the accuracy of temperature measurements at various depths, at the same or different times. With the exception of Problem 3, the results involve the determination of the slope of the temperature curve at any given point which introduces additional error.

The remaining problems, with the exception of Problem 15, are concerned with the depth of freezing, "x". Problem 15, deals with the effect of ground film and radiation. The effect of neglecting ground film and radiation in the prediction of frost penetration, gives values which are too large, but the percentage of error decreases with the increase in penetration. Problems 6 and 7 neglect the latent heat of fusion; both problems assuming that the air temperature is periodic over a sufficiently long period so that the interior soil temperature is also periodic. Problem 7 is further complicated by assuming that the soil is composed of two layers, the solution being obtained only by cut-and-try method. Problems 8 and 9 consider latent heat but neglect volumetric heat. Problems 10 through 14 consider both latent heat and volumetric heat. Problem 16 assumes that the temperature of the soil varies uniformly with the depth. Problem 17 considers the effect on the depth of freezing of an insulation layer placed over the soil.

a. Discussion of Equations. Equations (83), (93), (154), and (158) from Problems 9, 10, 16 and 17, respectively were selected for study and comparison with observed depths of frost penetration. The results of computations for these four formulae for all airfields are contained on Plate C-1 together with all pertinent data necessary for the computations. Equation (83) ($x = \sqrt{48kF/L}$) gives values which are consistently too high. Equation (93) ($x = \sqrt{\frac{48\ k\ F}{L + C\ (v_o - 32 + F/2t}}$) gives values of "x" which, though lower than those for equation (83), are still consistently too high. Equation (154) ($x = \sqrt{\frac{24\ k\ F}{L + C\ (v_o - 32 + F/2t}}$) gives values of "x" which range from higher to lower than the observed values. Assuming that the temperature at the surface of the pavement is essentially the same as the temperature at the bottom of the pavement, a column is contained in Plate C-11 in which the thickness of pavement is added to the predicted depth as determined by equation (154). Equation (158) ($x_R = -\frac{d}{2} + \sqrt{\left(\frac{d}{2}\right)^2 + \frac{24\ k\ F}{L + C\ (v_o - 32 + F/2t}}$) has been used in areas observations were made with a turf cover. The results of these calculations bracket the observed depths but in general the dispersion is great, with the average very high. Also contained in Plate C-1 are predicted depths using the design curve (Figure 2, E.M. Part XII, Chapter 4, Mar. 1946). The values of "x" thus obtained bracket the observed depths with the greatest percentage within 6 inches of the observed depths. Comparison of the relative merits of each formula is given below:

Equation	Ratios of Predicted to Observed Depths Avg.	Max.	Min.	Per Cent of Observations Within 6 ins.
83	1.60	3.39	1.09	6
93	1.32	2.69	.83	29
154	.94	1.89	.58	42
154 ≠ pave.	1.10	2.31	.67	54
Design Curve	1.08	1.93	.67	63
158 (Turf)	1.95	5.67	.92	50

In all calculations, the average value of 1.3 BTU/(ft)(^{o}F)(hr) was used for the thermal conductivity and the full value of the latent heat as derived from the nomogram in Figure 1, Plate B-16. Because of the inability to determine for each separate layer of soil, the exact quantity of water which froze, it was assumed that all the water to the maximum depth of freezing was frozen, which is contrary to the data presented and analyzed in paragraph 2-04.

SITE	TEST AREA	YEAR	MEAN ANNUAL AIR TEMP. °F (v_0)	FREEZING INDEX °F DAYS (F)	FREEZING INDEX DURATION DAYS (t)	PAVEMENT (I) TYPE	PAVEMENT THICK. IN INCHES	BASE (II) (III) CLASS.	BASE THICK. IN INCHES	BASE WATER CONTENT % (W)	BASE DENSITY LBS/FT.³ (γ)	SUBGRADE (II) (III) CLASS.	SUBGRADE THICK. IN INCHES	SUBGRADE WATER CONTENT % (W)	SUBGRADE DENSITY LBS./FT.³ (γ)
DOW	I AND III	1943-1944	42.8	1515	108	B.C.	4.0	GW	17	9.8	135	CL	-	30.5	81
	II			1890	123	B.C.	3.5	GW	38	4.2 *	135 *	CL	-	18.3 *	107 *
	IX TO XII			1745	130	P.C.C.	7.0	GW	15	9.2	133	CL	38	28.4	92
												GC	-	28.4 (+)	92 (+)
	A	1944-1945		1445	104	P.C.C.	7.0	GW	15	11.1	118	CL	42	25.7	98
												GC	-	25.4 NF	103 NF
	B			1445	104	B.C.	3.5	GW	31	8.9	131	CL	-	31.1	93
														24.2 NF	92 NF
	C			1345	88	B.C.	3.5	GW	42	9.2	121	CL	-	18.3	109
	C			1445	104	B.C.	3.8	GW	42	9.2	121	CL	-	18.3	109
	TURF			1445	104	T.S.	6.0	-	-	-	-	CL	-	23.4	98
														15.2 NF	112 NF
	D	1945-1946		1420	98	B.C.	3.5	GW	40	13.5 *	128 *	CL	-	17.7 *	115 *
	E			1420	98	B.C.	3.5	GW	38	10.1 *	138 *	CL	-	22.4 *	101 *
	E			1080	75	B.C.	3.5	GW	38	10.1 *	138 *	CL	-	22.4 *	101 *
	F			1060	74	P.C.C	7.0	GW	20	8.1 *	138 *	CL	-	22.5 *	110 *
	TURF			1420	98	T.S.	6.0	-	-	-	-	CL	-	22.4 (+)	101 (+)
PRESQUE ISLE	A	1944-1945	39.0	2060	115	P.C.C.	7.0	GW	33	6.3	134	GC	-	17.8	108
														18.2 NF	113 NF
	B			2060	115	B.C.	4.0	C.R.	4	-	-	GC	-	14.8	114
								GW	30	6.5	134			14.2 NF	114 NF
	TURF			140	25	T.S.	5.0	-	-	-	-	GC	-	18.6	105
														15.9 NF	110 NF
	A	1945-1946		2240	126	P.C.C	7.0	GW	32	10.4 *	133 *	GC	-	17.0 *	117 *
	C			2230	120	B.C	3.5	C.R.	3.5	-	-	GC	-	13.8 *	115 *
								GW	26	6.3 *	* 132				
	D			2230	124	B.C.	3.5	C.R.	3.5	-	-	GC	-	18.4 **	120 **
								GW	25	10.5 **	** 142				
	TURF			2240	128	T.S.	5.0	-	-	-	-	GC	-	13.8 (+)	115 (+)
BEDFORD	A	1945-1946	46.5	825	98	P.C.C.	9.0	GW	18	4.8 *	118 *	SW	-	5.3 *	103 *
	B			695	87	B.C.	5.0	GW	14	4.8 (+)	118 (+)	SW	-	5.3 (+)	103 (+)
	B			345	41	B.C.	5.0	GW	14	4.8 (+)	118 (+)	SW	-	5.3 (+)	103 (+)
OTIS	A	1944-1945	40.7	300	60	B.C.	8.0	-	-	-	-	SF OR ML	30	8.5 **	** 124
														23.5 **	** 87
												SP	24	1.2	119
												GP	-	0.8	126
HOULTON	A	1944-1945	40.5	1605	107	B.C.	1.5	S.CEM.	8	16.3	113	GF	30	14.7	110
												GC	-	8.3	134
														10.1 NF	NF 118
TRUAX	A	1944-1945	46.0	1210	88	B.C.	2.5	C.R.	8	-	-	CL	23	21.1 *	108 *
								GF	15	5.3 *	* 141	SF	38	8.1 *	118 *
												CL	-	21.1 *	108 *
	B			1245	95	B.C.	2.5	C.R.	18	-	-	CL	-	27.0	99
								GF	25	7.7	122				
	C			1245	97	P.C.C.	6.0	GF	48	12.7	112	CL	-	30.0	82
	A	1945-1946		1020	93	B.C.	2.5	C.R.	8	-	-	CL	28	27.5 *	95 *
								GF	18	8.0 *	* 140	SF	38	19.8 *	118 *
												CL	-	27.5 *	95 *
	C			1060	100	P.C.C.	7.0	GF	30	10.1 *	* 129	CL	32	35.5 *	87 *
												SF	-	20.4 *	113 *
	D			1055	99	B.C.	2.5	C.R.	20	-	-	CL	-	25.9 *	99 *
								GF	30	5.8 *	* 139				
SELFRIDGE	B	1945-1946	47.8	645	81	P.C.C.	10.0	GF	12	11.5	99	ML	13	18.0	112
												SF	30	22.3 *	100 *
												CL	-	38.2 *	85 (+)
PIERRE	A	1944-1945	47.5	980	104	P.C.C.	7.0	GF	7	8.7 *	135 *	CL	32	19.1 *	108 *
												CH	-	23.5 *	90 *
	B			695	71	B.C.	5.5	GF	9	6.4 *	140 *	CL	-	14.1 *	97 *
	TURF			680	69	T.S.	4.0 (1)	-	-	-	-	CL	60	12.1 *	98 *
												CH	-	18.7 *	90 *
	A	1945-1946		1023	99	P.C.C.	7.0	GF	7	7.4 *	* 142	CL	27	21.6 *	97 *
								CL	8	16.9 *	* 110	CH	-	21.7 **	97 **
	C			1025	99	B.C.	6.0	GF	8	8.7 *	* 126	CL	-	12.7 *	92 *
								CL	7	13.8 *	* 115				
SIOUX FALLS	A	1944-1945	48.2	915	78	B.C.	2.0	GC	10	7.0 *	* 132	CL OR CH	-	23.8 *	95 *
								CL	12	18.7 *	* 112			30.9 *	84 *
	A	1945-1946		1220	82	B.C.	2.0	GC	10	7.1 *	* 137	CL OR CH	48	29.0 *	89 *
								CL	12	21.4 *	* 103	SF-CL	-	15.9 *	97 *
	B			1310	100	P.C.C	6.0	-	-	-	-	CH	90	33.0 *	85 *
												CL	11	27.5 **	87 **
												SC	-	13.8 (+)	97 (+)
WATER-TOWN	A	1944-1945	42.5	860	62	P.C.C	8.0	-	-	-	-	SF-OL	32	14.6 *	112 *
												OL-CL	20	23.8 *	87 *
												GP	-	3.8 *	120 (+)
	B			840	59	B.C.	5.0	GF	8	4.9 *	139 *	SF-OL	22	14.1 *	103 *
												OL-CL	11	22.1 *	88 *
												GP	-	4.4 *	120 (+)
	TURF			880	64	T.S.	8.0	-	-	-	-	SF-OL	52	8.4 *	136 *
												GP	-	4.4 *	120 (+)
	A	1945-1946		1715	98	P.C.C.	8.0	-	-	-	-	SF-OL	24	14.8 (+)	112 (+)
												OL-CL	22	23.8 (+)	87 (+)
												GP	-	3.8 (+)	120 (+)
	B			1715	98	B.C.	5.0	GF	12	4.9 (+)	139 (+)	SF-OL	30	14.1 (+)	103 (+)
												GP	-	4.4 (+)	120 (+)
FARGO	A	1944-1945	39.2	1305	70	B.C	1.5	S.CEM	6.5	11.1 *	* 122	OH-CH	8	26.7 *	98 *
								CL-SF	14	10.6 *	* 126	CH	-	31.1 *	89 *
	A	1945-1946		2465	125	B.C.	1.5	S.CEM	6.5	11.1 (+)	122 (+)	OH-CH	12	26.7 (+)	98 (+)
								CL-SF	11	10.6 (+)	126 (+)	CH	-	31.1 (+)	89 (+)
GREAT BEND	A	1944-1945	55.0	50	5	P.C.C	7.0	SW OR SF	6	2.0 *	120 *	SF-CL OR CL-SF	35	15.1 *	109 *
												CL	-	13.1 *	102 *
														17.0 *	100 *
	A	1945-1946		130	11	P.C.C	7.0	SF	5	2.0 (+)	120 (+)	SF-CL OR CL-SF	35	15.1 (+)	109 (+)
												CL	-	13.1 (+)	102 (+)
														17.0 (+)	100 (+)
BISMARCK	A	1944-1945	39.0	1280	88	B.C	4.5	SC	8	4.7 *	130 *	CL-ML	49	18.8 *	87 *
												SP	-	8.1 *	98 *
CASPER	A	1944-1945	47.4	355	59	P.C.C	7.0	-	-	-	-	SF-CL	20	11.4 *	114 *
												SF	12	8.8 *	120 *
												SP	-	5.3 *	111 *
	B			355	59	B.C	5.0	GW	7	3.8 *	131 *	SF-CL	12	8.2 *	117 *
												SP	32	3.5 *	109 *
												SF-CL	-	8.2 *	117 *
FAIRMONT	A	1944-1945	52.0	360	70	P.C.C	8.0	-	-	-	-	CL	25	28.0 *	88 *
												CH	-	23.0 *	88 *
GARDEN CITY	A	1944-1945	55.0	25	7	B.C	1.5	SC	10	5.0 *	128 *	CL	38	15.8 *	107 *
												CH	-	18.1 *	95 *
												OR			
												CH-CL		16.3 *	97 *

K. / ES	BASE (II) (III) CLASS.	THICK. IN INCHES	WATER CONTENT % (W)	DENSITY LBS/FT.³ (γ)	SUBGRADE (II) (III) CLASS.	THICK. IN INCHES	WATER CONTENT % (W)	DENSITY LBS./FT.³ (γ)	AVG. VOL. HEAT B.T.U./(FT.³ X °F) (C)	AVG. LATENT HEAT B.T.U./FT.³ (L)	(IV) OBSERVED DEPTH OF FREEZING IN INCHES	PREDICTED DEPTH OF FR[EEZING] INCHES-(12 X) EQ. 83	EQ. 93	EQ. 154	EQ. 154 PLUS PAVE.
	GW	17	9.9	135	CL	-	30.5	81	39.6	2920	48	88	82	44◄	►48◄
	GW	36	4.2 *	135 *	CL	-	19.3 *	107 *	39.5	1300	50	108	87	62	65
	GW	15	9.2	133	CL	38	28.4	92	42.8	3800	48	83	58	41	►48◄
					GC	-	28.4 (+)	92 (+)							
	GW	15	11.1	118	CL	42	25.7	98	44.1	3035	54	85	58◄	41	48◄
					GC	-	25.4 NF	103 NF							
	GW	31	8.9	131	CL	-	31.1	93	39.2	2310	52	75	66	47◄	50◄
							24.2 NF	92 NF							
	GW	42	9.2	121	CL	-	19.3	109	40.0	1960	60	79	►67	47	50
	GW	42	9.2	121	CL	-	19.3	109	40.0	1995	62	81	►69	49	52
	-	-	-	-	CL	-	23.4	99	38.0	3300	24				
							15.2 NF	112 NF							
	GW	40	13.5 *	128 *	CL	-	17.7 *	115 *	42.1	2530	50	71	82	44◄	►47◄
	GW	36	10.1 *	136 *	CL	-	22.4 *	101 *	41.5	2205	46	76	66	►47◄	50◄
	GW	56	10.1 *	136 *	CL	-	22.4 *	101 *	41.6	2110	44	68	59	42◄	►45◄
	GW	20	8.1 *	136 *	CL	-	22.5 *	110 *	44.8	2700	54	59◄	►52◄	37	44
	-	-	-	-	CL	-	22.4 (+)	101 (+)	42.0	3210	26				
	GW	33	6.3	134	GC	-	17.9	108	36.7	1945	70	98	85	60	►67◄
							18.2 NF	113 NF							
	C.R.	4	-	-	GC	-	14.8	114	37.4	1870	71	99	87	62	►70◄
	GW	30	8.5	134			14.2 NF	114 NF							
	-	-	-	-	GC	-	18.6	105	39.1	2790	13				
							15.9 NF	110 NF							
	GW	32	10.4 *	133 *	GC	-	17.0 *	117 *	41.1	2450	78				
	C.R.	3.5	-	-	GC	-	13.6 *	115 *	37.0	1785	68	91	►80◄	57	64
	GW	26	6.3 *	* 132								108	92	►65◄	72◄
	C.R.	3.5	-	-	GC	-	18.4 **	120 **	44.0	2740	89	85	78	64	81
	GW	25	10.5 **	** 142											
	-		-	-	GC	-	13.8 (+)	115 (+)	37.5	2230	60				
	GW	18	4.8 *	119 *	SW	-	5.3 *	103 *	26.0	800	40	96	76	54	60
	GW	14	4.8 (+)	119 (+)	SW	-	5.3 (+)	103 (+)	26.0	805	26	68	70	49	54
	GW	14	4.8 (+)	119 (+)	SW	-	5.3 (+)	103 (+)	26.0	805	26	62	49	35	40
	-	-	-	-	SF OR	30	9.5 **	** 124	27.4	2285	26	34	31◄	22◄	20◄
					ML		23.5 **	** 87							
					SP	24	1.2	119							
					GP	-	0.8	128							
	S.CEM.	6	16.3	113	GF	30	14.7	110							
					GC	-	8.3	134	34.6	2180	49	81	72	►51◄	52◄
							10.1 NF	NF 118							
	C.R.	8	-	-	CL	23	21.1 *	108 *							
	GF	15	5.3 *	* 141	SF	36	8.1 *	118 *	39.9	2385	48	66	58	41	51◄
					CL	-	21.1 *	108 *							
	C.R.	18	-	-	CL	-	27.0	99							
	GF	25	7.7	122					43.5	1805	56	78	64	45	65
	GF	48	12.7	112	CL	-	30.0	92	38.8	2070	55	74	62	44	►50◄
	C.R.	8	-	-	CL	26	27.5 *	95 *	43.7	2430	46	62	53	37	►47◄
	GF	18	6.0 *	* 140	SF	36	18.8 *	118 *							
					CL	-	27.5 *	95 *							
	GF	30	10.1 *	* 129	CL	32	35.5 *	87 *	43.9	2550	48	81	53◄	37	44◄
					SF	-	20.4 *	113 *							
	C.R.	20	-	-	CL	-	25.9 *	99 *							
	GF	30	5.8 *	* 139					43.2	1560	59	78	►63◄	44	68
	GF	12	11.5	99	ML	13	18.0	112	44.8	2280	35	50	43	30◄	40◄
					SF	30	22.3 *	100 *							
					CL	-	30.2 *	85 (+)							
	GF	7	8.7 *	135 *	CL	32	16.1 *	105 *	37.9	2150	42	83	54	39◄	46◄
					CH	-	23.3 *	90 *							
	GF	9	6.4 *	140 *	CL	-	14.1 *	97 *							
(1)	-	-	-	-	CL	60	12.1 *	98 *	32.9	1640	25	62	52	► 37	42
					CH	-	18.7 *	90 *	33.8	1680	8				
	GF	7	7.4 *	* 142	CL	27	21.8 *	97 *	39.1	2025	48	59	52◄	37	44◄
	CL	8	15.9 *	* 110	CH	-	21.7 **	97 **							
	GF	8	8.7 *	* 126	CL	-	12.7 *	92 *	30.0	1670	44	74	63	►45◄	51
	CL	7	13.8 *	* 115											
	GC	10	7.0 *	* 132	CL OR CH	-	23.8 *	95 *	40.8	2840	40	56	49	35◄	►37◄
	CL	12	16.7 *	* 112			30.9 *	84 *							
	GC	10	7.1 *	* 137	CL OR CH	48	29.0 *	89 *	36.5	3020	47	60	53◄	38	40
	CL	12	21.4 *	* 103	SF-CL	-	15.9 *	97 *							
	-	-	-	-	CH	90	33.0 *	85 *	36.9	3960	42	54	50	35	►41◄
					CL	11	27.5 **	87 **							
					SC	-	15.9 (+)	97 (+)							
	-	-	-	-	SF-OL	32	14.6 *	112 *	30.7	2325	38	58	52	►37◄	45
					OL-CL	20	23.8 *	87 *							
					GP	-	3.8 *	120 (+)							
	GF	8	4.9 *	139 *	SF-OL	22	14.1 *	103 *	29.9	1970	42	62	55	39◄	44◄
					OL-CL	11	22.1 *	88 *							
					GP	-	4.4 *	120 (+)							
	-	-	-	-	SF-OL	52	4.4 *	136 *	30.8	1240	42				
					GP	-	4.4 *	120 (+)							
	-	-	-	-	SF-OL	24	14.6 (+)	112 (+)	29.7	2010	75 TH	88	►77◄	55	64
					OL-CL	22	23.8 (+)	87 (+)							
					GP	-	3.8 (+)	120 (+)							
	GF	12	4.9 (+)	139 (+)	SF-OL	30	14.1 (+)	103 (+)							
					GP	-	4.4 (+)	120 (+)	29.6	1330	78 TH	108	90	64	►69
	S CEM	6.5	11.1 *	* 122	OH-CH	8	26.7 *	99 *	43.2	2905	46	65	59	42◄	►43◄
	CL-SF	14	10.6 *	* 126	CH	-	31.1 *	89 *							
	S CEM	6.5	11.1 (+)	122 (+)	OH-CH	12	26.7 (+)	99 (+)	42.3	3305	72 TH	81	►73◄	52	53
	CL-SF	11	10.6 (+)	126 (+)	CH	-	31.1 (+)	89 (+)							
	SW OR SF	6	2.0 *	120 *	SF-CL	35	15.1 *	109 *	36.4	325	13	37	18◄	►13◄	20
					OR										
					CL-SF		13.1 *	102 *							
					CL		17.0 *	100 *							
	SF	5	2.0 (+)	120 (+)	SF-CL	35	15.1 (+)	109 (+)	36.2	1800	24 TH	27◄	21◄	15	►22◄
					OR										
					CL-SF		13.1 (+)	102 (+)							
					CL	-	17.0 (+)	100 (+)							
	SC	6	4.7 *	130 *	CL-ML	49	18.8 *	87 *	28.7	1905	46	78	70	►50◄	54
					SP		8.1 *	99 *							
	-	-	-	-	SF-CL	20	11.4 *	114 *	29.2	1850	30	42	30◄	26◄	►33◄
					SF	12	8.8 *	120 *							
					SP	-	5.3 *	111 *							
	GW	7	3.8 *	131 *	SF-CL	12	8.2 *	117 *	28.7	870	18	61	47	34	38
					SP	32	3.3 *	108 *							
					SF-CL	-	8.2 *	117 *							
	-	-	-	-	CL	25	28.0 *	89 *	38.1	3550	15	31	28	►20◄	28
					CH	-	23.0 *	88 *							
	SC	10	3.0 *	128 *	CL	38	15.9 *	107 *	36.2	990	12	15◄	►11◄	9◄	9◄
					CH	-	10.1 *	95 *							
					OR										
					CH-CL		16.3 *	97 *							

AVG. LATENT HEAT B.T.U./FT.^{3} (L)	(IV) OBSERVED DEPTH OF FREEZING IN INCHES	PREDICTED DEPTH OF FREEZING IN INCHES - (12 X) EQ. 83	EQ. 93	EQ. 154	EQ. 154 PLUS PAVE.	EQ. 158	DESIGN CURVE
2020	48	88	62	44◄	►48◄		54◄
1300	50	108	87	82	85		►57
3900	48	63	56	41	►48◄		58
3035	54	65	58◄	41	48◄		►53◄
2310	52	75	66	47◄	50◄		►63◄
1960	60	79	►67	47	50		51
1995	62	81	►69	49	52		53
3300	24					37	
2530	50	71	82	44◄	►47◄		►53◄
2205	48	76	66	►47◄	50◄		53◄
2110	44	68	59	42◄	►45◄		47◄
2700	54	59◄	►52◄	37	44		46
3210	26					37	
1945	70	98	85	60	►67◄		63
1870	71	99	87	62	►70◄		63
2790	13					12◄	
2450	78	91	►80◄	57	64		65
1785	68	106	92	►65◄	72◄		►65◄
2740	69	85	78	64	61		►65◄
2230	60					►56◄	
800	40	96	76	54	60		►41◄
805	28	88	70	49	54		►38
805	29	62	49	35	40		►27◄
2285	26	34	31◄	22◄	28◄		►26◄
2180	49	81	72	►51◄	52◄		56
2385	46	68	58	41	51◄		►49◄
1805	58	78	64	45	65		►50◄
2070	55	74	62	44	►50◄		►50◄
2430	46	62	53	37	►47◄		►45◄
2550	48	61	53◄	37	44◄		►46◄
1580	59	78	►63◄	44	66		46
2280	35	50	43	30◄	40◄		►36◄
2150	42	63	54	39◄	46◄		►44◄
1840	25	62	52	►37	42		38
1880	6					34	
2625	40	69	52◄	37	44◄		►45◄
1870	44	74	63	►45◄	51		►45◄
2640	40	56	49	35◄	►37◄		►43◄
3020	47	60	53◄	38	40		►48◄
3960	42	54	50	35	►41◄		61
2325	38	52	52	►37◄	45		42◄
1970	42	62	55	39◄	44◄		►41◄
1240	42					43◄	
2010	75 TH	88	►77◄	55	64		58
1330	79 TH	108	90	64	►69		68
2985	46	65	59	42◄	►43◄		52◄
3395	72 TH	81	►73◄	52	53		69◄
225	13	37	18◄	►13◄	20		11◄
1600	24 TH	27◄	21◄	15	►22◄		17
1905	46	76	70	►50◄	54		►50◄
1050	30	42	38◄	28◄	►33◄		►27◄
870	18	61	47	34	36		►27
3550	19	31	28	►20◄	28		28
990	12	15◄	►11◄	8◄	9◄		8◄

EQUATIONS:

83 $$x = \sqrt{\frac{48\,k\,F}{L}}$$

93 $$x = \sqrt{\frac{48\,k\,F}{L + C\left(v_o - 32 + \frac{F}{2t}\right)}}$$

154 $$x = \sqrt{\frac{24\,k\,F}{L + C\left(v_o - 32 + \frac{F}{2t}\right)}}$$

158 $$x = -\frac{d}{2} + \sqrt{\left(\frac{d}{2}\right)^2 + \frac{24\,k\,F}{L + C\left(v_o - 32 + \frac{F}{2t}\right)}}$$

DESIGN CURVE – FIG 2, E.M. PART XII, CHAPT. 4, MARCH 1946

x = DEPTH OF FROST PENETRATION IN FEET.
k = THERMAL CONDUCTIVITY IN B.T.U./(FT)(°F)(HR)
F = FREEZING INDEX IN DEGREE-DAYS
L = AVERAGE LATENT HEAT IN B.T.U./FT^3
C = AVERAGE VOLUMETRIC HEAT IN B.T.U./(FT^3)(°F)
v_o = MEAN ANNUAL AIR TEMPERATURE IN °F
t = DURATION OF FREEZING INDEX IN DAYS
d = THICKNESS OF INSULATION LAYER IN FEET

AN AVERAGE VALUE FOR THERMAL CONDUCTIVITY (k) = 1.3 B.T.U./(FT)(°F)(HR.), IS USED THROUGHOUT THESE CALCULATIONS.

VALUE FOR "d" USED IN EQUATION 158 IS THICKNESS OF TOPSOIL IN FEET.

NOTES:

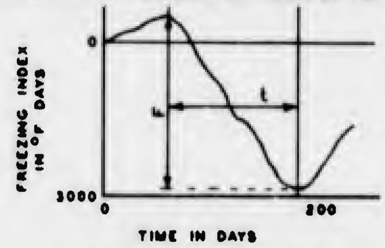
(I) PAVEMENT TYPES ARE AS FOLLOWS:
B.C. - BITUMINOUS CONCRETE.
P.C.C. - PORTLAND CEMENT CONCRETE.
T.S. - TOPSOIL (TURFED AREAS ONLY).

(II) VALUES USED FOR WATER CONTENT AND DENSITY ARE FOR FREEZING PERIOD WHEN AVAILABLE. EXCEPTIONS ARE NOTED AS FOLLOWS:
* - VALUES FOR NORMAL PERIOD.
** - VALUES FOR FROST MELTING PERIOD.
(+) - ASSUMED VALUES.
NF - VALUES FOR NON-FROZEN SUBGRADE SOIL (FREEZING PERIOD).

(III) SOIL CLASSIFICATION FOR AIRFIELDS EXCEPT AS FOLLOWS:
C.R. - CRUSHED ROCK.
S.CEM. - SOIL CEMENT.

(IV) DEPTHS OF FREEZING OBTAINED FROM TEST PIT OBSERVATIONS EXCEPT AS FOLLOWS:
TH - DEPTHS OF FREEZING OBTAINED FROM THERMOMETER AND THERMOCOUPLE OBSERVATIONS.

► CLOSEST VALUE TO OBSERVED DEPTH.
◄ VALUE WITHIN ± 6 INCHES OF OBSERVED DEPTH.



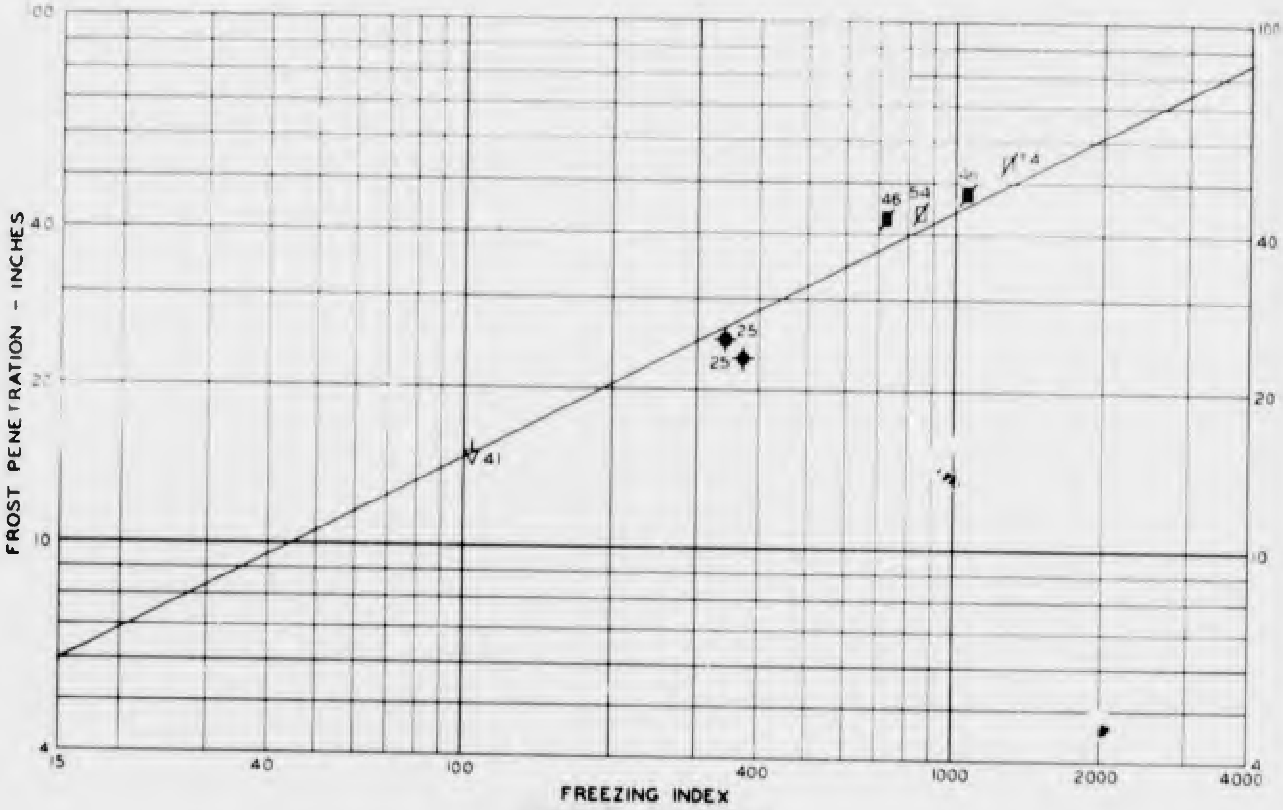
RELATIONSHIP BETWEEN F & t

FROST INVESTIGATION 1945-1946

PREDICTION OF FROST PENETRATION

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1946

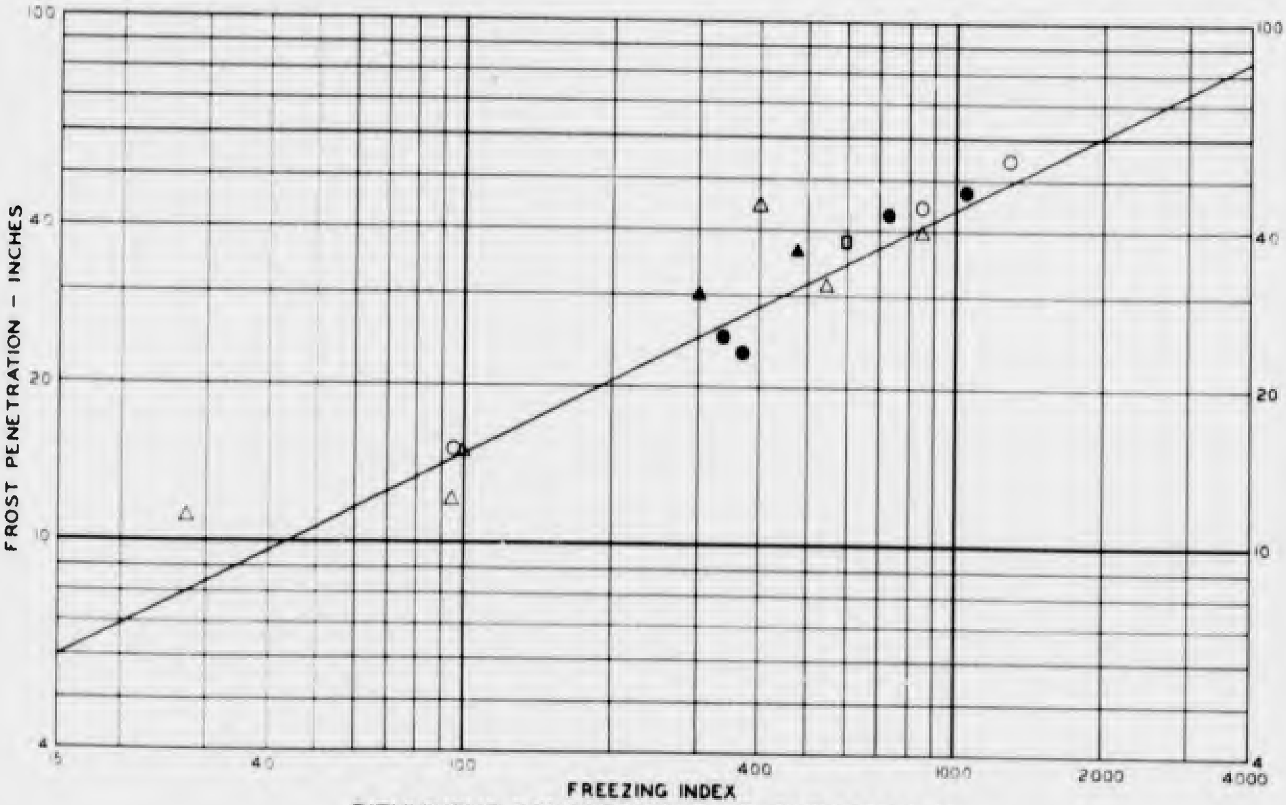
PLATE G1



FREEZING INDEX

CEMENT CONCRETE

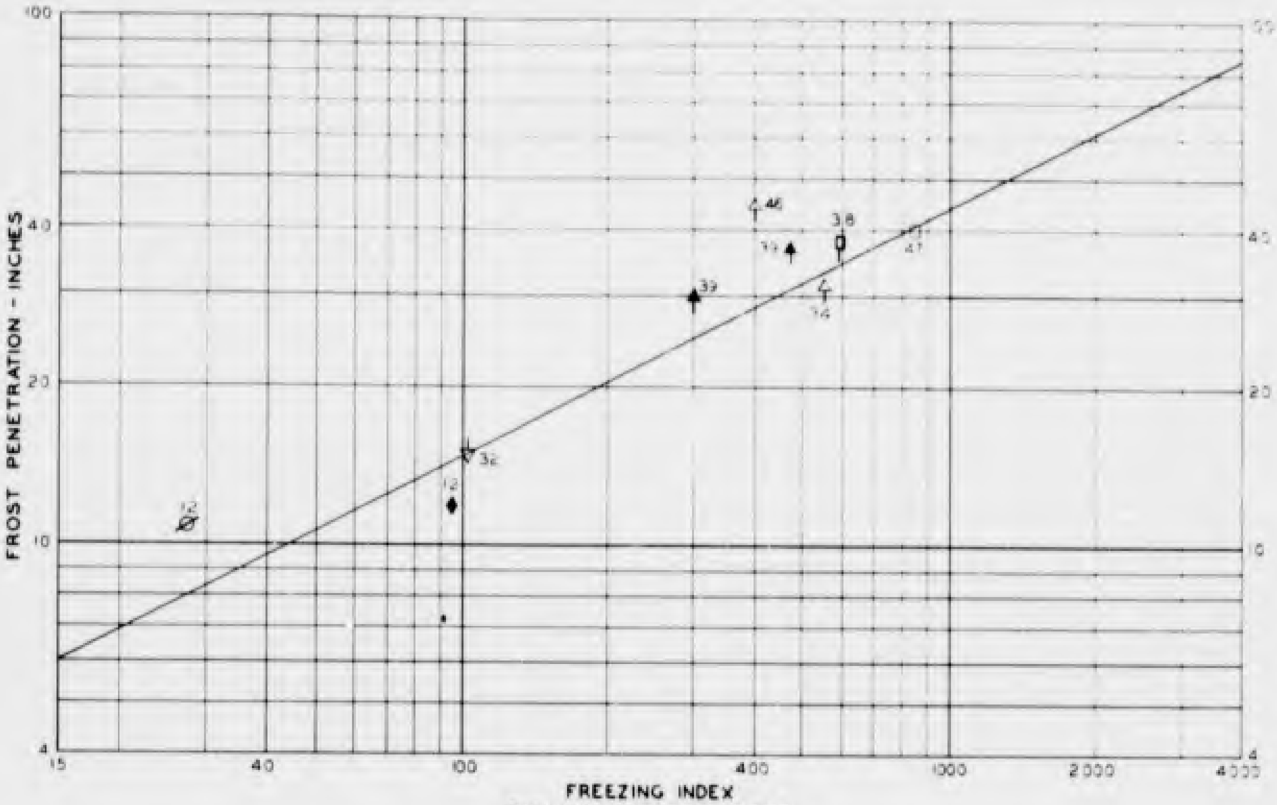
FIG. 1



FREEZING INDEX

BITUMINOUS CONCRETE AND CEMENT CONCRETE

FIG. 3



BITUMINOUS CONCRETE

FIG. 2

LEGEND

1944-1945	1945-1946	1946-1947	
▽	▼	—	PRESQUE ISLE
△	▲	▯	DOW
□	—	—	WATERTOWN
▯	■	—	TRUAX
—	◆	—	SIOUX FALLS
—	✦		BEDFORD
∅	—	—	GARDEN CITY
△	▲	□	BITUMINOUS CONCRETE
○	●	◉	CEMENT CONCRETE

—— DESIGN CURVE FROM ENGINEERING MANUAL PART XII CHAPTER 4, JULY 1946

NOTES -

NUMBERS NEXT TO PLOTTED VALUES SHOW COMBINED THICKNESS OF PAVEMENT PLUS BASE.

FROST PENETRATION IS IN NON-FROST SUSCEPTIBLE MATERIALS ONLY.

FROST INVESTIGATION

1946-1947

CORRELATION BETWEEN FROST PENETRATION AND FREEZING INDEX

FROST EFFECTS LABORATORY BOSTON MASS. JAN. 1948

PLATE C-2

APPENDIX A MATHEMATICAL STUDIES OF THERMAL PROPERTIES

Symbols and Definitions

The following symbols are used in the mathematical studies:

Symbol	Definition	Unit
A	Temperature difference between annual mean air temperature (v_o) and freezing temperature (32°)	°F
a	Thermal Diffusivity = k/C	ft²/hr.
B	Amplitude of air temperature change for yearly cycle = 1/2 range	°F
C	Volumetric heat	BTU/(ft³)(°F)
C_1, C_2, C_n	Volumetric heat of layers 1,2,..n respectively	BTU/(ft³)(°F)
C_f	Volumetric heat in frozen state	BTU/(ft³)(°F)
C_u	Volumetric heat in non-frozen state	BTU/(ft³)(°F)
c	Specific heat	BTU/(lb)(°F)
d_1, d_2, d_n	Thickness of insulation layers 1, 2,...n, respectively	ft.
E	Surface coefficient = $k\psi$	
e	Base of natural (Napierian) logarithms = 2.718 +	
F	Freezing index	°F days
H	Total heat given up by soil = Qt	BTU/ft²
h	Depth below ground surface	ft.
i	Thermal gradient	°F/ft
$\overline{K}$	Constant of integration	
k	Thermal conductivity	BTU /(ft)(°F)(hr)

Symbol	Definition	Unit
k_1, k_2, k_n	Thermal conductivity of layers 1,2,...n respectively	BTU/(ft)(^oF)(hr)
k_f	Thermal conductivity in frozen state	BTU/(ft)(^oF)(hr)
k_u	Thermal conductivity in non-frozen state	BTU/(ft)(^oF)(hr)
L	Latent heat of fusion of water in soil	BTU/ft^3
Q	Rate of heat flow from ground surface = ki	BTU/(ft^2)(hr)
R	Thermal resistance $= \frac{d_1}{k_1} + \frac{d_2}{k_2} + \ldots \frac{d_n}{k_n}$	$\frac{1}{BTU/(^oF)(hr)}$
s	Thickness of upper soil layer	ft
T	Time period of temperature change for 1 year	365 days
t	Time increment = duration of freezing index	day
V	Temperature amplitude in soil at depth "h"	^oF
v_f	Average air temperature during period of freezing	^oF
v_o	Average soil temperature = mean annual air temperature	^oF
v_p	Constant suddenly impressed air temperature	^oF
v_s	Variable air temperature during period "T"	^oF
x	Depth of freezing = depth of melting for rising soil temperatures	ft
x_R	Depth of freezing, when soil is overlain by an insulation layer	ft

Symbol	Definition	Unit
z	Elevation of a point from the boundary layer - measured in opposition to "h"	ft
β	Growth coefficient of melted layer = $\frac{h}{2\sqrt{24at}}$	
ω	Parameter = $2\pi/T$	
N,Z,θ	Dimensionless parameters for simplification of equations	
P,G,m,y,δ,ψ	Parameters for simplification of equations	
ϕ	Mean temperature gradient in period Δt	$^oF/ft$
ln	log to the base "e"	

PROBLEM NO. 1

Given a homogeneous, isotropic soil mass of semi-infinite extent, with its initial temperature at temperature "v_o". Its surface temperature is suddenly changed to temperature "v_p".

(a) Find the thermal diffusivity "a", by measuring the temperature gradients at different times, neglecting latent heat.

The temperature at any depth "h" at time "t" is

$$v_{(h,t)} = v_o + (v_p - v_o) \quad [1 - \text{erf}\ (\beta)] \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; [1]$$

where the erf (β) is the probability-integral, also known as the Gauss "error-function" of β, and can be expressed as

$$\text{erf}\ (\beta) = \frac{2}{\sqrt{\pi}} \int_0^\beta e^{-u^2}\, du \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; [2]$$

$$\text{By definition } \beta = \frac{h}{2\sqrt{24at}} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; [3]$$

At any time "t", the temperature gradient "i" can be expressed as the slope of the temperature

$$i = \frac{dv}{dh} = -(v_o - v_p)\frac{d}{d\beta}\ \text{erf}\ \beta\ \left(\frac{d\beta}{dh}\right) \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; [4]$$

$$\text{Now } \frac{d}{d\beta}\text{erf } \beta = \frac{2}{\sqrt{\pi}}\frac{d}{d\beta}\int_0^{\beta} e^{-u^2}du = \frac{2}{\sqrt{\pi}}e^{-\beta^2} \quad \ldots\ldots\ldots\ldots [5]$$

$$\therefore \frac{dv}{dh} = -(v_o - v_p)\frac{2}{\sqrt{\pi}}e^{-\beta^2}\cdot\frac{1}{2\sqrt{24at}} = -(v_o - v_p)\frac{e^{-\beta^2}}{\sqrt{24\pi at}} \quad \ldots\ldots [6]$$

$$\text{At time "}t_1\text{", } i_1 = -(v_o - v_p)\frac{e^{-\frac{h^2}{96\,at_1}}}{\sqrt{24\pi at_1}} \quad \ldots\ldots\ldots\ldots [7]$$

$$\text{and at time "}t_2\text{", } i_2 = -(v_o - v_p)\frac{e^{-\frac{h^2}{96at_2}}}{\sqrt{24\pi at_2}} \quad \ldots\ldots\ldots\ldots [8]$$

$$\therefore \frac{i_1}{i_2} = \frac{e^{-\frac{h^2}{96at_1}}}{e^{-\frac{h^2}{96at_2}}}\sqrt{\frac{t_2}{t_1}} = \sqrt{\frac{t_2}{t_1}}\cdot e^{\frac{h^2}{96a}\left(\frac{1}{t_2} - \frac{1}{t_1}\right)} \quad \ldots\ldots\ldots\ldots [9]$$

$$\text{Let } \frac{1}{t_2} - \frac{1}{t_1} = \delta$$

$$\text{Then } \frac{i_1}{i_2} = \sqrt{\frac{t_2}{t_1}}\cdot e^{\frac{h^2\delta}{96a}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

$$\text{or } e^{\frac{h^2\delta}{96a}} = \frac{i_1}{i_2}\sqrt{\frac{t_1}{t_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

$$\frac{h^2\delta}{96a} = \ln\left[\frac{i_1}{i_2}\sqrt{\frac{t_1}{t_2}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots [12]$$

$$\therefore a = \frac{h^2\delta}{96\ln\left[\frac{i_1}{i_2}\sqrt{\frac{t_1}{t_2}}\right]} = \frac{k}{C} \quad \ldots\ldots\ldots\ldots\ldots\ldots [13]$$

Values of "i_1" and "i_2" / be obtained by plotting the temperature profiles for times "t_1" and "t_2" and then drawing tangents to curves at depth "h".

This problem is generally one confined to the laboratory. In nature, the soil temperature is not uniform at any time and the temperature over a given period never changes from one constant value to another.

(b) Find the thermal diffusivity "a" by noting the time required for a point at depth "h" to change its temperature by $\frac{(v_o + v_p)}{2}$.

Substituting $\frac{v_o + v_p}{2}$ for $v_{h,t}$, equation [1] becomes

$$\frac{v_o + v_p}{2} = v_o + (v_p - v_o)\,[1 - \text{erf}\,(\beta)]$$

Then erf $(\beta) = 1/2$ . . . . [14]

From tables of error functions or Fig. 5, Plate A-2 when erf

$(\beta) = 1/2$, $\beta = 0.477$.

From definition $\beta = \frac{h}{2\sqrt{24at}}$

Then $h = 2\beta\sqrt{24at} = 2 \times 0.477\sqrt{24at}$

$$\text{or } a = \frac{h^2}{21.91\ t} = \frac{0.0458h^2}{t} \quad . . . . [15]$$

Thus, with a soil mass of very great depth at a uniform temperature "v_o", and the surface temperature is suddenly changed to temperature "v_p", then with a thermometer or thermocouple placed in the soil at depth "h" and the time noted when the soil temperature reaches a value halfway between "v_o" and "v_p", a value of "a" can be obtained. This problem is confined to the laboratory.

PROBLEM NO. 2

Given a homogeneous, isotropic soil mass of semi-infinite extent, exposed to periodic temperature changes over a sufficiently long period so that the interior temperatures are also periodic.

Find the thermal diffusivity "a", by measuring the temperature gradients at different times, one quarter year apart, neglecting latent heat.

The surface temperature can be expressed as

$$v_s = 32 + A + B \cos \omega t \quad [16]$$

The temperature at any depth "h" at any time "t" is

$$v_{(h,t)} = 32 + A + B e^{-mh} \cos (\omega t - mh) \quad [17]$$

$$\text{where } m = \sqrt{\omega/48a} = \sqrt{\frac{\pi}{24aT}}$$

At any time "t", the temperature gradient "i" can be expressed as the slope of the temperature versus depth curve,

$$\text{Then } i = \frac{dv}{dh} = -mBe^{-mh} \cos(\omega t - mh) + mBe^{-mh} \sin(\omega t - mh). \quad [18]$$

At time "t_1"

$$i_1 = mBe^{-mh}[\sin(\omega t_1 - mh) - \cos(\omega t_1 - mh)] \quad [19]$$

and at time "t_2"

$$i_2 = mBe^{-mh}[\sin(\omega t_2 - mh) - \cos(\omega t_2 - mh)] \quad [20]$$

Now let f(h) equal the sum of the squares of the thermal gradients at depth "h",

$$f(h) = i_1^2 + i_2^2 \quad [21]$$

$$i^2 = m^2B^2e^{-2mh}[\sin^2(\omega t - mh) - 2\sin(\omega t - mh)\cos(\omega t - mh) + \cos^2(\omega t - mh)]$$

$$= m^2B^2e^{-2mh}[1 - 2\sin(\omega t - mh)\cos(\omega t - mh)] \quad [22]$$

$$\therefore f(h) = m^2B^2e^{-2mh}[2 - 2\sin(\omega t_1 - mh)\cos(\omega t_1 - mh)$$

$$- 2\sin(\omega t_2 - mh)\cos(\omega t_2 - mh)] \quad [23]$$

Since by hypothesis is $t_2 = t_1 + T/4$; substitution in equation [23] gives

$$f(h) = 2m^2B^2e^{-2mh} \quad \ldots\ldots\ldots\ldots \quad [24]$$

At depth h_1, $f(h_1) = 2m^2B^2e^{-2mh_1}$, and at depth h_2

$$f(h_2) = 2m^2B^2e^{-2mh_2}$$

Then $$\frac{f(h_1)}{f(h_2)} = \frac{2m^2B^2e^{-2mh_1}}{2m^2B^2e^{-2mh_2}} = e^{2m(h_2-h_1)} \quad \ldots\ldots\ldots \quad [25]$$

$$\ln\frac{f(h_1)}{f(h_2)} = 2m(h_2 - h_1) \quad \ldots\ldots\ldots \quad [26]$$

$$m = \frac{1}{2(h_2 - h_1)} \ln\frac{f(h_1)}{f(h_2)} = \sqrt{\frac{\pi}{24aT}} \quad \ldots\ldots\ldots \quad [27]$$

from which the value of "a" can be computed.

Example

Temperature profiles are shown in Figure I on Plate A-I. Using equation [27] and drawing tangents to the temperature profiles for the months of June and September, the results of "a" are as follows:

Depth in feet	h_2-h_1	June i_1	June i_1^2	Sept. i_2	Sept. i_2^2	f(h)	$\frac{f(h_1)}{f(h_2)}$	$\ln\frac{f(h_1)}{f(h_2)}$	m	m^2	a
10.0		.38	.144	.60	.360	.504					
	4.3						2.431	.8883	.103	.0107	.0335
5.7		.96	.922	.55	.303	1.225					
	2.2						1.345	.2964	.067	.0045	.0797
3.5		1.3	1.64	.10	.010	1.648					
	2.0						2.495	.8998	.225	.0506	.0071
1.5		2.0	4.00	.23	.053	4.053					
	1.0						2.762	1.0159	.508	.2581	.0014
0.5		3.3	10.89	.55	.303	11.193					

The results of the example indicate the difficulty of determining "a" from field observations.

PROBLEM NO. 3

Given a homogeneous, isotropic soil mass of semi-infinite extent, exposed to periodic temperature changes over a sufficiently long period so that the interior temperatures are also periodic.

Find the thermal diffusivity "a" from the temperature amplitudes at various depths, neglecting latent heat.

From equations [16] and [17],

$v_s = 32 + A + B \cos \omega t$, and

$v_{(h,t)} = 32 + A + Be^{-mh} \cos(\omega t - mh)$

At depths "h_1" and "h_2",

$$v_{h_1} = 32 + A + Be^{-mh} \cos(\omega t - mh_1), \text{ and} \quad \ldots \quad [28]$$

$$v_{h_2} = 32 + A + Be^{-mh} \cos(\omega t - mh_2) \text{ respectively} \quad \ldots \quad [29]$$

For maximum values,

$$v_{h_1} = 32 + A + Be^{-mh_1}, \text{ and } v_{h_2} = 32 + A + Be^{-mh_2} \quad [30] \ \& \ [31]$$

$$\therefore \frac{v_{h_1}}{v_{h_2}} = \frac{32 + A + Be^{-mh_1}}{32 + A + Be^{-mh_2}} \text{ or } \frac{v_{h_1} - 32 - A}{v_{h_2} - 32 - A} = e^{m(h_2 - h_1)} \quad \ldots \quad [32]$$

$$m = \frac{1}{h_2 - h_1} \ln \left[\frac{v_{h_1} - 32 - A}{v_{h_2} - 32 - A}\right] \quad \ldots \quad [33]$$

Since $A = v_o - 32$, $v_h - 32 - A = V$

$$m = \sqrt{\frac{\pi}{24aT}} = \frac{1}{h_2 - h_1} \ln\left[\frac{V_1}{V_2}\right] \quad \ldots \quad [34]$$

Example

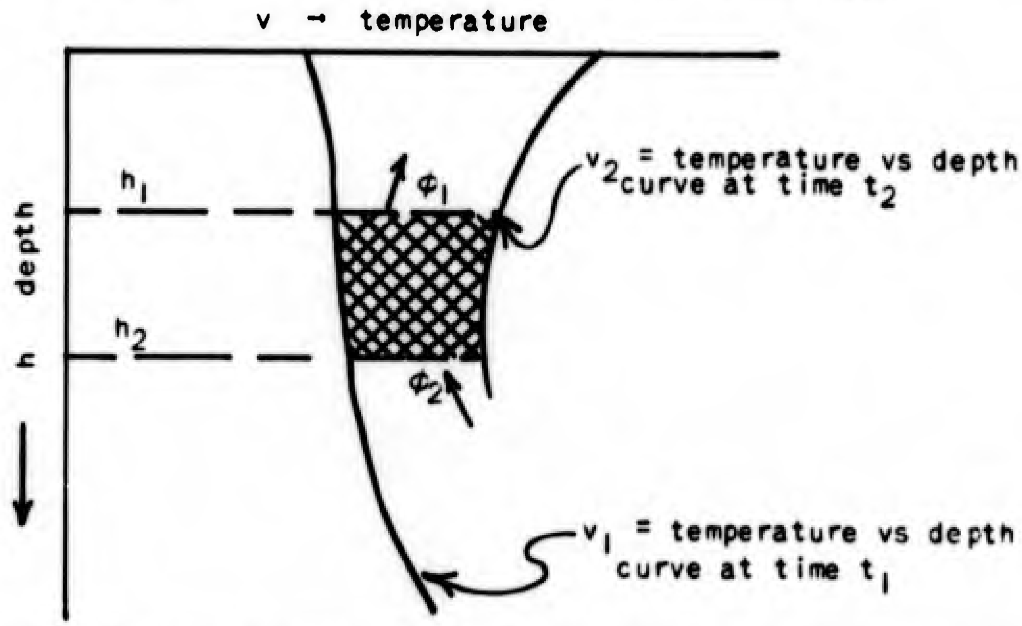
From the curves given in Figure 2, Plate A-1 the following values of "a" are derived

Depth in feet	$h_2 - h_1$	V °F	$\frac{V_1}{V_2}$	$\ln\frac{V_1}{V_2}$	m	m^2	a (ft^2/hr)
10.0		4.7					
	4.3		1.660	.5068	.1179	.01390	.0258
5.7		7.8					
	2.2		1.256	.2278	.1035	.01071	.0335
3.5		9.8					
	2.0		1.224	.2021	.1011	.01022	.0351
1.5		12.0					
	1.0		1.142	.1328	.1328	.01764	.0203
0.5		13.7					

PROBLEM NO. 4

Given a homogeneous, isotropic soil mass of semi-infinite extent, subjected to a change of temperature over a period of time.

Find the thermal diffusivity "a" from temperature variation with depth, at two or more different times, neglecting latent heat.



Let "Q" = total quantity of heat absorbed by a layer of soil of depth (h_2-h_1) and of unit cross sectional area in the period "Δt" $(\Delta t = t_2 - t_1)$.

$$\text{Then } Q = C\int_{h_1}^{h_2} (v_2 - v_1)\,(dh) \quad \ldots\ldots\ldots\ldots \quad [35]$$

$= C \times$ Area between temperature curves and depths "h_2" and "h_1"

Let "Q_1" and "Q_2" equal quantities of heat per unit area of surface, transmitted out of and into the layer through planes "h_1" and "h_2", respectively, in time "Δt".

$$Q_1 = 24k\phi_1\Delta t \quad \ldots\ldots\ldots\ldots \quad [36]$$

$$Q_2 = 24k\phi_2\Delta t \quad \ldots\ldots\ldots\ldots \quad [37]$$

Now the increase in heat in the layer during the time interval "Δt" is the difference between heat input and heat output.

$$Q = Q_2 - Q_1 = 24k(\phi_2 - \phi_1)\,(t_2 - t_1) = C \times \text{Area} \quad \ldots\ldots \quad [38]$$

$$\text{or } \frac{k}{C} = \frac{\text{Area}}{24(\phi_2 - \phi_1)(t_2 - t_1)} = a \quad \ldots\ldots\ldots\ldots \quad [39]$$

In general terms

$$a = \frac{(v_2 - v_1)\,(h_2 - h_1)}{(\phi_2 - \phi_1)\,(t_2 - t_1)} = \frac{\Delta v \Delta h}{\Delta i \Delta t}$$

$$= \frac{dv}{dt} \times \frac{dh}{di} = \frac{dv}{dt} \times \frac{1}{di/dh} \quad \ldots\ldots\ldots\ldots\ldots \quad [40]$$

where $\frac{"dv"}{dt}$ is the tangent to the time-temperature curve at a given depth and time and $\frac{"di"}{dh}$ is the tangent to the temperature-gradient curve. Time interval "Δt" must be expressed in hours.

Example

Using equation [39], and values of thermal gradient "ϕ" from Figure 1, Plate A-1 for the months of May and June (typical example is plotted in Figure 4, Plate A-1) the following values of "a" are obtained.

For May to June

$\Delta t = 31 \times 24 = 744$ hrs.

Depth in feet	$h_2 - h_1$	V ($^{\circ}$F)	$\frac{V_2 + V_1}{2}$	ϕ	$\phi_2 - \phi_1$ ($\Delta\phi$)	Δt times $\Delta\phi$	Area	a (ft^2/hr)
10.0		2.18		-0.23				
	4.3		3.23		.52	386.9	13.889	.0359
5.7		4.27		-0.75				
	2.2		4.81		.33	245.5	10.582	.0431
3.5		5.35		-1.08				
	2.0		5.68		.75	558.0	11.360	.0204
1.5		6.00		-1.83				
	1.0		6.11		1.72	1279.7	6.110	.0048
0.5		6.22		-3.55				

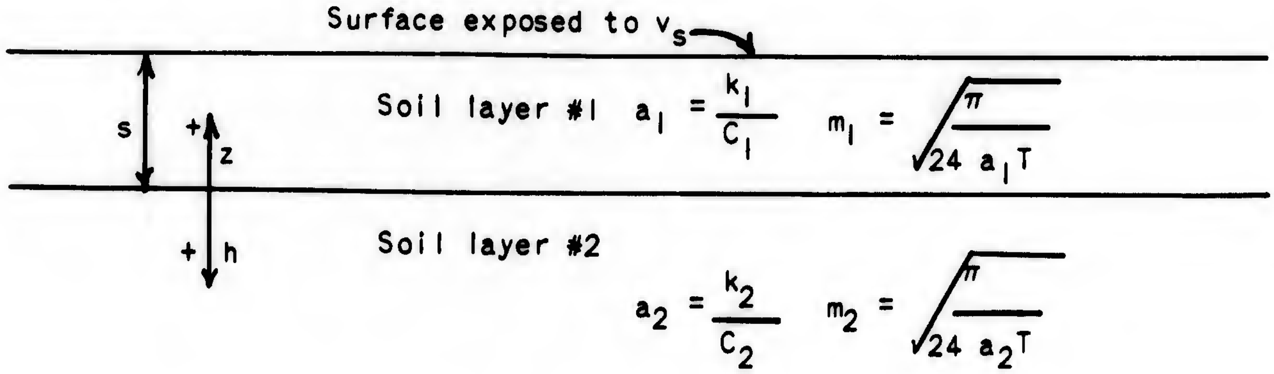
Using equation [40] and values of $\frac{"dv"}{dt}$ obtained from Figure 2, Plate A-1, and values of thermal gradient slope $\frac{"di"}{dh}$ obtained from Figure 3, Plate A-1. Values of $\frac{"dt"}{dh}$ were obtained from tangents drawn to the gradient curves.

Depth in feet	$\frac{dv}{dt}$ = °F/month			$\frac{di}{dh}$ = °F/ft²			a = ft²/hr		
	Apr.	June	Nov.	Apr.	June	Nov.	April	June	Nov.
10.0	0.7	2.5	-2.1	.035	.135	-.070	.0278	.0257	.0417
5.7	2.5	3.9	-4.3	.085	.135	-.150	.0408	.0402	.0398
3.5	3.6	4.7	-5.8	.170	.190	-.245	.0294	.0344	.0328
1.5	5.3	4.0	-5.0	.620	.720	-.355	.0119	.0097	.0125
0.5	6.5	5.0	-6.2	1.57	2.64	-.380	.0057	.0027	.0226

PROBLEM NO. 5

Given two layers of homogeneous, isotropic soils, possessing different soil properties, the uppermost of which is exposed to a periodic temperature change.

Find the thermal diffusivity "a" of both layers, neglecting latent heat.



Layer #2 of infinite extent
Arrows indicate direction of measurements for "z" and "h"

It is assumed that the impressed periodic surface temperature can be expressed by equation [16]

$$v_s = 32 + A + B\cos\omega t$$

It can then be shown that the temperature at any point "z" in layer #1 at time "t" is,

$$v_{1(z,t)} = 32 + A + \frac{B}{Z}\left[e^{m_1 z}\cos(\omega t + m_1 z - \theta) + Ne^{-m_1 z}\cos(\omega t - m_1 z - \theta)\right] \quad [41]$$

and the temperature at any point "h" in layer #2 at time "t" is,

$$v_{2(h,t)} = 32 + A + \frac{B}{Z}(1 + N)e^{-m_2 h}\cos(\omega t - m_2 h - \theta) \; . \; . \; . \; . \; . \; . \; . \quad [42]$$

where "N", "Z" and "θ" are parameters expressed as follows:

$$N = \frac{\sqrt{k_1C_1} - \sqrt{k_2C_2}}{\sqrt{k_1C_1} + \sqrt{k_2C_2}} \quad . . . . [43]$$

$$Z = \sqrt{e^{2m_1s} + 2N(-1 + 2\cos^2 m_1s) + N^2e^{-2m_1s}} \quad . . . . [44]$$

$$\tan\theta = \tan m_1s\left[\frac{1-Ne^{-2m_1s}}{1+Ne^{-2m_1s}}\right] \quad . . . . [45]$$

Now, differentiating equations [41] and [42] and following the procedure outlined in Problem 2, equations [18] to [27] inclusive, it can be found that

$$m_1 = \sqrt{\frac{\pi}{24a_1T}} = \frac{1}{2(z_1 - z_2)} \ln\frac{f(z_1)}{f(z_2)} \quad . . . . [46]$$

and

$$m_2 = \sqrt{\frac{\pi}{24a_2T}} = \frac{1}{2(h_2 - h_1)} \ln\frac{f(h_1)}{f(h_2)} = \text{equation [27]}$$

However, values of "a" may be as much as 20 per cent in error.

If the data were available as to the exact location of layer boundaries and for soil temperature profiles, then, at the soil interface, we have

$$k_1 i_1 = k_2 i_2 \quad . . . . [47]$$

This ratio of thermal conductivities may be of some help.

PROBLEM NO. 6

Given a semi-infinite, homogeneous soil mass, the surface of which is exposed to periodic temperature changes over a sufficiently long period so that the interior temperatures are also periodic.

Find the depth of frost penetration "x", neglecting latent heat.

It is assumed that the periodic surface temperature can be expressed by the equation

$$v_s = 32 + A - B\sin\omega t \quad . . . . [48]$$

and that B>A, so that the temperature drops below freezing.

The temperature at depth "h" at any time "t" is

$$v_{(h,t)} = 32 + A - Be^{-mh} \sin(\omega t - mh) \quad [49]$$

To find the trace of freezing temperature ($32^{\circ}F$) surface "x",

Then

$$32 = 32 + A - Be^{-mx} \sin(\omega t - mx) \quad [50]$$

$$\text{or } A = Be^{-mx} \sin(\omega t - mx) \quad [51]$$

$$Ae^{mx} = B \sin(\omega t - mx) \quad [52]$$

$$\text{or} \quad mx = \ln \left[\frac{B}{A} \sin(\omega t - mx)\right]$$

$$\text{and } x = \frac{1}{m} \ln \frac{B}{A} \sin(\omega t - mx) = \sqrt{\frac{24aT}{\pi}} \ln \frac{B}{A} \sin(\omega t - mx) \quad [53]$$

Now "x" is a maximum when $\sin(\omega t - mx) = 1$

$$\therefore x_{max} = \sqrt{\frac{24aT}{\pi}} \ln \frac{B}{A} \quad [54]$$

<u>Example</u>

Given: $v_o = 42^{\circ}$; $B = 20^{\circ}$; $a = 0.03 \text{ ft}^2/\text{hr}$

Find "x".

$$x = \sqrt{\frac{24 \times 0.03 \times 365}{3.1416}} \ln \frac{20}{10} = \sqrt{83.60} \quad \ln 2$$

$$= 9.14 \times 0.693 = 6.34 \text{ ft.}$$

PROBLEM NO. 7

Given two layers of homogeneous, isotropic soil possessing different soil properties, the uppermost of which is exposed to periodic surface temperature changes over a sufficiently long period so that the interior temperatures are also periodic.

Find the depth of frost penetration "x", neglecting latent heat.

Let the surface temperature be expressed by equation [48]

$$v_s = 32 + A - B \sin \omega t$$

and let B>A so that the temperature drops below freezing.

As indicated by equations [41] and [42], the temperature at any point "z" at time "t" in layer #1 can be expressed as

$$v_{1(z,t)} = 32 + A - \frac{B}{Z}\left[e^{m_1 z}\sin(\omega t + m_1 z - \theta) + Ne^{-m_1 z}\sin(\omega t - m_1 z - \theta)\right] \quad [55]$$

and at any point "h" at time "t" in layer #2 by

$$v_{2(h,t)} = 32 + A - \frac{B}{Z}(1 + N)e^{-m_2 h} \sin(\omega t - m_2 h - \theta) \; . \; . \; . \; . \; . \; . \; . \; . \quad [56]$$

where "N", "Z" and "θ" are parameters given by equations [43] [44] and [45] respectively.

Proceeding in the manner indicated in Problem #6, the trace of freezing temperature (32°F) surface "x" in layer #1 is

$$\frac{AZ}{B} = e^{m_1 z} \sin(\omega t + m_1 z - \theta) + Ne^{-m_1 z}\sin(\omega t - m_1 z - \theta) \; . \; . \; . \; . \quad [57]$$

and in layer #2

$$\frac{AZ}{B(1 + N)} = e^{-m_2 x} \sin(\omega t - m_2 x - \theta) \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad [58]$$

Solution for "x" in equations [57] and [58] is by cut and try methods only.

PROBLEM NO. 8

Given a homogeneous, isotropic soil mass of semi-infinite extent, the surface of which is exposed to periodic temperature changes over a sufficiently long period so that the interior temperatures are also periodic.

Find the depth of freezing "x", neglecting volumetric heat but considering latent heat of fusion "L".

It is assumed that the periodic temperature change can be expressed by equation [48]

$$v_s = 32 + A - B \sin\omega t$$

The temperature gradient through a frozen layer of thickness "x" is

$$i = \frac{32 - A - 32 + B\sin\omega t}{x} = \frac{B\sin\omega t - A}{x} \quad \ldots\ldots\ldots\ldots \quad [59]$$

Now, the heat liberated in freezing a layer of thickness "x" is

$$dH = L\,dx \quad \ldots\ldots\ldots\ldots \quad [60]$$

The heat conducted out in time "dt" is

$$dH = 24\,ki\,dt \quad \ldots\ldots\ldots\ldots \quad [61]$$

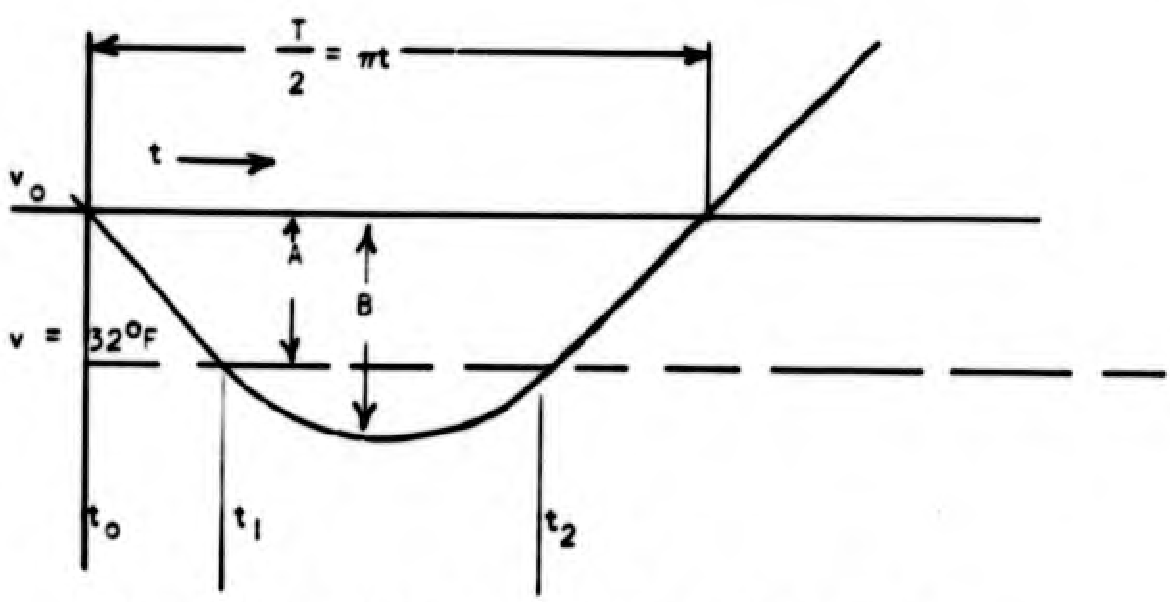
Equating [60] and [61], and substituting [59] for "i"

$$L\,dx = 24ki\,dt = \frac{24k}{x}(B\sin\omega t - A)\,dt \quad \ldots\ldots\ldots\ldots \quad [62]$$

$$\text{or } \frac{Lx\,dx}{24k} = (B\sin\omega t - A)dt \quad \ldots\ldots\ldots\ldots \quad [63]$$

Integrating

$$\frac{Lx^2}{24k} = \frac{-B}{\omega}\cos\omega t - At + \bar{K} \quad \ldots\ldots\ldots\ldots \quad [64]$$



From sketch, when $t = t_1$, $x = 0$ and $A = B\sin\omega t_1$

$$\therefore \sin\omega t_1 = \frac{A}{B} \text{ and } t_1 = \frac{1}{\omega}\arcsin\frac{A}{B} \quad \ldots\ldots\ldots\ldots \quad [65]$$

$$\text{and } \cos t = \frac{1}{B}\sqrt{B^2 - A^2}$$

$\therefore$ for [64] at time "t_1"

$$0 = \frac{-B}{\omega} \cdot \frac{1}{B} \sqrt{B^2 - A^2} - \frac{A}{\omega} \text{arc sin} \frac{A}{B} + \quad \bar{K}$$

$$\text{and } \bar{K} = \frac{\sqrt{B^2 - A^2}}{\omega} + \frac{A}{\omega} \text{arc sin} \frac{A}{B}$$

$$\text{and } \frac{Lx^2}{24k} = -\frac{B}{\omega} \cos\omega t - At + \frac{1}{\omega}\sqrt{B^2 - A^2} + \frac{A}{\omega} \text{arc sin} \frac{A}{B} \quad \ldots\ldots \quad [66]$$

$$x = \sqrt{\frac{24k}{L}[-\frac{B}{\omega} \cos \omega t - At + \frac{1}{\omega}\sqrt{B^2 - A^2} - \frac{A}{\omega} \text{arc sin} \frac{A}{B}]} \quad \ldots\ldots \quad [67]$$

By rewriting equation [63] we have

$$\frac{dx}{dt} = \frac{24k(B \sin \omega t - A)}{Lx} \quad \ldots\ldots \quad [68]$$

Equating $\frac{"dx"}{dt}$ to 0, the maximum and minimum penetration is reached when

$$t = \frac{1}{\omega} \text{arc sin} \frac{A}{B} \quad \ldots\ldots \quad [69]$$

Two values of "t" satisfy equation [69] as can be seen from foregoing sketch. At time "t_1", penetration is zero and at time "t_2", melting begins and penetration is maximum.

$$\text{Now } t_1 - t_o = \frac{T}{2} - t_2$$

$$\therefore t_2 = t_{max} = \frac{T}{2} - t_1 \quad \ldots\ldots \quad [70]$$

Integrating equation [63]

$$\frac{L}{24k} \int_o^{x_{max}} xdx = \int_{t_1}^{t_2} K(B \sin \omega t - A)\, dt$$

$$\frac{Lx_{max}^2}{48k} = \left[-\frac{B}{\omega} \cos \omega t - At\right]_{t_1}^{t_2} \quad \ldots\ldots \quad [71]$$

$$= \frac{-B}{\omega}(\cos\omega t_2 + \cos\omega t_1) - A(t_2 - t_1)$$

$$= \frac{B}{\omega}(\cos\omega t_1 - \cos\omega t_2) - A(\frac{T}{2} - 2t_1) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad [72]$$

Now $\cos\omega t_1 = \frac{\sqrt{B^2 - A^2}}{B}$ and $\cos\omega t_2 = -\frac{\sqrt{B^2 - A^2}}{B}$

Substituting these values in equation [72]

$$\frac{Lx^2_{max}}{48\ k} = \frac{B}{\omega}\frac{\sqrt{B^2 - A^2}}{B} + \frac{B}{\omega}\frac{\sqrt{B^2 - A^2}}{B} - A(\frac{T}{2} - 2t_1)$$

$$= \frac{2}{\omega}\sqrt{B^2 - A^2} - A(\frac{T}{2} - 2t_1) = \frac{2}{\omega}\sqrt{B^2 - A^2} + A(2t_1 - \frac{T}{2}) \quad [73]$$

Substituting $\frac{2\pi}{T}$ for "ω" and $\frac{1}{\omega}$ arc sin $\frac{A}{B}$ for "t_1"

Then $x^2_{max} = \frac{2k}{L}[\frac{24T}{\pi}\sqrt{B^2 - A^2} + A(\frac{24T}{\pi}\text{arc sin}\frac{A}{B} - \frac{24T}{2}\ \frac{\pi}{\pi})]$

$$= \frac{2kT}{\pi L}[24\sqrt{B^2 - A^2} + A(24\ \text{arc sin}\frac{A}{B} - 12\pi)]$$

$$x_{max} = \sqrt{\frac{48kT}{\pi L}[\sqrt{B^2 - A^2} + A(\text{arc sin}\frac{A}{B} - \frac{\pi}{2})]} \quad . \; . \; . \; . \; . \quad [74]$$

If the portion of the curve below 32°F is assumed to be parabolic, the equation for the surface temperature for that portion can be expressed by

$$v_s = (B - A)(\frac{4t^2}{(t_2 - t_1)^2} - 1) + 32 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad [75]$$

$$\text{or} \quad = (B - A)[(\frac{2t - t_2 - t_1}{t_2 - t_1})^2 - 1] + 32 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad [76]$$

Proceeding in the manner outlined by equations [59] through [74] inclusive, then

$$x_{max} = \sqrt{\frac{4k}{3L}(B - A)\ (t_2 - t_1)} \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad [77]$$

Example

Using the same data as was used for example for Problem No. 6,

$v_o = 42^o$; $B = 20^o$; $a = 0.03\ ft^2/hr$ and further

assuming C = 30 and L = 2880, then for use in equation [74]

$$k = aC = 0.03 \times 30 = 0.9$$

Then

$$x_{max} = \sqrt{\frac{48 \times 0.9 \times 365}{3.1416 \times 2880}\left[\sqrt{400 - 100} + 10(\text{arc sin}\frac{10}{20} - 1.5708)\right]}$$

$$= \sqrt{1.74 \times (17.32 - 10.47)} = \sqrt{11.9} = 3.45 \text{ ft.}$$

for use in equation [77]

$$t_1 = \frac{12T}{\pi} \cdot \frac{\pi}{6} = 2T \text{ hours} = \frac{T}{12} \text{ days}$$

$$t_2 = \frac{T}{2} - t_1 = \frac{5T}{12} = 10T \text{ hours}$$

Then

$$x_{max} = \sqrt{\frac{4 \times 0.9}{3 \times 2880}(20 - 10)(10T - 2T)}$$

$$= \sqrt{.000417 \times 10 \times 8 \times 365} = \sqrt{12.15} = 3.49 \text{ ft.}$$

PROBLEM NO. 9

Given a homogeneous, isotropic soil mass of semi-infinite extent, the surface of which is exposed to a variable surface temperature which is a general function of time.

Find the depth of freezing "x", neglecting volumetric heat but considering latent heat of fusion "L".

The surface temperature can be expressed as

$$v_s = f(t) \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad [78]$$

Proceeding in the manner indicated by equations [59] to [62] inclusive, then

$$i = \frac{32 - f(t)}{x} \qquad [79]$$

$$dH = Ldx = 24\ kidt = 24k[\frac{32 - f(t)}{x}]dt \qquad [80]$$

$$\text{Then } xdx = \frac{24k}{L}[32 - f(t)]dt \qquad [81]$$

Integrating

$$\frac{x^2}{2} = \frac{24k}{L}\int_0^t [32-f(t)]dt \qquad [82]$$

Now $\int_0^t 32 - f(t)dt = F$ = freezing index in degree days

$$\therefore x_{max} = \sqrt{\frac{48kF}{L}} \qquad [83]$$

Example

Using data from examples for Problems No. 6 and No. 8 $v_o = 42^o$; $B = 20^o$; $a = 0.03\ ft^2/hr$; $C = 30$ and $L = 2880$.

$F = (32-v_s)\ t \qquad v_s = v_o - B = 42 - 20 = 22^oF.$

$t = t_2 - t_1 = \frac{T}{3} = 121.7$ days

$$x = \sqrt{\frac{48 \times 0.9 \times 1217}{2880}} = 4.26\ ft.$$

PROBLEM NO. 10

Given a homogeneous, isotropic soil mass of semi-infinite extent, the surface of which is exposed to a uniform temperature above freezing "v_o" which is suddenly reduced to below freezing "v_f".

Find the depth of freezing "x", assuming that the latent heat "L" is greatly in excess of the volumetric heat "C".

The heat liberated in freezing a small depth "dx" is "L dx", which must be conducted upwards through a distance "x".

The thermal gradient is therefore,

$$i = \frac{32 - v_f}{x} \qquad [84]$$

Hence the rate of upward flow

$$= \frac{24k}{x}(32 - v_f)\,dt \quad \ldots\ldots\ldots\ldots\ldots \quad [85]$$

Now, if the unfrozen soil has a heat capacity of "C_u" per unit volume and is originally at temperature "v_o", then the heat liberated in lowering the temperature of the layer of thickness "dx" from "v_o" to the freezing point (32°F), is

$$dH = C_u(v_o - 32)dx \quad \ldots\ldots\ldots\ldots\ldots \quad [86]$$

Then, $Ldx + C_u(v_o - 32)dx = \frac{24k}{x}(32 - v_f)dt$. . . . . [87]

$$\text{or } x\,dx = \frac{24k(32 - v_f)}{L + C_u(v_o - 32)}\,dt \quad \ldots\ldots\ldots\ldots\ldots \quad [88]$$

Integrating,

$$\frac{x^2}{2} = \frac{24k(32 - v_f)\,t}{L + C_u(v_o - 32)} + \bar{K}$$

When $t = 0$, $x = 0$, therefore $\bar{K} = 0$, and

$$x = \sqrt{\frac{48k\,(32 - v_f)t}{L + C_u(v_o - 32)}} \quad \ldots\ldots\ldots\ldots\ldots \quad [89]$$

If the volumetric heat of frozen soil, "C_f", is considered, then equation [87] becomes

$$Ldx + C_u(v_o - 32)dx + \frac{1}{2}C_f(32 - v_f)dx = \frac{24k}{x}(32 - v_f)\,dt. \; . \; . \quad [90]$$

and equation [89] therefore becomes

$$x_{max} = \sqrt{\frac{48k\,(32 - v_f)\,t}{L + C_u(v_o - 32) + \frac{C_f}{2}(32 - v_f)}} \quad \ldots\ldots\ldots \quad [91]$$

But by definition $(32 - v_f)t = F$ (in degree days)

Therefore equation [90] becomes

$$x_{max} = \sqrt{\frac{48\,k\,F}{L + C_u(v_o - 32) + \frac{C_f\,F}{2t}}} \quad \ldots\ldots\ldots\ldots\ldots \quad [92]$$

Substituting a weighted average value "C" for "C_u" and "C_f", equation [92] becomes

$$x_{max} = \sqrt{\frac{48\ k\ F}{L + C(v_o - 32 + \frac{F}{2t})}} \qquad [93]$$

Example

Using same data as for Example for Problem No. 9, v_o=42°; B = 20°; a = 0.03 ft²/hr; C = 30; and L = 2880 and further C_u = 32 and C_f = 28.

Using equation [92]

$$x = \sqrt{\frac{48 \times 0.03 \times 30 \times 1217}{2880 + 32[(10) + \frac{28 \times 1217}{2 \times 121.7}]}} = \sqrt{\frac{52,600}{2880 + 320 + 140}}$$

$$= \sqrt{15.75} = 3.97 \text{ ft.}$$

Using equation [93]

$$x = \sqrt{\frac{48 \times 0.03 \times 30 \times 1217}{2880 + 30(10 + \frac{1217}{243.4})}} = \sqrt{\frac{52,600}{2880 + (30 \times 15)}}$$

$$= \sqrt{15.80} = 3.98 \text{ ft.}$$

PROBLEM NO. 11

Given a homogeneous, isotropic soil mass of semi-infinite extent, the surface of which is exposed to periodic temperature changes over a sufficiently long period so that the interior temperatures are also periodic.

Find the depth of freezing "x", assuming that the latent heat "L" is greatly in excess of the volumetric heat "C".

The surface temperature is assumed to follow the form expressed by equation [48]

$$v_s = 32 + A - B \sin\omega t, \text{ in which } A = 0$$

$$\therefore v_s = 32 - B \sin\omega t \qquad [94]$$

The thermal gradient "i" through a frozen layer of thickness "x", is

$$i = \frac{32 - v_s}{x} = \frac{B \sin \omega t}{x} \qquad [95]$$

Proceeding in the same manner as in Problem #10, equations [85] to [87] inclusive,

$$Ldx + C_u(v_o - 32)\,dx = \frac{24k}{x}(B \sin \omega t)dt \quad . \; . \; . \; . \; . \; . \; . \; . \; . \qquad [96]$$

Transposing and integrating

$$\frac{x^2}{2} = \frac{24kB}{L + C_u(v_o - 32)}\left(-\frac{1}{\omega}\cos\omega t\right) + \bar{K}$$

Now when $t = 0$, $x = 0$

$$\bar{K} = \frac{24\ k\ B}{L + C_u(v_o - 32)} \cdot \frac{1}{\omega}$$

$$\therefore\ x^2 = \frac{48\ k\ B}{\omega[L + C_u(v_o - 32)]}(1 - \cos\omega t) \quad . \; . \; . \; . \; . \; . \; . \qquad [97]$$

But $1 - \cos\omega t = 2 \sin^2 \frac{\omega t}{2}$

$$\therefore\ x^2 = \frac{96kB \sin^2 \frac{\omega t}{2}}{\omega[L + C_u(v_o - 32)]}$$

$$\text{or } x = 2 \sin\frac{\omega t}{2} \sqrt{\frac{24kB}{\omega[L + C_u(v_o - 32)]}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \qquad [98]$$

When $\omega t = \pi$, $\sin\frac{\omega t}{2} = 1$, "x" is max. and $t = \frac{T}{2}$

$$\therefore\ x_{max} = 2\sqrt{\frac{24\ kBT}{2\pi[L + C_u(v_o - 32)]}} = \sqrt{\frac{48\ kBT}{\pi[L + C_u(v_o - 32)]}} \quad . \; . \; . \qquad [99]$$

Example

Using values from examples for preceding Problems
$v_o = 42^\circ$; $B = 20^\circ$; $a = 0.03\ ft^2/hr$; $C = 30$; $C_u = 32$; $C_f = 28$;
and $L = 2880$

$$x = \sqrt{\frac{48 \times 0.03 \times 30 \times 20 \times 365}{3.1416(2880 + 32 \times 10)}} = \sqrt{\frac{315{,}000}{3.1416 \times 3200}}$$

$$= \sqrt{31.35} = 5.60\ ft.$$

PROBLEM NO. 12

Given a homogeneous, isotropic soil mass at the freezing point, but with the soil moisture unfrozen. The surface temperature varies as a general function of time but always below freezing.

Find the depth of freezing "x".

The surface temperature "v_f" can be expressed by equation [78]

$$v_f = f(t)$$

Proceeding in the manner indicated by equations [79] and [80] in Problem #9, then

$$i = \frac{32 - f(t)}{x}$$

$$\text{and } dH = Ldx = 24\ kidt = 24k\,\frac{32 - f(t)}{x}\,dt \quad \ldots\ldots\ldots\ldots \quad [100]$$

$$\text{or } \frac{Lx}{24k}\,dx = [32 - f(t)]dt \quad \ldots\ldots\ldots\ldots \quad [101]$$

Integrating

$$\frac{x^2L}{48k} = \int_o^t [32 - f(t)]dt \quad \ldots\ldots\ldots\ldots \quad [102]$$

$$\text{or } x = \frac{48\ k}{L}\int_o^t [32 - f(t)]dt \quad \ldots\ldots\ldots \quad [103]$$

Now considering the volumetric heats "C_u" and "C_f" and proceeding in the manner indicated in Problem #10, equations [87] to [90] inclusive, equation [100] becomes

$$Ldx + C_u[32 - f(t)]dx + \frac{C_f}{2}[32 - f(t)]dx = \frac{24k}{x}[32 - f(t)]dt \ . \quad [104]$$

and equation [103] becomes

$$x = \sqrt{\frac{48\ k\int_o^t [32 - f(t)]dt}{L + C_u[32 - f(t)] + \frac{C_f}{2}[32 - f(t)]}} \quad \ldots\ldots \quad [105]$$

Substituting the weighted average value "C" for "C_u" and "C_f" equation [105] becomes

$$x = \sqrt{\frac{48\,k \int_0^t [32 - f(t)]dt}{L + \frac{3C}{2}\,[32 - f(t)]}} \quad . . . . \quad [106]$$

Now since "v_f" is always below freezing,

$$\int_0^t [32 - f(t)]dt = F$$

Therefore equation [106] can be written

$$x = \sqrt{\frac{48\,k\,F}{L + \frac{3C}{2}\,(32 - v_f)}} \quad . . . . \quad [107]$$

Example

Using values from examples for previous Problems

$v_f = 22^o$; $a = 0.03$; $C = 30$; and $L = 2880$

$$x = \sqrt{\frac{48 \times 0.03 \times 30 \times 1217}{2880 + 45 \times 10}} = \sqrt{\frac{52,600}{3330}}$$

$$= \sqrt{15.80} = 3.98 \text{ ft.}$$

PROBLEM NO. 13

Given a homogeneous, isotropic, semi-infinite mass of frozen soil at freezing temperature, the surface of which is exposed to a constant temperature above freezing "v_p".

Find the depth of melting "x".

The temperature at any point "x" at any time "t" can be expressed by the equation

$$v_{(x,t)} = f(x,t) = 32 + A \int_{\frac{x}{2\sqrt{24at}}}^{\beta} e^{-u^2}\,du \quad . . . . \quad [108]$$

From equation [62]

$$-L\frac{dh}{dt} = 24\ k\frac{dv}{dx} \text{....(minus sign denotes melting)} \quad ... \quad [109]$$

Now, differentiating equation [108]

$$v = f(x,t)$$

$$dv = \frac{dv}{dx}dx + \frac{dv}{dt}dt \quad .... \quad [110]$$

When $x = h$, $dv = 0$

$$\therefore 0 = \left(\frac{dv}{dx}\right)_{x=h} \cdot \left(\frac{dh}{dt}\right) + \left(\frac{dv}{dt}\right)_{x=h} \quad .... \quad [111]$$

Combining equations [109] and [111]

$$0 = \left(\frac{dv}{dx}\right)_{x=h} \cdot \frac{24k}{L}\left(\frac{dv}{dx}\right) + \left(\frac{dv}{dt}\right)_{x=h} \quad \text{or} \quad \frac{dv}{dt} = \frac{24k}{L}\left(\frac{dv}{dx}\right)^2_{x=h} \quad .. \quad [112]$$

From equation [108] by differentiation,

$$\frac{dv}{dt} = Ae^{\frac{-x^2}{96at}} \quad \frac{x}{4t\sqrt{24at}} \quad .... \quad [113]$$

and

$$\frac{dv}{dt} = Ae^{\frac{-x^2}{96at}} \quad \frac{1}{2\sqrt{24at}} \quad .... \quad [114]$$

Substituting "h" for "x" and substituting equations [113] and [114] in equation [112],

$$Ae^{-\frac{h^2}{96at}} \cdot \frac{h}{4t\sqrt{24\ at}} = \frac{24k\ A^2\ e^{-\frac{2h^2}{96at}}}{96\ L\ at} \quad ... \quad [115]$$

Now from equation [3]

$$\beta = \frac{h}{2\sqrt{24at}}$$

Equation [115] becomes

$$Ae^{-\beta^2} \cdot \frac{\beta}{2t} = \frac{k\,A^2\,e^{-2\beta^2}}{4\,at\,L} \qquad [116]$$

$$\text{or}\quad \beta = \frac{k\,Ae^{-\beta^2}}{2aL} \qquad [117]$$

$$\text{Hence}\quad \frac{\beta e^{\beta^2}}{A} = \frac{k}{2aL} \qquad [118]$$

Now from equation [108]

$$\frac{1}{A} = \frac{1}{v_p - 32} \cdot \int_0^{\beta} e^{-u^2}\,du \qquad [119]$$

Substituting equation [119] in equation [118]

$$\beta e^{\beta^2} \int_0^{\beta} e^{-u^2}\,du = \frac{k(v_p - 32)}{2aL} \qquad [120]$$

Now from equation [2] $\int_0^{\beta} e^{-u^2}\,du = \frac{\operatorname{erf}(\beta)\sqrt{\pi}}{2}$

$$\therefore\ \beta e^{\beta^2} \operatorname{erf}(\beta) = \frac{k(v_p - 32)}{\sqrt{\pi}\,aL} = \frac{C(v_p - 32)}{L\sqrt{\pi}} \qquad [121]$$

If β is small, then

$$\beta e^{\beta^2} \int_0^{\beta} e^{-u^2}\,du \approx \beta^2 \qquad [122]$$

Substituting in equation [120]

$$\beta^2 \approx \frac{C(v_p - 32)}{2L} \qquad [123]$$

Since from equation [3] $\beta = \frac{h}{2\sqrt{24at}}$

$$\beta^2 = \frac{h^2}{96at} = \frac{x^2}{96at} \qquad [124]$$

$$\text{Then}\quad x \approx \frac{48\,kt\,(v_p - 32)}{L} \qquad [125]$$

Now, consider the series expansion

$$e^{\beta^2} = 1 + \beta^2 + \frac{\beta^4}{2!} + \frac{\beta^6}{3!} \ldots\ldots\ldots$$

Then

$$\beta\, e^{\beta^2} = \beta + \beta^3 + \frac{\beta^5}{2!} + \frac{\beta^7}{3!} \ldots\ldots$$

and $\int_0^{\beta} e^{-u^2} du = \beta - \frac{\beta^3}{3 \cdot 1!} + \frac{\beta^5}{5 \cdot 2!} - \frac{\beta^7}{7 \cdot 3!} + \ldots\ldots\ldots$

Hence

$$\beta e^{\beta^2} \int_0^{\beta} e^{-u^2} du = (\beta + \beta^3 + \frac{\beta^5}{2} + \frac{\beta^7}{6})(\beta - \frac{\beta^3}{2} + \frac{\beta^5}{10} - \frac{\beta^7}{42} \ldots)$$

$$= (\beta^2 + \frac{2\beta^4}{3} + \ldots\ldots) \quad \ldots\ldots\ldots\ldots \quad [126]$$

Then equation [120] becomes

$$\beta^2 + \frac{2\beta^4}{3} = \frac{C(v_p - 32)}{2L} \quad \ldots\ldots\ldots\ldots\ldots \quad [127]$$

and

$$x = \sqrt{72at\left(\sqrt{1 + \frac{4(v_p - 32)C}{3L}} - 1\right)} \quad \ldots\ldots\ldots \quad [128]$$

__Example__

Using data from examples for previous Problems.

$a = 0.03$; $C = 30$; and $L = 2880$. Also assuming $v_p = 42^{\circ}$

Using equation [125]

$$x = \sqrt{\frac{48 \times 0.03 \times 30 \times 121.7 \times 10}{2880}} = \sqrt{\frac{52,600}{2880}}$$

$$= \sqrt{18.25} = 4.27 \text{ ft.}$$

Using equation [128]

$$x = \sqrt{72 \times 0.03 \times 121.7 \left[\sqrt{1 + \frac{4 \times 10 \times 30}{3 \times 2880}} - 1\right]}$$

$$= \sqrt{263(\sqrt{1.139} - 1)}$$

$$= \sqrt{263 \times .065} \qquad = \sqrt{17.09} = 4.14 \text{ ft}$$

Using equation [120] and Figure 6, Plate A-2

$$\frac{C(v_p - 32)}{L \times 2} = \frac{30 \times 10}{2880 \times 2} = 0.0529 = \lambda\beta$$

From Figure 6, Plate A-2, $\beta = 0.225$

$$\text{Since } x = 2\beta\sqrt{24\ at} = 2 \times 0.225\sqrt{24 \times 0.03 \times 121.7}$$

$$= 0.45\sqrt{87.62} = 0.45 \times 9.36$$

$$= 4.22 \text{ ft.}$$

The solutions by these three methods are in very close agreement, but the method using equation [120] and Figure 6, Plate A-2, gives the exact answer and is the easiest to use.

PROBLEM NO. 14

Given a homogeneous, isotropic, semi-infinite soil mass just above freezing temperature which is exposed to a constant temperature below freezing "v_p".

Find the depth of freezing "x", assuming that the thermal gradient varies uniformly from the surface to the depth of freezing.

The surface temperature can be expressed by equation [78]

$$v_p = f(t)$$

Then, as indicated in equation [100]

$$L dx = 24k \frac{[32 - f(t)]}{x} dt$$

The volumetric heat "C_f" liberated in the frozen zone of thickness "dx" in time "t", is

$$dH = \frac{C_f[32 - f(t)]}{2} dx \qquad \ldots\ldots\ldots\ldots\ldots \quad [129]$$

$$\therefore \frac{24k}{x}[32-f(t)]dt = Ldx + \frac{C_f[32 - f(t)]}{2}dx$$

$$= L + \frac{C_f}{2}[32 - f(t)]\, dx \quad \ldots\ldots \quad [130]$$

or

$$xdx = \frac{24k[32 - f(t)]\, dt}{L + \frac{C_f}{2}[32 - f(t)]} \quad \ldots\ldots\ldots\ldots \quad [131]$$

Integrating

$$x^2 = 48k \int_{t_1}^{t_2} \frac{[32 - f(t)]dt}{L + \frac{C_f}{2}[32 - f(t)]} \quad \ldots\ldots\ldots\ldots \quad [132]$$

Now since "v_p" is always below freezing

$\int_{t_1}^{t_2} [32 - f(t)]\, dt = F$ and equation [132] becomes

$$x^2 = \frac{48kF}{L + \frac{C_f}{2}[32 - f(t)]} \quad \ldots\ldots\ldots\ldots \quad [133]$$

and

$$x = \sqrt{\frac{48k\, F}{L + \frac{C_f}{2}(32 - v_p)}} \quad \ldots\ldots\ldots\ldots\ldots \quad [134]$$

If the surface temperature is expressed by the form

$$v_s = 32 + B \sin \omega t \quad \ldots\ldots\ldots\ldots \quad [135]$$

Then

$$x^2 = \frac{48k}{\omega}\{(A - \frac{DB}{G})(\frac{2}{\sqrt{D^2 - G^2}})[\text{arc tan}(\frac{G + D\tan\frac{\omega t_2}{2}}{\sqrt{D^2 - G^2}}) -$$

$$\text{arc tan}(\frac{G + D\tan\frac{\omega t_1}{2}}{\sqrt{D^2 - G^2}})] + \frac{B}{G}\omega(t_2 - t_1)\}. \quad [136]$$

where $D = L + \frac{C_f A}{2}$ and $G = \frac{C_f B}{2}$

Examples

Using data from examples for preceding Problems

$v_o = 42^o$; $B = 20^o$; $a = 0.03\ ft^2/hr$; $C = 30$; $C_f = 28$;

$C_u = 32$; $L = 2880$; and $v_p = 22^o$

Using equation [134]

$$x = \sqrt{\frac{48 \times 0.03 \times 30 \times 1217}{2880 \times \frac{28}{2}(32 - 22)}} = \sqrt{\frac{52,600}{3020}}$$

$$= \sqrt{17.40} = 4.17\ ft.$$

Using equation [136]

$$D = 2880 + \frac{28 \times 10}{2} = 3020$$

$$G = \frac{28 \times 20}{2} = 280$$

$$\omega = \frac{2\pi}{T} = \frac{2 \times 3.1416}{365} = 0.01724$$

$$t_1 = \frac{T}{12} \text{ and } t_2 = \frac{5T}{12} \text{ (from example Problem \#8)}$$

Now $\frac{\omega t_1}{2} = \frac{2\pi}{T} \times \frac{T}{24} = \frac{\pi}{12}$

$$\frac{\omega t_2}{2} = \frac{2\pi}{T} \times \frac{5T}{24} = \frac{5\pi}{12}$$

$$(A - \frac{DB}{G}) = 10 - \frac{3020 \times 20}{280} = 10 - 215.7 = -205.7$$

$$\sqrt{D^2 - G^2} = \sqrt{3020^2 - 280^2} = \sqrt{9,042,000} = 3007$$

$$G + D \tan\frac{\omega t_1}{2} = 280 + 3020 + \tan\frac{\pi}{12} = 280 + 3020 \tan 15^{\circ}$$

$$= 280 + 3020 \times 0.26795$$

$$= 1089$$

$$G + D \tan\frac{\omega t_2}{2} = 280 + 3020 \quad \tan\frac{5\pi}{12} = 280 + 3020 \tan 75^{\circ}$$

$$= 280 + 3020 \times 3.84103$$

$$= 11,550$$

$$\text{arc tan } \left(\frac{G + D \tan\frac{\omega t_1}{2}}{\sqrt{D^2 - G^2}}\right) = \text{arc tan } \frac{1089}{3007} = \text{arc tan } 0.36215$$

$$= 19.91^{\circ}$$

$$\text{arc tan } \left(\frac{G + D \tan\frac{\omega t_2}{2}}{\sqrt{D^2 - G^2}}\right) = \text{arc tan } \frac{11550}{3007} = \text{arc tan } 3.84105$$

$$= 75.41^{\circ}$$

$$\frac{B}{G}\omega(t_2 - t_1) = \frac{20 \times 2\pi}{280 \times T} \cdot \frac{T}{3} = \frac{40\pi}{840} = 0.14960$$

Therefore

$$x^2 = \frac{48 \times 0.03 \times 30}{0.01724}[(-205.7)(\frac{2}{3007})(75.41^{\circ}-19.91^{\circ})+0.14960]$$

$$= 2505.8 \ [(-0.13681)(55.50^{\circ}) + 0.14960]$$

$$= 2505.8 \ [(-0.13681)(0.96866 \text{ radians}) + 0.14960]$$

$$= 2505.8 \ (-0.1325 + 0.14960)$$

$$= 2505.8 \times 0.0171 = 42.85$$

$$x = \sqrt{42.85} = 6.55 \text{ ft.}$$

PROBLEM NO. 15

Given a homogeneous, isotropic mass of frozen soil of semi-infinite extent, exposed to a surface temperature "v_s" which is below freezing.

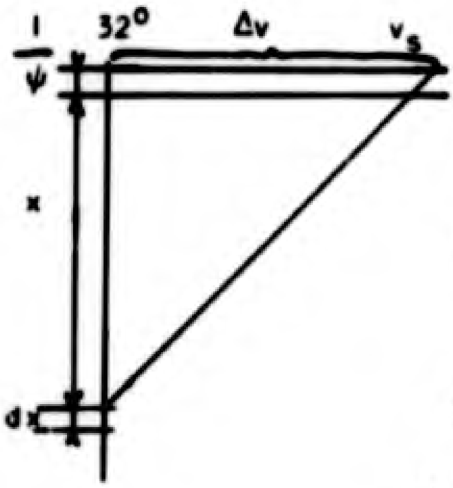
Find the effect of radiation and ground film.

In accordance with Newton's Law of cooling

$$i_{x=0} = \psi (v_{x=0} - v_s) = \psi\Delta v \quad \ldots\ldots\ldots\ldots\ldots [137]$$

The rate at which heat passes out through a unit area of surface is

$$\frac{dQ}{dt} = 24k\,i_{x=0} = 24k\psi(v_{x=0} - v_s) = \frac{24k}{\frac{1}{\psi}}(v_{x=0} - v_s) = 24E(v_{x=0}-v_s) \quad [138]$$



$$\frac{dQ}{dt} = L dx + \frac{C_f\,\Delta v}{2}dx = \frac{24k\Delta v}{x + \frac{1}{\psi}} \quad \ldots \quad [139]$$

$$\text{or } (x + \frac{1}{\psi})dx = \frac{24k\Delta v}{L + \frac{C_f}{2}\Delta v}(dt) \quad \ldots \quad [140]$$

Now let $y = x + \frac{1}{\psi}$

$\therefore dy = dx$

$$\text{Then } ydy = \frac{24k\Delta v}{L + \frac{C_f}{2}\Delta v}dt \quad \ldots\ldots\ldots\ldots \quad [141]$$

$$\text{or } y^2 = \frac{48k\Delta vt}{L + \frac{C_f}{2}\Delta v} + \bar{K} = (x + \frac{1}{\psi})^2 \quad \ldots\ldots \quad [142]$$

When $t = 0$, $x = 0$. $\therefore \bar{K} = (\frac{1}{\psi})^2$

$$\therefore (x + \frac{1}{\psi})^2 = \frac{48k\Delta vt}{L + \frac{C_f}{2}\Delta v} + (\frac{1}{\psi})^2 \quad \ldots\ldots\ldots \quad [143]$$

$$x = -\frac{1}{\psi} + \sqrt{\frac{48k\Delta vt}{L + \frac{C_f}{2}\Delta v} + \left(\frac{1}{\psi}\right)^2} \quad \ldots\ldots\ldots \quad [144]$$

From figure above $\Delta v = 32 - v_s$

$$\therefore \; x = -\frac{1}{\psi} + \sqrt{\frac{48kt(32 - v_s)}{L + \frac{C_f}{2}(32 - v_s)} + \left(\frac{1}{\psi}\right)^2} \quad \ldots\ldots\ldots \quad [145]$$

The value $\frac{"1"}{\psi}$ may be regarded as an extra layer of soil having the same thermal conductivity "k" as the base soil, but having no volumetric heat capacity. The value $\frac{"1"}{\psi}$ is also a function of the velocity of air over the surface. For large values of "E" (5 or 6), the value of $\frac{"1"}{\psi}$ is small, but for small values of "E" (1 or 2), the value of $\frac{"1"}{\psi}$ becomes appreciable. The following table indicates the effect of neglecting the value $\frac{"1"}{\psi}$ in equation [145] using the following values:

$L = 800$; $t = 180$; and $C_f = 30$.

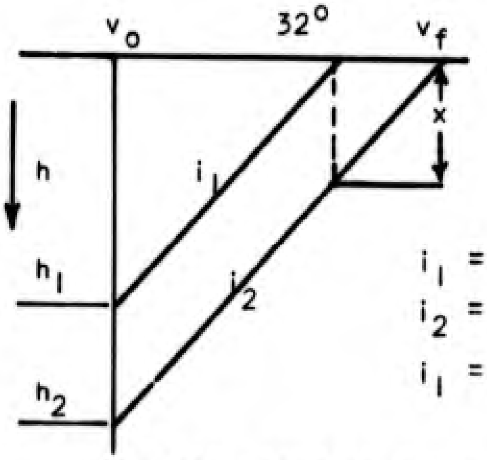
v_s (°F)	Per Cent Error in Omitting $1/\psi$ from Equation [145]											
	E = 6			E = 5			E = 2			E = 1		
	k=0.5	k=1.0	k=1.5	k=0.5	k=1.0	k=1.5	k=0.5	k=1.0	k=1.5	k=0.5	k=1.0	k=1.5
31	3.6	5.1	6.2	4.4	6.1	7.5	10.8	15.2	18.5	21.5	29.4	36.2
27	1.7	2.4	2.8	2.0	2.9	3.4	5.0	7.1	8.5	10.0	14.1	16.7
22	1.2	1.8	2.1	1.5	2.1	2.6	3.7	5.2	6.4	7.4	10.4	12.8
17	1.0	1.5	1.8	1.3	1.8	2.2	3.1	4.4	5.4	6.3	8.9	10.8
12	.9	1.3	1.6	1.1	1.6	2.0	2.8	4.0	4.9	5.7	7.8	9.7
7	.9	1.2	1.5	1.0	1.5	1.8	2.6	3.7	4.5	5.2	7.4	9.0
2	.8	1.2	1.4	1.0	1.4	1.7	2.5	3.5	4.3	4.9	6.9	8.5

The per cent error in omitting the value $\frac{"1"}{\psi}$ from equation [145] for airport runways and highways where the snow is plowed off and the surface exposed to the wind, will be small, since the value of "E" will be about 5 or 6 and the temperatures involved will be the temperatures indicated in the middle and lower portions of the above table.

PROBLEM NO. 16

Given a homogeneous, isotropic soil mass at a temperature "v_o" suddenly exposed to a surface temperature below freezing "v_f".

Find the depth of freezing "x", assuming that the temperature varies uniformly with the depth.



i_1 = thermal gradient at start of freezing

i_2 = thermal gradient at end of freezing

$i_1 = i_2$

The heat conducted out of the soil is given by equation [61]

$$dH = 24k\ i\ dt$$

and $H = \int_0^t 24ki\ dt + \bar{K}$ . . . . [146]

when $t = 0 \quad H = 0 \quad \therefore \bar{K} = 0$ and $H = 24kit$ . . . . [147]

The total heat given up the soil as indicated in sketch is

$$H = \frac{h_2 - h_1}{2} (v_o - 32 + v_o - v_f)\ C + Lx$$

But $h_2 - h_1 = x$

$\therefore H = x\ [\frac{C}{2} (2v_o - 32 - v_f) + L] = 24kit$ . . . . [148]

Now

$i = \dfrac{32 - v_f}{x}$ and $32 - v_f = \dfrac{F}{t}$ . . . . [149]

$\therefore i = \dfrac{F}{xt}$ . . . . [150]

Substituting equation [150] in equation [148]

$$x\left[\frac{C}{2}(2v_o - 32 - v_f) + L\right] = \frac{24kF}{x} \qquad [151]$$

$$\text{and } x = \sqrt{\frac{24\ k\ F}{\frac{C}{2}(2v_o - 32 - v_f)+L}} \qquad [152]$$

From equation [149]

$$- v_f = \frac{F}{t} - 32$$

Hence equation [152] becomes

$$x = \sqrt{\frac{24\ k\ F}{L + \frac{C}{2}(2v_o - 64 + \frac{F}{t})}} \qquad [153]$$

$$\text{or } x = \sqrt{\frac{24\ k\ F}{L + C(v_o - 32 + \frac{F}{2t})}} \qquad [154]$$

Example

Using data from examples for previous Problems

$v_o = 42^o$; $C = 30$; $a = 0.03$; and $L = 2880$

Then

$$x = \sqrt{\frac{24 \times 0.03 \times 30 \times 1217}{2880 + 30(42 - 32 + \frac{1217}{2 \times 121.7})}} = \sqrt{\frac{26,300}{3330}}$$

$$= \sqrt{7.88} = 2.81 \text{ ft.}$$

PROBLEM NO. 17

Given a homogeneous, isotropic soil mass of semi-infinite extent, overlain by an insulation layer of thickness "d", all at temperature "v_o" and suddenly exposed to a surface temperature below freezing "v_f".

Find the depth of freezing "x_R", assuming that the temperature varies uniformly with the depth, that there is no significant change in temperature gradients due to the insulation layer, and neglecting latent heat "L_R" and volumetric heat "C_R" of the insulation layer.

Now equation [151] can be written as

$$x_R[\frac{C}{2}(2v_o - 32 - v_f) + L] = \frac{24\ kF}{d + x_R} \quad \ldots\ldots\ldots\ldots \quad [155]$$

$$\text{or } x_R(d + x_R) = \frac{24\ k\ F}{L + \frac{C}{2}(2v_o - 32 - v_f)} \quad \ldots\ldots\ldots\ldots \quad [156]$$

Solving for x_R

$$x_R = -\frac{d}{2} + \sqrt{(\frac{d}{2})^2 + \frac{24\ k\ F}{\frac{C}{2}(2v_o - 32 - v_f) + L}} \quad \ldots\ldots \quad [157]$$

Substituting equation [149] for v_f

$$x_R = -\frac{d}{2} + \sqrt{(\frac{d}{2})^2 + \frac{24\ k\ F}{L + C(v_o - 32 + \frac{F}{2t})}} \quad \ldots\ldots \quad [158]$$

<u>Example</u>

Using same data as for examples for previous Problems

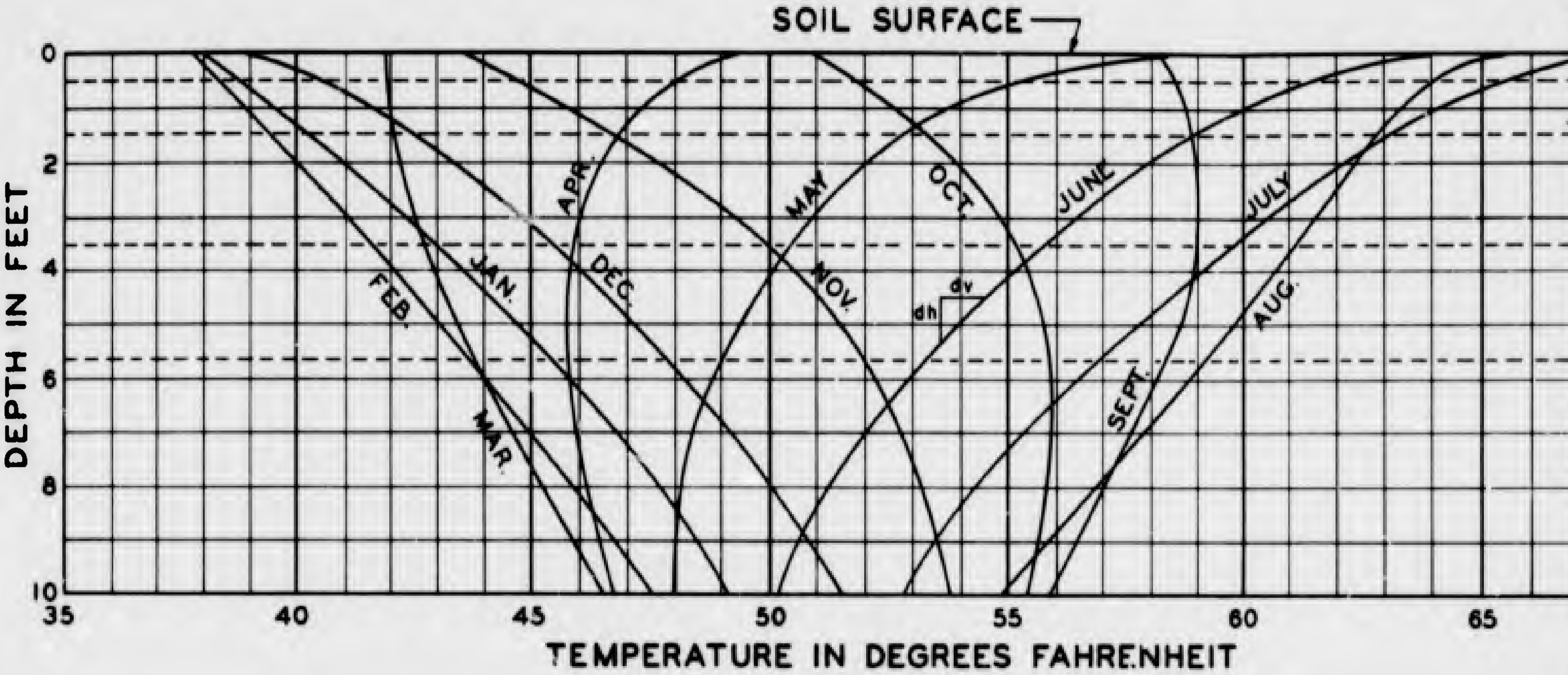
$v_o = 42^o$; $C = 30$; $a = 0.03$ and $L = 2880$; also $d = 1.0$ ft.

$$x_R = -0.5 + \sqrt{(0.5)^2 + \frac{24 \times 0.03 \times 30 \times 1217}{2880 + 30(42 - 32 + \frac{1217}{2 \times 121.7})}}$$

$$x_R = -0.50 + \sqrt{0.25 + \frac{26300}{3330}} = -0.50 + \sqrt{8.13}$$

$$= -0.50 + 2.85$$

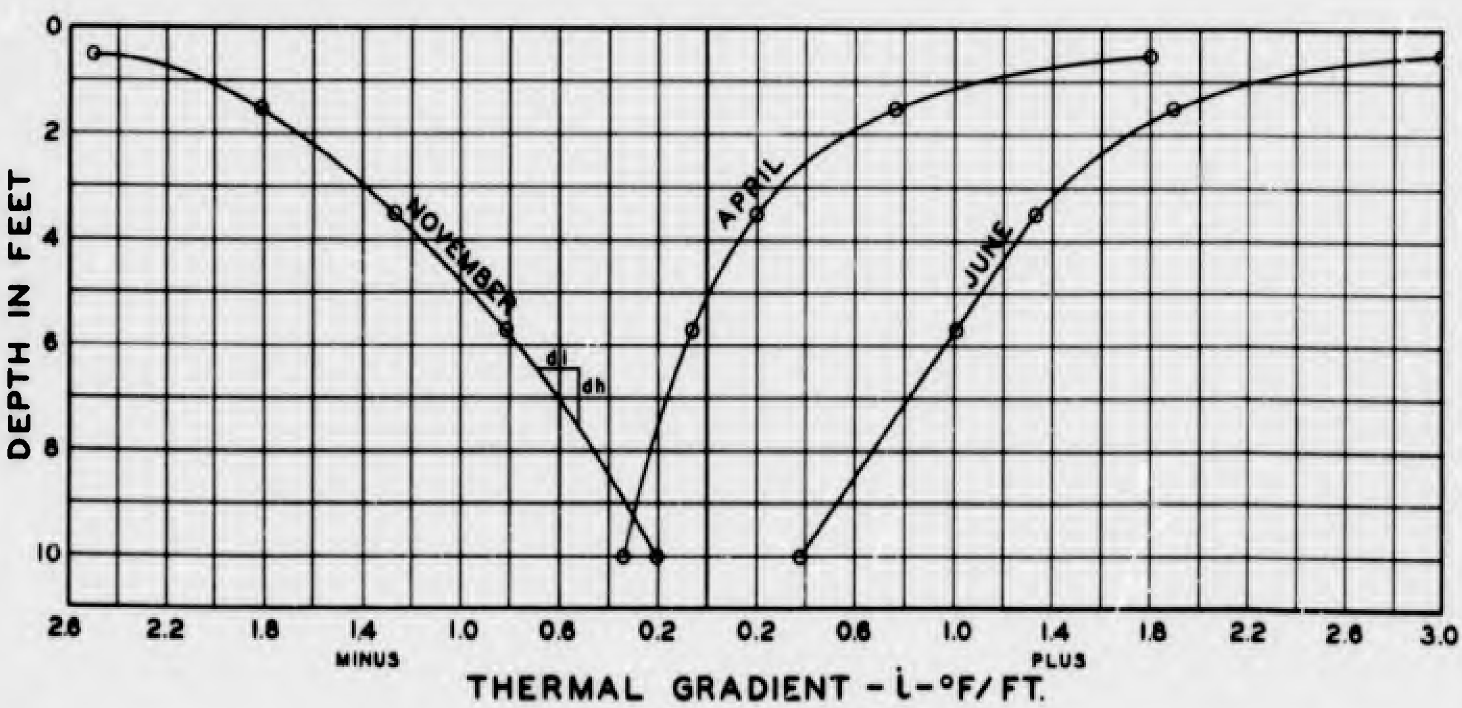
$$= 2.35 \text{ ft.}$$



MONTHLY TEMPERATURE PROFILES FOR A TURFED SOIL

(ADAPTED FROM "RADCLIFFE OBSERVATIONS, RADCLIFFE OBSERVATORY, ENGLAND, 1915

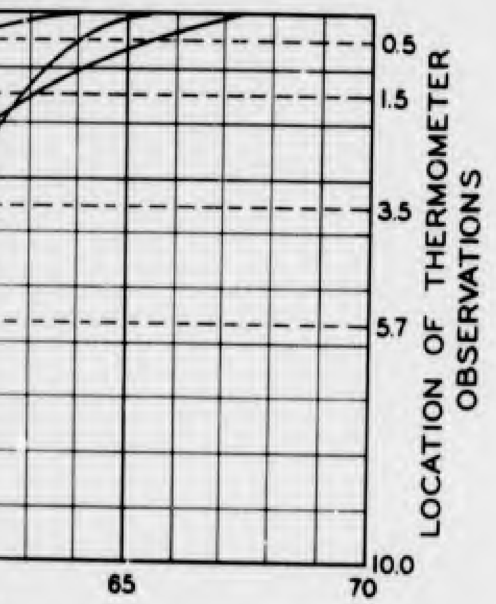
FIG. 1



THERMAL GRADIENTS FOR MONTHS OF APRIL, JUNE AND NOVEMBER

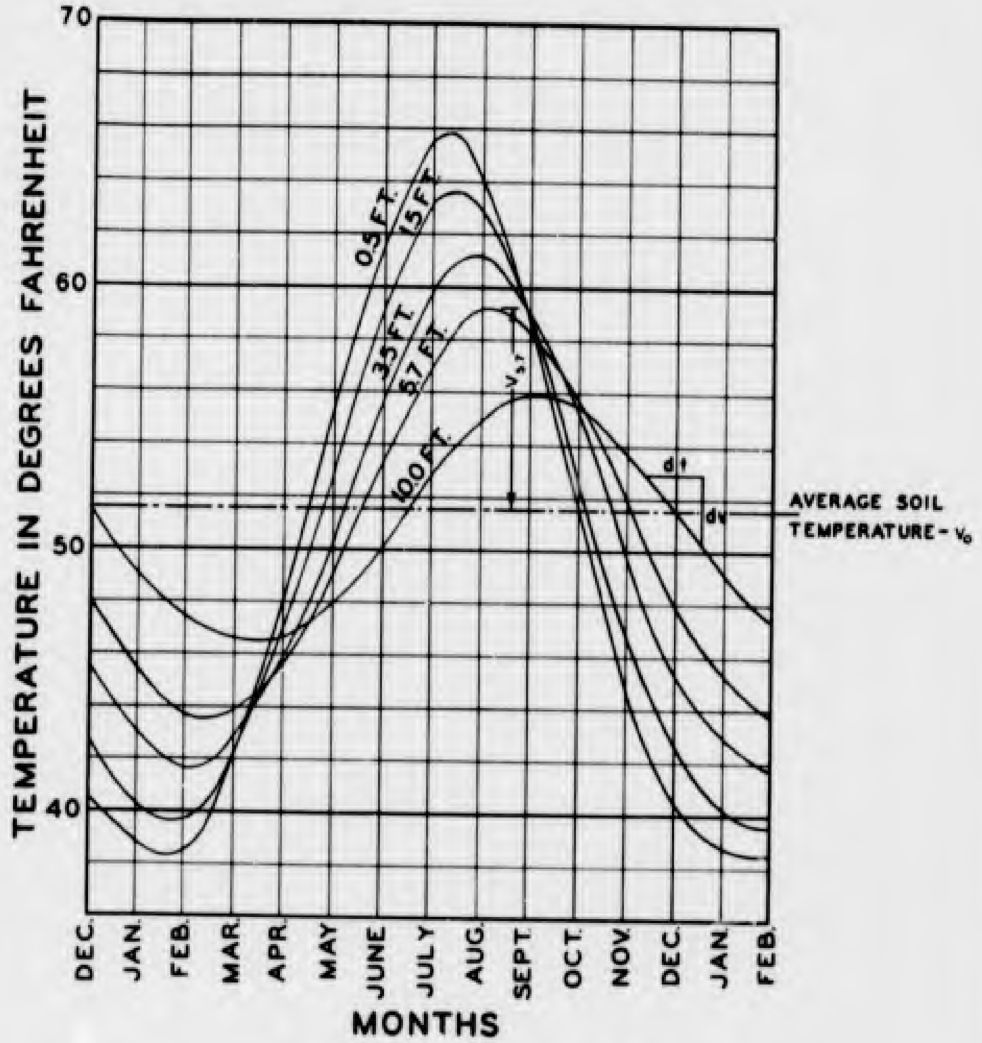
FIG. 3

MONTHS

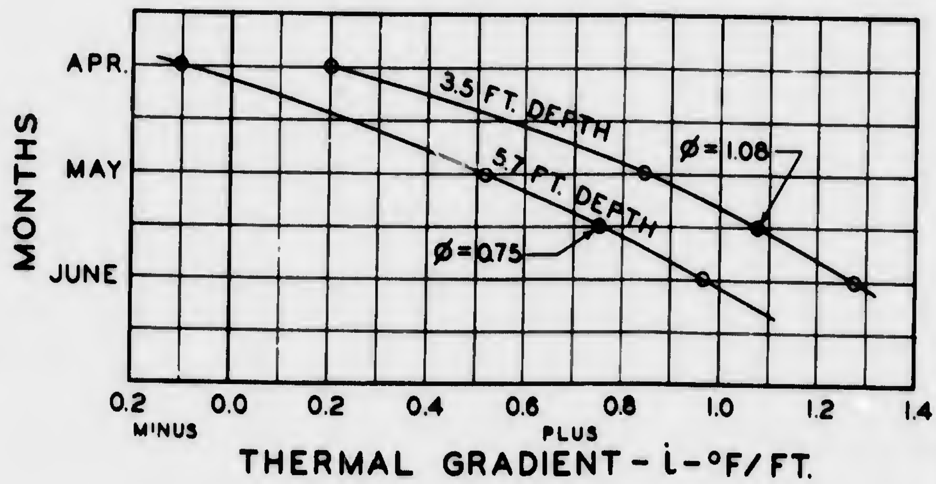


SOIL

NGLAND, 1915")



ANNUAL SOIL TEMPERATURE CURVES
AT DEPTHS OF OBSERVATION
FIG. 2



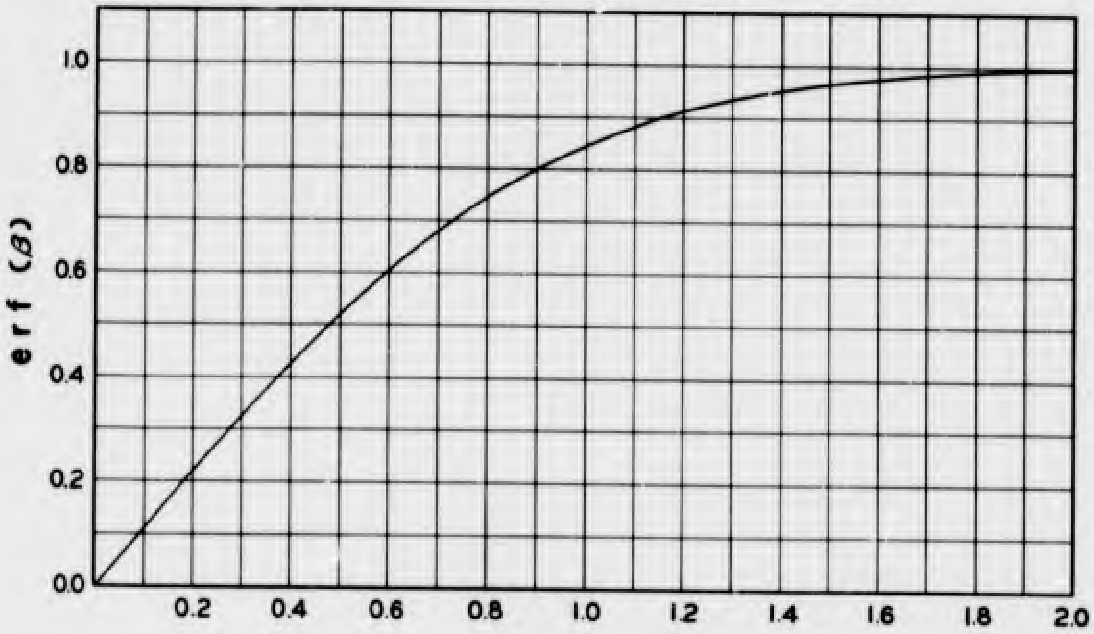
THERMAL GRADIENTS AT 3.5 AND 5.7 FOOT
DEPTHS OF OBSERVATION
FIG. 4

FROST INVESTIGATION
1945 - 1946

THERMAL CURVES FOR A TURFED SOIL

FROST EFFECTS LAB., BOSTON, MASS JUNE 1946

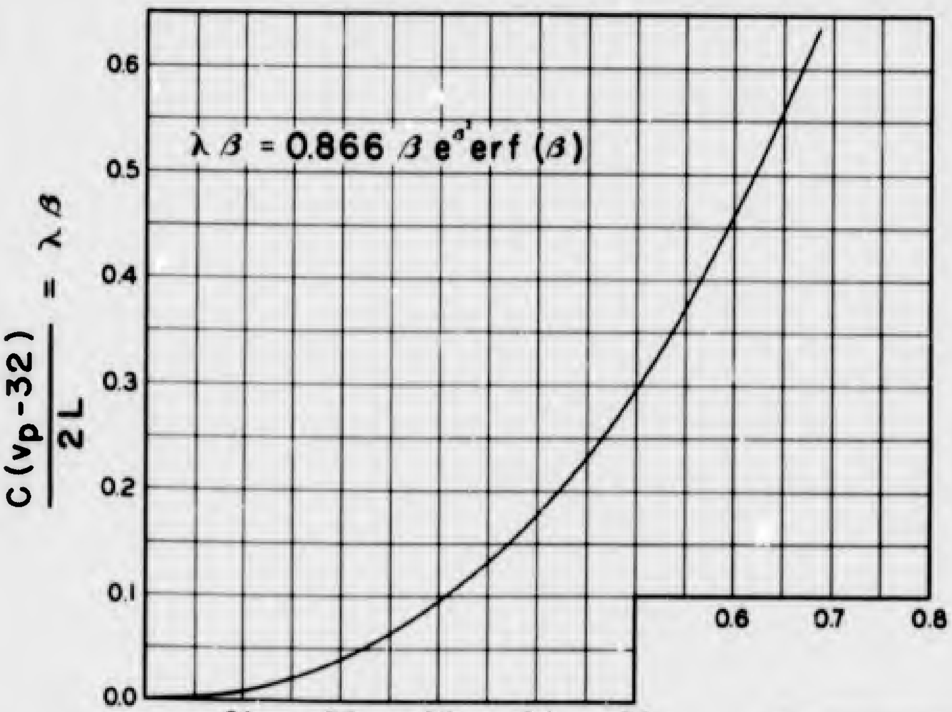
SUPPLEMENT A PLATE A-1



$$\beta = \frac{h}{2\sqrt{24at}}$$

THE PROBABILITY INTEGRAL (GAUSS "ERROR FUNCTION")

FIG. 5



DETERMINATION OF β FROM SOIL AND TEMPERATURE DATA

FIG. 6

FROST INVESTIGATION
1945 - 1946

CURVES FOR DETERMINATION OF erf (β) AND β

FROST EFFECTS LAB, BOSTON, MASS. JUNE 1946

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U. S. ARMY
BOSTON, MASSACHUSETTS

DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

APPENDIX D

REPORT ON SPECIAL TEST SECTION AT DOW FIELD
1946 - 1947

FROST EFFECTS LABORATORY

June 1949

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FOREWORD

The special test section at Dow Field, Bangor, Maine, was constructed for correlation with controlled laboratory tests and to determine the rate of frost penetration in non-frost susceptible base materials covered with rigid and flexible pavements, and to study the effect of density, degree of saturation and water supply on frost action in frost susceptible soils for a period of several years while exposed to natural weather conditions. The test section was made up of 14 portland cement concrete cylinders, eight feet high and five feet inside diameter containing either cinders, sand and gravel, crushed rock, or silty clay.

This report presents the construction details and results of observations. The data presented contain complete records showing changes in soil temperature with variations of air temperature pavement heave and settlement. Unexpected difficulty was experienced during the first season of observations due to the generation of heat in the fresh, moist sawdust used for insulation between the cylinders (elements). Corrective measures were applied with some success.

The test section was abandoned after the first season and later dismantled due to curtailment of investigational program and lack of funds.

REPORT ON TEST SECTION
DOW FIELD, BANGOR, MAINE

I. INTRODUCTION

1-01. Authorization. The frost investigation program was continued by authorization contained in two letters from the Chief of Engineers to the Division Engineer, New England Division, dated 25 July 1946 and 12 August 1946, Subject: "Funds for Investigational Program for Fiscal Year 1947". The Frost Effects Laboratory, established at the New England Division by direction of the Chief of Engineers, as stated in Circular Letter No. 3221, dated 11 August 1944, was continued in its function. Addendum No. 1 to the original instructions and outline dated August 1946 from the Chief of Engineers, covers the details of the Test Section constructed at Dow Field, Bangor, Maine.

1-02. Purpose. A test section was constructed and observed (a) to determine the rate of frost penetration into non-frost susceptible base materials with rigid and flexible pavements and (b) to study the effect of density, degree of saturation and water supply on frost action in frost susceptible soils for a period of several years.

1-03. Scope. This report contains the construction details and results of observations made in a test section containing 14 combinations of pavement, base, and subgrade materials exposed to freezing temperature during the first year of observations. The test section includes 14 portland cement concrete cylinders each eight feet high and five feet inside diameter, referred to hereinafter as elements, containing specimen material of either cinders, sand and gravel, crushed rock or silty clay. The flexible type pavement was simulated by a four-inch cover of bituminous concrete placed over the specimen material, and the rigid pavement by a six-inch cover of portland cement concrete. The effect of shallow ground water was obtained in four of the elements by connections to a controlled water supply. The rate of frost penetration in each test element was determined by temperatures recorded by thermocouple installations. Observations were made of degree of saturation, water content, and density at time of placing, and pavement heave and subsidence during freezing and frost melting periods. Observations of the water content and density were made after the frost melting period in the four elements in which the subgrade was placed at a low density.

1-04. Definitions. The description of the tests and analysis of results involve a specialized use of certain terms and words. These words and terms are defined for use in paragraph 1- , main body of this report.

II. DESCRIPTION OF TEST SECTION

2-01. General. An area, "Reclamation Yard", located at the southerly end of Dow Field, was made available for the construction of a test section. The work was performed by hired labor during the period from August to October 1946. The test section consisted of 14 elements, A to H inclusive, J to N inclusive and P, five feet in diameter and eight feet in depth. Each element was enclosed in a reinforced cement concrete pipe of standard tongue and groove construction eight feet long and 5 feet 10 inches outside diameter set upright in a reinforced cement concrete base of 12-inch thickness placed one foot below the original ground surface. The elements were placed in two rows 7.75 feet from center to center. The embankment surrounding the elements was constructed of sand and gravel to a height approximately five feet below the top of the elements. Sawdust was placed on the gravel fill to six inches below the finished grade and a blanket of sand and gravel was placed to bring the embankment up to the top of the elements. Details of the test section are shown on Plates D-2 and D-2. Photographs taken during construction are shown on Plates D-16 and D-17. The sawdust was used for insulation to minimize heat transfer between elements and adjoining fill. Additional insulation was provided along the top of the pipe, as shown in Figure 4, Plate D-2 to reduce heat transfer down through the concrete pipe.

The top of the test section, 60.5 feet in length by 21.75 feet in width, was sloped for surface drainage. The side slopes were two feet horizontal to one foot vertical.

2-02. Pavements. To simulate the effect of airfield pavements, the test elements were capped with portland cement concrete or bituminous concrete. Three elements B, D, and F had six inches of portland cement concrete pavements. The remaining 11 elements were designed for two inches of bituminous concrete pavement. Replacement of bituminous concrete at the end of the year indicated that the pavement averaged four inches thick. The pavements are similar in quality to those used in airfield construction. The cement concrete was a ready mixed, 1:2:4 proportion, with six bags of cement per cubic yard and with aggregate sizes shown by grain size curve in Figure 8, Plate D-3. Compression test results on six molded 12-inch cylindrical samples from the portland cement concrete batches were as follows:

7 day strength = 1,894 pounds per square inch
14 day strength = 2,770 pounds per square inch
28 day strength = 3,646 pounds per square inch

The bituminous concrete contained five per cent of 85 to 100 penetration asphalt cement. The gradation of the aggregate in the mix is shown by the grain size curve in Figure 8, Plate D-3 The pavement was sealed with an application of RC-2 at a rate of 0.25 gallon per square yard. Clean well-graded cover sand was applied to the seal coat at a rate of 20 pounds per square yard.

2-03. Non-Frost Susceptible Base Materials.

a. Cinders (Elements A and B). The behavior of cinders as a base course and insulating material when subject to freezing was investigated in elements A and B. The cinders used were retained on a ¼-inch screen to remove excessive fines and were hand tamped into the portland cement concrete cylinders to avoid excessive crushing of the particles. The dry densities obtained ranged from 53 to 68 pounds per cubic foot with the water contents between one and two per cent as shown in Figures 1 and 2 on Plate D-3. Four inches of bituminous concrete and six inches of cement concrete were placed directly on the cinders in elements A and B respectively.

b. Sand and Gravel (Elements C and D). Sand and gravel was compacted in elements C and D at dry densities ranging from 127 to 131 pounds per cubic foot and at water contents ranging from six to eight per cent as shown in Figures 3 and 4 on Plate D-3. The grain size gradation is shown by curve 2 of Figure 7 on Plate D-3. The material is well graded, and of GW classification. Four inches of bituminous concrete and six inches of cement concrete were placed directly on the sand and gravel in elements C and D respectively.

c. Crushed Rock (Elements E and F). Crushed rock was placed in elements E and F at dry densities ranging from 107 to 112 pounds per cubic foot and one per cent water content as shown in Figures 5 and 6 on Plate D-3. The grain size gradation is shown by curve 1 of Figure 7 on Plate D-3. The original placing of material in element E did not result in the desired 110 pounds per cubic foot density. The material was removed and, in the second attempt, each foot layer was compacted to take a pre-weighed quantity necessary for the required density. The crushed rock was placed by dumping from a high-body dump truck and compacted with a power tamper. Four inches of bituminous concrete and six inches of cement concrete were placed directly on the crushed rock in elements E and F respectively.

2-04. Frost Susceptible Materials (Elements G,H,J,K,L,M,N and P). A frost susceptible silty clay (CL) representative of the existing top five feet of the subgrade soil in place under the airfield pavement at Dow Field was placed as a subgrade at controlled densities and water contents in eight elements. The grain size gradation curve is shown on Figure 7 on Plate D-3. Four of the elements, G, H, J, and K, had a controlled water surface seven feet below the pavement and four elements, L, M, N, and P, were not in contact with a water surface to simulate a water table at infinity. The silty clay was placed dense at a high water content, loose at a high water content, dense at a low water content, and loose at a low water content in elements G, H, J, and K, respectively. These conditions were duplicated in elements L, M, N, and P, respectively. Table of element variables is shown on Plate D-2. The silty clay was difficult to handle but the densities and water contents at which it was placed were approximately those desired. Plate D-18 shows the material placed in element M at 28 per cent water content after the silty clay had been run through a mixer to bring the water content up ten per cent and element P with the material placed at 22 per cent water content. During the frost melting period the pavement in those elements, H, K, M, and P, in which the subgrade was placed in a loose condition settled so that the pavement and base had to be removed, the subgrade brought up to grade by the addition of silty clay and new base and pavement placed. The condition of pavement in elements H and M after settlement and prior to reconstruction is shown on Plate D-19. At the time of reconstruction density and water content determinations were made by driving a 2.75-inch diameter thin-walled, seamless steel tubing into the subgrade. These density and water content values showed considerable variation from those determined during the construction of the test elements. All values of density and water content determinations are shown on Plates D-3 and D-4.

The silty clay subgrade was covered with a six-inch layer of sand and gravel which was treated with RT-5 sprayed at the rate of one gallon per square yard. A four-inch layer of bituminous concrete pavement was placed over the sand and gravel.

2-05. Insulation.

a. The top edges and top 14 inches of the sides of each concrete cylinder were insulated with sawdust as shown in Figure 4, Plate D-2. It was originally planned to use cork board and granulated cork for the insulating material. Failure to get delivery of the material necessitated the use of readily available sawdust. The sawdust was held in place by a permanent plywood form. After the sawdust was placed in the form, a plywood cover was nailed on. For waterproofing against surface seepage the cover was treated with double-ply

15-lb. felt thoroughly coated on all surfaces with three coats of roofing pitch. The felt overlapped the pavement surface by two inches and extended three inches outside the perimeter of the plywood form, as shown by Plate D-19.

b. The insulating fill between cylinders and the bulk of the embankment consisted of sawdust as shown in section in Figure 3, Plate D-1. Because of the scarcity of cinders in this vicinity, it was necessary to use sawdust. The sawdust was hauled by truck and shovelled into place by hand. Where possible, the trucks were driven over successive layers of the material in an effort to obtain as great an initial settlement as possible. Attempts to compact the sawdust by hand in the constructed areas did not appear to be successful. Sawdust insulation was also used in backfilling the trench excavated for the water supply lines.

c. The use of sawdust introduced a heating effect not originally anticipated. The decomposition of the sawdust used in the embankment generated sufficient heat to raise its temperature to over 100 degrees Fahrenheit. This condition was observed at the start of measuring temperatures in the test section. Two corrective measures were attempted. On November 14, the surface of the test section was soaked with water. This resulted in reducing the temperature of the sawdust from approximately 100 degrees to 50 degrees Fahrenheit. Soaking was continued until the beginning of freezing weather on 28 November. The cooling effect of the water was only temporary as subsequent temperature readings again indicated a rise in the sawdust temperature. A second corrective measure was attempted from the 3rd to the 10th of December 1946. A total of 120 auger holes on two-foot centers surrounding the test elements were dug in order to reduce the volume of sawdust in the embankment. The holes, nine inches in diameter, were dug through the sawdust to gravel and backfilled with gravel, as the gravel was intended to serve as a ventilation tube for releasing the heat within the sawdust. Temperatures decreased upon completion of this work, but it is possible that colder weather had a greater influence than the replacement of a small portion of sawdust.

2-06. Source of Water. Elements G, H, J, and K, were connected at the base to a controlled water supply as shown in Figure 5 on Plate D-2. A two-layer filter 12 inches thick consisting of sand with gradation of grain sizes shown by curves 5 and 6 in Figure 7 of Plate D-3. designed to prevent the washing out of the fines contained in the silty clay was placed between the subgrade and the base of the element. A reservoir was installed in the instrument room by excavating a pit of 2 x 4 foot area to a depth of five feet. The excavation was lined with cement concrete taken from the same batches used for the test element bases. A galvanized metal supply tank with ball and cock valve to control the water level was installed in the pit as shown on Plate D-20. The water level was maintained at the top surface of the filter material. Copper tubing was laid from the tank to the cylinders as shown in Figure 5, Plate D-2.

2-07. Ground Water Observation Wells. Observation wells for measuring the actual depth to the controlled source of water was installed in test elements G, H, J, and K. The observation wells consisted of 3/4-inch pipe perforated at the lower end and capped at the top with a coupling and plug. A short iron rod was welded to the coupling to facilitate removal of the plug. Figure 5 of Plate D-2 shows the installation detail. Observation wells also were installed in the north and south edge of the test section embankment. The north and south wells were used to detect a possible rise of the natural ground water capable of seeping into the cylinders. This precaution was made since the controlled supply of water from the reservoir was intended to serve as the only source of ground water.

2-08. Thermocouples. The temperature of the pavement, base, and subgrade materials in each test element was measured by thermocouples set in the positions shown on Plates D-3 and D-4. The thermocouple details are the same as used in the previous investigations and are shown on Plates 3 and 4, Volume II. Nine thermocouples were installed in each of the 14 test elements. A vertical board in the center of the empty cylinder, as shown in Figure 1, Plate D-2 was used to hold the thermocouple at the desired position. As the material was filled over a thermocouple, it was detached from the board and the lower part of the board was sawed off and removed. Precaution against the wire snapping because of frost action was made by allowing sufficient slack and covering the cables with a heavy coating of grease. The outlet sleeve of the cylinders shown in Figure 3, Plate D-2 was made watertight by sealing with battery compound. The entire thermocouple line leading to the entrance of the instrument room was buried in a trench backfilled with cinders and gravel to a depth of one foot above the top bank of ducts. Figure 2, Plate D-21 and Figure 1, Plate D-22 show several thermocouple cables in position before backfilling.

Thermocouples R and S in Figure 1, Plate D-1 were installed at two locations in the embankment outside the test elements. These installations each consist of seven units spaced in the gravel and sawdust fill as shown in Figure 5, Plate D-1. Temperatures within the embankment were observed for comparison with those obtained within the test elements.

2-09. Temperature Measuring Equipment. The temperatures of the thermocouples were measured during the period 11 October to 23 December 1946 on a Leeds and Northrup direct reading portable type potentiometer by connecting each of the thermocouple leads with the instrument separately. On 23 December 1946 a Leeds and Northrup Micromax Temperature Indicator was installed. Each of the thermocouple leads was connected permanently to the instrument and the temperature at any thermocouple was obtained by switching the proper switch. The switch panels and the temperature indicating scale are shown on Plate D-23.

2-10. Instrument Room. A section of Building T162 in the Reclamation Yard at Dow Field was partitioned off for use as an instrument room to contain the temperature measuring instruments and water supply controls. The interior walls were constructed of ½-inch insulation board and the exterior wall was sheathed with matched boards with the space between the studs packed with sawdust. Two 3-Kilowatt electric heaters, with a thermostatic control, were installed to maintain a constant room temperature.

2-11. Thermograph. A thermograph was installed in a shelter located 25 feet north of the test section as shown in Figure 2, Plate D-1. to obtain continuous records of air temperature.

2-12. Bench Marks. Two bench marks were established for reference points to measure changes in elevation of the element pavements throughout the freezing and frost melting periods. One bench mark consisted of a bolt set in the concrete foundation of the northwest corner of the nearest warehouse building in the Reclamation Area. The second bench mark consisted of a 1½-inch pipe set inside a 2½-inch pipe casing. The casing was approximately five feet long to protect the bench mark pipe through the frost zone and the bench mark pipe was set firmly in the clay subgrade. This bench mark was located approximately 40 feet south of the elements.

III. OBSERVATIONS AND MEASUREMENTS

3-01. General. Observations of conditions pertinent to frost action studies such as rate of frost penetration, subsurface temperatures, ice lens formation, pavement heave, and changes in density and water content were proposed for the investigations. No suitable means for measuring rate of frost penetrattion, ice lens formation, and changes in density and water content were developed consequently only weather conditions, subsurface temperature, and pavement heave measurements were made. A summary of the test data is presented on Table D-1.

3-02. Subsurface Temperature Measurements. Subsurface temperature measurements were made at intervals ranging from two to nine days, commencing 11 October 1946 and ending 26 December 1946. Two sets of readings were made daily, except Sunday, beginning 27 December 1946. The first set of readings was made between 7 a.m. and 10 a.m.; the second was made between 1:30 p.m. and 4:30 p.m. The morning readings were made to measure the effect of the more constant, colder night temperature. Typical subsurface temperature gradients for the elements are shown on Plate D-5. The afternoon readings were made to determine the time lag between the varying air temperature and the soil temperature within the elements.

To further investigate the time effect of air temperature fluctuations, measurements were made at two-hour intervals on the following days:

4 April 1947; 5 a.m. to 7 p.m., (Clear)

5 April 1947; 5 a.m. to 1 -.m., (Clear until 11 a.m.)

12 April 1947; 5 a.m. to 3 p.m., (Cloudy until 1:30 p.m.)

15 April 1947; 5 a.m. to 7 p.m., (Clear)

21 April 1947; 5 a.m. to 1 p.m., (Cloudy)

26 April 1947; 5:30 and 7:30 a.m., (Cloudy until 7:30 a.m.)

The results of all thermocouple temperature measurements are tabulated in Tables D-2 to D-17. All temperatures are shown in degrees Fahrenheit.

Prior to the installation on 23 December 1946 of the Micromax temperature measuring equipment, the hand operation of the potentiometer required two hours to obtain a set of temperature readings. The automatic equipment required 15 minutes. For this reason, a greater range in air temperature occurred during the time required to obtain the sets of temperature readings made from 11 October to 23 December 1946.

3-03. Air Temperature. Continuous records of air temperature were obtained from the thermograph. The minimum and maximum daily temperatures from the thermograph records shown on Plate D-6 were used to calculate the 1946-1947 freezing index plotted on Plate D-7. The air temperatures at the time of reading the thermocouples were obtained from the thermograph recordings.

3-04. Surface Temperature. The temperature at the surface of each element was measured by a mercury thermometer. While reading the thermocouples for a given test element, the thermometer was placed on the pavement surface of the test section and shielded from the sun by a wooden board. These readings are tabulated for comparison with other temperature readings in Tables D-2 to D-17 inclusive.

3-05. Weather Conditions. The direction and intensity of the wind as indicated by the Beaufort scale is tabulated with the temperature data in Tables D-2 to D-17. Cloud and sun conditions prevailing during the time of temperature measurements also are shown. The test section was kept clear of snow cover to eliminate consideration of its insulation effect during this investigation.

3-06. Water Table. The observation wells in elements G, H, J, and K were examined each time temperature measurements were made. The measured depth from surface of element to water varied from 7.1 to 7.3 feet.

The north and south observation wells were dry except on four separate occasions during the latter part of November and December when the water table appeared in the wells at depths ranging from 7.6 to 7.9 feet.

3-07. Pavement Heave. The heave of the pavement on each of the test elements was determined by level surveys as an indication of the frost action which occurred. The original elevation of five points on each test cylinder pavement was referenced to a bench mark not subject to frost action. The five level points on top of each test element consisted of the center of pavement and the quarter points along the pavement circumference. Changes in elevation were measured to the nearest hundredth foot on the following dates:

19 Nov. 1946	7 Feb. 1947
31 Dec. 1946	11 Feb. 1947
27 Jan. 1947	17 Feb. 1947
31 Jan. 1947	10 Mar. 1947
4 Feb. 1947	13 Mar. 1947
17 Mar. 1947	8 Apr. 1947
27 Mar. 1947	16 Apr. 1947
1 Apr. 1947	22 Apr. 1947

Changes in elevation of the pavement at the center of the elements are plotted on Plates D-8 to D-11 for comparison with the penetration of the 32°F. temperature.

IV. ANALYSIS OF RESULTS

4-01. Weather. The winter during this investigation was milder than usual for Bangor, Maine. The 1946-1947 freezing index shown on Plate D-7 was 965 as compared with a 13-year normal of 1275. Rainfall and snowfall are not pertinent to this study because of controlled ground water conditions and because the top of the test section was maintained clear of snow. The direction and intensity of the wind may have an effect on the rate of drying the pavement surfaces, but no measurable influence is evident from the pavement temperature data.

4-02. Test Element Temperatures. At the time of reading, morning and afternoon, the pavement surface temperatures were usually warmer than the air temperatures. The bituminous concrete surface was warmer than the cement concrete during a majority of the observations. The continuous air temperatures recorded on the thermograph show that the daily maximum and minimum air temperatures usually occurred at the time of measuring the afternoon and morning test element temperatures. The hourly change in air temperature is reflected in the elements to a depth of approximately one foot. Below this depth the temperature gradient in all the test elements was approximately the same. The warming effect of the sawdust embankment surrounding each test element may have limited the depth to which the daily fluctuations of air temperature were transferred within the test elements.

The effect of fluctuations in air temperature measured at two-hour intervals during clear and cloudy days is shown in Plates D-12 and D-13. The same data is tabulated in Tables D-2 to D-17, but the plotted data are arranged to facilitate a comparison of the temperature changes of the various materials as a function of air temperature changes. The clear day selected for analysis is 4 April 1947 when temperature measurements were made every two hours from 5 a.m. to 7 p.m. The cloudy day selected for analysis is 12 April 1947 when an unusually warm spell occurred. Temperature measurements on this day were made from 5 a.m. to 3 p.m.; at 1:30 p.m. on 12 April the weather cleared and the sun appeared at 2 p.m. However, the rain until 11 a.m. and cloudy weather until 2 p.m. offered a good contrast with the readings of the clear day. The thermograph records of continuous air temperature are reproduced in Figure 1 of Plates D-12 and D-13, for consideration of air temperature conditions for three days prior to the time of making the two-hour interval readings. The curves in Fig.2, Plates D-12 and D-13 indicate the surface temperature reaction of each test element. The surface temperature of all elements was warmer than the air during a clear day. The rain on 12 April during the 5 a.m., 7 a.m., and 9 a.m. readings kept the surface temperature of all test elements approximately equal to the air temperature. However, the surface temperature of all test elements became warmer than the air after the rain ended despite continued cloudiness.

Figures 3, 4, and 5 on Plates D-12 and D-13 show the temperature changes within the elements and embankment during the same two-hour intervals. The thermal characteristics of the material is indicated by comparing the temperature versus time curves. During the daylight hours the surface temperature is higher than the air temperature and reaches its peak one to three hours ahead of the air temperature. Approximately two hours were required for changes in surface temperature to reach the midpoint of either four inches of bituminous concrete or six inches of cement concrete. However, consideration must be given to the magnitude and rate of change in air temperature. For the test period on 4 April there was a 20 degree Fahrenheit drop in air temperature during the 12 hous prior to the measurements, as shown on Plate D-12. For the test period on 12 April the air temperature was more constant and dropped nine degrees Fahrenheit prior to the measurements, as shown on Plate D-13. The peaks of temperature changes in relation to time are thus more pronounced for the 4 April measurements. The results on Plates D-12 and D-13 show a consistently lower temperature on top of the base course for the elements capped with cement concrete. During a clear day the base course surface beneath the cement concrete pavement is from 4 to 20 degrees Fahrenheit colder than the base course surface beneath the bituminous concrete. Although there is no distinction between the various materials for temperatures measured below approximately one foot, consideration must be given to the effect of the sawdust embankment. It is believed that the insulation value of the sawdust embankment, in addition to its heat producing characteristics had a greater effect through the side walls of the test element than the air temperature acting vertically through the element surface.

The continued effect of the decomposition of the sawdust insulation is indicated by the temperature gradients of the four elements adjacent to the thermocouple installation (S) located in the center of the test embankment. Typical temperature gradients are shown on Plate D-14. The temperature lag in the sawdust is shown and a comparison of the temperature measurements in the test embankment and those in the test areas indicates that temperatures were consistently higher in the test elements than in the runway test areas. The average depth of freezing temperature penetration was 17 inches in the test elements and 47 inches in the runway test areas.

4-03. Depth of Freezing Temperature. The frozen zones of the materials in each test element is best analyzed by comparing the depth of freezing temperature versus time. The graphs on Plates D-8 thru D-11 show the freezing temperature zone determined from thermocouple readings made in the morning about one hour after daybreak. The boundary of the frozen zone is considered to be the depth of penetration of the 32-degree Fahrenheit temperature. The plotted depth of the 32-degree temperature was interpolated by assuming a straight line temperature gradient between the temperature of any two adjacent thermocouples which bracket 32 degrees Fahrenheit.

An additional summary of the depth of the 32-degree Fahrenheit penetration is shown on Plate D-15. The maximum depth during the test period is shown in Figure 1 by a bar graph representative of each test element. The mean depth of the 32-degree temperature for the month of January is correspondingly shown in Figure 2, Plate D-15.

In the elements containing the non-frost susceptible base materials the maximum depth of freezing temperature penetration was consistently greater under the portland cement concrete than under the bituminous concrete. The freezing temperature penetration under the portland cement concrete pavement was greatest in the crushed rock and least in the sand and gravel. Under the bituminous concrete pavement there was very little difference between the three types of base materials with the penetration in the crushed rock slightly greater than in the sand and gravel and into the cinders slightly less than in the sand and gravel. The actual depths of freezing temperature penetration is shown below.

Material	Depth of Freezing Temperature Penetration: Bituminous Concrete	Depth of Freezing Temperature Penetration: Cement Concrete
Cinders	19 inches	26 inches
Crushed Rock	22 inches	30 inches
Sand and Gravel	20 inches	23 inches

Based upon the depth of freezing temperature penetration these tests do not indicate the insulating value of cinders compared with the other materials tested.

In the elements containing the frost susceptible subgrade materials, the frost penetration was least in the elements with ground water with the exception of elements K and M as shown in the following table:

ELEMENT	DENSITY	WATER CONTENT	DEGREE OF SATURATION	WATER TABLE	FREEZING TEMPERATURE PENETRATION (inches)
G	dense	high	high	yes	12
H	loose	high	high	yes	14
J	dense	low	low	yes	16
K	loose	low	low	yes	18
L	dense	high	high	no	22
M	loose	high	high	no	17
N	dense	low	low	no	21
P	loose	low	low	no	19

A similar study of the thermocouple readings obtained during the afternoon show the same bottom depth of the frozen zone. The distincition between the morning and afternoon readings is the greater number of periods during the afternoon when the temperature near the surface was above 32 degrees Fahrenheit. These values measured during the afternoon appear as thawing periods.

4-04. Pavement Heave and Settlement. The only evidence of frost action available in this investigation is indicated by the amount of pavement heave. The pavement heave, and in some cases the pavement settlement, are shown related to time and depth of freezing temperature on Plates D-8 to D-11.

Pavement heave occurred in elements containing the frost susceptible silty clay. The heave and settlement in the elements limited to base course material was of a negligible amount being not greater than one-quarter of an inch.

The four elements G, H, J, and K, containing a source of water can be compared for frost action with the four elements L, M, N, and P, which were sealed off from a source of water and are considered to have water table at infinite depth. The elements exposed to a source of water developed the most heave although element H showed a consistent settlement. The elements with water table at infinite depth, heaved and settled to a lesser degree depending on the original degree of compaction. The appearance of the paved surface of element H and M during settlement are shown on Plate D-19.

Elements H, K, M, and P, developed settlement mainly after the freezing period. The original dry density at which the silty clay was placed in these cylinders was fairly loose ranging from 90 to 98 pounds per cubic foot. Elements G, J, L, and N heaved and returned nearly to their original elevation. The original dry density at which the silty clay was placed in elements which heaved was more dense, ranging from 101 to 107 pounds per cubic foot. It is apparent that a poorly compacted frost-susceptible subgrade will settle during the frost melting period.

SUMMARY OF DATA

TEST SECTION	SURFACE		BASE			SUBGRADE			WATER CONTENT PER CENT DRY WT.		
	TYPE	THICKNESS (INCHES)	CLASSIFICATION	THICKNESS (INCHES)	PER CENT FINER THAN 0.02 mm	CLASSIFICATION	THICKNESS (INCHES)	PER CENT FINER THAN 0.02 mm	AS PLACED OCT. 1946	ON JUNE 1947	AS PL OCT.
A	Bit. Conc.	4	Cinders	92	- (A)	-	-	-	1	-	5
B	P.C.C.	6	Cinders	90	- (A)	-	-	-	1	-	6
C	Bit. Conc.	4	Sand and Gravel (GW)	92	<2	-	-	-	7	-	12
D	P.C.C.	6	Sand and Gravel (GW)	90	<2	-	-	-	7	-	13
E	Bit. Conc.	4	Crushed Rock (B)	92	<1	-	-	-	1	-	11
F	P.C.C.	6	Crushed Rock (B)	90	<1	-	-	-	1	-	10
G	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	74	51	Base - Subg. 18	- -	11 10
H	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	74	51	Base - Subg. 9	2 24	11 9
J	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	74	51	Base - Subg. 16	- -	12 10
K	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	74	51	Base - Subg. 19	4 23	12 9
L	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	86	51	Base - Subg. 17	- -	12 10
M	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	86	51	Base - Subg. 20	- 24	11 9
N	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	86	51	Base 5 Subg. 15	- -	11 10
P	Bit. Conc.	4	Sand and Gravel (GW)	6	<2	Silty Clay (CL)	86	51	Base 6 Subg. 21	4 25	12 9
EMBANKMENT LOCATION											
R	Sand and Gravel (GW)	6	-	-	-	Sawdust	60	-	-	-	-
S	Sand and Gravel (GW)	6	-	-	-	Sawdust	60	-	-	-	-

(A) Cinders retained on 1/4" sieve prior to placing.
(B) Crushed rock 3/8" to 1 1/8" diameter.

NOTES:

Freezing Index was 965.

Atterberg Limits of Subgrade Cla

	Average	Range
Liquid Limit	33	29-36
Plastic Limit	20	19-22
Plasticity Index	13	11-17

Specific Gravity of Subgrade Cla

Y OF DATA

WATER CONTENT PER CENT DRY WT.		DENSITY PCF		DEGREE OF SATURATION			GROUND WATER DEPTH (INCHES)	FREEZING TEMPERATURE PENETRATION (INCHES)	MAXIMUM PAVEMENT HEAVE (INCHES)	MAXIMUM PAVEMENT SETTLEMENT (INCHES)
AS PLACED OCT. 1946	ON JUNE 1947	AS PLACED OCT. 1946	ON JUNE 1947	PROPOSED	AS PLACED OCT. 1946	ON JUNE 1947				
1	-	58	-	-	-	-	Infinity	19	0.1	0.1
1	-	62	-	-	-	-	-	26	0.0	0.2
7	-	128	-	-	-	-	-	20	0.4	0.0
7	-	130	-	-	-	-	-	23	0.1	0.1
1	-	110	-	-	-	-	-	22	0.1	0.1
1	-	109	-	-	-	-	-	30	0.0	0.2
Base - Subg. 18	- -	116 102	- -	- 80 - 90	- 74	- -	84	18	1.2	0.0
Base - Subg. 29	2 24	118 95	130 104	- 80 - 90	- 100	- 100	84	14	0.0	3.2
Base - Subg. 16	- -	123 104	- -	- 60 - 70	- 69	- -	84	16	1.3	0.0
Base - Subg. 19	4 23	121 92	123 103	- 60 - 70	- 61	- 96	84	18	0.8	1.2
Base - Subg. 17	- -	128 104	- -	- 80 - 90	- 73	- -	Infinity	22	1.0	0.0
Base - Subg. 28	- 24	110 94	123 100	- 80 - 90	- 94	- 93	-	17	0.1	2.3
Base 3 Subg. 15	- -	115 103	- -	- 60 - 70	- 63	- -	-	21	0.6	0.0
Base 6 Subg. 21	4 25	124 91	134 100	- 60 - 70	- 66	- 97	-	19	0.5	1.2
-	-	-	-	-	-	-	-	12	-	-
-	-	-	-	-	-	-	-	10	-	-

ing Index was 965.

berg Limits of Subgrade Clay (CL).

	Average	Range
Limit	33	29-36
e Limit	20	19-22
city Index	13	11-17

fic Gravity of Subgrade Clay was 2.74.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

SUMMARY OF DATA

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG 1947

TABLE *

D-1

DATE AND TIM

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11 0900	16 1100	20 1352	22 0902	31 1450	7 0950	15 1030	19 0915	21 1050	23 0915	25 1030	27 0850	29 1525	3 0915	7 0910	10 1140	12 0910	14 1115	16 0920	24 0830	26 0930	27 0840	27 1415	28 0940	30 0915	30 1500
1	0.2	Bit. Conc.	44	45	61	41	62	46	46	29	34	33	43	45	39	10	26	4	7	32	13	3	18	-9	18	6	2	20
2	0.3	Cinders	57	60	58	41	62	44	45	30	38	35	43	41	40	11	26	38	28	32	14	31	19	-6	18	8	2	22
3	1.0	"	64	55	50	53	58	52	53	51	50	51	45	50	48	41	38	38	41	43	40	[illegible]	36	33	34	33	[illegible]	3[illegible]
4	1.8	"	58	57	55	56	62	61	61	60	58	57	55	53	53	51	48	46	46	49	48	[illegible]	44	43	43	42	41	41
5	2.7	"	58	57	58	59	65	60	66	65	64	63	61	60	59	57	54	53	52	53	53	49	49	49	49	49	48	48
6	3.5	"	59	58	60	61	66	69	70	69	68	67	66	65	62	61	60	58	57	58	58	56	57	55	55	55	54	54
7	4.8	"	59	59	60	63	66	70	71	71	70	67	65	64	63	63	63	62	62	62	62	60	59	59	59	59	58	58
8	6.2	"	60	60	61	62	65	68	70	69	69	66	64	63	64	65	65	64	64	64	64	63	62	62	62	62	62	62
9	7.5	"	61	60	62	63	63	[illegible]	67	66	56	61	62	62	63	65	63	64	64	63	63	63	63	63	63	62	62	62
Air Temperature			55	64	56	46	63	41	41	[illegible]	34	3[illegible]	[illegible]	41	31	18	32	40	[illegible]	[illegible]	[illegible]	34	22	-6	0	-4	23	[illegible]
Surface Temperature			65	72	58	41	62	46	[illegible]	30	[illegible]	42	44	42	33	17	32	40	34	30	14	30	24	2	19	6	20	7
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Snow	Clear	Clear	Snow	Clear	Clear
Wind (Beaufort Scale)				SW1			WSW2	NW2	N3	N2	E1	NW3	S2	NW2		W2	SW1	NE1	SW	NW3	NW3	W1	S1	NW3	N2	NE3	N3	NW3

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18 1400	20 [illegible]	20 [illegible]	21 [illegible]	21 1420	22 [illegible]	22 [illegible]	23 [illegible]	23 1600	25 0700	25 1410	27 [illegible]	27 1335	28 [illegible]	28 1410	29 [illegible]	30 [illegible]	30 1430	31 [illegible]	31 1410	1 0745	1 1410	3 0915	3 1440	4 0930	4 14[illegible]
1	0.2	Bit. Conc.	34	18	11	14	14	10	16	-7	22	-1	1	31	35	31	17	16	27	20	31	41	25	35	9	37	22	4[illegible]
2	0.3	Cinders	12	13	10	24	24	11	19	-3	21	1	27	31	34	31	15	27	21	30	31	38	28	34	9	34	22	38
3	1.0	"	10	27	27	30	31	31	30	25	24	26	27	31	31	31	31	31	31	31	31	31	3[illegible]	31	29	24	30	30
4	1.8	"	33	35	33	35	33	35	35	33	33	34	32	34	34	34	35	34	34	33	35	35	35	35	35	35	35	35
5	2.7	"	41	40	41	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
6	3.5	"	47	47	47	47	47	47	47	46	46	46	46	46	46	46	46	46	46	46	45	46	45	46	45	46	45	46
7	4.8	"	53	52	52	52	52	52	52	52	52	51	51	51	51	51	51	50	50	50	50	5[illegible]	50	50	50	50	50	50
8	6.2	"	58	57	57	57	57	57	57	57	58	56	56	56	56	56	56	56	55	55	55	55	55	55	55	55	54	55
9	7.5	"	[illegible]	57	57	57	57	57	57	57	57	58	58	58	58	57	58	58	59	58	57	57	57	57	57	57	57	57
Air Temperature			2	11	40	6	14	[illegible]	9	-1	12	21	29	33	34	31	34	26	26	20	32	39	26	27	15	32	27	42
Surface Temperature			[illegible]	15	14	34	34	9	3	-1	13	25	40	34	36	31	36	28	27	28	32	41	24	29	15	30	27	41
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			W4	[illegible]	E1	W2	W3	SW2	NW3	W2	W3	None	SE1	None	NE1	None	None	NW1	None	NE1		None	NW4	NW3	NW2	NE2	None	SW2

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																									
			21 [illegible]	21 1410	22 [illegible]	22 [illegible]	24 [illegible]	24 1410	25 0815	25 1340	26 1430	27 [illegible]	27 1435	28 [illegible]	28 [illegible]	1 [illegible]	1 1410	3 [illegible]	4 [illegible]	4 1500	5 0810	5 1510	6 0800	6 1400	7 [illegible]	7 [illegible]	8 [illegible]	8 1405
1	0.2	Bit. Conc.	4	7	23	32	-4	41	17	27	36	47	43	26	12	28	44	38	31	30	29	41	32	50	34	37	32	40
2	0.3	Cinders	[illegible]	8	23	27	25	38	17	28	43	27	43	44	27	32	36	37	32	38	30	39	32	47	32	35	32	37
3	1.0	"	31	31	32	31	31	31	31	31	31	31	32	41	31	32	31	32	31	31	31	32	32	31	31	32	34	32
4	1.8	"	33	33	33	35	33	33	35	33	35	33	36	33	33	35	35	35	35	33	33	35	35	35	35	35	35	35
5	2.7	"	37	37	39	39	37	37	39	37	38	38	39	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
6	3.5	"	41	44	43	44	43	43	43	43	43	41	44	43	43	43	43	43	43	43	42	43	43	43	43	43	43	43
7	4.8	"	47	48	47	47	47	47	47	47	47	47	47	47	46	47	47	47	47	46	46	47	46	46	46	46	46	46
8	6.2	"	52	52	52	52	52	52	51	52	51	51	52	51	51	51	51	51	51	51	51	51	51	51	51	51	51	50
9	7.5	"	54	53	53	54	54	54	54	54	54	54	54	54	54	53	54	54	53	53	53	53	53	53	53	53	53	53
Air Temperature			3	7	28	21	22	-4	12	10	37	-4		22	30	23	38	37	29	35	28	36	36	43	36	41	32	37
Surface Temperature			10	13	29	31	24	41	24	32	44	30	36	27	36	33	41	37	37	37	33	41	36	48	37	43	34	41
Weather			Cloudy	Snow	Snow	Snow	Clear	Cloudy	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Snow	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow	Snow
Wind (Beaufort Scale)			NE2	NW4	N2	NW1	None	SW2	None	W2	NW2	None	W3	None	W2	None	W1	S3	None	NE1	W1	NW2		NW3	NW3	NW3	NW2	NE2

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26 [illegible]	27 [illegible]	27 [illegible]	28 [illegible]	28 [illegible]	29 0730	29 [illegible]	31 [illegible]	31 [illegible]	1 0810	1 1330	2 [illegible]	2 1445	3 0800	3 1330	4 0510	4 0705	4 0905	4 1110	4 1310	4 1500	4 1700	4 1850	5 0500	5 0705	5 0900
1	0.2	Bit. Conc.	32	19	13	21	44	27	27	[illegible]	7	36	77	43	49	35	71	24	38	46	59	73	74	68	57	28	30	43
2	0.3	Cinders	49	36	48	22	37	29	41	31	44	36	72	46	65	36	67	26	29	37	53	69	71	68	59	30	31	41
3	1.0	"	40	39	38	37	38	38	37	34	37	40	39	43	43	44	42	44	43	43	43	42	42	42	41	44	44	44
4	1.8	"	40	40	43	39	39	33	39	40	39	40	40	40	41	41	41	42	42	42	42	42	42	42	41	42	42	42
5	2.7	"	41	40	41	41	41	42	42	41	41	40	41	41	40	41	41	41	41	41	41	41	41	41	41	42	42	42
6	3.5	"	41	41	42	41	42	42	42	41	43	43	43	43	43	43	43	43	44	44	43	44	44	44	43	44	44	44
7	4.8	"	46	45	45	45	46	45	46	46	45	45	43	43	43	45	45	43	45	45	45	45	45	45	45	45	45	45
8	6.2	"	49	49	49	49	49	49	49	49	48	49	48	49	49	49	49	48	48	48	49	48	48	48	48	48	48	48
9	7.5	"	51	51	50	50	50	51	51	51	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Air Temperature			32	[illegible]	33	23	38	[illegible]	[illegible]	28	42	31	50	41	32	31	43	23	[illegible]	[illegible]	41	48	50	49	42	26	31	43
Surface Temperature			36	37	36	25	46	3[illegible]	51	33	50	40	58	48	42	33	51	24	34	44	50	41	58	54	41	27	31	47
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			SW2	W2	W4	NNW2	NE2	None	SW2	SW2	NW2	NW3	N2	NW1	SW1	NW3	N3	None	None	N3	N3	N3	N3	NW2	None	None	S1	SE2

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18 1400	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Cinders	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1.0	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.7	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.5	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	[illegible]	41	[illegible]	[illegible]
8	6.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47
9	7.5	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

D TIME

														JANUARY 1947															
30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
0915	1500	0845	1400	0830	1545	0915	1615	0840	1500	0840	1615	1100	0710	1500	0830	1515	0715	1400	0740	1500	0830	1400	0940	1530	0915	1555	0830	1530	0730
21	20	[illegible]	14	12	14	[illegible]	20	10	24	14	30	27	-2	18	-11	14	-4	1	12	27	4	25	30	33	30	33	27	33	20
2	22	2	14	11	15	21	21	12	25	14	31	27	-1	18	-10	14	-3	2	13	27	3	25	29	33	29	33	28	32	20
[illegible]	31	2	30	28	28	-9	30	29	29	28	28	30	20	27	25	24	24	23	26	26	26	24	28	29	31	31	31	31	31
41	41	41	40	40	40	34	38	38	38	37	37	37	37	37	27	36	36	38	35	35	35	35	33	33	38	35	33	35	34
48	48	47	47	46	46	46	46	45	45	42	44	44	44	41	43	43	43	43	42	42	42	42	41	41	4[illegible]	41	41	41	41
54	54	54	54	53	53	53	52	52	52	51	50	51	51	[illegible]	50	50	50	50	49	49	49	49	49	49	48	48	48	48	47
58	58	58	58	58	58	57	[illegible]	57	57	56	56	56	56	[illegible]	55	55	55	56	55	55	54	54	54	54	54	54	53	53	53
62	62	62	62	60	61	61	61	61	61	62	62	60	60	[illegible]	59	60	59	59	59	57	58	59	58	59	58	58	58	58	58
62	62	62	62	62	62	62	62	62	62	61	61	61	61	61	61	61	61	61	60	60	60	60	60	60	60	60	60	60	60
27	14	-5	12	7	17	22	18	8	21	25	21	24	-1	11	-8	[illegible]	-6	7	-2	20	-1	23	34	34	32	35	21	32	30
26	7	7	12	6	20	23	23	13	24	23	21	7	1	9	-3	[illegible]	[illegible]	[illegible]	7	19	3	23	33	31	33	31	21	31	26
[illegible]	Snow	Cloudy	Cloudy	[illegible]	Snow	Snow	[illegible]	Clear	Clear	[illegible]	[illegible]	[illegible]	[illegible]	Clear	Clear	Clear	Cloudy	[illegible]	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
[illegible]	NW3	SW1	[illegible]	[illegible]	[illegible]	NE1	[illegible]	N1	N1	W2	[illegible]	NW2	[illegible]	NW3	NW2	NW2	N2	[illegible]	NW4	NW2	NE1	NE1	None	NE1	SE1	SE1	W2	W2	SW3

														FEBRUARY 1947															
4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
0830	1400	0830	1525	0830	1400	[illegible]	1400	0800	1435	0845	1400	0720	1400	0815	14[illegible]	0710	1350	0820	1450	0920	1400	0830	1425	0720	1345	0810	1500	0825	1400
22	42	42	42	21	17	21	23	[illegible]	32	20	33	[illegible]	40	7	34	7	34	16	34	32	40	29	33	30	44	25	38	10	41
22	38	[illegible]	40	24	31	22	[illegible]	31	3[illegible]	26	31	[illegible]	38	8	34	9	31	17	32	31	36	31	32	31	43	27	36	12	37
[illegible]	35	31	31	31	3[illegible]	3[illegible]	31	32	36	31	31	3[illegible]	3[illegible]	30	3[illegible]	3[illegible]	29	30	29	31	31	31	31	32	32	31	32	32	32
35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	34	35	35	35	35	35	35	35	36	35	35
40	40	40	40	40	40	34	34	39	39	34	34	39	39	39	35	34	34	37	38	39	39	39	39	39	39	38	40	39	39
45	46	40	45	45	45	45	45	44	45	44	47	44	44	44	44	44	44	44	44	44	44	44	44	44	44	43	44	43	45
[illegible]	50	50	50	55	55	49	49	49	49	49	48	48	48	44	46	48	48	48	48	48	48	48	48	48	48	47	48	47	47
54	55	[illegible]	55	54	59	54	54	54	54	53	53	53	53	53	52	53	53	53	52	52	53	52	52	52	52	52	62	52	52
57	57	[illegible]	57	57	57	57	57	56	57	56	56	56	58	55	55	55	55	55	55	55	55	55	55	55	55	54	55	55	55
27	42	47	30	15	27	20	22	30	35	22	27	2[illegible]	27	10	26	12	29	20	35	39	41	25	37	27	37	20	20	6	23
27	41	45	39	17	29	[illegible]	32	34	32	21	24	14	33	9	30	11	32	23	37	36	46	28	33	30	40	21	23	7	26
Clear	Clear	Rain	Clear	Clear	Clear	Snow	Snow	[illegible]	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
None	SW2	SW3	SW2		NW2	[illegible]	E2	None	None	SW3	NW3		NW4	NW3	NW4	NW4	NW4	NW1	NW2	None	SW1	NE2	NE4	NW2	NW2	NW3	NW3	NW2	NW3

														MARCH 1947															
8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
[illegible]	1405	0845	1400	0815	14[illegible]	[illegible]	1430	[illegible]	1430	0700	1400	[illegible]	1345	0815	[illegible]	0800	1500	0715	1530	0705	1400	0730	1330	0830	1400	0850	1530	0930	1115
32	40	32	41	24	57	[illegible]	72	33	71	33	43	14	57	32	57	32	51	25	64	28	66	31	60	33	60	46	59	41	44
32	37	32	43	30	[illegible]	31	41	32	66	33	1[illegible]	34	51	31	54	[illegible]	47	27	60	29	60	31	56	32	55	44	58	41	42
32	32	32	32	32	32	32	31	31	32	32	32	32	32	35	35	35	33	34	34	35	35	37	37	38	36	41	41	42	40
35	35	35	36	35	33	33	33	35	35	35	35	33	35	35	[illegible]	35	35	36	36	36	36	36	37	37	37	39	39	39	40
38	38	38	39	38	38	[illegible]	37	34	38	38	34	38	38	38	37	38	37	38	38	38	38	38	38	38	38	39	40	39	40
43	43	43	43	42	43	42	42	4.	4.	42	42	[illegible]	42	42	4.	42	4.	42	42	4.	42	42	42	42	41	41	42	42	43
46	46	46	47	46	46	46	46	45	46	46	46	[illegible]	46	46	45	4[illegible]	45	45	45	40	40	45	45	45	44	45	45	45	45
51	50	50	51	50	50	50	50	50	50	50	50	[illegible]	50	50	49	[illegible]	44	47	49	49	49	49	49	49	49	49	49	49	49
53	53	53	53	53	52	53	[illegible]	[illegible]	52	52	52	5[illegible]	52	52	5.	52	5.	52	52	5.	[illegible]	51	51	51	51	51	51	51	51
32	37	33	35	27	31	[illegible]	[illegible]	[illegible]	50	37	44	41	41	29	36	[illegible]	[illegible]	[illegible]	43	27	47	30	47	31	47	45	52	41	27
34	41	33	36	28	40	[illegible]	[illegible]	34	51	37	45	[illegible]	34	35	40	[illegible]	40	[illegible]	53	[illegible]	57	31	54	35	47	51	54	43	34
Snow	Snow	Snow	Rain	Clear	Clear	Clear	[illegible]	Clear	Clear	Rain	Rain	[illegible]	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
SW2	NE2	N1	NE2	N2	NE2	None	[illegible]	SW1	SW1	S3	S3	W2	W2			[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	N3	NW3	NW2	NW3	E1	None	NE1	SW4

														APRIL 1947															
5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
0705	0900	1100	1300	0805	1330	0715	1400	0800	1335	0800	1400	0715	1335	0505	0700	0900	1100	1300	1505	0815	1400	0505	0700	0900	1100	1300	1600	1650	1830
31	43	54	54	46	67	32	72	35	48	33	87	42	79	5[illegible]	54	55	58	74	78	38	43	41	39	41	64	81	88	78	63
31	41	58	53	46	64	32	69	35	49	33	68	42	73	53	54	55	51	71	73	38	43	37	39	46	60	76	80	76	66
40	44	43	43	43	43	45	43	45	44	43	42	47	46	49	49	49	50	50	49	41	46	45	45	44	44	44	44	45	46
42	42	42	42	42	43	43	43	43	44	43	43	44	44	45	45	45	45	45	45	45	41	46	46	46	46	46	46	46	46
42	42	42	42	42	42	42	43	43	43	43	43	43	43	43	43	[illegible]	43	43	43	45	45	42	45	45	43	45	45	43	45
44	44	44	44	44	44	44	43	45	44	45	45	45	43	43	43	45	43	45	45	45	46	46	46	46	46	46	46	46	46
45	45	45	45	45	45	45	45	45	46	45	46	46	46	46	4[illegible]	46	46	46	46	46	46	46	46	46	46	46	46	46	46
48	48	48	49	48	49	49	48	48	48	49	48	49	49	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
50	50	50	50	50	50	50	49	50	50	50	50	50	50	50	50	50	[illegible]	50	50	50	50	50	50	50	50	50	50	50	50
[illegible]	43	45	45	45	49	32	45	33	36	33	50	44	68	55	54	55	59	60	67	35	37	37	34	47	52	55	55	54	47
[illegible]	48	62	48	46	58	35	60	43	47	4[illegible]	73	4[illegible]	70	55	53	57	64	70	71	37	18	37	43	41	61	61	67	60	50
[illegible]	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Clear	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Clear	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear
[illegible]	SE2	SE3	S3	W3	W4	NW3	NW4	SE2	SW2	NW2	SW2	SW2	SW2	SW2	W2	W2	SW1	SW2		SE2	SE2	None	NW1	NW2	NW4	NW3	NW3	NW2	W2

28	28
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	47
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

NOTES:

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT A

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE 2

DATE AND TI

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	30
			1030	0955	1345	0930	1420	1025	1030	0950	1030	0930	1050	0930	1440	1010	1520	1035	1010	1020	1020	0935	0935	0940	1455	0945	0915	15[illegible]
1	0.3	Cement Conc	65	49	54	43	57	43	41	31	37	35	40	43	39	19	28	36	29	28	5	30	18	-4	10	8	22	21
2	0.5	Cinders	60	49	47	43	57	40	41	32	37	38	34	45	39	18	27	33	31	31	19	30	19	+3	10	10	22	23
3	1.3	"	60	53	48	51	58	47	49	45	45	48	40	49	43	36	33	35	38	39	34	33	32	27	26	22	28	28
4	2.2	"	57	57	59	60	66	62	62	60	58	58	55	44	54	51	46	46	47	47	47	43	43	42	42	42	40	40
5	3.0	"	57	59	64	64	69	70	67	66	64	64	62	61	61	58	55	54	54	54	54	50	50	49	49	49	48	48
6	3.8	"	58	60	65	67	71	73	72	70	70	68	67	65	65	63	[illegible]	60	59	59	59	55	55	59	54	59	59	53
7	5.2	"	58	61	65	67	71	74	73	73	71	70	70	68	68	67	66	64	64	64	63	61	61	61	60	60	60	60
8	6.5	"	59	61	65	66	59	71	72	70	70	69	69	68	68	67	67	66	66	66	65	63	62	62	62	62	61	61
9	7.8	"	61	61	62	64	65	67	67	67	67	66	66	66	67	65	[illegible]	65	65	65	64	63	63	63	63	63	62	62
Air Temperature			65	59	56	49	66	50	48	40	38	36	52	47	36	19	20	37	36	27	19	21	22	-6	10	-9	23	18
Surface Temperature			73	61	57	50	59	49	45	38	38	35	48	41	36	22	38	45	37	30	17	30	29	+2	10	6	20	17
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Clear
Wind (Beaufort Scale)				SW1			WSW2	NW2	N3	N2	E1	NW3	S2	NW2		N2	SW1	NE1	SW1	NW3	NW3	N2	S1	NW3	W2	NE3	N3	NW

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			1400	0840	1635	0830	1420	0830	1535	0835	1500	0700	1410	0845	1435	0810	1410	[illegible]	0855	1430	0840	1400	0945	1410	0815	1445	0830	140[illegible]
1	0.3	Cement Conc	28	11	29	35	35	13	14	-2	12	16	24	32	34	31	36	25	27	28	31	3[illegible]	26	33	10	27	21	35
2	0.5	Cinders	25	12	24	32	33	20	18	3	10	16	19	30	31	31	32	28	28	28	29	[illegible]	30	30	12	22	21	28
3	1.3	"	28	20	22	30	31	29	26	18	11	20	21	30	31	31	31	32	30	30	30	[illegible]	31	[illegible]	21	23	26	27
4	2.2	"	34	34	34	33	34	33	34	34	33	33	33	33	33	33	33	33	33	33	34	3[illegible]	34	34	34	34	34	34
5	3.0	"	40	40	40	40	40	40	40	40	40	40	40	39	39	39	39	39	39	39	39	3[illegible]	39	39	39	39	39	40
6	3.8	"	46	46	46	46	46	45	46	45	46	45	45	45	45	45	44	44	44	44	44	44	44	44	44	44	44	44
7	5.2	"	54	53	53	53	53	52	53	52	52	52	52	52	52	51	52	51	51	51	51	51	51	51	51	51	51	51
8	6.5	"	57	56	56	56	56	56	56	56	56	55	55	55	55	55	55	55	55	55	54	5[illegible]	54	54	54	54	54	54
9	7.8	"	59	59	59	58	58	58	58	58	58	58	58	57	57	57	57	57	57	57	57	57	57	57	56	56	56	56
Air Temperature			28	11	40	40	34	6	3	-3	12	31	39	33	36	31	34	26	26	28	32	3[illegible]	26	27	15	32	27	42
Surface Temperature			28	17	38	38	33	9	0	-1	13	26	34	32	34	32	37	27	26	28	32	31	29	28	16	29	27	40
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			W4	E1	E1	SW2	W3	NW2	NW3	W2	W3	None	SE1	None	NE1	None	None	NW1	None	NE1		None	NW4	NW3	W2	NE2	None	SW

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																								
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
			[illegible]	1410	0800	1330	0840	1410	0815	1240	1420	0825	1400	0810	1505	0935	1410	1350	0800	1500	0830	1500	0900	1400	0830	1440	0730	140[illegible]
1	0.3	Cement Conc	12	15	22	29	25	25	18	25	42	25	39	22	25	21	38	38	30	39	28	31	32	43	33	47	31	38
2	0.5	Cinders	[illegible]	18	21	26	26	21	20	23	31	25	31°	22	30	18	28	32	31	33	30	3[illegible]	32	35	31	38	32	32
3	1.3	"	25	24	[illegible]	26	28	21	28	23	29	30	31	30	28	27	27	32	31	31	32	32	32	32	32	32	32	32
4	2.2	"	[illegible]	[illegible]	[illegible]	34	34	34	34	34	34	34	35	34	34	34	34	34	34	33	34	34	34	34	34	34	34	34
5	3.0	"	[illegible]	[illegible]	[illegible]	38	38	38	38	38	38	38	39	38	38	38	38	38	38	38	38	38	[illegible]	38	38	38	38	38
6	3.8	"	[illegible]	42	42	42	42	42	42	42	42	42	43	42	42	42	42	42	41	41	41	41	42	41	41	41	42	42
7	5.2	"	[illegible]	48	48	48	48	48	48	48	48	48	48	47	47	47	48	47	47	47	47	41	47	47	47	47	47	47
8	6.5	"	[illegible]	51	51	51	51	51	50	51	50	50	51	50	50	50	50	50	50	50	49	49	50	49	49	49	49	49
9	7.8	"	[illegible]	54	54	54	53	53	53	53	53	53	54	53	53	53	53	53	53	52	52	53	52	52	52	52	52	52
Air Temperature			[illegible]	13	28	28	22	28	12	30	29	24		22	29	25	38	37	29	35	28	3[illegible]	36	40	36	41	32	37
Surface Temperature			9	16	30	31	24	37	22	30	29	31	37	26	31	35	41	37	35	39	30	38	35	44	38	43	35	40
Weather			Snow	Snow	Snow	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Snow	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow	Snow
Wind (Beaufort Scale)			NE2	NE4	NE3	SW3	None	SW2	None	W2	NW2	None	W3	None	W2	None	W1	S3	None	NE1	W2	NW2		NW3	NW3	NW3	NW2	NE

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
			[illegible]	0800	1400	[illegible]	1400	[illegible]	14[illegible]	07[illegible]	1410	0810	1310	0815	1445	0700	1330	0510	0715	0905	1110	1310	1500	1700	1850	0500	0705	090[illegible]
1	0.3	Cement Conc	[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	[illegible]	[illegible]	52	33	33	41	53	32	49	27	28	[illegible]	46	55	55	55	51	34	34	40
2	0.5	Cinders	[illegible]	[illegible]	[illegible]	[illegible]	33	[illegible]	[illegible]	31	40	[illegible]	42	41	47	33	42	32	31	[illegible]	35	42	46	50	50	31	38	38
3	1.3	"	[illegible]	[illegible]	[illegible]	[illegible]	34	34	34	36	35	36	36	41	41	41	39	40	40	37	38	38	39	40	41	42	42	41
4	2.2	"	[illegible]	[illegible]	[illegible]	[illegible]	3[illegible]	[illegible]	38	38	[illegible]	38	38	39	39	40	40	40	40	40	40	41	41	40	40	41	41	41
5	3.0	"	40	40	[illegible]	[illegible]	[illegible]	40	40	40	[illegible]	40	39	40	40	40	40	41	40	40	40	41	41	41	41	41	41	41
6	3.8	"	[illegible]	[illegible]	[illegible]	[illegible]	42	42	42	42	41	42	42	42	42	42	42	4[illegible]	42	42	42	42	42	42	42	42	42	42
7	5.2	"	[illegible]	41	[illegible]	[illegible]	[illegible]	46	46	46	43	46	46	46	46	46	45	46	46	46	46	46	46	46	45	46	46	46
8	6.5	"	41	[illegible]	48	[illegible]	41	48	48	41	47	47	47	47	41	47	41	41	41	41	47	41	41	47	47	47	47	41
9	7.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	47	50	50	50	47	50	50	47	50	50	50	49	50	50	50	50	50	50	50
Air Temperature			30	17	30	[illegible]	[illegible]	25	[illegible]	28	42	38	52	41	52	31	43	23	33	38	43	45	50	45	42	26	31	43
Surface Temperature			38	20	38	[illegible]	42	28	46	24	41	39	52	49	36	33	47	[illegible]	32	40	38	57	54	47	44	32	40	41
Weather			[illegible]	Clear	Clear	[illegible]	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			SW3	W2	W4	SW2	NE2	None	SW2	NW2	NW2	NW3	W2	SW1	SW1	NW1	N3	None	None	N3	N3	N3	N3	NW2	None	None	S1	SE

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																								
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1900	0700	1345	0515	0715	[illegible]	[illegible]	1500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.3	Cement Conc	22	42	22	51	22	58	28	41	22	22	22	44	51	[illegible]	[illegible]	41	[illegible]	45	55	[illegible]	27	42	41	[illegible]	[illegible]	[illegible]
2	0.5	Cinders	[illegible]	45	[illegible]	44	36	41	29	41	38	36	35	27	42	[illegible]	[illegible]	39	46	43	[illegible]	41	44	44	42	[illegible]	[illegible]	4[illegible]
3	1.3	"	[illegible]	45	[illegible]	[illegible]	42	42	44	43	42	42	41	41	42	41	[illegible]	45	44	45	45	[illegible]	45	41	41	[illegible]	42	[illegible]
4	2.2	"	[illegible]	45	44	44	44	43	44	44	44	44	44	44	42	42	42	44	44	45	45	44	[illegible]	42	45	[illegible]	[illegible]	[illegible]
5	3.0	"	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	45	45	44	44	[illegible]	[illegible]	44	[illegible]	[illegible]
6	3.8	"	44	[illegible]	45	45	[illegible]	45	45	45	45	45	45	45	46	45	[illegible]	[illegible]	45	45	46	[illegible]	45	46	45	[illegible]	[illegible]	[illegible]
7	5.2	"	[illegible]	[illegible]	[illegible]	42	42	42	42	42	42	42	42	42	46	46	42	42	42	42	42	[illegible]	48	42	47	42	42	42
8	6.5	"	42	42	42	[illegible]	42	[illegible]	42	42	42	42	42	48	42	42	42	42	42	42	42	42	47	42	42	42	42	42
9	7.8	"	44	41	42	[illegible]	41	41	42	48	48	48	48	48	48	48	48	48	42	42	41	48	48	48	42	40	[illegible]	[illegible]
Air Temperature			31	38	38	45	30	[illegible]	31	45	26	26	31	30	41	38	52	40	46	42	54	44	52	31	31	53	22	4[illegible]
Surface Temperature			17	41	42	[illegible]	[illegible]	[illegible]	[illegible]	55	27	29	34	42	42	45	62	42	55	53	52	42	58	32	45	[illegible]	34	5[illegible]
Weather			[illegible]	Cloudy	Clear	[illegible]	[illegible]	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Cloudy	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)				[illegible]	W2	[illegible]	[illegible]	[illegible]	NW2	SW4	NE3	NE3	NE3	NE3	NE3	NE2	NW1		SW3	SW2		N3	SW2	NE1	NE2	NW2	NW4	NW

AND TIME

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28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9
[illegible]	0915	1500	0845	1400	0910	1545	0925	1615	0840	1500	0845	1615	1100	0910	1500
[illegible]	22	21	4	12	9	13	19	20	13	21	19	26	25	1	11
[illegible]	22	23	8	13	11	13	19	21	16	20	18	22	34	6	11
[illegible]	28	28	21	23	21	22	29	26	29	28	22	28	28	21	20
[illegible]	46	40	39	39	38	38	37	37	37	39	36	36	36	36	36
[illegible]	48	48	47	47	47	46	46	46	45	45	42	44	44	44	42
[illegible]	59	53	52	52	52	52	52	52	51	52	50	50	49	50	49
[illegible]	60	60	59	59	59	59	59	58	58	58	57	57	57	56	56
[illegible]	61	61	61	61	61	61	60	61	60	60	59	59	59	60	57
[illegible]	62	62	62	62	62	62	61	62	61	62	61	61	61	61	61
[illegible]	23	18	6	12	7	17	22	18	8	20	23	29	28	7	11
[illegible]	26	17	8	12	14	15	21	23	12	23	19	29	25	2	7
[illegible]	Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear
[illegible]	N2	NW3	SW1	NE1	NE1	NE1	NE1	NE2	N1	W3	SW2	SW2	NW4	N3	NW4

10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
0830	1515	0715	1400	0740	1500	0830	1800	0900	1510	0915	1555	0830	[illegible]	0730
-7	7	-3	1	12	19	6	12	28	31	30	32	29	27	27
-2	6	-1	2	14	18	10	14	24	28	29	31	30	31	27
19	25	14	14	21	22	21	30	24	27	30	31	31	31	39
36	35	35	35	34	34	34	34	33	33	33	34	34	33	34
43	43	43	43	42	42	41	41	41	41	40	40	40	[illegible]	40
49	49	49	49	48	48	47	47	47	47	46	47	46	46	46
56	56	56	56	55	55	55	55	55	55	54	54	54	54	53
59	59	59	59	58	58	58	58	58	57	57	57	57	57	57
60	60	60	60	60	60	60	61	60	59	57	57	59	59	59
-7	6	-6	7	-2	20	-1	23	34	36	32	15	25	32	30
-5	2	-1	7	6	15	4	20	33	33	33	32	27	29	26
Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
NW2	NW2	N2	N2	NW1	NW2	NE1	NE1	None	NE1	SE1	SE1	[illegible]	W2	SW3

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3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12
[illegible]	0820	1400	0830	1525	[illegible]	[illegible]	[illegible]	1900	0900	[illegible]	[illegible]	1910	[illegible]	1920	0710
27	21	35	42	40	21	21	21	24	31	31	20	27	17	11	9
22	21	28	36	37	29	21	21	22	29	30	21	25	18	28	12
23	26	27	31	31	32	32	29	28	30	30	22	22	26	28	32
34	34	39	39	34	34	34	34	34	34	34	34	35	34	34	34
39	39	40	40	40	39	39	39	39	39	39	39	39	39	39	39
44	44	44	44	44	44	44	42	44	42	44	42	43	43	42	43
51	50	51	51	50	50	50	50	50	50	50	49	49	43	31	44
54	54	54	59	54	53	53	53	53	53	53	52	52	52	52	52
56	56	56	56	56	56	56	56	56	55	55	55	55	55	55	55
[illegible]	27	42	42	36	15	27	20	33	36	35	22	27	21	27	10
[illegible]	27	40	45	36	18	20	18	32	33	32	22	28	18	28	10
[illegible]	Clear	Clear	Rain	Clear	Clear	Clear	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear
[illegible]	None	SW2	SW3	SW2		NW3	NE3	E2	None	None	SW2	NW3		NW4	NW3

12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
1415	0710	1350	0820	1450	0920	1400	0830	1925	0730	1345	0830	1500	0825	1900
28	8	28	16	28	30	35	29	32	29	41	23	39	7	27
22	13	21	13	24	28	30	31	31	30	31	28	31	12	21
24	23	23	25	25	29	30	32	32	32	32	31	32	26	24
34	34	34	34	33	34	34	34	34	39	39	33	34	34	29
39	39	39	39	38	38	38	38	39	38	38	38	39	38	29
43	43	42	43	42	47	43	42	42	42	42	42	42	42	42
44	44	41	44	49	49	49	49	49	48	48	48	48	48	48
52	52	52	52	52	52	52	51	51	51	51	50	52	52	51
55	55	55	55	54	54	54	54	54	54	54	53	54	54	54
26	12	29	20	36	24	41	25	33	29	37	20	20	6	23
22	10	30	20	35	35	43	28	32	30	39	20	24	7	25
Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
NW4	NW4	NW4	NW1	NW2	None	SW1	NE2	NE4	NW2	NW2	NW3	NW3	NW2	NW3

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7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17
[illegible]	0730	1405	0845	1400	0715	1445	0720	1410	0520	1430	0700	1400	0700	1345	0815
[illegible]	31	38	32	41	29	45	29	51	31	53	36	43	36	47	30
[illegible]	32	32	12	36	31	36	31	38	31	42	35	34	36	39	31
32	32	32	32	33	32	32	32	31	32	32	33	33	34	34	33
34	34	34	34	35	34	34	34	34	34	34	34	34	34	34	35
38	38	38	38	38	38	38	38	37	38	38	38	35	38	38	38
41	42	42	41	42	41	41	41	41	42	41	41	41	41	41	41
47	47	47	47	47	47	47	47	47	46	46	46	47	46	46	46
49	49	49	49	50	49	47	49	49	48	49	49	49	49	49	49
52	52	52	52	52	52	51	52	51	51	51	37	51	51	51	51
[illegible]	32	37	33	35	27	39	29	49	33	50	37	44	37	47	29
33	35	40	33	33	28	40	34	51	33	56	37	44	37	52	32
Clear	Snow	Snow	Snow	Rain	Clear	Clear	Clear	Clear	Clear	Clear	Rain	Rain	Clear	Clear	Cloudy
NW3	NW2	NE2	N1	NE2	N2	NE2	None	E1	SW1	SW1	S3	S3	W2	W2	

17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
1400	0900	1500	0715	1500	0705	1400	0720	1330	0830	1400	0850	1530	0800	1100
44	29	45	25	49	27	51	31	50	31	44	43	54	42	38
34	31	34	30	35	31	36	32	40	30	39	41	47	42	34
31	33	32	32	32	33	33	36	35	30	35	40	42	43	37
33	34	34	35	35	35	35	35	36	37	36	39	39	39	40
37	38	38	38	38	38	38	38	38	38	38	39	40	39	40
40	41	41	41	41	41	41	41	41	41	40	41	42	41	42
45	46	46	46	46	46	46	46	46	46	45	45	46	45	46
48	48	48	48	48	48	48	48	48	48	47	48	49	41	48
50	51	51	51	51	51	51	50	51	50	50	50	51	50	50
36		39	26	43	27	47	30	47	31	47	45	52	41	28
45	35	46	27	47	31	55	32	49	33	48	50	51	40	37
Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
	W3	N2	NW3	NW2	None	S2	N3	NW3	NW2	NW3	E1	None	NE1	SW4

APRIL 1947

5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12
[illegible]	0705	0900	1100	1300	0705	1330	0715	1400	0800	1335	0800	1400	0715	1325	0505
[illegible]	34	40	41	48	44	55	34	53	36	43	35	61	42	69	59
[illegible]	38	38	40	43	43	48	37	47	36	40	33	41	49	57	51
[illegible]	42	41	4	41	43	43	43	41	42	41	40	40	45	45	50
[illegible]	41	41	41	41	41	41	42	41	42	42	42	42	42	42	41
[illegible]	41	41	41	41	41	41	42	41	42	42	42	42	42	42	42
[illegible]	42	42	42	42	43	[illegible]	43	43	43	43	41	41	43	41	41
[illegible]	46	46	[illegible]	46	46	46	46	45	46	46	46	46	46	46	46
[illegible]	47	47	[illegible]	41	41	41	41	47	41	47	41	42	41	41	42
[illegible]	50	50	50	50	49	41	41	49	41	41	41	41	41	42	42
[illegible]	31	43	43	43	43	47	32	43	[illegible]	36	39	50	41	[illegible]	[illegible]
[illegible]	40	41	51	46	48	[illegible]	34	57	45	45	40	60	46	62	[illegible]
[illegible]	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Clear	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	[illegible]
None	S1	SE2	SE3	[illegible]	W[illegible]	W2	NW3	NW4	SE2	SW2	NW2	SW2	SW2	SW2	[illegible]

12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
0700	0900	1100	1300	1505	0815	1400	0505	0700	0900	1100	1300	1500	1655	[illegible]
51	55	57	65	67	28	41	28	29	44	57	64	62	65	57
52	53	57	58	60	38	41	29	29	39	44	50	55	58	54
57	50	50	50	52	44	42	42	42	42	42	43	44	45	42
41	42	44	44	44	45	45	45	45	45	44	44	44	44	44
42	42	42	42	43	44	44	44	44	44	44	44	44	44	44
42	42	42	42	42	44	41	44	44	44	44	44	44	44	44
46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
42	42	42	42	42	42	42	42	42	41	41	42	42	42	42
41	41	41	44	48	41	48	48	41	41	42	41	44	44	42
57	52	27	[illegible]	67	25	[illegible]	32	39	41	[illegible]	[illegible]	[illegible]	[illegible]	41
57	56	62	68	72	27	28	32	44	48	[illegible]	[illegible]	[illegible]	57	48
Rain	Rain	Cloudy	Cloudy	Clear	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear
SW2	SE2	NE2	SW2		SE2	SE2	None	[illegible]	NW2	NW4	NW3	NW2	NW2	WE

6	28	28
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	35
[illegible]	[illegible]	41
[illegible]	42	4[illegible]
[illegible]	4[illegible]	40
[illegible]	4[illegible]	40
[illegible]	42	40
[illegible]	42	42
7	42	42
[illegible]	4[illegible]	41
[illegible]	[illegible]	40
[illegible]	24	50
[illegible]	Clear	Clear
[illegible]	[illegible]	[illegible]

NOTES:

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT B

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE 3

D-5

DATE AND TIM[E]

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946 11 1345	16 1140	20 1110	22 1130	31 0955	NOVEMBER 1946 7 1400	15 0850	19 1110	21 0920	23 1105	25 0930	27 1035	29 1317	DECEMBER 1946 3 1115	7 1110	10 0930	12 1110	14 [illegible]	16 1110	[illegible]	26 [illegible]	27 0940	27 1455	28 [illegible]	30 0920	30 [illegible]
1	0.2	Bit. Conc.	82	65	53	61	56	54	43	45	42	44	43	51	45	31	37	38	36	28	29	[illegible]	28	10	26	13	29	15
2	0.3	Sand & Gravel	76	60	50	54	56	51	48	42	42	44	43	48	45	29	34	38	35	31	29	[illegible]	29	14	26	17	29	27
3	1.0	"	61	60	50	53	59	51	52	48	51	49	46	51	48	39	40	42	40	42	38	[illegible]	31	30	33	22	31	31
4	1.8	"	59	66	56	58	64	56	57	56	58	53	51	54	53	48	45	46	46	48	45	[illegible]	43	42	41	40	39	38
5	2.7	"	57	58	59	59	65	61	60	60	59	58	57	56	57	53	51	51	51	51	37	[illegible]	46	45	45	44	43	41
6	3.5	"	57	60	61	62	66	64	63	64	6[illegible]	61	60	59	59	58	54	59	54	54	53	[illegible]	50	49	46	49	48	47
7	4.8	"	57	60	62	62	66	66	66	65	65	63	63	62	62	61	60	59	58	58	57	[illegible]	55	[illegible]	54	50	50	54
8	6.2	"	59	61	62	63	65	66	66	66	66	64	64	65	63	63	62	61	60	61	61	[illegible]	59	57	59	59	59	57
9	7.5	"	60	61	61	63	64	64	66	66	66	64	63	63	64	64	63	63	61	63	62	[illegible]	60	60	60	60	[illegible]	60
Air Temperature			70	66	52	64	60	51	42	[illegible]	36	38	45	49	40	34	[illegible]	37	39	24	[illegible]	[illegible]	22	[illegible]	[illegible]	[illegible]	21	17
Surface Temperature			77	73	57	66	61	60	41	47	37	38	47	46	41	24	40	38	40	24	[illegible]	[illegible]	23	[illegible]	[illegible]	[illegible]	20	[illegible]
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Clear	Clear	[illegible]	Clear	Clear	[illegible]	[illegible]	Snow	Clear	Snow	Snow	Clear	Clear
Wind (Beaufort Scale)				SW1			NSW2	NW2	N3	N2	E1	NW3	S3	NW2		W2	SW2	[illegible]	SW2	NW3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947 18 1900	20 [illegible]	20 [illegible]	21 0820	21 1420	22 0830	22 [illegible]	23 [illegible]	23 1500	25 [illegible]	25 [illegible]	27 [illegible]	27 1825	28 0830	28 1910	29 [illegible]	30 [illegible]	30 [illegible]	31 [illegible]	3[illegible]	1 [illegible]	1 [illegible]	3 [illegible]	3 [illegible]	4 [illegible]	4 [illegible]
1	0.2	Bit. Conc.	35	20	32	35	35	2[illegible]	[illegible]	[illegible]	20	27	33	38	35	38	36	29	29	[illegible]	38	[illegible]	29	39	30	34	29	[illegible]
2	0.3	Sand & Gravel	31	21	30	33	39	29	[illegible]	[illegible]	35	27	30	38	33	38	33	30	29	[illegible]	[illegible]	[illegible]	31	34	[illegible]	32	30	[illegible]
3	1.0	"	30	29	30	31	[illegible]	[illegible]	[illegible]	29	27	28	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.8	"	35	36	35	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	34	34	34	34	35	[illegible]	35	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.7	"	38	38	38	38	[illegible]	39	38	38	[illegible]	37	37	37	37	37	37	38	38	37	37	[illegible]	38	38	38	37	38	38
6	3.5	"	42	42	42	42	42	42	41	42	42	41	41	41	41	41	41	41	41	41	[illegible]	41	42	42	42	42	41	41
7	4.8	"	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	[illegible]	[illegible]	[illegible]	48	48	48	48	48	48
8	6.2	"	54	53	53	53	53	53	53	53	53	[illegible]	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
9	7.5	"	56	55	55	55	55	[illegible]	[illegible]	55	55	[illegible]	55	54	54	54	54	54	54	54	54	54	54	54	54	54	53	53
Air Temperature			28	11	[illegible]	40	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29	33	[illegible]	[illegible]	34	[illegible]	26	38	[illegible]	[illegible]	[illegible]	33	16	24	29	[illegible]
Surface Temperature			30	[illegible]	38	39	22	[illegible]	[illegible]	[illegible]	[illegible]	25	41	30	35	[illegible]	[illegible]	22	22	[illegible]	[illegible]	30	23	[illegible]	[illegible]	30	[illegible]	[illegible]
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	Rain	Rain	Snow	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			W4	E1	E1	SW2	W2	[illegible]	[illegible]	[illegible]	W3	None	SE1	None	NE1	None	None	[illegible]	None	[illegible]		None	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947 21 0830	21 [illegible]	22 [illegible]	22 [illegible]	24 [illegible]	24 [illegible]	25 [illegible]	25 [illegible]	26 [illegible]	27 [illegible]	27 [illegible]	28 [illegible]	28 [illegible]	1 [illegible]	1 [illegible]	3 [illegible]	4 [illegible]	4 [illegible]	5 [illegible]	5 [illegible]	6 [illegible]	6 [illegible]	7 [illegible]	7 [illegible]	8 [illegible]	8 [illegible]
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	35	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	29	[illegible]	[illegible]	[illegible]	29	34	26	33	38	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	[illegible]
3	1.0	"	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]
4	1.8	"	36	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	36	[illegible]	[illegible]	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.7	"	38	[illegible]	[illegible]	38	38	[illegible]	38	38	[illegible]	[illegible]	39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.5	"	41	[illegible]	41	[illegible]	[illegible]	41	41	[illegible]	[illegible]	40	41	[illegible]	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39	[illegible]	[illegible]	[illegible]	[illegible]
7	4.8	"	45	44	45	[illegible]	[illegible]	45	45	45	45	45	45	45	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.2	"	50	50	50	[illegible]	49	[illegible]	50	49	49	49	50	49	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.5	"	51	[illegible]	[illegible]	[illegible]	[illegible]	51	[illegible]	51	[illegible]	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			10	[illegible]	29	[illegible]	24	41	24	[illegible]	44	29	[illegible]	[illegible]	33	[illegible]	41	[illegible]	31	[illegible]	33	40	[illegible]	[illegible]	47	[illegible]	[illegible]	32
Weather			Cloudy	[illegible]	[illegible]	Snow	[illegible]	Clear	Snow	[illegible]	Clear	[illegible]	[illegible]	[illegible]	[illegible]	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Snow
Wind (Beaufort Scale)			NE3	[illegible]	[illegible]	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947 26 [illegible]	27 [illegible]	27 [illegible]	28 [illegible]	28 [illegible]	29 [illegible]	29 [illegible]	31 [illegible]	31 [illegible]	1 [illegible]	1 [illegible]	2 [illegible]	2 [illegible]	3 [illegible]	3 [illegible]	4 [illegible]	4 [illegible]	4 [illegible]	4 [illegible]	4 [illegible]	4 [illegible]	4 [illegible]	4 [illegible]	5 [illegible]	5 [illegible]	5 [illegible]
1	0.2	Bit. Conc.	41	26	50	[illegible]	[illegible]	32	54	32	51	38	61	41	58	38	[illegible]	[illegible]	39	45	54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	[illegible]	29	45	38	51	32	45	32	52	36	56	41	55	[illegible]	55	[illegible]	[illegible]	42	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49
3	1.0	"	[illegible]	[illegible]	37	37	37	38	38	38	39	40	40	41	44	41	42	42	42	44	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.8	"	43	[illegible]	[illegible]	[illegible]	[illegible]	42	41	42	41	42	41	44	41	41	44	44	41	44	41	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]
5	2.7	"	44	[illegible]	[illegible]	[illegible]	42	42	41	42	42	42	42	44	42	44	44	42	44	44	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.5	"	44	44	44	44	44	44	44	44	44	43	44	44	44	44	44	44	44	44	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.8	"	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.2	"	48	48	49	[illegible]	48	49	49	48	48	49	49	49	48	49	49	48	49	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.5	"	[illegible]	[illegible]	[illegible]	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	38	25	[illegible]	[illegible]	[illegible]	[illegible]	53	[illegible]	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			36	[illegible]	30	20	46	30	31	[illegible]	[illegible]	[illegible]	[illegible]	48	61	[illegible]	55	24	24	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			Cloudy	[illegible]	[illegible]	[illegible]	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	NNE2	NE2	None	SW2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947 16 [illegible]	16 [illegible]	17 [illegible]	17 1845	18 [illegible]	18 [illegible]	19 [illegible]	19 [illegible]	21 [illegible]	21 [illegible]	21 [illegible]	21 [illegible]	21 [illegible]	22 [illegible]	22 [illegible]	23 [illegible]	23 [illegible]	24 [illegible]	24 [illegible]	2[illegible]	25	26	26	26	28	28
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1.0	"	[illegible]	43	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.8	"	44	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.7	"	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.5	"	43	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.8	"	[illegible]	[illegible]	[illegible]	[illegible]	48	48	[illegible]	[illegible]	43	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.2	"	[illegible]	[illegible]	[illegible]	[illegible]	49	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.5	"	[illegible]	[illegible]	[illegible]	[illegible]	49	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NW2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
					JANUARY 1947																									
[illegible]	0920	1500	0950	1400	0910	1545	0920	1615	0910	1500	0905	1615	1100	0910	1500	0935	1515	0715	1400	0900	1500	0810	1600	09A	1540	0915	1555	0830	1530	0710
11	29	25	18	23	21	24	27	24	18	29	19	31	30	9	23	4	20	9	11	20	30	13	29	31	35	32	33	30	34	25
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-4	21	18	8	12	7	17	21	8	8	25	21	29	28	-1	[illegible]	-8	6	-6	7	-1	20	-1	23	34	36	32	35	25	32	30
6	20	17	7	11	10	20	20	21	13	26	21	29	21	1	1	-9	9	8	6	1	19	5	23	35	35	30	32	25	31	26
Snow	Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
NW1	N2	NW1	SW1	NW1	NE	NE	NE	NE2	N1	W1	SW1	SW1	NW2	N1	NW1	NW1	NW3	N2	N1	NW1	NW2	NW1	NE1	None	NE1	SE1	SE1	W2	W2	SW3

3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
													FEBRUARY 1947																	
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Clear	Clear	Clear	Rain	Clear	Clear	Clear	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
[illegible]	None	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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									MARCH 1947																					
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[illegible]	Snow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	[illegible]	Cloudy
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5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
							APRIL 1947																							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	W2

26	28	28
[illegible]	[illegible]	[illegible]

NOTES

Air temperature obtained from thermograph record

Surface temperatures obtained from mercury thermometer laid on the surface of the pavement

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT C

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE 4

D-4

DATE AND T

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	3[illegible]
			1045	1420	1245	1050	1040	1045	1045	0940	1035	0950	1045	0940	1420	1020	1010	[illegible]	1020	1015	1050	0940	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.3	Cement Conc	63	57	56	53	60	47	45	35	41	39	43	45	41	23	33	19	33	21	22	33	25	8	18	18	28	25
2	0.5	Sand & Gravel	59	55	51	50	57	46	47	39	44	43	43	47	43	28	34	[illegible]	35	35	29	35	30	20	24	23	30	30
3	1.3	"	56	56	55	56	61	52	53	50	51	52	47	52	48	41	41	44	44	44	39	39	38	35	34	32	33	33
4	2.2	"	56	59	61	61	65	60	58	57	56	57	58	55	55	50	42	48	49	50	46	43	43	42	42	40	39	34
5	3.0	"	55	61	64	65	67	69	63	62	61	60	59	59	58	56	54	53	54	53	52	47	49	48	48	47	46	[illegible]
6	3.8	"	56	62	66	67	69	67	66	65	64	63	62	61	62	60	58	56	56	57	56	55	52	51	51	51	50	49
7	5.2	"	57	65	67	66	68	68	68	67	66	65	65	64	64	64	60	61	60	60	59	55	57	56	56	56	55	55
8	6.5	"	59	63	65	67	67	68	68	67	65	66	65	65	66	66	65	63	63	62	62	60	60	60	60	59	57	59
9	7.8	"	60	61	64	65	65	66	67	67	66	66	65	66	65	[illegible]	[illegible]	64	64	64	67	63	62	62	62	62	[illegible]	[illegible]
Air Temperature			61	66	55	64	68	50	41	31	[illegible]	[illegible]	[illegible]	18	37	[illegible]	[illegible]	37	37	27	14	25	[illegible]	[illegible]	13	[illegible]	13	18
Surface Temperature			68	67	56	59	53	50	51	[illegible]	41	31	43	42	37	24	[illegible]	45	38	32	16	35	24	2	13	3	23	17
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	[illegible]	Clear	Cloudy	[illegible]	Cloudy	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Clear
Wind (Beaufort Scale)				SW			NW[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	S2	NW2		W[illegible]	SW1	NE1	SW1	NW3	NW3	W1	S1	NW3	W2	NE3	N3	[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			[illegible]	0840	1435	[illegible]	1420	[illegible]	1535	[illegible]	[illegible]	[illegible]	[illegible]	0835	1435	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1445	[illegible]	[illegible]
1	0.3	Cement Conc	29	18	[illegible]	34	34	17	18	7	11	25	24	[illegible]	34	31	36	[illegible]	[illegible]	24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	[illegible]	[illegible]
2	0.5	Sand & Gravel	[illegible]	22	27	[illegible]	33	26	[illegible]	7	21	20	28	31	[illegible]	32	33	[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]
3	1.3	"	31	24	[illegible]	[illegible]	32	32	[illegible]	24	28	24	27	31	[illegible]	[illegible]	32	32	[illegible]	32	[illegible]	[illegible]	33	33	[illegible]	[illegible]	32	32
4	2.2	"	[illegible]	35	35	35	35	35	36	35	35	34	34	34	34	[illegible]	35	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]	[illegible]	[illegible]
5	3.0	"	[illegible]	[illegible]	[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	40	[illegible]	40	[illegible]	[illegible]	[illegible]	40	40	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	[illegible]
6	3.8	"	43	43	44	43	43	43	43	43	43	43	43	42	[illegible]	42	42	43	43	[illegible]	43	[illegible]	43	43	43	43	43	[illegible]
7	5.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.5	"	54	54	54	53	53	53	53	[illegible]	[illegible]	53	53	53	[illegible]	52	52	52	[illegible]	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.8	"	[illegible]	57	57	57	57	57	57	[illegible]	[illegible]	[illegible]	56	[illegible]	[illegible]	56	56	[illegible]	[illegible]	[illegible]	55	[illegible]	[illegible]	[illegible]	55	55	[illegible]	[illegible]
Air Temperature			[illegible]	11	[illegible]	40	34	[illegible]	3	[illegible]	[illegible]	31	31	[illegible]	[illegible]	31	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	38	34	32	1	2	[illegible]	[illegible]	26	33	[illegible]	34	32	[illegible]	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			Clear	Cloudy	Snow	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	[illegible]	Clear	[illegible]	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			W4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	SW3	[illegible]	W3	None	[illegible]	None	[illegible]	None	None	[illegible]	None	[illegible]		None	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																									
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
			0820	[illegible]	[illegible]	1330	0910	[illegible]	[illegible]	[illegible]	1420	0825	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1500	0930	[illegible]	0800	1400	[illegible]	[illegible]	[illegible]	[illegible]
1	0.3	Cement Conc	18	23	24	24	28	[illegible]	22	24	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39	[illegible]	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.5	Sand & Gravel	25	25	26	24	[illegible]	[illegible]	26	28	32	24	33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	32	31	32	35	[illegible]	[illegible]	[illegible]	31
3	1.3	"	32	32	33	33	31	31	31	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	33	[illegible]	33	33	[illegible]	[illegible]	33	[illegible]
4	2.2	"	[illegible]	36	35	35	34	[illegible]	35	35	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.0	"	[illegible]	[illegible]	37	38	39	[illegible]	37	37	37	37	37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	37	37	[illegible]	37	[illegible]	[illegible]	[illegible]	[illegible]
6	3.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	45	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.5	"	[illegible]	[illegible]	[illegible]	[illegible]	49	[illegible]	[illegible]	[illegible]	[illegible]	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.8	"	[illegible]	[illegible]	[illegible]	[illegible]	52	[illegible]	52	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	24	[illegible]	[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	37	[illegible]	35	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	22	30	39	31	[illegible]	[illegible]	31	[illegible]	39	37	[illegible]	39	31	[illegible]	35	44	[illegible]	43	35	40
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	[illegible]	[illegible]	Clear	[illegible]	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Snow	Clear	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	Snow	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0705	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.3	Cement Conc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1.3	"	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	2.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.0	"	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.5	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	42	28	46	29	41	39	55	[illegible]	[illegible]	32	[illegible]	25	32	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
1	[illegible]	Cement Conc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59	52	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	Cloudy	Clear	Cloudy	C[illegible]	Clear	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		W3	SW2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

… AND TIME

						JANUARY 1947																									
28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
[illegible]	0915	1500	0845	1900	0920	1545	0940	1615	0840	1500	0840	1620	1100	0910	1500	0830	1515	0715	1900	0740	1530	0830	1400	0940	1520	0915	1555	0830	1530	0730
[illegible]	24	25	12	20	18	21	23	24	18	25	18	28	[illegible]	9	17	3	13	6	10	20	24	12	22	29	32	29	33	29	31	22
[illegible]	30	39	21	24	22	24	29	28	24	27	22	28	[illegible]	17	21	13	11	13	15	24	25	19	22	28	30	30	32	31	31	27
[illegible]	33	33	32	32	30	30	31	31	30	30	30	30	[illegible]	30	29	27	26	25	24	28	29	27	27	29	30	31	31	31	32	31
[illegible]	34	34	39	39	37	37	37	37	37	37	36	36	30	37	36	35	35	34	34	33	33	33	33	33	33	33	34	34	35	31
[illegible]	46	46	46	45	45	44	44	44	42	43	43	43	43	42	43	42	42	42	41	40	40	40	40	40	39	40	40	40	40	40
[illegible]	50	49	49	47	48	48	48	47	47	47	46	46	44	41	40	46	46	45	45	44	44	44	44	43	43	43	43	43	43	42
[illegible]	55	55	55	55	54	54	54	53	53	53	52	52	52	52	52	51	52	51	51	50	50	50	50	50	49	49	49	49	49	49
[illegible]	57	59	59	58	58	58	58	58	58	57	58	56	56	57	56	56	56	56	56	55	55	55	55	55	55	54	54	54	54	54
[illegible]	6[illegible]	6[illegible]	61	61	61	61	61	60	60	60	60	59	59	59	59	59	59	59	57	58	58	58	58	58	58	58	58	58	58	57
[illegible]	23	18	-5	2	7	17	22	18	8	25	23	[illegible]	24	-1	11	-8	6	-6	7	[illegible]	20	4	23	34	30	32	35	25	32	30
[illegible]	20	17	8	12	4	15	21	23	12	23	19	24	25	0	7	-5	5	[illegible]	7	6	15	4	20	33	33	12	12	27	29	26
[illegible]	Clear N3	Clear NW3	Cloudy SW1	Cloudy NE1	Snow NE	Snow NE1	Snow NE1	Snow NE2	Clear N1	Clear W3	Clear SW3	Cloudy SW2	Clear NW1	Clear N3	Clear NW4	Clear NW2	Clear NW3	Cloudy N2	Snow N2	Clear NW1	Clear NW2	Clear NE1	Cloudy NE1	Rain None	Rain NE1	Clear SE1	Cloudy SE1	Clear W2	Clear W2	Clear SW3

												FEBRUARY 1947																			
3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
[illegible]	[illegible]	1400	0930	1525	[illegible]	1400	[illegible]	1420	[illegible]	1405	[illegible]	1330	0920	[illegible]	[illegible]	1415	[illegible]	1350	[illegible]	[illegible]	0920	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1400
[illegible]	[illegible]	38	41	38	23	34	[illegible]	21	33	32	23	31	21	[illegible]	15	31	14	[illegible]	[illegible]	[illegible]	7	[illegible]	21	31	[illegible]	7	[illegible]	30	15	27
[illegible]	[illegible]	32	37	30	31	32	[illegible]	[illegible]	32	32	24	31	27	[illegible]	24	28	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	21	29
[illegible]	[illegible]	32	33	[illegible]	33	33	[illegible]	33	[illegible]	34	33	33	22	[illegible]	32	31	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	33	[illegible]	34	33	32
[illegible]	[illegible]	36	[illegible]	[illegible]	[illegible]	36	[illegible]	[illegible]	30	38	38	30	38	38	36	38	35	35	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	38	[illegible]	[illegible]	30	36
[illegible]	40	41	41	40	41	42	42	[illegible]	[illegible]	[illegible]	42	40	43	41	40	43	40	40	40	37	40	40	[illegible]	[illegible]	40	40	37	40	40	40
[illegible]	43	43	43	43	42	43	42	[illegible]	[illegible]	[illegible]	42	42	42	[illegible]	42	42	42	42	42	41	42	[illegible]	[illegible]	[illegible]	[illegible]	41	41	41	42	[illegible]
[illegible]	48	44	47	48	47	47	47	47	[illegible]	[illegible]	47	47	47	47	47	47	47	47	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51	51	51	51	51	50	[illegible]	53	50	50	50	50	[illegible]	[illegible]	53	49	[illegible]	53	49
[illegible]	55	55	57	[illegible]	[illegible]	[illegible]	54	54	54	[illegible]	54	54	54	54	54	53	53	54	54	53	57	53	57	53	[illegible]	57	52	53	53	49
[illegible]	[illegible]	40	41	[illegible]	[illegible]	[illegible]	[illegible]	33	[illegible]	[illegible]	[illegible]	27	21	[illegible]	10	20	12	29	21	24	34	41	25	32	27	37	20	20	[illegible]	23
[illegible]	[illegible]	41	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34	32	[illegible]	29	19	-1	10	29	[illegible]	30	25	34	30	42	27	32	30	31	20	24	7	25
[illegible]	[illegible] None	Clear NW	[illegible]	[illegible]	[illegible]	[illegible] NE2	[illegible]	Snow SE	[illegible] None	[illegible] None	[illegible] NE2	Snow NW2	Clear	Clear NW4	Clear NW2	Clear NW4	Clear NW4	Clear NW1	Cloudy NW1	Clear NW2	Clear None	Clear SW1	Cloudy NE2	Cloudy [illegible]	Cloudy NE2	Clear NW2	Clear NW2	Clear NW3	Clear NW2	Clear NW2

								MARCH 1947																						
[illegible]	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
[illegible]	[illegible]	1405	[illegible]	1400	[illegible]	1415	0720	1420	[illegible]	1422	[illegible]	1420	0722	1345	0815	1400	0700	1500	0715	1500	0705	1400	0722	1330	0730	1430	0850	1530	0800	1115
[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	41	[illegible]	[illegible]	33	54	[illegible]	41	37	40	[illegible]	41	24	45	28	44	29	52	32	[illegible]	33	45	42	51	41	40
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	[illegible]	44	[illegible]	43	37	[illegible]	[illegible]	40	32	34	32	41	33	41	39	41	35	40	41	47	43	37
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39	[illegible]	[illegible]	40	[illegible]	[illegible]	37	37	37	37	36	38	37	34	38	34	38	41	42	43	43
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	39	40	34	37	39	40	34	40	40	40	39	41	41	42	42
[illegible]	43	[illegible]	43	[illegible]	43	43	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	[illegible]	42	41	42	42	42	41	42	42	42	42	42	41	43	41
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	[illegible]	[illegible]	[illegible]	[illegible]	42	42	42	42	42	42	42	42	43	42	43	43	43	44
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	45	45	45	45	45	45	45	45	45	46	46	46
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48	[illegible]	[illegible]	[illegible]	47	[illegible]	48	48	48	48	48	48	48	48	48	48	49	48	48
[illegible]	[illegible]	[illegible]	5[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53	[illegible]	[illegible]	[illegible]	41	[illegible]	53	[illegible]	[illegible]	[illegible]	53	[illegible]	[illegible]	50	50	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	[illegible]	[illegible]	[illegible]	[illegible]	31	41	[illegible]	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	31	41	[illegible]	[illegible]	41	[illegible]
[illegible]	35	40	34	37	[illegible]	40	34	51	[illegible]	[illegible]	[illegible]	44	37	54	32	42	[illegible]	43	[illegible]	41	[illegible]	[illegible]	[illegible]	41	33	41	50	51	40	37
[illegible]	Snow [illegible]	[illegible]	[illegible] N1	[illegible]	[illegible]	[illegible]	[illegible] None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] NW2	[illegible] None	[illegible]	[illegible]	[illegible] NW3	Clear NW2	[illegible]	Cloudy E1	[illegible] None	Rain NE1	[illegible] NW4

								APRIL 1947																							
[illegible]	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1335	[illegible]	1415	[illegible]	[illegible]	0535	0720	0920	1120	1300	1535	0915	1400	0505	0700	0900	1100	1300	1500	1600	1650
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	47	37	[illegible]	43	[illegible]	[illegible]	57	58	55	63	65	41	43	34	40	45	57	64	66	63	56
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	[illegible]	[illegible]	[illegible]	41	[illegible]	37	44	45	[illegible]	[illegible]	[illegible]	51	52	53	57	42	43	42	42	42	45	50	53	56	55
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	41	45	[illegible]	[illegible]	44	47	48	48	[illegible]	40	43	44	44	44	44	44	45	46	47
[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	43	43	44	44	[illegible]	43	40	40	40	40	43	43	45	45	45	43	45	45	45	45
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	40	40	42	40	43	41	41	41	41	41	41	47	41	41	41
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	43	[illegible]	[illegible]	45	45	45	45	45	43	40	40	46	40	40	40	46	46	46
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	41	41	41	47	41	41	41	41	41	47	47	47	47	47
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48	48	48	48	48	48	48	48	48	48	49	48	49	49	48
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	[illegible]	41	53	53	[illegible]	[illegible]	49	41	41	41	41	53	41	[illegible]	53	53	53	53	53	53	53
[illegible]	[illegible]	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	56	44	[illegible]	[illegible]	54	55	59	63	67	35	3[illegible]	37	31	41	52	53	57	54	47
[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	62	45	[illegible]	55	54	55	63	70	7[illegible]	37	38	37	42	41	58	63	[illegible]	55	48
[illegible]	[illegible]	[illegible]	[illegible] SE3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy [illegible]	Cloudy [illegible]	[illegible]	[illegible] NW2	[illegible] NW2	Cloudy NW1	Cloudy NW2	[illegible]	Cloudy SE2	[illegible] SE2	Cloudy None	Clear NW1	[illegible] NW2	Clear NW1	[illegible] NW3	[illegible] NW2	[illegible] NW2	[illegible] NW2

[illegible]	28	28
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	41
[illegible]	[illegible]	47
[illegible]	[illegible]	48
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

NOTE:

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT D

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE D-5

DATE AND TI

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	30
			1030	1045	1355	0915	1430	1045	1000	0920	1045	0925	1100	0915	1450	0955	0950	1100	0950	1035	0955	0845	0945	0840	1520	0950	0920	[illegible]
1	0.2	Bit Conc	74	32	66	51	64	55	46	37	41	39	48	41	44	21	31	43	34	35	21	32	24	0	22	6	24	[illegible]
2	0.3	Crushed Rock	61	51	59	46	63	44	45	33	42	39	45	44	44	22	30	42	32	32	21	35	25	0	23	10	25	[illegible]
3	1.0	"	59	56	54	55	60	58	53	49	51	51	45	51	49	40	39	40	42	43	38	38	38	35	34	32	31	32
4	1.8	"	57	57	57	58	64	57	58	55	55	54	51	53	54	47	45	46	44	48	45	42	42	41	40	39	37	37
5	2.7	"	56	58	61	60	66	63	62	57	60	58	58	57	58	54	51	51	51	52	51	47	47	46	46	45	44	44
6	3.5	"	59	59	62	64	64	66	66	64	64	61	62	60	61	59	56	56	56	56	55	52	51	52	51	[illegible]	47	44
7	4.8	"	59	60	63	65	67	68	66	66	66	65	64	62	63	62	60	59	62	59	58	55	55	55	55	55	54	[illegible]
8	6.2	"	59	58	63	63	66	67	67	67	66	66	67	65	65	64	62	62	62	62	61	60	54	54	54	54	54	54
9	7.5	"	60	61	63	63	67	65	66	67	66	64	64	64	65	63	64	63	63	63	62	[illegible]	62	62	62	61	61	[illegible]
Air Temperature			65	63	56	48	66	50	47	34	38	30	53	46	35	19	35	34	34	27	4	35	[illegible]	[illegible]	[illegible]	4	23	[illegible]
Surface Temperature			75	69	60	49	62	54	49	41	38	33	62	40	30	21	37	45	36	35	14	35	14	–	[illegible]	6	[illegible]	[illegible]
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				SW1			WSW2	NW1	N3	N2	E1	NW3	S2	NW2		N2	SW1	NE1	SW2	NW3	NW3	[illegible]	[illegible]	NW3	[illegible]	NE3	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0940	1413	0830	0855	1430	0840	1410	0945	1410	0915	1435	0830	1400
1	0.2	Bit Conc	38	[illegible]	33	35	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	38	26	28	30	31	43	24	45	15	41	26	45
2	0.3	Crushed Rock	[illegible]	[illegible]	[illegible]	33	34	[illegible]	[illegible]	[illegible]	24	[illegible]	22	[illegible]	39	31	35	27	28	31	31	39	29	38	17	34	26	40
3	1.0	"	[illegible]	[illegible]	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32	[illegible]	33	33	33	33	34	34	34	33	33	33	33
4	1.8	"	[illegible]	35	35	35	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	37	[illegible]	35	35	35	36	36	36	36	36	36	36	36	36	38
5	2.7	"	37	[illegible]	[illegible]	39	[illegible]	37	[illegible]	[illegible]	37	[illegible]	[illegible]	[illegible]	[illegible]	38	39	39	39	39	40	40	40	40	40	40	40	40
6	3.5	"	44	44	44	44	44	44	43	44	43	[illegible]	43	[illegible]	[illegible]	42	43	43	43	43	43	43	43	43	43	44	43	44
7	4.8	"	48	48	48	48	48	[illegible]	48	48	48	[illegible]	48	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
8	6.2	"	[illegible]	54	54	54	54	[illegible]	[illegible]	[illegible]	53	53	53	53	53	53	53	53	52	[illegible]	52	53	52	52	52	52	52	52
9	7.5	"	[illegible]	57	57	57	57	[illegible]	57	57	57	[illegible]	57	[illegible]	[illegible]	56	56	56	56	56	56	56	56	56	56	56	56	56
Air Temperature			[illegible]	12	[illegible]	[illegible]	34	[illegible]	3	-2	[illegible]	[illegible]	32	[illegible]	30	41	34	26	20	[illegible]	32	39	[illegible]	27	15	32	27	42
Surface Temperature			[illegible]	5	38	[illegible]	33	1	[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	35	31	36	28	[illegible]	[illegible]	32	40	[illegible]	31	15	30	27	41
Weather			Cloudy	Cloudy	Cloudy	[illegible]	Cloudy	Cloudy	Cloudy	[illegible]	[illegible]	Cloudy	Clear	[illegible]	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			W1	[illegible]	[illegible]	SW2	N2	[illegible]	[illegible]	[illegible]	W3	None	NE1	None	NE1	None	None	NW1	None	[illegible]		None	NW4	NW3	[illegible]	NE2	None	SW2

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																									
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
			0835	1510	0800	1330	0840	1410	0815	1340	1420	0825	1900	0810	1505	0925	1410	1350	0800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0838	1435	0730	[illegible]
1	0.2	Bit Conc	16	19	24	31	26	47	20	35	53	29	53	27	44	30	60	40	30	47	30	45	35	53	38	31	33	44
2	0.3	Crushed Rock	14	21	24	29	27	40	22	30	45	27	44	26	41	28	49	38	31	43	29	42	[illegible]	41	35	34	33	41
3	1.0	"	33	33	31	31	32	32	33	32	32	32	34	33	33	34	37	34	35	35	35	35	36	36	38	38	38	38
4	1.8	"	36	36	35	35	34	35	35	35	35	35	36	35	35	35	35	36	36	36	37	36	37	37	37	38	39	39
5	2.7	"	39	39	39	39	38	38	38	38	38	38	39	38	38	39	38	39	39	38	39	39	39	39	39	40	40	40
6	3.5	"	43	42	42	42	42	42	42	42	42	42	43	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
7	4.8	"	46	46	45	45	45	45	45	45	45	45	46	45	45	45	45	45	45	45	45	45	45	45	46	45	45	45
8	6.2	"	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	49	49	49	49	49	49	49	49	49	49
9	7.5	"	53	53	53	53	53	53	53	53	53	53	53	53	53	53	52	53	52	52	52	52	52	52	52	52	52	52
Air Temperature			4	13	28	28	22		12	30	39	24		22	28	25	38	37	29	35	28	30	30	40	36	4	32	37
Surface Temperature			1	5	29	31	24	41	24	32	42	30	40	27	33	35	42	37	37	41	33	40	36	41	37	47	34	4
Weather			Cloudy	Snow	Snow	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow	Snow
Wind (Beaufort Scale)			NE3	NE4	NE3	SW3	None	SW2	None	W2	NW2	None	W3	None	W2	None	W1	S3	None	NE1	W2	NW2		NW3	NW3	NW2	NW2	NE2

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
			[illegible]	[illegible]	1700	0705	1400	0730	1405	0730	1410	0800	1330	0815	1415	0800	1510	0530	0730	[illegible]	1110	1310	1500	1700	1850	0530	[illegible]	[illegible]
1	0.2	Bit Conc	37	20	57	23	71	30	64	33	73	41	77	45	67	40	75	25	33	[illegible]	67	77	76	66	53	31	[illegible]	41
2	0.3	Crushed Rock	47	24	44	24	59	28	46	31	62	35	65	43	60	35	62	31	32	42	54	63	60	63	57	35	35	42
3	1.0	"	42	40	38	38	31	40	38	40	39	42	41	44	45	44	43	45	44	43	43	42	43	44	45	40	46	45
4	1.8	"	43	42	41	[illegible]	40	41	41	41	40	42	42	43	43	44	44	45	44	44	44	44	44	44	44	45	45	45
5	2.7	"	44	44	43	43	43	42	42	43	42	43	4	43	43	44	44	44	44	44	44	44	44	44	44	44	44	44
6	3.5	"	45	45	45	44	44	44	44	44	44	44	44	44	44	45	45	45	45	45	45	45	45	45	45	45	45	45
7	4.8	"	46	46	46	46	46	46	46	46	45	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	44	46
8	6.2	"	49	49	49	49	41	49	49	49	48	49	49	49	49	49	41	49	41	41	49	41	41	41	49	49	41	41
9	7.5	"	51	51	[illegible]	51	51	51	51	51	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Air Temperature			30	17	30	20	38	25	38	28	42	32	52	41	32	31	43	20	33	38	42	48	30	48	42	26	31	43
Surface Temperature			35	20	36	24	46	30	51	30	52	41	58	48	54	33	52	24	35	43	30	52	36	53	4	30	37	44
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	[illegible]
Wind (Beaufort Scale)			NW5	N2	W4	NNE2	NE2	None	SW2	NW2	NW2	NW3	N2	SW1	SW1	NW2	N3	None	None	N3	[illegible]	[illegible]	[illegible]	NW2	None	None	S1	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
			[illegible]	[illegible]	0730	1340	0720	1400	0720	[illegible]	0515	0715	0915	1105	1300	0820	1400	0830	1400	0815	1400	0815	1400	0545	0710	1315	[illegible]	[illegible]
1	0.2	Bit. Conc.	4	22	33	65	37	68	40	59	32	35	47	57	67	51	84	26	61	50	64	44	71	37	34	47	41	[illegible]
2	0.3	Crushed Rock	[illegible]	[illegible]	35	55	35	63	40	50	30	36	41	43	57	42	70	43	54	46	34	45	61	41	44	79	17	[illegible]
3	1.0	"	41	41	45	44	46	45	47	46	40	46	45	43	45	45	45	47	47	48	48	48	48	50	50	47	48	[illegible]
4	1.8	"	48	47	47	46	46	46	47	46	47	47	46	46	46	46	46	48	48	48	48	48	48	49	47	48	49	[illegible]
5	2.7	"	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	48	48	48	48	49	[illegible]
6	3.5	"	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	48	47	48	48	48	48	47	[illegible]
7	4.8	"	47	47	47	47	47	47	47	47	47	47	47	47	48	47	47	48	47	48	48	47	48	48	48	47	49	[illegible]
8	6.2	"	49	49	49	49	49	49	49	49	49	48	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	[illegible]
9	7.5	"	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	51	50	50	50	50	50	50	[illegible]
Air Temperature			32	38	38	41	36	52	37	45	26	26	31	36	40	39	52	40	46	47	34	44	52	31	34	23	27	30
Surface Temperature			43	46	44	54	34	54	43	57	26	24	42	32	43	44	63	47	56	52	61	42	[illegible]	33	37	73	[illegible]	[illegible]
Weather			Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	[illegible]	Cloudy	[illegible]	[illegible]	Clear	[illegible]
Wind (Beaufort Scale)				SE2	N2	N2	S2	NW1	NW2	NW4	NE2	NE3	NE3	NE3	NE3	NE2	NW1		SW3	SW2		[illegible]	[illegible]	NE1	[illegible]	[illegible]	[illegible]	[illegible]

ID TIME

	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
					JANUARY 1947																									
	0920	[illegible]	0850	[illegible]	[illegible]	1555	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1505	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1525	[illegible]
	24	21	5	8	15	17	13	21	13	21	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16	[illegible]	[illegible]	[illegible]	24	6	20	30	35	33	33	27	35	22
	25	24	9	9	16	20	24	21	16	24	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	24	33	30	33	29	34	24
	31	32	31	30	24	29	30	32	30	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27	27	29	29	32	32	32	32	32
	37	37	37	37	35	35	35	35	35	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32	32	32	32	33	34	34	35	35
	44	44	43	41	42	46	42	42	[illegible]	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	38	38	38	38	38	38	37	37
	47	49	49	49	48	48	48	48	47	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	[illegible]	44	44	44	44	44	44	44	44	44	44
	54	54	53	53	53	51	52	52	52	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]	49	49	49	49	48	48	49	48	48	48
	58	58	57	54	58	58	58	57	[illegible]	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55	55	55	55	55	53	55	54	54	54
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59	58	58	58	58	58	58	58	58	58
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1	[illegible]	[illegible]	27	30	35	36	35	25	34	31
	[illegible]	[illegible]	[illegible]	[illegible]	16	[illegible]	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23	35	35	33	32	25	[illegible]	26
	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Snow	Cloudy	[illegible]	Clear	[illegible]	[illegible]	Cloudy	[illegible]	[illegible]	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Cloudy	Clear	Cloudy	Clear	Clear	Clear
	NW	NW1	SW1	NE	NE	NE	NE1	NE2	N1	N3	NW	[illegible]	[illegible]	[illegible]	[illegible]	NW	NW	[illegible]	[illegible]	NW1	NW2	NE	NW	None	NE	SE1	SE1	W2	W2	SW1

	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
	FEBRUARY 1947																													
	0830	1400	0830	1525	0830	1400	0815	1400	0900	1405	0945	1410	0720	1410	0710	1415	0710	1350	0820	1450	0920	1400	0830	1425	0730	1345	0835	[illegible]	0825	1420
	26	45	43	43	20	40	22	30	33	32	22	34	19	37	10	40	10	44	20	39	36	46	29	35	30	56	25	42	15	46
	26	40	39	40	23	37	24	29	32	32	23	33	21	36	15	38	14	38	21	34	32	39	30	33	30	44	26	40	16	34
	33	33	33	33	34	34	34	34	33	34	33	33	33	32	32	31	31	30	31	30	32	32	33	33	34	31	33	35	31	33
	36	38	36	36	35	36	36	36	36	36	36	36	36	36	35	35	35	35	34	34	34	34	35	35	36	36	35	36	36	36
	40	40	39	40	39	39	39	39	39	39	39	39	39	39	33	39	39	39	38	38	38	38	39	39	39	39	38	40	39	39
	43	44	43	43	43	43	42	43	43	43	43	43	43	43	43	43	43	42	42	42	42	42	42	42	42	42	42	43	42	42
	47	47	47	47	46	46	46	46	46	46	46	46	46	46	48	46	46	46	46	45	46	46	46	45	46	46	45	46	45	45
	52	52	52	52	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	50	51	51	51	51	50	50	50	51	51	52
	56	56	56	56	55	55	55	55	55	55	54	54	54	54	54	54	54	54	54	54	54	54	54	53	54	54	53	54	53	53
	27	42	47	36	15	27	20	33	36	35	22	27	21	27	10	26	12	29	21	36	34	41	25	33	27	37	20	20	6	22
	27	41	45	36	16	28	20	32	35	32	21	29	20	30	10	29	11	32	24	35	35	45	27	34	30	[illegible]	21	23	7	26
	Clear	Clear	Rain	Clear	Clear	Clear	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
	None	SW2	SW3	SW2		NW3	NE3	E2	None	None	SW3	NW3		NW4	NW3	NW4	NW4	NW4	NW1	NW2	None	SW1	NE2	NE4	NW2	NW2	NW3	NW3	NW2	NW3

	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
	MARCH 1947																													
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	33	44	33	41	32	62	31	76	38	74	37	45	36	64	34	[illegible]	34	62	27	59	28	52	33	67	32	[illegible]	44	38	42	40
	33	40	33	40	31	54	31	64	33	64	38	44	37	51	32	55	[illegible]	54	28	59	30	59	33	50	33	50	45	30	42	43
	38	38	33	37	37	39	39	38	40	40	43	42	41	41	41	32	40	34	40	34	41	34	41	41	41	40	45	40	42	43
	39	39	38	39	38	38	39	38	41	41	41	41	41	41	42	42	40	39	41	39	41	39	41	41	41	40	44	41	41	42
	43	43	40	41	40	40	40	40	41	41	41	42	42	42	43	41	41	41	41	41	41	41	41	41	42	41	43	43	43	43
	42	42	41	41	41	41	41	42	43	43	43	43	43	43	41	40	42	42	42	42	42	42	42	42	42	42	43	43	41	44
	45	45	45	46	45	45	45	45	45	45	45	45	45	45	45	45	44	47	44	44	44	44	44	44	44	44	44	45	44	45
	49	49	49	49	49	49	49	49	49	49	49	49	49	49	45	45	45	45	46	46	45	45	45	46	46	46	46	46	46	46
	52	52	52	52	52	52	52	51	52	51	52	52	51	52	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49
	[illegible]	37	33	35	22	32	29	44	35	50	37	44	37	12	[illegible]	30	28	34	26	17	22	19	30	17	[illegible]	[illegible]	45	52	[illegible]	21
	34	[illegible]	33	30	28	42	32	60	38	37	37	45	28	53	35	45	33	46	27	53	30	57	31	52	34	47	52	53	43	39
	Snow	Snow	Snow	Rain	Clear	Clear	Clear	Clear	Clear	Clear	Rain	Rain	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
	NW2	NE2	N1	NE2	NE	NE2	None	E1	SW1	SW1	S3	S3	W2	W2			NW2	NE	NW2	NW2	None	S2	NW	NW1	NW2	NW1	E1	None	NE	SW1

	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
	APRIL 1947																													
	[illegible]	[illegible]	1100	1330	0825	[illegible]	[illegible]	[illegible]	0900	[illegible]	0810	1400	0825	1335	[illegible]	[illegible]	0900	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	41	58	55	46	66	35	78	41	51	44	83	43	82	53	58	55	81	[illegible]	81	41	44	[illegible]	42	55	39	83	82	74	56
	35	43	51	52	45	58	30	60	40	49	38	70	44	64	53	53	53	55	[illegible]	68	41	40	41	[illegible]	[illegible]	57	64	[illegible]	64	69
	46	45	44	44	45	41	40	44	40	[illegible]	[illegible]	43	38	47	[illegible]	51	[illegible]	51	51	51	47	41	40	45	45	45	41	46	48	58
	45	45	45	44	44	45	45	45	40	[illegible]	45	44	40	40	47	47	47	47	47	47	47	47	40	47	[illegible]	[illegible]	[illegible]	40	48	58
	44	44	44	44	45	44	45	45	41	45	45	45	45	46	41	46	41	46	41	47	47	47	46	47	40	40	40	46	46	40
	45	45	45	45	45	45	40	45	41	46	46	41	41	46	41	46	41	41	41	41	47	47	41	41	41	41	41	47	47	47
	46	46	46	46	46	46	46	46	47	46	47	47	47	47	47	47	[illegible]	47	47	47	47	47	47	41	47	47	47	47	47	47
	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49
	[illegible]	50	50	50	50	50	50	50	[illegible]	50	50	50	50	50	50	50	50	50	50	50	50	50	49	49	49	49	49	49	49	49
	[illegible]	43	45	45	45	41	32	42	33	30	37	50	44	[illegible]	[illegible]	54	55	54	[illegible]	67	35	37	37	54	48	52	55	52	[illegible]	[illegible]
	[illegible]	44	52	45	47	54	32	54	37	44	44	70	44	64	55	55	36	63	[illegible]	74	37	38	37	[illegible]	53	60	61	65	59	41
	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Clear	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	Rain	Clear	Rain	Cloudy	Cloudy	Clear	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear
	[illegible]	E2	NE2	S1	W2	[illegible]	NW3	NW4	[illegible]	SW2	NW2	NW2	SW2	NW2	[illegible]	SW2	SW2	SW1	SW2		NE2	NE2	None	NW1	NW2	NW1	NW2	NW2	NW2	[illegible]

28	28
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	50
[illegible]	[illegible]
Clear	Cloudy
[illegible]	[illegible]

NOTES:

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT E

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS AUG 1947

TABLE D 6

DATE AND TI

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946 11	16	20	22	31	NOVEMBER 1946 7	15	19	21	23	25	27	29	DECEMBER 1946 3	7	10	12	14	16	24	26	27	27	28	30	30
1	0.3	Cement Conc.	61	47	54	44	53	41	41	31	39	35	49	43	38	13	27	38	30	30	10	31	20	0	11	9	21	[illegible]
2	0.5	Crushed Rock	59	45	50	43	57	40	41	33	40	37	40	46	40	17	30	37	31	31	19	31	23	6	14	11	22	23
3	1.3		58	54	52	53	59	51	52	47	47	50	45	50	47	38	38	44	41	41	37	36	35	31	47	27	28	[illegible]
4	2.2		56	57	57	57	61	58	63	56	54	55	51	54	54	48	45	46	47	47	44	46	41	40	40	37	36	[illegible]
5	3.0		56	57	60	61	66	64	63	62	60	60	58	58	57	55	57	52	52	54	51	47	47	46	46	45	43	[illegible]
6	3.9		56	59		64	67	68	66		65	63	61	62	62	59	56	56	55	55	55	51	51	50	50	50	41	[illegible]
7	5.2		57	61	64	63	68	70	67	68	68	68	67	63	66	64	63	61	61	61	60	59	58	58	58	57	56	[illegible]
8	6.5		59	61	64	65	66	68	69	68	69	68	67	67	67	65	66	65	64	64	64	61	61	61	60	60	60	[illegible]
9	7.8		61	61	58	63	64	65	68	67	67	67	69	66	67	65	66	65	65	65	65	63	63	63	62	61	63	[illegible]
Air Temperature			60	66	55	45	62	47	47	36	35	35	53	43	40	16	26	39	33	27	10	35	[illegible]	-8	18	-8	13	[illegible]
Surface Temperature			68	66	57	48	61		41	36	39	32	42	32	33	18	36	40	43	28	15	34	24	2	20	0	20	[illegible]
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	[illegible]	Clear	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	[illegible]	Clear	Clear	[illegible]	Clear	[illegible]
Wind (Beaufort Scale)				SW1			NW2	NW2	NW3	N2	E1	Calm	S2	[illegible]		N2	SW1	NE1	[illegible]	[illegible]	NW3	N1	[illegible]	[illegible]	N2	[illegible]	N3	[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947 18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
1	0.3	Cement Conc.	28	[illegible]	28	34	[illegible]	[illegible]	[illegible]	1	4	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28	[illegible]	[illegible]
2	0.5	Crushed Rock	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1.3		30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	2.2		34	33	33	33	33	34	34	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.0		38	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.9		42	42	42	42	42	42	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.5		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.8		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			29	[illegible]	40	40	33	6	[illegible]	-6	[illegible]	[illegible]	[illegible]	34	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27	[illegible]	[illegible]	33	[illegible]
Surface Temperature			28	[illegible]	34	34	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29	27	[illegible]
Weather			Clear	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	[illegible]	Clear	Cloudy	Clear	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	None	[illegible]	None	None	[illegible]	[illegible]	[illegible]		None	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947 21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
1	0.3	Cement Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.5	Crushed Rock	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1.3		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	2.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.0		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.9		[illegible]	[illegible]	[illegible]	[illegible]	40	40	40	[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.5		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.8		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53	[illegible]	[illegible]	[illegible]	[illegible]	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	30	[illegible]	37	[illegible]	30	34	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Snow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	Snow	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947 26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
1	0.3	Cement Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.5	Crushed Rock	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1.3		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	2.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.0		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.9		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.5		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.8		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			38	[illegible]	38	24	41	24	46	27	47	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	[illegible]	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	[illegible]	[illegible]	Clear	[illegible]	[illegible]	[illegible]	Clear	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947 16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
1	0.3	Cement Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.5	Crushed Rock	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1.3		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	2.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.0		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.9		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	6.5		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.8		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	Cloudy	Clear	[illegible]	[illegible]	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	[illegible]
Wind (Beaufort Scale)				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NE3	NE3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

AND TIME

30	30	31	31	JANUARY 1947 2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
0815	1500	0815	1400	0910	1500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	22	7	14	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	29	11	15	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	27	10	21	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	38	36	36	38	[illegible]	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	42	42	42	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	48	47	47	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
56	56	56	56	53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	60	60	60	57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
62	62	62	62	62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	11	-3	12	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	11	8	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Clear	Clear	Cloudy	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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FEBRUARY 1947 4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
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27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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MARCH 1947 8	8	10	10	11	11	12	12	13	13	14	14	15	16	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Clear	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

28	28
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

NOTE:

Air temperature obtained from thermograph record. Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT F

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE D-7

DATE AND TIM

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	30
			1430	1315	1345	0950	1415	0930	1020	1005	1020	1000	1115	0900	1415	0940	0930	1130	0920	1110	0935	0955	0955	0845	1455	0950	0920	1505
1	0.2	Bit. Conc.	84	38	61	52	64	47	46	41	41	41	46	43	43	20	32	44	31	33	21	32	27	8	24	17	29	24
2	0.3	Sand & Gravel	80	37	57	49	62	45	44	37	42	41	44	44	44	22	32	40	32	33	23	32	29	13	25	19	29	26
3	0.8	Silty Clay	61	36	55	56	60	53	53	50	49	49	45	49	49	41	40	42	42	43	40	38	38	37	37	36	35	35
4	1.5	"	59	56		58	62	56	56	54	52	52	48	50	51	45	44	44	45	46	44	41	41	40	40	40	38	38
5	2.3	"	57	57	60	61	64	62	60	58	57	55	55	54	54	52	50	50	50	50	50	47	47	47	41	47	46	46
6	3.2	"	57	58	60	62	64	64	64	61	61	59	56	57	58	56	55	54	52	53	53	52	52	52	51	51	50	50
7	4.4	"	58	59	61	62	64	63	65	64	63	60	60	57	60	59	57	57	56	56	57	55	55	55	55	55	54	54
8	5.7	"	58	57	61	63	64	65	65	64	63	62	60	60	61	59	59	58	58	58	58	58	57	51	57	51	56	57
9	6.9		60	60	62	62	63	64	65	65	64	61	61	60	62	61	61	61	60	60	60	59	54	57	59	59	57	57
Air Temperature			70	67	50	50	66	48	41	40	38	35	59	40	32	17	34	40	32	24	15	35	22	-6	10	-4	23	18
Surface Temperature			75	71	60	50	62	46	51	45	37	35	50	41	35	18	35	47	32	30	14	35	24	2	10	6	20	17
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Clear
Wind (Beaufort Scale)				NW1			NSW2	NW2	N3	N2	E1	NW3	S2	NW2		W2	W1	NE1	SW1	NW3	NW3	W1	S1	NW3	W2	NE3	N3	NW3

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			1405	0845	1640	0815	1430	0940	1545	0840	1505	0735	1415	[illegible]	1440	0345	1420	0835	[illegible]	1435	[illegible]	[illegible]	[illegible]	1420	[illegible]	1455	0835	1405
1	0.2	Bit. Conc.	35	20	32	34	33	15	18	5	[illegible]	[illegible]	34	21	34	31	30	28	28	33	21	[illegible]	26	[illegible]	[illegible]	30	[illegible]	40
2	0.3	Sand & Gravel	32	[illegible]	30	33	33	20	23	11	[illegible]	[illegible]	31	31	33	31	33	43	[illegible]	31	31	34	24	34	14	32	[illegible]	34
3	0.8	Silty Clay	32	32	[illegible]	32	32	32	32	32	32	[illegible]	31	[illegible]	[illegible]	32	32	32	[illegible]	33	33	33	33	33	33	33	33	[illegible]
4	1.5	"	34	35	35	35	35	[illegible]	35	[illegible]	35	[illegible]	34	[illegible]	[illegible]	35	35	35	[illegible]	35	[illegible]	35	35	35	[illegible]	36	[illegible]	[illegible]
5	[illegible]	"	41	42	41	[illegible]	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
6	[illegible]	"	46	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	45	[illegible]
7	4.4	"	50	[illegible]	[illegible]	[illegible]	[illegible]	50	50	[illegible]	[illegible]	[illegible]	47	47	41	47	51	41	51	[illegible]	[illegible]	51	47	41	47	47	41	41
8	[illegible]	"	53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51	51	51	[illegible]
9	6.9		56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54	54	54
Air Temperature			28	12	[illegible]	[illegible]	[illegible]	6	[illegible]	[illegible]	[illegible]	21	24	24	[illegible]	21	24	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21	15	32	21	[illegible]
Surface Temperature			33	15	[illegible]	[illegible]	[illegible]	13	1	[illegible]	10	[illegible]	[illegible]	24	[illegible]	21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24	21	19	[illegible]	21	41
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			W4	E1	E1	SW2	W3	NW2	NW3	W2	W1	None	E1	None	NE1	None	None	NW1	[illegible]	NE1		None	NW2	NW3	NW2	NE2	None	SW2

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																									
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
			0835	1415	0805	1315	0840	1415	0820	1345	1435	0830	1905	0815	1510	0940	1410	1350	0805	1505	0835	1515	0805	1405	0835	1440	0735	1410
1	0.2	Bit. Conc.	19	20	25	31	29	4	22	32	47	30	45	29	37	32	41	30	31	41	31	39	32	45	35	51	32	39
2	0.3	Sand & Gravel	22	23	26	30	28	34	25	30	37	29	37	29	34	28	38	38	31	37	31	35	32	40	32	46	32	34
3	0.8	Silty Clay	34	34	33	32	33	31	34	33	33	33	34	33	33	32	33	33	33	33	34	33	34	33	34	34	34	34
4	1.5	"	36	36	35	35	35	35	35	35	35	35	36	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
5	2.3	"	41	40	40	40	40	40	40	40	40	40	41	40	40	40	40	39	40	40	40	40	40	40	40	40	40	40
6	3.2	"	44	44	44	44	44	44	44	44	44	44	45	44	44	44	44	43	43	43	43	43	44	43	43	43	43	44
7	4.4	"	47	47	47	47	47	47	47	47	47	47	47	47	47	46	46	46	46	46	46	46	46	46	46	46	46	46
8	5.7	"	49	50	49	49	49	49	49	49	49	49	50	49	49	49	49	48	49	49	48	48	48	48	48	49	48	48
9	6.9		52	52	53	52	52	52	52	52	52	52	52	51	51	51	51	51	51	51	51	51	51	51	50	51	51	51
Air Temperature			9	13	28	28	32	28	12	30	39	24		22	28	25	38	37	29	35	28	36	36	40	36	41	32	32
Surface Temperature			9	15	29	30	24	41	24	32	39	30	36	27	33	35	42	37	37	42	33	37	36	45	37	43	34	41
Weather			Cloudy	Snow	Snow	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Snow	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow	Snow
Wind (Beaufort Scale)			NE3	NE4	NE3	SW3	None	SW2	None	W2	NW2	None	W3	None	W2	None	W1	S2	None	NE1	W2	NW2		NW3	NW3	NW3	NW2	NE2

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
			1430	1315	1400	0705	1400	0730	1405	0730	1410	0810	1330	0815	1445	0800	1330	0510	0705	0932	1110	1310	1500	1700	1850	0500	0705	[illegible]
1	0.2	Bit. Conc.	44	[illegible]	49	23	64	30	55	32	67	38	70	41	63	37	68	27	31	46	60	69	71	64	54	32	34	45
2	0.3	Sand & Gravel	41	[illegible]	44	26	56	30	46	32	60	45	63	41	59	35	60	30	31	41	51	61	64	62	56	35	35	42
3	0.8	Silty Clay	42	41	[illegible]	39	39	40	40	41	40	41	40	41	43	44	43	44	44	43	43	43	43	43	43	45	44	44
4	1.5	"	42	42	41	41	40	41	41	41	41	42	41	41	43	43	43	44	44	44	43	43	43	43	43	44	44	44
5	2.3	"	44	44	44	44	43	43	43	43	43	44	44	44	44	44	44	45	45	45	45	45	45	45	45	45	45	45
6	3.2	"	44	44	45	44	45	45	44	45	45	45	45	45	45	45	45	46	46	46	46	46	46	46	46	46	46	46
7	4.4	"	46	47	47	47	[illegible]	47	47	47	46	46	46	46	47	47	46	47	47	47	47	47	47	47	47	47	47	47
8	5.7	"	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
9	6.9		50	50	50	50	50	50	50	50	49	49	49	49	49	49	49	50	49	49	49	49	49	49	49	49	49	49
Air Temperature			30	17	30	30	38	25	38	28	42	38	52	41	51	31	43	23	23	38	43	48	50	48	42	26	31	43
Surface Temperature			37	20	36	25	46	29	51	30	52	42	59	47	58	33	51	24	34	42	50	57	57	51	46	30	40	50
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			SW5	W1	N4	NW2	NE2	None	SW2	NW2	NW2	NW3	W2	SW1	SW1	NW3	N3	None	None	N3	N3	N3	N3	NW2	None	None	S1	SE2

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1305	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1905	0530	[illegible]	1540	0835	[illegible]
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67	37	45	67	37	67
2	0.3	Sand & Gravel	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60	[illegible]	43	75	36	62
3	0.8	Silty Clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47
4	1.5	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.3	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.4		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.7	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49	[illegible]	[illegible]
9	6.9		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	[illegible]	53	27	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

AND TIME

28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
					JANUARY 1947																									
0750	0920	1505	0850	1405	0915	1550	0940	1625	0805	1505	0850	1620	1105	0915	1505	0835	1520	0720	1410	0745	1505	0835	1405	0940	1535	0920	1600	0835	1535	0735
17	29	24	12	22	20	24	26	23	18	25	19	30	28	9	20	2	17	8	13	11	26	10	28	30	34	32	32	28	33	24
19	29	26	15	23	21	24	27	25	20	26	20	30	28	11	20	6	19	10	14	13	26	14	26	29	32	30	32	24	32	25
36	35	35	35	35	34	34	34	34	34	33	33	33	33	33	33	33	32	32	31	31	31	31	30	31	31	31	32	32	32	32
40	38	38	38	38	38	37	37	37	37	37	36	36	36	36	[illegible]	36	36	35	35	34	34	34	34	34	34	34	34	34	34	34
47	46	46	46	46	45	45	44	44	44	44	44	43	43	43	43	43	43	43	43	42	42	42	42	41	41	41	41	42	41	41
51	50	50	50	50	50	50	50	49	49	49	48	48	48	48	48	48	48	48	48	47	47	47	47	48	47	46	46	46	46	46
55	54	54	54	54	54	54	57	53	53	53	52	52	52	52	52	52	52	52	52	52	51	51	51	51	51	50	51	50	50	50
57	56	57	56	58	56	56	56	56	56	55	56	55	55	55	55	55	55	55	54	54	54	54	54	54	53	53	53	57	53	53
59	59	59	59	60	59	58	57	57	58	58	58	57	57	57	57	57	57	57	57	57	57	57	57	56	56	58	56	56	56	56
-4	13	18	-5	12	7	17	22	18	8	25	23	27	24	-1	11	-8	6	-6	7	-1	20	-1	23	34	36	32	35	25	32	30
6	20	17	7	12	16	20	21	21	12	23	23	29	27	1	8	-3	5	-1	6	7	15	5	20	35	35	33	32	27	34	26
[illegible]	Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
NE3	N3	NW3	SW1	NE1	NE1	NE1	NE1	NE2	N1	W1	SW2	SW2	NW2	N3	NW4	NW2	NW3	N2	N2	NW1	NW2	NE1	NE1	None	NE1	SE1	SE1	W2	W2	SW3

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3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
1455	0835	1405	0940	1520	0815	1410	[illegible]	1405	[illegible]	1410	0950	1440	[illegible]	1430	[illegible]	1440	[illegible]	[illegible]	[illegible]	1500	1140	1410	[illegible]	1410	0735	1350	0940	1510	[illegible]	1400
36	[illegible]	40	40	37	25	34	35	31	[illegible]	[illegible]	[illegible]	33	41	38	15	[illegible]	14	24	[illegible]	[illegible]	34	40	[illegible]	34	31	40	[illegible]	37	16	17
32	[illegible]	34	37	30	28	[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	41	34	17	[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	34	31	32	31	37	[illegible]	34	[illegible]	34
33	33	[illegible]	33	29	33	34	[illegible]	33	33	[illegible]	[illegible]	[illegible]	[illegible]	34	34	[illegible]	[illegible]	[illegible]	33	[illegible]	[illegible]	33	[illegible]	33	33	33	33	34	[illegible]	33
36	[illegible]	[illegible]	35	[illegible]	35	35	35	35	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	35	35	[illegible]	[illegible]	35	35	35	35	35	35	36	35	35
41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	43	43	40	41	41	[illegible]	40	41	40	41	41	41
46	45	45	45	45	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	44	44
47	47	47	47	47	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	41
51	51	51	51	51	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
54	54	54	54	54	54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	[illegible]	[illegible]	41	[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	21	41	[illegible]	25	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
Clear	Clear	Clear	Rain	Clear	Clear	Clear	Snow	[illegible]	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	[illegible]	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
NE2	None	SW2	SW3	SW2		NW3	[illegible]	[illegible]	[illegible]	None	SW3	NW3		NW4	NW5	NW4	NW4	NW4	NW1	NW2	[illegible]	SW1	NE2	NE4	NW2	NW2	NW3	NW3	NW2	NW3

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7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
[illegible]	0835	1410	0850	1405	0920	1450	0825	1435	0825	1430	0700	1405	0705	1350	0820	1400	0805	1505	0720	1505	0710	1405	0725	1400	0835	1805	0855	1535	0800	1120
[illegible]	32	39	32	41	30	55	33	68	35	67	37	44	36	58	33	57	33	57	28	63	30	65	32	60	35	60	49	55	42	40
[illegible]	32	34	32	40	31	50	32	60	33	60	32	43	37	50	36	52	32	52	29	58	30	57	33	52	33	52	44	54	42	38
[illegible]	34	34	34	35	35	35	39	36	39	38	40	40	40	40	40	39	40	39	40	39	40	39	41	40	41	40	42	43	43	42
[illegible]	35	35	35	36	36	36	37	36	39	38	39	40	40	40	41	39	40	40	40	40	40	40	41	41	41	40	42	42	43	43
[illegible]	40	40	40	40	40	40	40	40	41	41	41	41	42	41	42	41	42	42	42	43	43	42	43	43	43	42	43	44	43	44
[illegible]	47	44	47	44	43	43	43	43	44	43	44	43	44	44	44	43	44	44	44	45	45	44	45	45	45	44	45	46	45	45
[illegible]	46	46	46	46	46	46	46	45	46	46	46	46	46	46	46	45	46	46	46	46	46	46	46	46	46	46	47	47	46	47
[illegible]	48	48	48	48	48	49	48	48	48	48	48	48	48	48	41	47	48	47	48	49	48	48	48	48	49	49	48	48	48	49
[illegible]	51	51	51	51	50	50	50	50	50	50	50	50	50	50	50	49	50	49	50	50	50	49	50	50	50	49	49	50	49	50
[illegible]	32	37	32	35	27	39	29	49	35	50	37	44	32	42	29	36	28	39	26	43	27	47	30	47	31	47	45	52	41	28
[illegible]	34	41	33	36	28	42	33	60	37	57	37	45	38	52	35	48	34	45	27	51	31	57	31	50	34	47	54	53	43	38
[illegible]	Snow	Snow	Snow	Rain	Clear	Clear	Clear	Clear	Clear	Clear	Rain	Rain	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
[illegible]	NW2	NE2	N1	NE2	N2	NE2	None	E1	SW1	SW1	S3	S2	W2	W2			W3	N2	NW3	NW2	None	S2	N3	NW3	NW2	NW3	E1	None	NE1	SW4

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5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
1500	0705	0905	1105	1305	0810	1335	0720	1405	0805	1340	0805	1405	0720	1340	0510	0705	0905	1105	1305	1510	0820	1405	0510	0705	0905	1105	1305	1505	1700	1855
[illegible]	34	45	55	57	46	61	35	72	40	50	40	78	43	77	32	53	54	58	73	77	41	45	39	41	50	63	76	71	70	57
[illegible]	35	42	50	52	45	58	36	64	37	48	37	69	44	69	52	52	53	57	68	70	41	45	40	41	46	56	67	70	68	60
[illegible]	44	44	44	44	44	44	45	44	45	45	44	43	46	46	48	48	48	48	48	48	47	47	46	46	46	45	45	46	46	46
[illegible]	44	44	44	44	44	44	45	44	45	45	44	44	45	45	46	46	46	47	47	47	47	47	46	46	46	46	46	46	46	46
[illegible]	45	45	45	45	45	45	45	45	46	46	44	46	46	46	46	46	46	46	46	46	47	47	47	47	47	47	47	47	47	47
[illegible]	46	46	46	46	46	46	46	46	46	46	47	41	47	47	47	47	47	47	47	47	47	47	48	48	48	48	48	48	48	48
[illegible]	47	47	41	47	47	47	47	47	47	47	41	41	47	47	47	47	47	47	47	47	47	47	48	48	48	48	48	48	48	48
[illegible]	48	48	48	48	48	48	48	48	48	48	44	48	48	49	48	48	48	48	48	48	48	49	47	49	49	49	49	49	49	49
[illegible]	49	49	49	49	49	49	49	47	49	49	49	49	49	50	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49
[illegible]	31	43	45	45	45	49	32	45	33	36	37	56	44	68	53	54	55	59	66	67	35	37	37	39	47	52	55	55	54	47
[illegible]	40	50	51	48	46	51	35	54	43	45	43	67	45	69	53	55	57	64	72	77	38	40	38	42	50	63	65	63	60	49
Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Clear	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Clear	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear
[illegible]	S1	SE2	SE3	S3	W3	W6	NW3	NW4	SE2	SW2	NW2	SW2	SW2	SW2	SW2	SW2	SW2	SW1	SW2		SE3	SE2	None	NW1	NW2	NW4	NW3	NW3	NW2	W2

26	28	28
[illegible]	0835	[illegible]
[illegible]	32	67
[illegible]	36	62
[illegible]	48	47
[illegible]	49	48
[illegible]	49	49
[illegible]	49	49
[illegible]	49	49
49	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	27	[illegible]
[illegible]	35	[illegible]
[illegible]	Clear	[illegible]
[illegible]	[illegible]	[illegible]

NOTES:

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT G

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE D-8

B

DATE AND TIM

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	30
			1515	1112	1235	1100	1050	1105	0840	1315	0848	1030	1000	1015	1350	1055	1055	0955	1055	[illegible]	[illegible]	[illegible]	[illegible]	0840	1505	1005	0930	[illegible]
1	0.2	Bit Conc.	78	64	60	61	58	53	45	44	42	43	43	49	44	32	35	38	35	32	31	32	30	[illegible]	28	25	31	27
2	0.3	Sand & Gravel	70	52	51	52	57	48	45	49	44	44	42	46	44	33	34	38	35	35	31	33	32	25	30	27	31	30
3	0.8	Silty Clay	61	54	51	52	58	50	51	47	48	49	44	44	46	39	38	40	40	41	38	[illegible]	36	35	34	33	33	34
4	1.5	"	58	56	55	56	61	56	56	55	54	59	51	53	52	47	46	46	46	47	45	42	42	41	41	41	40	40
5	2.3	"	57	57	58	59	63	60	60	59	58	58	55	56	55	52	52	49	49	50	49	46	46	46	46	45	44	44
6	3.2	"	56	58	59	60	63	63	62	61	61	60	59	58	57	56	55	52	52	52	52	48	48	48	48	48	47	47
7	4.4	"	57	58	60	61	64	66	[illegible]	65	65	64	68	63	63	62	61	60	58	60	59	[illegible]	55	55	55	55	54	54
8	5.7	"	58	59	60	61	64	65	67	[illegible]	[illegible]	65	65	65	60	63	63	62	61	[illegible]	[illegible]	[illegible]	58	58	58	58	57	57
9	6.9	"	58	59	59	62	63	64	[illegible]	66	66	65	65	65	65	64	64	[illegible]	63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			69	65	54	63	63	50	45	44	37	36	50	49	29	27	41	35	38	25	25	[illegible]	23	[illegible]	[illegible]	4	23	[illegible]
Surface Temperature			78	63	58	67	62	56	46	47	37	36	48	44	30	24	39	45	40	29	[illegible]	[illegible]	24	2	17	6	20	17
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Clear
Wind (Beaufort Scale)				SW1			NW2	NW2	[illegible]	N2	E1	NW3	S2	NW2		W1	SW1	NE1	SW2	NW2	NW2	[illegible]	SW1	NW2	N2	NE3	N3	[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			1405	1550	1640	0840	1420	0840	1545	0845	1505	0710	1420	0855	1435	0845	1430	0840	1355	1440	0850	1420	0755	1620	0820	1355	0840	[illegible]
1	0.2	Bit Conc.	32	31	31	33	32	19	20	12	24	26	31	32	32	32	32	28	27	30	31	[illegible]	29	33	19	32	27	[illegible]
2	0.3	Sand & Gravel	30	22	27	31	31	24	25	16	24	27	27	31	31	31	31	27	29	30	31	31	31	31	22	30	27	[illegible]
3	0.8	Silty Clay	31	28	27	31	31	31	30	27	27	27	27	31	31	31	32	32	31	31	31	31	31	31	36	30	31	[illegible]
4	1.5	"	35	35	35	35	35	35	35	35	35	34	34	34	32	35	35	35	35	35	35	35	35	35	35	35	35	[illegible]
5	2.3	"	39	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	[illegible]	38	38	38	38	38	[illegible]
6	3.2	"	41	41	41	41	41	41	41	41	41	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
7	4.4	"	47	47	47	48	48	48	48	48	48	48	48	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
8	5.7	"	52	52	52	52	52	51	52	51	51	51	51	51	51	50	50	50	50	50	50	50	50	50	50	50	50	50
9	6.9	"	54	55	55	55	55	55	55	55	[illegible]	54	54	54	54	54	54	54	53	53	53	[illegible]	53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			28	12	40	40	33	[illegible]	9	-2	12	31	37	34	[illegible]	31	34	26	26	28	32	38	[illegible]	[illegible]	15	32	[illegible]	[illegible]
Surface Temperature			30	15	38	35	32	11	1	3	16	26	37	34	35	31	31	28	20	28	32	1	24	31	15	30	47	40
Weather			Cloudy	Windy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Windy	Cloudy	Cloudy	Windy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Rain	Clear	Cloudy
Wind (Beaufort Scale)			N2	E1	E1	NW2	N3	NW2	NW3	N2	N3	None	SE1	None	NE1	None	None	NW1	None	NE1		None	NW4	NW2	NW2	NE2	None	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																									
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
			0835	1420	0810	[illegible]	0850	[illegible]	0820	[illegible]	[illegible]	0835	[illegible]	0825	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit Conc.	20	[illegible]	26	27	27	31	24	31	28	32	37	28	32	30	40	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	[illegible]	[illegible]	32	[illegible]
2	0.3	Sand & Gravel	24	22	27	28	28	31	26	29	30	29	32	28	31	28	[illegible]	[illegible]	[illegible]	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32	[illegible]
3	0.8	Silty Clay	31	31	31	31	31	31	32	31	31	31	33	32	31	[illegible]	[illegible]	[illegible]	31	[illegible]	32	[illegible]	[illegible]	[illegible]	32	[illegible]	32	[illegible]
4	1.5	"	35	35	35	35	35	35	35	35	35	35	35	33	35	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]
5	2.3	"	38	38	37	38	37	37	37	37	37	37	38	37	37	37	37	37	37	37	37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	[illegible]
6	3.2	"	39	40	39	39	39	39	39	39	39	31	40	39	31	39	39	39	[illegible]	39	31	31	[illegible]	31	[illegible]	[illegible]	39	[illegible]
7	4.4	"	45	45	45	45	45	45	45	45	45	48	45	45	44	44	44	44	44	44	44	[illegible]	[illegible]	44	[illegible]	44	44	44
8	5.7	"	48	48	48	48	48	48	47	48	47	47	47	47	47	[illegible]	47	[illegible]	47	47	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]
9	6.9	"	50	51	50	50	50	50	50	50	50	51	51	[illegible]	50	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			9	13	28	28	22	29	12	30	38	24		22	28	[illegible]	36	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32	[illegible]
Surface Temperature			9	[illegible]	29	33	24	31	24	32	39	30	36	27	33	33	42	37	37	41	33	[illegible]	[illegible]	45	31	48	34	40
Weather			Cloudy	Snow	[illegible]	[illegible]	[illegible]	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	[illegible]	[illegible]	[illegible]	[illegible]	Snow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Snow	[illegible]
Wind (Beaufort Scale)			NE2	NE4	NE3	SW3	None	SW2	NW1	N2	NE2	None	N3	None	W2	None	W1	[illegible]	None	[illegible]	N2	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																											
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
			[illegible]	0810	1410	0810	1410	0735	1415	0740	1425	0815	1310	0825	1450	0810	1340	0820	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit Conc.	44	30	38	31	53	32	45	32	57	32	51	42	57	32	54	32	32	44	54	[illegible]	32	52	47	33	35	[illegible]
2	0.3	Sand & Gravel	40	33	33	32	34	33	35	34	45	34	40	40	44	32	47	35	36	32	42	41	37	52	52	38	32	[illegible]
3	0.8	Silty Clay	37	37	32	35	35	36	32	37	37	38	38	41	41	40	40	41	40	39	39	40	40	41	41	42	41	[illegible]
4	1.5	"	[illegible]	40	40	39	39	39	39	39	39	40	39	40	41	42	41	42	42	42	42	42	41	41	41	43	42	42
5	2.3	"	40	41	41	41	40	40	40	40	40	40	40	41	41	41	41	42	42	42	42	42	42	42	42	42	42	42
6	3.2	"	42	42	42	42	41	41	41	41	41	41	41	41	41	42	42	42	42	42	42	42	42	42	42	42	42	42
7	4.4	"	44	45	45	45	45	45	45	45	44	44	44	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
8	5.7	"	46	46	46	46	46	47	47	47	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
9	6.9	"	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
Air Temperature			31	32	30	30	38	25	38	28	42	38	52	41	52	[illegible]	43	23	22	38	43	48	52	44	42	26	31	41
Surface Temperature			31	31	34	25	30	28	47	33	53	41	58	46	58	22	51	29	33	43	[illegible]	[illegible]	57	44	40	31	41	[illegible]
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	[illegible]
Wind (Beaufort Scale)			NW2	N2	N4	NW2	NW2	None	SW2	NW2	NW2	NW2	N2	SW2	SW2	NW2	S2	None	None	N2	S2	[illegible]	N2	NW2	None	None	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
			[illegible]	1340	0800	1355	[illegible]	1410	[illegible]	[illegible]	[illegible]	0725	[illegible]	[illegible]	1320	0825	1410	[illegible]	1410	0825	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit Conc.	36	40	34	44	33	47	36	41	34	35	40	43	54	44	70	42	54	41	[illegible]	[illegible]	[illegible]	34	45	36	36	[illegible]
2	0.3	Sand & Gravel	32	41	33	44	36	45	37	40	38	37	38	41	45	39	45	41	42	43	[illegible]	41	[illegible]	43	43	53	37	41
3	0.8	Silty Clay	43	43	40	41	41	41	41	41	41	41	41	41	41	41	42	44	42	44	45	[illegible]	45	40	41	42	42	43
4	1.5	"	45	44	44	43	44	43	44	43	43	43	43	43	43	43	43	45	45	44	45	[illegible]	45	46	46	46	42	[illegible]
5	2.3	"	45	44	45	44	44	44	44	44	44	44	44	44	44	44	44	44	45	45	45	45	45	45	45	45	46	[illegible]
6	3.2	"	45	45	45	45	45	45	44	44	45	44	44	44	44	44	44	44	45	45	45	45	45	45	45	45	45	[illegible]
7	4.4	"	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	47	46	46	46	46	46	46	[illegible]
8	5.7	"	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	[illegible]
9	6.9	"	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	[illegible]
Air Temperature			34	34	38	45	36	12	39	40	2	[illegible]	[illegible]	[illegible]	[illegible]	36	38	40	46	47	54	[illegible]	52	31	39	[illegible]	37	[illegible]
Surface Temperature			41	41	40	54	35	[illegible]	40	41	[illegible]	48	40	[illegible]	45	45	43	41	58	[illegible]	58	[illegible]	58	36	46	53	36	[illegible]
Weather			Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Cloudy	Cloudy	Cloudy	Cloudy	[illegible]	Clear	Cloudy	Clear	Clear	Clear	[illegible]
Wind (Beaufort Scale)				NE2	SW2	SW2	S2	SW2	NW2	NW1	NE2	N3	NE2	NE2	NE3	NE2	NW1		SW3	SW2		[illegible]	SW2	NE1	NE2	SW2	NW3	[illegible]

AND TIME

	28	30	30	31	31	JANUARY 1947 2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
	[illegible]	0930	1515	0855	1405	0930	1610	0940	1625	0845	1505	0850	1620	1110	0915	1505	0835	1520	0720	1415	0745	1505	0835	1405	0940	1535	0920	1600	0835	1535	0735
	25	31	27	19	26	25	27	27	28	27	30	22	31	30	13	27	9	20	13	17	22	29	16	29	30	32	32	32	30	32	25
	27	31	30	23	28	26	28	30	29	29	31	24	30	29	19	24	15	22	16	19	25	29	20	27	29	31	31	31	30	31	27
	33	33	34	33	32	32	32	32	32	32	32	31	31	32	31	30	28	28	27	27	29	29	28	28	30	30	31	31	31	31	31
	40	40	40	39	39	38	38	38	39	38	38	37	37	37	37	37	38	36	36	36	35	35	35	35	35	35	35	35	35	35	35
	45	44	44	44	44	42	43	42	42	42	42	41	41	41	41	41	41	41	40	40	39	39	39	39	39	39	38	38	38	38	39
	48	47	47	47	46	46	46	45	45	45	45	44	44	44	44	44	43	43	43	43	42	42	42	42	41	41	41	41	41	41	41
	55	54	54	54	54	53	54	53	53	53	53	52	52	52	52	51	51	51	51	51	50	50	50	50	50	50	49	49	49	49	49
	58	57	57	57	57	57	56	56	56	56	56	55	55	55	55	55	54	54	54	54	54	54	53	53	53	53	53	53	52	53	52
	[illegible]	[illegible]	[illegible]	59	59	59	59	59	59	59	58	58	58	58	58	57	57	57	57	57	57	56	56	56	56	56	56	56	56	56	56
	-4	23	18	-5	12	7	17	22	18	9	25	23	29	24	-1	11	-8	6	-6	7	-1	20	-1	23	34	36	32	35	25	32	30
	6	20	17	7	12	10	20	23	21	12	23	23	29	27	1	8	-3	5	0	6	7	15	6	20	35	35	34	32	27	31	26
	Snow	Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
	NE3	N3	NW1	SW1	NE1	NE1	NE1	NE1	NE2	N1	W3	SW2	SW2	NW2	N3	NW4	NW2	NW3	N2	N2	NW1	NW2	NE1	NE1	None	NE1	SE1	SE1	W2	W2	SW3

	FEBRUARY 1947 3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
	[illegible]	0840	1410	0840	1540	0840	1410	0820	1410	0920	1410	0850	1420	0730	1430	0720	1425	0720	1355	0830	1455	0930	1410	0825	1430	0735	1400	0840	1510	0835	1410
	[illegible]	27	[illegible]	37	[illegible]	30	[illegible]	26	31	[illegible]	32	25	32	23	33	[illegible]	32	16	32	24	31	32	33	32	32	31	36	30	33	19	33
	[illegible]	27	[illegible]	31	32	32	32	25	30	[illegible]	31	26	31	25	30	21	30	21	27	25	27	30	31	32	31	31	32	31	32	22	30
	[illegible]	31	31	31	32	31	31	31	32	32	[illegible]	31	31	[illegible]	31	30	30	30	30	30	30	31	31	32	31	32	32	31	32	32	31
	35	35	35	35	35	35	35	35	35	35	35	[illegible]	35	35	35	[illegible]	35	35	35	35	34	35	35	35	35	35	35	34	36	35	35
	38	38	[illegible]	38	38	38	38	38	[illegible]	38	39	38	38	38	38	38	38	38	38	38	37	38	37	37	37	38	37	37	38	37	37
	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	37	40	40	37	37	39	39	37	40	39	39
	47	47	[illegible]	47	46	[illegible]	[illegible]	46	46	46	46	46	46	46	46	46	46	45	46	46	45	46	46	45	45	45	45	45	46	45	45
	[illegible]	50	50	49	50	[illegible]	[illegible]	47	47	47	47	47	49	47	47	47	47	48	48	48	48	48	48	48	48	48	48	47	48	47	47
	[illegible]	[illegible]	[illegible]	52	53	53	52	52	52	52	52	52	52	52	52	51	52	51	51	52	51	51	51	51	51	51	51	50	51	51	51
	12	[illegible]	42	47	36	15	2	26	33	36	35	22	27	21	27	10	26	12	27	22	36	34	41	25	33	27	38	20	19	6	23
	[illegible]	27	40	45	35	17	23	17	32	35	32	25	[illegible]	21	27	7	27	11	33	25	35	35	42	28	34	30	35	19	23	7	25
	Clear	Clear	Clear	Rain	Clear	Clear	Clear	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
	NE2	None	NW2	N3	NW2		NW2	NE3	E2	None	None	N3	[illegible]		NW4	NW3	NW4	NW4	NW4	NW1	NW2	None	SW1	NE2	NE4	NW2	NW2	NW3	NW3	NW2	NW3

	MARCH 1947 7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0825	[illegible]	0825	1440	0710	[illegible]	0710	[illegible]	0825	1435	0810	1510	0725	1510	0715	1410	0730	1340	0840	1410	0855	1540	[illegible]	[illegible]
	[illegible]	32	33	32	37	32	41	32	[illegible]	33	34	34	40	35	41	32	42	32	48	32	52	32	56	33	57	32	57	45	52	[illegible]	[illegible]
	[illegible]	32	[illegible]	32	35	32	35	32	42	32	42	33	36	35	38	33	40	33	40	33	42	33	43	34	44	34	42	[illegible]	44	[illegible]	38
	[illegible]	32	32	32	32	32	34	32	34	33	32	33	34	35	36	36	35	36	35	36	36	36	36	38	38	38	37	41	42	41	39
	[illegible]	35	35	35	36	35	35	35	34	36	35	35	36	36	36	38	37	38	37	38	38	38	38	39	39	40	39	[illegible]	41	[illegible]	[illegible]
	[illegible]	37	37	37	38	37	37	37	37	38	37	37	37	37	37	37	38	39	38	39	39	39	39	39	40	40	40	40	[illegible]	[illegible]	42
	[illegible]	39	39	39	39	39	39	39	38	39	39	39	39	39	39	40	39	41	40	41	40	40	40	40	40	40	40	41	42	41	42
	[illegible]	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	43	44	43	44	44	44	44	44	44	44	44	44	45	44	45
	[illegible]	47	46	46	47	47	46	46	46	47	46	46	46	46	46	46	45	46	46	46	46	46	46	46	46	46	46	46	47	46	47
	[illegible]	47	48	48	[illegible]	48	48	48	48	48	49	49	48	49	49	48	48	48	48	48	48	48	48	48	49	48	48	48	49	48	49
	[illegible]	32	[illegible]	33	35	22	32	22	41	35	50	32	44	38	41	33	36	28	34	26	41	22	41	30	47	32	41	45	52	41	28
	[illegible]	34	40	33	36	28	42	33	60	37	57	32	45	38	51	35	47	35	45	27	50	31	57	30	48	34	47	53	51	43	38
	[illegible]	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Rain	Rain	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	E1	SW1	SW1	S2	S2	W2	W2			N2	N2	NW2	NW2	None	S2	N2	NW3	NW2	NW2	E1	None	NE1	SW2

	APRIL 1947 5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1340	0725	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0725	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0825	[illegible]	0520	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	33	38	43	[illegible]	52	42	55	35	61	39	40	40	62	43	48	51	52	52	54	55	67	38	41	39	40	45	50	55	56	55	48
	[illegible]	37	39	42	45	42	43	37	53	37	43	36	53	43	54	52	50	50	51	55	57	40	41	40	40	41	44	48	52	50	49
	[illegible]	41	41	41	41	42	43	41	41	41	41	39	41	44	44	47	42	47	47	48	48	43	43	42	42	42	42	47	44	45	45
	43	42	42	42	42	42	42	43	42	43	43	42	42	43	44	45	45	45	45	45	45	[illegible]	45	45	44	44	44	44	44	44	44
	42	42	[illegible]	42	42	42	42	43	43	43	43	43	43	43	43	44	44	44	44	44	44	45	45	45	45	45	45	45	45	45	45
	42	42	42	42	42	43	43	43	43	43	43	43	43	43	43	43	43	43	44	44	44	45	45	45	45	45	45	45	45	45	45
	[illegible]	45	45	45	45	45	45	45	45	45	45	45	45	45	46	45	45	45	45	45	45	46	46	47	46	46	46	46	46	46	46
	46	46	46	46	46	47	46	47	47	47	46	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
	48	48	48	48	48	48	48	48	48	48	48	48	48	49	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
	[illegible]	[illegible]	43	45	45	45	49	32	45	23	36	39	50	44	[illegible]	55	54	55	57	66	67	35	39	37	39	47	52	55	55	54	47
	[illegible]	[illegible]	50	57	40	40	52	36	44	43	44	41	62	45	69	54	54	57	64	69	71	37	38	36	42	49	56	57	56	57	45
	[illegible]	Cloudy	Clear	Cloudy	Cloudy	Cloudy	[illegible]	Cloudy	Clear	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Clear	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear
	None	[illegible]	[illegible]	SE2	[illegible]	[illegible]	[illegible]	NW2	NW1	SE2	SW2	NW2	SW2	SW2	SW2	SW2	SW2	SW2	SW1	SW2		SE2	SE2	None	[illegible]	NW2	NW4	NW2	NW2	NW2	W2

	26	28	28
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	32	[illegible]
	[illegible]	42	43
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	48	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

NOTES:

Air temperatures obtained from thermograph record.
Surface temperatures obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT H

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE B
D-9

DATE AND TIME

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	10
			1120	1435	1315	[illegible]	1105	1100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit. Conc.		64	61	57	59	51	44	38	[illegible]	41	44	45	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel		61	56	58	57	48	44	37	42	41	42	44	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty Clay	55	58	54	54	59	51	51	44	43	40	41	40	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.5	"	56	54	58	56	62	56	56	52	[illegible]	52	48	49	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.3	"	57	58	60	59	64	61	59	57	54	50	57	53		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.2	"	57	58	61	62	65	66	63	[illegible]	60	[illegible]	57	55	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.4	"	58	58		63	[illegible]	66	65	63	63	[illegible]	59	60	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.7	"	59	58	61	62	64	66	67	65	60	[illegible]	[illegible]	59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	6.9	"	60	60		62	63	65	65	65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	56	56	64	50	41	41	[illegible]	[illegible]	[illegible]	44	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	60	55	64	59	42	[illegible]	[illegible]	[illegible]	[illegible]	43	33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				SW1			[illegible]	[illegible]	N3	[illegible]	[illegible]	[illegible]	S2	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			1410	[illegible]	1445	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit. Conc.	34	[illegible]	32	34	34	18	[illegible]	[illegible]	24	[illegible]	33	32	[illegible]	32	[illegible]	[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	31	[illegible]	30	33	32	24	35	[illegible]	[illegible]	[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty Clay	[illegible]	[illegible]	30	31	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	31	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.5	"	34	[illegible]	34	34	[illegible]	[illegible]	[illegible]	[illegible]	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.3	"	[illegible]	[illegible]	38	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.2	"	44	44	44	44	44	[illegible]	44	44	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.4	"	[illegible]	[illegible]	48	48	48	[illegible]	[illegible]	41	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.7	"	[illegible]	[illegible]	52	52	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	6.9	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	12	[illegible]	[illegible]	33	[illegible]	[illegible]	-2	[illegible]	[illegible]	[illegible]	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	33	[illegible]	[illegible]	[illegible]	[illegible]	26	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	Rain	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Rain	Rain	Rain	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	E1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	SE1	None	[illegible]	None	None	[illegible]	None	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																										
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
1	0.2	Bit. Conc.	[illegible]	[illegible]	25	[illegible]	21	[illegible]	24	24	[illegible]	30	[illegible]	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	[illegible]	[illegible]	[illegible]	29	21	[illegible]	[illegible]	[illegible]	[illegible]	29	[illegible]	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty Clay	33	[illegible]	32	32	[illegible]	32	32	32	[illegible]	32	[illegible]	32	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.5	"	35	35	35	35	35	35	35	35	34	35	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.3	"	38	38	38	38	37	38	38	38	37	37	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.2	"	42	42	42	42	42	42	42	42	42	42	42	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.4	"	45	45	45	45	45	45	45	45	45	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.7	"	49	49	49	49	49	49	49	49	49	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	6.9	"	52	[illegible]	52	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	28	28	22	29	[illegible]	[illegible]	31	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	24	30	24	[illegible]	24	[illegible]	39	30	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	Snow	Snow	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	None	SW2	None	[illegible]	[illegible]	None	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	57	[illegible]	52	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty Clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.5	"	[illegible]	[illegible]	[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.3	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.4	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.7	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	6.9	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			33	[illegible]	35	[illegible]	47	[illegible]	[illegible]	[illegible]	54	41	57	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty Clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.5	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.3	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.4	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.7	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	6.9	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ND TIME

30	30	31	31	2	2	3	3	4	6	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

JANUARY 1947

4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FEBRUARY 1947

8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MARCH 1947

5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APRIL 1947

29	29
[illegible]	[illegible]

NOTES

Air temperatures obtained from thermograph record.
Surface temperatures obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD
OF
TEST ELEMENT J

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE D-10

DATE AND T

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946											
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30
			1530	1440	1020	1150	0925	1125	0905	1052	0935	1047	0947	1023	1333	1110	1055	0945	1050	0945	1045	0906	1010	0840	1505	1000	0945
1	0.2	Bit. Conc.		67	52	63	56	53	43	42	40	43	43	48	45	30	33	31	36	32	27	32	28	12	25	16	29
2	0.3	Sand & Gravel		64	50	55	55	49	44	40	42	43	41	47	43	31	32	37	32	33	28	32	30	20	27	21	29
3	0.9	Silty Clay	58	57	50	52	57	48	49	44	46	46	42	48	44	35	35	38	37	38	35	34	34	32	32	30	31
4	1.5	"	55	57	56	56	62	54	55	53	52	51	49	51	51	45	42	43	43	45	43	40	40	39	39	38	37
5	2.3	"	55	57	60	60	64	60	59	58	57	56	55	53	55	51	50	48	48	49	48	45	45	45	45	44	43
6	3.2	"	55	57	61	62	64	64	63	61	61	60	58	57	58	55	55	53	57	52	57	50	49	49	47	49	48
7	4.4	"	56	57	61	62	66	66	67	65	65	65	65	61	61	61	57	56	57	58	57	56	55	55	55	55	54
8	5.7	"	57	58	61	62	65	66	67	66	66	66	64	64	63	67	61	61	60	61	60	59	58	58	58	58	57
9	6.9	"	57	57	61	64	64	66	67	67	66	66	65	64	64	63	63	62	62	62	62	61	60	61	60	60	60
Air Temperature			68	65	54	65	58	51	43	45	37	37	49	49	39	23	41	35	38	26	4	31	23	-6	10	-4	23
Surface Temperature			78	65	58	67	58	57	46	45	38	37	47	44	36	24	40	40	40	30	17	24	24	2	10	6	20
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear
Wind (Beaufort Scale)				SW1			NW2	NW2	N3	N2	E1	NW3	S3	NW3		W2	SW1	NE1	SW2	NW3	NW3	[illegible]	S1	NW3	W2	NE3	N2

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																				FEBRUARY 1947				
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4
			1410	0850	1645	0840	1435	0840	1545	0805	1505	0710	1420	0855	1445	0840	1420	0840	0900	1440	0850	[illegible]	0735	1400	0820	1500	0840
1	0.2	Bit. Conc.	34	20	31	34	33	18	20	10	23	26	32	32	33	32	34	28	28	30	[illegible]	[illegible]	28	35	18	34	26
2	0.3	Sand & Gravel	30	21	29	32	32	23	24	13	21	26	29	31	31	32	32	29	29	30	31	34	31	32	20	31	27
3	0.8	Silty Clay	30	26	28	31	31	30	29	23	24	27	27	31	31	31	31	31	30	31	31	34	31	31	27	29	29
4	1.5	"	33	33	33	33	33	33	33	33	33	32	32	32	32	33	33	33	33	33	33	32	33	33	34	34	33
5	2.3	"	38	38	38	38	31	38	38	38	38	37	37	37	37	37	37	32	37	32	32	[illegible]	37	37	38	38	38
6	3.2	"	41	41	41	42	42	42	42	42	42	42	42	42	42	42	41	42	41	41	42	41	42	42	42	42	42
7	4.4	"	50	44	49	49	49	49	49	49	49	49	49	48	48	48	48	48	48	48	48	48	48	48	48	48	47
8	5.7	"	53	53	53	52	52	52	52	52	52	52	52	51	51	53	51	51	51	51	51	51	51	51	51	51	51
9	6.9	"	56	56	56	56	56	55	56	55	55	55	55	55	55	55	55	55	54	54	54	[illegible]	54	54	54	54	54
Air Temperature			28	12	10	40	33	6	3	-2	12	31	39	34	36	31	34	27	26	28	32	38	26	23	15	32	28
Surface Temperature			30	15	38	40	33	9	3	5	15	26	40	38	35	31	37	28	26	29	32	[illegible]	24	29	15	30	27
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			NW1	E1	E1	SW2	W2	NW2	NW1	W2	W3	None	SE1	None	NE1	None	None	NW1	None	NE1		None	NW1	NW2	NW2	NE2	None

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947													MARCH 1947											
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8
			0845	1420	0810	1340	0850	1420	0820	1350	1250	0825	1410	0825	1510	0945	1420	1900	0805	1510	0840	1515	0810	1405	0835	1450	0740
1	0.2	Bit. Conc.	19	21	25	29	28	32	24	30	42	30	40	29	35	31	42	36	32	39	31	37	32	43	34	48	32
2	0.3	Sand & Gravel	22	23	26	28	28	31	25	29	32	29	33	29	32	28	32	32	32	33	32	31	32	36	34	40	32
3	0.8	Silty Clay	29	28	28	29	30	30	30	30	30	31	32	32	31	30	30	31	31	31	32	31	32	31	32	32	32
4	1.5	"	34	34	34	34	34	34	34	34	34	33	34	33	33	34	34	34	34	34	34	32	32	34	34	34	34
5	2.3	"	32	33	33	33	32	32	32	33	32	37	38	37	32	32	32	32	33	32	33	33	32	37	37	37	37
6	3.2	"	41	41	41	41	40	40	40	41	40	40	41	42	40	40	40	40	40	40	40	40	40	40	40	40	40
7	4.4	"	46	46	46	46	46	46	46	46	46	45	46	45	45	45	45	45	45	45	45	45	45	45	45	45	45
8	5.7	"	48	48	48	48	48	48	48	48	48	48	48	48	47	48	48	47	47	47	48	47	47	47	47	47	47
9	6.9	"	51	51	51	51	51	51	51	51	51	51	52	51	51	51	51	50	50	50	50	50	50	50	50	50	50
Air Temperature			1	13	28	28	22	29	12	30	38	24		28	28	26	32	37	24	35	28	30	36	40	36	41	32
Surface Temperature			12	15	29	30	24	1	24	32	39	30	36	27	33	35	42	37	32	40	33	30	36	44	37	43	33
Weather			Cloudy	Snow	Snow	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow
Wind (Beaufort Scale)			NE3	NE4	NE3	SW3	None	SW2	None	W2	NW2	None	W3	None	W2	None	W1	S2	None	NE1	W2	NW2		NW1	NW2	SW2	NW2

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947									APRIL 1947															
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5
			1455	0810	1420	0710	1410	0735	1410	0840	1420	0850	1345	0520	1450	0810	1345	0320	0710	0910	1120	1320	1510	1710	18[illegible]	0510	0710
1	0.2	Bit. Conc.	41	25	48	27	59	31	52	32	62	36	67	43	61	36	44	28	32	34	58	65	66	61	[illegible]	32	36
2	0.3	Sand & Gravel	44	29	42	30	48	32	40	32	32	33	56	41	55	[illegible]	33	33	33	38	46	54	57	57	[illegible]	36	36
3	0.8	Silty Clay	40	36	36	35	36	36	36	37	35	35	40	42	43	[illegible]	41	41	40	40	40	41	42	45	46	43	42
4	1.5	"	[illegible]	41	40	39	39	40	39	40	37	40	42	42	42	[illegible]	42	43	43	43	42	42	42	42	42	43	43
5	2.3	"	[illegible]	42	42	41	41	41	41	41	41	41	41	41	42	42	42	43	43	43	43	43	43	43	43	43	43
6	3.2	"	43	43	43	43	43	43	43	43	42	42	42	43	43	43	43	43	43	43	43	43	43	43	43	43	43
7	4.4	"	45	45	45	45	45	45	45	45	45	45	45	45	45	45	43	[illegible]	45	45	45	45	45	45	45	45	[illegible]
8	5.7	"	46	47	47	47	47	47	47	47	46	47	46	47	47	47	46	47	49	47	47	47	47	47	47	47	47
9	6.9	"	47	49	47	49	49	49	49	47	48	47	48	49	47	49	48	47	49	49	49	49	49	49	49	49	49
Air Temperature			29	17	30	20	38	25	38	38	42	38	32	41	52	31	43	23	33	35	43	28	30	48	42	26	31
Surface Temperature			33	20	33	25	44	30	52	30	54	41	56	45	57	34	30	24	33	44	47	34	57	51	45	30	35
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy
Wind (Beaufort Scale)			SW5	W2	W4	NW2	NE2	None	SW2	NW2	NW2	NW3	W2	SW1	SW1	NW3	N3	None	None	N3	N3	N3	N3	NW2	None	None	S1

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																								
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28
			0710	1340	0740	1320	0710	1420	0710	1350	0520	0720	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0520	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit. Conc.	43	50	34	37	40	65	39	52	34	35	43	57	61	45	79	45	[illegible]	48	61	[illegible]	61	37	44	[illegible]	[illegible]
2	0.3	Sand & Gravel	37	42	37	30	37	[illegible]	40	46	38	37	40	44	52	40	65	43	57	[illegible]	46	42	38	43	43	62	[illegible]
3	0.8	Silty Clay	41	46	46	43	46	44	44	44	43	43	42	46	43	42	46	[illegible]	46	43	37	42	46	47	42	43	43
4	1.5	"	46	46	46	46	46	46	45	45	46	46	45	45	45	45	44	47	46	[illegible]	46	[illegible]	46	47	47	47	47
5	2.3	"	46	46	46	46	[illegible]	45	45	45	45	45	45	45	45	45	45	46	46	46	46	46	46	46	47	47	47
6	3.2	"	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	47	46	46	46	47	46	46
7	4.4	"	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
8	5.7	"	47	47	48	48	48	47	47	48	48	48	48	48	48	48	47	48	48	48	48	47	47	48	48	47	48
9	6.9	"	47	47	47	47	47	47	47	47	47	47	48	48	47	48	48	49	49	48	49	48	48	49	49	48	47
Air Temperature			36	38	38	40	36	32	39	41	26	26	31	36	40	38	52	[illegible]	46	47	54	48	42	31	39	38	27
Surface Temperature			44	41	42	[illegible]	38	36	41	37	26	30	43	46	42	43	20	40	50	52	60	48	37	35	47	47	38
Weather			[illegible]	Cloudy	[illegible]	[illegible]	Clear	Cloudy	Cloudy	Drizzle	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	[illegible]
Wind (Beaufort Scale)				E2	N2	SW2	W2	NW2	NW2	NW4	NE3	NE3	NE3	NE3	NE3	NE2	NW1		SW3	SW2		N3	SW2	NE1	NE2	SW2	NW2

AND TIME

JANUARY 1947

28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
1000	0945	1515	0900	1410	0930	1605	0945	1625	0854	1510	0850	1620	1110	0920	1510	0840	1525	0720	1410	0750	1510	0840	1410	0940	1540	0925	1605	0840	1540	0740
16	20	24	14	23	21	24	22	24	18	28	20	30	29	11	20	5	17	9	14	18	27	12	27	30	32	31	32	28	32	24
21	29	28	18	24	23	25	28	27	22	28	21	30	28	15	22	11	19	12	15	20	26	17	25	28	31	30	31	30	31	26
30	31	31	28	28	27	28	30	30	27	29	27	29	30	25	26	22	23	20	21	25	26	24	24	28	29	30	30	31	31	29
38	37	37	37	37	36	36	36	35	35	35	35	34	35	35	35	34	34	33	33	32	32	32	32	32	32	32	32	32	32	33
44	43	43	43	42	42	42	41	41	41	41	40	40	40	40	40	40	40	40	39	38	38	38	38	38	37	38	37	38	38	38
49	48	48	48	47	47	47	47	47	46	46	46	45	45	45	45	45	45	45	45	44	44	43	43	43	43	43	43	42	41	43
55	54	54	54	54	54	54	54	54	53	53	52	52	52	52	52	52	52	52	51	51	51	51	51	50	50	50	50	50	50	50
58	57	57	57	57	57	57	58	58	56	56	55	55	55	55	55	55	55	55	55	54	54	54	54	54	53	53	53	53	53	53
60	60	60	60	61	60	59	59	59	59	59	58	58	58	58	58	58	58	58	58	57	57	57	57	57	57	57	57	56	57	56
-4	23	18	-4	12	2	17	22	18	9	25	24	29	24	-1	11	-8	6	-6	7	0	20	-1	23	34	36	32	35	25	32	30
6	20	17	7	12	16	20	23	21	12	22	23	29	27	1	8	-3	5	0	6	7	19	6	21	34	35	35	33	25	31	26
Snow	Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
NE2	N2	NW2	SW1	NE1	NE1	NE1	NE1	NE2	N1	N3	SW2	SW2	NW2	N3	NW4	NW2	NW3	N2	N2	NW	NW2	NE1	NE1	None	NE1	SE1	SE1	W2	W2	SW3

FEBRUARY 1947

3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
1500	0840	1410	0840	1535	0840	1410	0825	1410	0910	1415	0855	1420	0730	1430	0720	1425	0720	1355	0830	1505	0830	1410	0840	1435	0735	1355	0840	1510	0835	1410
34	26	33	38	38	27	35	25	31	32	32	24	32	22	35	16	33	16	32	33	33	33	36	31	33	31	41	29	34	17	35
31	27	31	33	34	31	32	27	30	31	32	25	31	24	31	21	31	20	29	34	30	31	31	32	31	31	32	30	34	20	31
29	29	30	31	31	31	31	31	31	31	31	29	30	28	30	28	29	27	28	28	28	31	31	31	31	31	31	31	32	29	30
34	33	34	33	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	33	34	34	33	34	34	34	32	35	34	30
38	38	38	38	38	38	38	37	37	37	37	37	38	37	38	37	38	37	38	38	37	37	37	37	37	37	37	31	38	37	37
42	42	42	41	42	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	40	41	41	41	41	41	41	40	42	41	41
48	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	46	46	46	46	46	46	46	46	46	46	45	47	46	46
51	51	50	50	50	50	50	50	50	50	50	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	48	49	49	49
54	54	54	53	54	53	53	53	53	53	53	53	53	52	53	52	53	52	52	52	52	52	52	52	52	52	52	51	52	51	51
32	28	42	47	36	15	22	20	33	36	35	22	27	21	37	11	36	13	30	22	36	35	42	25	33	27	38	20	19	6	28
30	27	40	45	35	17	31	21	32	35	32	25	29	22	28	11	37	12	30	24	35	35	44	28	34	29	38	19	21	7	24
Clear	Clear	Clear	Rain	Clear	Clear	Clear	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
NE2	None	SW2	SW2	SW2		NW2	NE2	E2	None	None	SW2	NW2		NW4	NW2	NW4	NW4	NW4	[illegible]	NW2	None	SW1	NE2	NE4	NW2	NW2	NW3	NW3	NW2	NW2

MARCH 1947

7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
1450	0840	1415	0855	1420	0725	1450	0825	1430	0830	1440	0720	1410	0710	1355	0820	1410	0910	1510	0720	1510	0710	1410	0730	1340	0840	1410	0855	1540	1420	1120
41	32	32	32	40	31	51	33	60	34	61	36	[illegible]	36	54	33	54	32	53	29	53	31	61	33	5	34	57	46	56	42	44
40	32	32	32	37	32	43	32	48	33	50	31	40	37	44	33	47	32	46	31	47	32	50	34	41	33	48	43	53	42	40
32	32	32	32	32	32	32	32	32	33	35	31	37	38	38	36	37	36	37	36	37	36	38	38	31	38	38	42	45	43	39
34	34	34	34	35	34	34	34	33	35	35	31	37	38	38	37	38	37	38	37	35	39	39	40	34	40	39	41	42	42	42
37	37	32	32	38	37	37	37	36	37	37	37	35	38	38	40	37	40	39	40	40	40	40	40	40	40	40	41	42	41	42
40	40	40	40	41	40	40	40	40	40	40	40	40	40	40	41	40	41	41	41	41	41	41	41	41	42	41	42	43	42	43
45	45	45	45	45	45	45	45	44	45	44	44	44	44	44	44	44	44	44	44	43	45	45	44	45	45	44	45	45	45	46
47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	46	46	46	46	46	46	46	46	46	47	46	47	47	47	47
50	50	50	50	[illegible]	50	50	50	49	50	50	50	49	49	49	49	49	47	47	49	47	49	47	49	47	49	48	49	49	49	49
41	33	37	32	31	27	31	24	47	35	50	32	44	38	47	27	36	28	37	26	43	21	47	30	47	32	47	45	52	41	28
42	33	40	34	36	25	41	35	59	37	57	37	45	38	51	34	47	36	45	21	47	31	56	31	48	34	40	52	52	42	38
Clear	Snow	Snow	Snow	Rain	Clear	Clear	Clear	Clear	Clear	Clear	Rain	Rain	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
NW2	NW2	NE2	N1	NE2	N2	NE2	None	E1	SW1	SW1	S3	S3	W2	W2			W3	N2	NW3	NW2	None	S2	N3	NW3	NW2	NW2	E1	None	NE1	SW4

APRIL 1947

5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
0510	0710	0910	1110	1310	0810	1340	0715	1410	0810	1340	0810	1410	0720	1340	0510	0710	0910	1110	1310	1510	0820	1410	0510	0710	0910	1110	1310	1510	1655	1900
32	34	44	53	52	45	60	35	67	3[illegible]	47	40	73	43	73	52	53	54	57	70	73	41	45	39	41	50	60	72	73	68	57
36	36	40	46	49	44	53	37	57	39	46	37	61	44	61	51	51	52	53	60	64	41	45	40	41	44	57	67	63	63	59
43	42	41	41	42	43	45	42	44	42	43	40	44	46	47	50	50	50	50	50	57	44	44	43	43	43	44	45	41	49	50
43	43	43	43	43	43	43	44	43	44	44	43	43	45	45	46	46	46	46	46	47	46	46	45	45	45	45	45	45	45	45
43	43	43	43	43	43	43	43	43	44	44	44	44	44	44	45	45	45	45	45	45	46	46	46	46	46	46	46	46	46	46
43	43	43	43	43	44	44	44	44	44	44	45	44	45	45	45	45	45	45	45	45	46	46	46	46	46	46	46	46	46	46
43	4[illegible]	45	45	45	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	47	47	47	47	47	47	47	47
47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
49	49	49	49	49	48	49	49	49	47	48	47	49	49	49	49	49	48	48	48	48	49	49	49	49	49	49	49	49	49	47
26	31	43	45	45	45	49	32	45	33	36	34	56	44	68	53	54	55	57	66	67	35	37	37	39	47	52	55	55	54	47
30	35	48	50	45	47	52	35	53	43	47	42	67	45	69	54	55	57	64	70	75	39	38	37	42	50	60	67	65	57	47
Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Clear	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Clear	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear
None	S1	SE2	SE3	S3	W3	W6	NW3	NW3	SE2	SW2	NW2	SW2	SW2	W2	SW2	SW2	SW2	SW1	SW2		SE2	SE2	None	NW1	NW2	NW4	NW3	NW3	NW2	W2

26	28	26
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	43	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	47
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	56
[illegible]	[illegible]	Clear
[illegible]	[illegible]	[illegible]

NOTES:

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT K

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE [illegible]

D-11

DATE AND TIME

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946 11 / 1415	16 / 1320	20 / 1245	22 / 1115	31 / 1350	NOVEMBER 1946 7 / 1150	15 / 0915	19 / 1045	21 / 0940	23 / 1040	25 / 1010	27 / 1000	29 / 1400	DECEMBER 1946 3 / 1005	7 / 1040	10 / 1015	12 / 1025	14 / 1000	16 / 1020	24 / 0910	26 / 1015	27 / 0945	27 / 1500	28 / 0955	30 / 0945	30 / 1515	31 / 0955
1	0.2	Bit Conc		73	48	66	60	56	43	46	61	43	48	48	45	30	30	40	36	32	25	32	28	7	22	10	28	22	11
2	0.3	Sand & Gravel		64	53	56	57	50	44	41	41	42	43	46	44	28	33	38	33	31	25	32	29	13	25	15	28	25	16
3	0.8	Silty Clay	60	56	50	52	58	53	54	44	47	[illegible]	45	41	45	36	36	40	39	40	35	35	35	33	32	31	31	31	29
4	1.5	"	56	57	53	60	62	54	52	52	52	[illegible]	48	51	50	43	42	43	42	45	41	39	37	38	38	37	33	35	35
5	2.3	"	56	56	58	59	64	61	60	59	[illegible]	57	[illegible]	[illegible]	53	32	50	48	49	49	47	45	45	45	45	44	43	42	42
6	3.2	"	57	57	60	61	66	65	64	63	[illegible]	[illegible]	[illegible]	[illegible]	57	35	55	54	54	54	53	51	50	50	50	50	49	49	48
7	4.5	"	59	58	61	51	[illegible]	66	66	66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60	60	57	58	57	57	55	55	55	55	55	54	54	54
8	5.8	"	59	59			65	66	67	67	[illegible]	[illegible]	[illegible]	[illegible]	64	63	61	61	61	61	61	59	59	59	59	59	58	58	58
9	7.2	"	60	60	61	62	62	65	66	67	66	[illegible]	[illegible]	[illegible]	[illegible]	62	61	63	62	63	61	61	61	61	61	61	60	60	60
Air Temperature			70	67	54	[illegible]	[illegible]	30	43	[illegible]	27	[illegible]	[illegible]	31	[illegible]	23	40	36	31	21	14	13	23	-6	10	-4	23	18	-4
Surface Temperature			75	70	58	[illegible]	[illegible]	36	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24	21	46	39	34	11	33	24	2	10	6	20	11	7
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	[illegible]	Clear	[illegible]	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy
Wind (Beaufort Scale)				SW1			WSW	NW2	S3	N	[illegible]	NW1	S3	[illegible]		N2	W1	NE1	SW1	[illegible]	NW1	W1	S1	NW3	W2	NE3	N3	NW3	SW1

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947 18 / 1410	20 / 0850	20 / 1645	21 / 0840	21 / 1450	22 / 0845	22 / 1550	23 / 0945	23 / 1505	25 / 0910	25 / 1425	27 / 0905	27 / 1440	28 / 0840	28 / 1420	29 / 0840	30 / 0905	30 / 1440	31 / 0850	31 / 1420	1 / 1155	1 / 1440	3 / 0820	3 / 1455	4 / 0840	4 / 1410	5 / 1405
1	0.2	Bit Conc.	21	19	33	35	32	15	16	7	23	26	35	32	33	32	30	27	28	30	32	37	26	39	17	37	20	40	41
2	0.3	Sand & Gravel	30	20	30	33	32	21	22	10	23	26	30	31	32	32	33	28	29	30	31	33	28	33	18	32	[illegible]	33	35
3	0.8	Silty Clay	29	27	28	30	31	31	30	24	25	27	28	31	31	31	31	31	30	31	31	31	31	31	28	29	29	30	[illegible]
4	1.5	"	32	31	31	32	32	32	32	32	32	32	31	31	31	32	31	31	32	32	32	32	31	32	33	32	33	33	[illegible]
5	2.3	"	37	38	38	37	37	37	37	38	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
6	3.2	"	43	43	43	43	43	43	43	43	43	42	43	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
7	4.5	"	47	48	48	48	48	48	48	48	48	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
8	5.8	"	53	53	53	53	53	53	53	52	52	52	52	52	52	52	52	52	51	51	51	51	51	51	51	51	51	51	51
9	7.2	"	57	56	56	56	56	56	[illegible]	56	[illegible]	55	55	55	[illegible]	55	55	55	55	55	54	[illegible]	54	54	54	54	53	[illegible]	[illegible]
Air Temperature			28	12	40	40	33	6	3	-2	12	31	[illegible]	35	36	31	34	21	26	27	32	38	26	27	16	32	28	32	41
Surface Temperature			30	15	38	39	32	10	3	7	15	26	40	34	33	31	31	27	27	27	32	37	23	29	15	30	35	40	45
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	[illegible]
Wind (Beaufort Scale)			W4	E1	E1	SW2	W3	NW2	NW3	W2	W3	None	[illegible]	None	[illegible]	None	None	NW1	None	NE1		None	[illegible]	NW1	[illegible]	NE1	None	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947 21 / 0840	21 / 1420	22 / 0810	22 / 1340	24 / 0850	24 / 1420	25 / 0820	25 / 1330	26 / 1440	27 / 0840	27 / 1410	28 / 0830	28 / 1510	1 / 0945	1 / 1420	3 / 1335	4 / 0805	4 / 1510	5 / 0810	5 / 1515	6 / 0815	6 / 1405	7 / 0830	7 / 1345	8 / 0840	8 / 1415	10 / 0830
1	0.2	Bit Conc.	17	20	25	31	27	33	[illegible]	36	48	31	34	24	31	33	38	38	31	41	31	31	33	43	30	[illegible]	33	40	32
2	0.3	Sand & Gravel	21	22	25	29	28	33	34	30	36	29	34	27	33	28	36	34	32	[illegible]	32	32	32	37	32	33	32	34	32
3	0.8	Silty Clay	29	28	28	29	30	30	30	31	30	31	[illegible]	31	31	31	30	31	31	31	32	31	32	31	32	32	32	32	32
4	1.5	"	33	33	33	33	32	32	33	33	32	33	[illegible]	33	33	33	[illegible]	33	33	33	33	33	33	33	33	33	33	33	33
5	2.3	"	37	37	37	37	37	37	37	37	36	38	37	36	36	36	36	36	36	36	36	37	37	37	36	37	37	37	37
6	3.2	"	41	41	41	41	40	41	41	41	40	40	41	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
7	4.5	"	45	45	45	45	45	45	45	45	44	44	45	40	44	44	44	44	43	44	44	43	43	43	44	44	44	44	43
8	5.8	"	49	49	49	49	48	48	48	48	48	48	49	48	48	48	48	48	47	48	48	47	48	47	48	47	47	47	47
9	7.2	"	52	52	52	51	51	51	51	51	51	51	52	51	51	51	51	50	50	50	50	[illegible]	50	50	50	50	50		50
Air Temperature			9	13	28	28	22	29	12	30	38	24		22	28	26	18	31	29	33	28	36	36	40	36	41	32	31	33
Surface Temperature			12.	15	29	30	24	41	23	32	39	30	37	27	33	33	42	37	37	40	32	31	36	44	37	43	33	43	38
Weather			Cloudy	Snow	Snow	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Snow	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow	Snow	Snow
Wind (Beaufort Scale)			NE3	NE4	NE3	SW3	None	SW2	None	W2	NW2	None	W3	None	W2	None	W1	S3	None	NE1	W2	None		NW3	NW1	NW1	NW2	NE2	N1

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947 26 / 1455	27 / 0810	27 / 1410	28 / 0710	28 / 1415	29 / 0745	29 / 1413	31 / 0730	31 / 1420	1 / 0815	1 / 1330	2 / 0820	2 / 1430	3 / 0815	3 / 1345	4 / 0520	4 / 0703	4 / 0903	4 / 1110	4 / 1310	4 / 1500	4 / 1710	4 / 1900	5 / 0510	5 / 0710	5 / 0910	5 / 1110
1	0.2	Bit Conc.	49	22	53	25	66	31	59	33	67	37	61	43	63	38	68	25	32	47	[illegible]	70	67	61	31	31	33	43	54
2	0.3	Sand & Gravel	46	26	45	27	54	30	45	32	57	33	54	42	58	35	37	30	31	40	[illegible]	58	[illegible]	[illegible]	33	30	33	40	48
3	0.8	Silty Clay	40	37	36	36	36	37	36	37	38	38	40	[illegible]	43	41	41	41	40	31	40	41	[illegible]	43	43	41	42	41	41
4	1.5	"	41	40	39	39	38	39	39	40	39	40	40	42	41	43	42	43	42	42	42	41	41	42	42	41	43	41	41
5	2.3	"	42	42	41	41	41	41	41	41	41	41	41	41	42	42	42	43	42	42	41	43	[illegible]	43	43	41	[illegible]	[illegible]	41
6	3.2	"	43	43	43	43	43	43	43	43	42	43	42	43	43	43	43	43	43	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	43
7	4.5	"	44	45	45	45	45	45	45	45	44	45	46	43	45	45	45	[illegible]	[illegible]	43	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43
8	5.8	"	47	47	47	47	47	47	47	41	[illegible]	47	41	[illegible]	[illegible]	47	47	41	49	41	41	[illegible]	[illegible]	41	47	[illegible]	[illegible]	[illegible]	47
9	7.2	"	49	49	49	49	41	49	49	41	41	47	[illegible]	41	41	47	[illegible]	41	47	41	41	[illegible]	[illegible]	47	47	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			29	11	30	20	38	25	38	[illegible]	42	38	52	[illegible]	[illegible]	31	[illegible]	23	33	38	43	[illegible]		[illegible]	32	26	[illegible]	[illegible]	[illegible]
Surface Temperature			33	20	35	25	40	30	52	[illegible]	55	41	55	45	57	34	[illegible]	[illegible]	33	[illegible]	41	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	[illegible]	Clear	[illegible]	[illegible]	Clear	[illegible]	Clear	[illegible]	[illegible]	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			SW5	W2	W4	NNW2	NE2	None	SW2	[illegible]	NE2	NW3	W2	SW1	SW1	NW3	[illegible]	None	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947 16 / 0705	16 / [illegible]	17 / [illegible]	17 / 1350	18 / [illegible]	18 / [illegible]	19 / [illegible]	19 / [illegible]	21 / [illegible]	21 / [illegible]	21 / [illegible]	21 / [illegible]	21 / 1222	22 / [illegible]	22 / [illegible]	23 / [illegible]	23 / [illegible]	24 / [illegible]	24 / [illegible]	25 / [illegible]	25 / [illegible]	26 / [illegible]	26 / [illegible]	26 / [illegible]	28 / [illegible]	28 / [illegible]
1	0.2	Bit Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.3	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty Clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1.5	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2.3	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	3.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.5	"	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.8	"	[illegible]	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	57	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ND TIME

30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
				JANUARY 1947																									
0925	1515	0855	1500	0925	1600	0945	1630	0850	1510	0850	1640	1110	0920	1510	0840	1545	0725	1420	0750	1510	0940	1410	0940	1500	0945	1605	0840	1940	0940
28	22	11	20	20	24	26	22	16	27	19	30	30	8	19	1	15	7	13	5	26	9	29	31	34	33	33	21	31	29
28	25	14	23	21	24	27	25	19	28	30	30	28	11	20	6	11	10	14	10	24	13	26	29	32	29	32	31	31	25
31	31	29	27	28	28	30	30	28	29	28	29	30	27	26	24	24	23	23	24	24	24	25	28	29	30	30	30	31	29
35	35	35	35	34	34	33	34	32	34	33	33	33	34	33	33	32	32	32	31	30	30	30	30	31	31	31	31	32	31
43	42	42	42	42	41	41	41	41	41	40	40	40	40	40	40	40	39	37	38	38	37	37	37	37	37	37	37	39	37
49	49	48	48	48	48	47	47	47	41	46	46	46	46	46	45	46	43	43	44	44	44	44	42	43	43	43	43	43	43
54	54	54	54	53	53	52	53	52	52	51	51	51	51	51	51	51	51	51	50	50	49	49	49	49	49	49	45	49	48
58	58	58	58	58	57	57	57	57	57	56	56	56	56	56	57	55	53	55	55	53	55	54	54	58	54	54	54	54	53
60	60	60	60	60	60	60	60	59	59	59	58	57	59	58	58	58	58	58	58	58	57	57	57	57	57	57	57	57	57
23	18	-4	12	8	19	22	19	9	24	26	29	24	9	11	-5	6	-0	7	0	20	-1	31	34	36	36	33	21	28	30
20	17	7	12	16	20	23	21	12	22	21	29	27	1	8	-3	5	0	6	5	15	6	21	33	33	34	31	21	31	[illegible]
Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	[illegible]	Rain	Clear	Cloudy	Clear	Clear	Clear
N3	NW3	SW1	NE1	NE1	NE1	NE1	NE2	N1	W3	SW2	SW2	[illegible]	N3	NW4	NW2	NW3	N2	N2	NW1	NW2	NE1	NE1	[illegible]	NE1	SE1	SE1	[illegible]	[illegible]	[illegible]

4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
										FEBRUARY 1947																			
0840	1410	0805	1530	0740	1415	0820	1410	0910	1415	0855	1420	0730	[illegible]	0720	[illegible]	0720	1355	[illegible]	1500	0930	1400	[illegible]	1435	[illegible]	1353	0740	[illegible]	0730	[illegible]
20	20	21	20	24	17	25	31	31	32	26	31	21	39	[illegible]	26	15	19	23	27	16	[illegible]	20	26	[illegible]	47	21	35	15	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	22	21	30	[illegible]	[illegible]	20	25	30	33	22	26	21	21	[illegible]	[illegible]	13	30	22	16	[illegible]	00	20	33	27	37	20	[illegible]	0	[illegible]
25	20	[illegible]	[illegible]	17	[illegible]	20	[illegible]	[illegible]	32	25	29	20	29	7	20	12	30	21	16	[illegible]	00	28	34	29	43	19	21	7	[illegible]
Clear	Clear	[illegible]	[illegible]	Snow	Cloudy	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	[illegible]	[illegible]	[illegible]
None	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	None	[illegible]	SW1	[illegible]		NW4	NW3	NW4	NW4	NW4	NW1	NW1	[illegible]	SW1	NE1	NE4	NW4	NW4	NW3	NW3	[illegible]	[illegible]

8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
								MARCH 1947																					
0740	1415	[illegible]	[illegible]	0730	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1415	0715	1355	0725	1400	0715	[illegible]	0730	1515	0705	1420	0755	1300	0740	[illegible]	[illegible]	[illegible]	0704	[illegible]
33	40	32	40	30	53	[illegible]	[illegible]	38	[illegible]	[illegible]	44	36	61	38	30	38	[illegible]	49	61	[illegible]	41	31	41	31	41	49	40	42	40
[illegible]	34	[illegible]	38	[illegible]	41	[illegible]	34	33	57	37	42	36	49	32	31	36	49	47	58	31	30	[illegible]	33	36	33	44	33	40	41
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	37	38	38	38	33	37	36	37	38	37	37	38	[illegible]	37	37	37	40	43	43	40
33	33	[illegible]	34	33	[illegible]	36	33	36	33	38	38	38	38	37	37	39	37	38	38	37	30	37	37	40	39	40	40	40	40
37	37	[illegible]	37	37	37	37	30	37	37	37	38	37	37	40	39	40	39	40	40	40	40	40	40	40	40	40	40	40	40
40	38	43	41	43	40	40	40	40	40	40	40	41	41	41	41	41	41	41	41	41	41	41	40	41	40	41	43	40	41
44	44	43	44	44	44	43	41	44	44	44	44	44	44	40	43	44	44	44	44	44	44	44	44	44	44	44	43	40	43
41	41	41	48	47	47	47	41	41	41	47	41	41	47	41	41	41	47	47	41	41	41	41	41	41	40	41	41	41	41
50	[illegible]	50	50	50	[illegible]	50	49	50	[illegible]	50	[illegible]	50	50	49	49	49	49	49	49	49	49	49	49	49	[illegible]	[illegible]	49	49	49
32	33	32	33	27	[illegible]	29	49	33	[illegible]	[illegible]	44	30	41	47	30	27	42	20	41	41	41	30	41	30	[illegible]	[illegible]	30	40	47
30	43	38	50	40	41	31	58	38	58	31	45	37	56	[illegible]	47	33	45	47	37	30	36	31	41	39	40	30	32	40	37
Snow	Snow	Snow	Rain	[illegible]	[illegible]	Clear	Clear	[illegible]	[illegible]	Rain	Rain	[illegible]	Clear	Cloudy	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	Clear	Clear	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	[illegible]	Rain	[illegible]
NE2	NE2	N1	NE2	NE	NE2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NE	NE2			NW3	NE	NW3	NE2	[illegible]	[illegible]	NE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
							APRIL 1947																						
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28	28
[illegible]	[illegible]

NOTES

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT L

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE [illegible]

DATE AND TIME

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946													
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	30	31
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																										
			19	20	20	21	21	22	22	23	23	25	25	27	27	28	29	29	30	30	31	31	1	1	3	3	4	4	5
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																										
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	[illegible]	6	6	7	7	8	9	10
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																										
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5	5
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

P

E AND TIME

28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

JANUARY 1947

3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FEBRUARY 1947

7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MARCH 1947

5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	13	13	14	14	15	15	15	15	15	16	16	16
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APRIL 1947

26	28	28
[illegible]	[illegible]	[illegible]

NOTES

Air temperatures obtained from thermograph record.
Surface temperatures obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT M

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE M-3

DATE AND TI

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	3
			1145	1309	1145	1645	1120	1010	1010	0955	1020	0945	1020	0955	1520	1400	0920	1125	0930	1050	0945	0910	1615	0940	1505	1005	0930	[illegible]
1	0.2	Bit. Conc.		70	61	53	61	50	45	39	41	40	48	47	41	41	32	43	30	33	19	31	25	4	31	13	21	2[illegible]
2	0.4	Sand Gravel		63	58	52	51	[illegible]	45	37	21	41	43	44	44	26	32	41	30	33	22	34	27	11	21	19	28	2[illegible]
3	0.8	Silty clay	55	57	51	53	47	56	56	49	49	50	46	51	47	37	39	46	31	41	37	17	35	33	33	32	31	3[illegible]
4	1.5	"	56	53	55	56	62	57	57	55	54	54	50	52	52	45	44	45	45	45	47	41	40	39	38	37	36	3[illegible]
5	[illegible]	"	58	53	57	55	65	63	66	61	53	57	56	56	53	52	47	49	48	50	46	41	45	45	44	44	42	4[illegible]
6	[illegible]	"	57	60	61	61	61	65	66	64	66	66	66	61	61	58	56	50	51	55	50	51	51	50	50	50	48	4[illegible]
7	[illegible]	"	60	60	62	62	62	70	69	67	68	68	66	65	65	63	61	60	57	60	57	51	56	56	55	56	55	5[illegible]
8	[illegible]	"	60	61	63	68	66	67	70	70	67	68	67	67	67	65	64	64	66	63	62	61	60	61	60	57	57	5[illegible]
9	[illegible]	"	62	62	63	63	65	67	68	68	67	67	67	66	66	60	65	65	68	68	63	62	66	62	62	62	61	6[illegible]
Air Temperature			70	67	76	77	66	67	48	40	35	36	38	46	35	35	35	39	33	25	13	[illegible]	24	-6	18	-4	22	[illegible]
Surface Temperature			76	68	67	75	61	81	50	48	28	33	50	42	24	17	33	46	35	23	18	[illegible]	21	6	10	6	20	[illegible]
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Cl[illegible]
Wind (Beaufort Scale)				SW1			NW3	NW1	NJ	NE	E1	NW1	S2	NW1		W2	SW1	NE1	SW1	NW1	NW1	[illegible]	3	NW1	W2	NE1	NJ	N[illegible]

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0915	1500	0940	[illegible]
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27	[illegible]	30	[illegible]	31	26	18	26	37	26	[illegible]
2	0.2	Sand Gravel	[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27	[illegible]	29	[illegible]	26	[illegible]
3	0.8	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21	[illegible]	29	34	30	[illegible]
4	1.5	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	[illegible]	31	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	37	31	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	41	41	41	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	47	41	41	46	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	52	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53	[illegible]	54	54	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]	-7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27	[illegible]	[illegible]	[illegible]	38	26	[illegible]	15	32	27	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29	15	29	28	[illegible]
Weather			Cloudy	Cloudy	[illegible]	Clear	Cloudy	Clear	[illegible]	Clear	[illegible]	[illegible]	Rain	[illegible]	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	[illegible]	Clear	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	None	[illegible]	None	None	[illegible]	None	[illegible]		None	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																									
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	[illegible]
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22	[illegible]	[illegible]	[illegible]	[illegible]	27	[illegible]	28	[illegible]	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]	[illegible]
2	0.2	Sand Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			Cloudy	[illegible]	[illegible]	[illegible]	Clear	Clear	[illegible]	[illegible]	[illegible]	Cloudy	Clear	Clear	Cloudy	[illegible]	Clear	Cloudy	Cloudy	Cloudy	[illegible]	[illegible]	[illegible]	Cloudy	[illegible]	Clear	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	None	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	[illegible]
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.2	Sand Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	Clear	[illegible]	Clear	Clear	[illegible]	Clear	Clear	Clear	Clear	Clear	[illegible]	Clear	[illegible]	[illegible]	[illegible]	Clear	Clear	Clear	Clear	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	[illegible]
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.2	Sand Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.8	Silty clay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

P

AND TIME

					JANUARY 1947																									
28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
1005	0930	1530	0945	1425	0935	1555	0945	1630	0850	1515	0850	1620	1115	0920	1515	0940	1525	0725	1425	0750	1515	0840	1415	0945	1545	0930	1615	0845	1545	0745
13	27	21	10	21	19	23	26	26	16	28	18	30	29	7	18	0	14	6	12	5	25	9	29	31	35	34	33	29	33	25
17	28	25	19	21	21	24	27	25	20	28	28	30	29	11	20	6	18	10	14	10	26	13	28	29	33	32	32	31	32	27
32	31	32	30	38	30	30	30	31	30	30	29	30	31	29	28	26	26	25	25	26	26	26	26	28	29	31	31	31	31	31
37	36	37	36	38	35	35	34	34	34	34	34	34	34	34	34	33	33	32	32	31	31	31	30	30	31	31	32	32	32	32
48	42	42	42	42	41	45	40	40	40	40	39	39	39	39	39	39	38	38	38	37	37	36	36	36	36	36	36	36	38	36
50	48	48	42	48	47	47	46	46	46	46	45	45	45	45	45	44	44	44	44	43	43	43	43	42	42	42	42	42	42	42
56	53	55	55	55	54	54	54	54	51	51	52	52	52	52	52	51	51	51	51	50	50	50	50	49	49	49	49	49	49	49
59	59	59	58	58	57	57	57	57	57	57	56	56	58	56	56	55	55	55	55	55	55	58	58	58	58	58	58	58	53	53
62	61	61	61	61	61	61	60	60	60	60	59	59	59	59	59	59	59	59	59	58	58	57	58	58	57	58	57	57	57	57
-4	27	18	4	12	8	17	22	18	9	24	24	29	24	-1	11	-8	6	-5	7	8	20	-1	23	34	36	32	35	25	32	30
6	20	17	10	12	16	20	23	21	12	21	23	29	27	1	8	-3	5	0	6	6	16	6	26	33	35	18	32	25	31	26
Snow	Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
NE1	N3	NW2	SW1	NE1	NE1	NE1	NE1	NE2	N1	W3	SW2	SW2	NW2	N3	NW3	NW2	NW3	N2	N2	NW1	NW2	NE1	NE1	None	NE1	SE1	SE1	W2	W2	SW3

												FEBRUARY 1947																		
3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
1500	0940	1410	0945	1535	0940	1420	0830	1415	0915	1425	0900	1325	0740	1435	0715	1425	0723	1400	0835	1505	0930	1415	0845	1440	0740	1400	0840	1515	0840	1430
37	26	26	42	40	21	37	23	31	34	36	23	33	21	38	15	34	14	35	23	37	35	43	29	34	30	45	26	35	15	38
36	26	33	36	36	27	34	27	31	32	32	25	32	24	33	10	31	20	31	24	31	31	34	31	32	31	35	28	33	19	32
30	30	[illegible]	31	31	31	32	32	32	32	32	31	31	31	31	30	30	29	27	29	29	31	31	31	31	32	32	28	33	31	30
33	33	[illegible]	33	33	33	33	33	33	33	33	34	33	33	33	33	33	31	33	33	32	33	31	33	33	33	31	32	34	33	33
33	[illegible]	37	36	36	37	37	36	36	37	37	37	37	37	37	37	37	37	36	36	36	36	36	36	36	36	36	35	37	36	36
41	41	41	41	40	41	41	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	41	40	39	40	37	40
47	46	46	46	46	46	46	46	46	46	46	46	46	45	45	45	45	45	45	45	45	45	45	45	45	45	45	44	45	45	45
50	51	50	50	50	52	50	50	50	49	49	49	47	49	49	49	49	49	49	47	48	49	49	49	49	48	48	48	49	48	48
48	50	53	54	56	56	56	56	53	53	53	53	53	53	53	53	53	52	53	53	52	52	52	52	52	52	52	51	52	51	52
36	29	46	47	36	15	21	20	31	36	35	26	27	21	27	11	26	13	30	22	36	35	42	25	33	27	39	20	19	6	23
29	28	42	45	35	16	28	20	32	35	32	24	27	20	31	10	28	13	31	28	36	35	40	28	34	29	42	19	22	7	24
[illegible]	Clear	Snow	Rain	Clear	Clear	Clear	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
NE1	None	SW2	SW3	SW2		NW3	NE1	E2	None	None	SW3	NW3		NW4	NW3	NW4	NW4	NW4	NW1	NW2	None	SW1	NE1	NE4	NW2	NW2	NW3	NW3	NW2	NW3

											MARCH 1947																			
7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
[illegible]	0850	1420	0900	1410	0735	1455	0830	1435	0830	1430	0730	1410	0730	1410	0830	1420	0800	1515	0735	1520	0730	1410	0800	1350	0800	1415	0900	1510	0800	1125
37	32	41	32	41	29	59	34	66	36	67	37	44	36	59	31	55	32	55	27	60	29	65	33	61	36	61	47	57	42	45
42	32	34	32	38	36	45	32	52	33	55	37	41	36	47	34	41	31	48	29	52	30	53	32	51	33	51	47	54	42	40
32	33	34	32	32	32	32	32	31	35	36	38	37	38	38	37	37	37	37	36	37	37	37	39	38	38	38	42	43	43	40
33	32	33	33	38	38	38	38	32	36	35	37	37	38	38	38	33	38	32	38	37	38	38	39	39	40	38	41	41	42	41
36	36	36	36	33	36	36	36	35	33	36	37	37	38	38	39	38	39	39	39	39	39	39	39	40	40	39	41	41	41	42
39	39	39	39	42	39	39	39	38	39	39	39	39	40	40	40	40	40	40	41	41	41	40	40	41	41	40	41	42	41	42
41	43	43	43	44	43	43	42	43	44	43	43	43	43	43	43	43	44	43	44	43	44	44	43	44	44	43	44	44	44	44
43	47	47	46	47	47	47	46	46	47	46	46	46	46	46	46	45	46	46	46	46	46	46	46	46	46	46	46	47	46	46
48	50	50	50	50	50	50	50	49	50	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	48	49	49	49	49
36	36	37	32	36	37	37	39	49	35	61	38	44	38	43	39	36	38	39	26	43	33	47	30	47	32	47	45	52	41	38
42	33	41	34	36	29	43	31	50	39	60	38	45	38	54	35	47	34	41	27	50	30	56	32	48	35	48	55	52	42	38
Clear	Snow	Snow	Snow	Rain	Clear	Clear	Clear	Clear	Clear	Clear	Rain	Rain	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
NW2	NW2	NE2	N1	NE2	N2	NE2	None	E1	SW1	SW1	S3	S3	W2	W2			W2	N2	NW3	NW2	None	S2	N3	NW3	NW2	NW3	E1	None	NE1	SW4

											APRIL 1947																			
5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
[illegible]	[illegible]	[illegible]	[illegible]	1325	[illegible]	[illegible]	0735	[illegible]	0820	[illegible]	0815	[illegible]	[illegible]	1355	[illegible]	[illegible]	[illegible]	1115	1320	1520	0830	1420	0530	0720	0920	1115	1320	1515	1710	1910
[illegible]	29	40	59	52	40	67	35	30	40	40	42	30	43	34	61	52	54	59	72	76	41	41	38	42	52	62	70	74	68	56
[illegible]	35	[illegible]	[illegible]	41	44	55	36	57	38	46	22	44	44	62	56	52	52	53	62	65	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	60	64	63	58
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]	43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]	[illegible]	60	60	62	58	[illegible]
Clear	Clear	Clear	Cloudy	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Clear	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear
None	[illegible]	SE2	SE3	S3	[illegible]	[illegible]	[illegible]	[illegible]	SE2	SW2	[illegible]	SW2	SW2	SW2	SW2	SW2	SW2	SW1	SW2		SE2	SE2	None	NW1	NW2	NW2	NW2	NW3	NW2	W2

26	28	28
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

NOTES:

Air temperature obtained from thermograph record.
Surface temperature obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT N

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE 14
D-14

DATE AND TIME

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946													
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	30	31
			1415	1345	1100	1150	0945	1135	0900	1055	0930	1055	0940	1030	1330	1100	1105	0920	1100	0920	1105	0920	1030	0840	1500	1000	0925	1515	0945
1	0.2	Bit. Conc.		61	57	65	56	55	43	44	41	44	43	50	45	25	35	38	38	29	27	32	27	8	24	16	28	24	12
2	0.3	Sand & Gravel		57	47	54	55	48	44	40	42	43	41	46	44	28	32	37	34	33	27	33	29	17	26	22	27	28	18
3	0.8	Silty Clay	60	56	47	51	57	46	41	43	44	46	43	41	49	33	36	39	37	38	33	35	33	30	30	28	30	30	26
4	1.5	"	56	58	54	55	61	55	55	53	53	53	43	49	51	45	43	45	44	46	43	40	41	40	39	38	37	37	37
5	2.3	"	58	58	57	57	63	61	60	59	58	57	56	55	56	53	50	50	49	50	49	46	46	46	45	46	43	42	43
6	3.2	"	59	59	58	59	64	65	65	62	61	61	59	60	58	58	55	58	53	58	52	50	50	52	52	52	48	48	48
7	4.5	"	60	58	60	61	64	66	67	66	66	64	64	63	62	62	57	57	57	57	59	58	55	55	55	55	54	54	54
8	5.8	"	60	59	60	61	64	68	67	68	67	66	65	65	64	64	64	62	61	62	62	60	59	57	59	58	58	58	57
9	7.2	"	62	60	60	61	63	64	66	67	66	66	65	65	66	65	65	63	63	63	63	63	61	61	61	61	60	60	60
Air Temperature			70	68	52	64	57	51	43	45	37	38	43	41	40	23	42	35	39	25	25	35	24	-6	10	-4	22	18	4
Surface Temperature			75	68	58	67	59	59	45	45	38	38	43	46	40	24	40	38	40	28	18	35	27	2	10	6	20	17	[illegible]
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy
Wind (Beaufort Scale)				SW1			WSW2	NW2	N3	N2	E1	NW3	S2	NW2		W2	SW1	NW1	SW2	NW3	NW3	W1	S1	NW3	W2	NE2	N3	NW3	SW1

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																										
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	29	29	30	30	31	31	1	1	3	3	4	4	5
			1410	0850	1645	0840	1430	0930	1545	0845	1505	0710	1420	0855	1450	0840	1425	0845	0910	1435	0855	1425	0900	1430	0825	1505	0805	1415	0915
1	0.2	Bit. Conc.	34	19	32	34	33	18	19	[illegible]	21	26	[illegible]	36	34	32	35	28	28	30	31	35	28	37	18	35	26	19	39
2	0.3	Sand & Gravel	30	21	29	32	32	24	25	13	22	26	28	31	31	32	32	29	27	30	31	32	31	32	30	30	27	31	33
3	0.8	Silty Clay	29	25	28	31	31	30	28	22	24	26	21	31	31	31	31	31	30	31	31	31	31	31	26	25	29	30	31
4	1.5	"	32	32	32	32	32	32	32	33	32	36	31	34	32	32	32	32	36	32	32	32	33	33	33	33	33	33	33
5	2.3	"	38	38	38	37	37	37	38	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
6	3.2	"	43	42	42	42	42	42	42	42	42	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
7	4.5	"	46	48	48	48	48	48	48	47	47	47	47	47	47	47	46	46	46	46	46	46	46	46	46	46	46	46	46
8	5.8	"	53	53	53	53	53	56	56	56	56	56	56	51	51	51	51	51	51	51	51	51	51	51	51	50	50	50	50
9	7.2	"	56	56	56	56	56	56	56	55	55	55	55	55	55	55	54	54	54	54	54	54	54	54	53	54	54	53	53
Air Temperature			28	13	40	40	33	6	3	-1	12	31	37	35	36	31	34	27	26	28	26	36	26	27	15	32	29	32	41
Surface Temperature			30	15	38	39	31	11	3	7	13	26	40	34	36	31	31	27	26	25	26	34	24	25	15	40	27	31	45
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Rain
Wind (Beaufort Scale)			W4	E1	E1	SW2	W3	NW2	NW3	W2	W3	None	SE1	None	NE1	None	None	NW1	None	NE1		None	[illegible]	NW3	NW2	NE2	None	SW2	W3

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																										
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8	10
			0840	1425	0815	1345	0900	1430	0825	1355	1443	0843	1415	[illegible]	1515	0950	1425	1400	0820	1515	0845	1520	0820	1410	0840	1450	0800	1420	0900
1	0.2	Bit. Conc.	19	21	25	30		40	23	31	45	30	[illegible]	27	37	34	46	37	31	40	31	39	33	44	35	49	33	38	32
2	0.3	Sand & Gravel	23	23	26	29		31	26	29	32	27	[illegible]	27	32	28	32	32	32	33	32	33	32	36	32	40	32	32	32
3	0.8	Silty Clay	27	27	27	29		30	29	29	31	31	32	31	31	30	30	31	31	31	32	32	32	31	32	32	32	32	32
4	1.5	"	33	33	33	33		33	31	33	33	33	34	33	33	33	33	33	33	33	34	33	33	33	33	33	33	33	33
5	2.3	"	37	37	37	37		37	37	36	36	36	37	36	36	36	36	38	36	36	36	36	36	36	36	37	36	36	36
6	3.2	"	41	40	40	41		40	41	40	40	39	40	40	39	40	39	39	39	39	40	39	39	39	39	39	39	39	39
7	4.5	"	44	44	44	44		44	44	44	44	43	44	44	43	44	44	43	43	43	43	43	43	43	43	43	43	43	43
8	5.8	"	48	48	48	48		48	48	48	48	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
9	7.2	"	51	51	51	51		51	51	51	51	50	51	50	50	50	50	50	50	50	50	50	50	49	50	50	49	49	49
Air Temperature			9	13	28	28		29	12	30	38	24		27	28	26	38	37	29	35	28	36	36	40	36	41	32	37	33
Surface Temperature			12	15	29	30		40	22	31	37	30	33	31	33	35	42	38	37	38	31	35	36	43	39	44	33	40	34
Weather			Cloudy	Snow	Snow	Snow		Clear	Snow	Clear	Clear	Cloudy	Clear	[illegible]	Clear	Clear	Clear	Cloudy	Cloudy	Snow	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow	Snow	Snow
Wind (Beaufort Scale)			NE3	NE4	NE3	SW3		SW2	None	W2	NW1	None	W1	None	W2	None	W1	S3	None	NE1	W2	NW2		NW3	NW3	NW3	NW2	NE2	N1

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																										
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5	5
			1500	0810	1920	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit. Conc.	[illegible]	25	51	21	62	32	65	32	64	33	57	[illegible]	61	36	65	28	33	[illegible]	58	[illegible]	[illegible]	[illegible]	52	33	36	45	[illegible]
2	0.3	Sand & Gravel	42	[illegible]	41	[illegible]	42	32	40	32	52	[illegible]	57	[illegible]	53	36	51	38	38	[illegible]	[illegible]	[illegible]	55	[illegible]	52	38	38	43	[illegible]
3	0.8	Silty Clay	[illegible]	25	36	25	32	36	36	36	42	32	41	[illegible]	[illegible]	38	42	41	39	38	[illegible]	[illegible]	[illegible]	42	42	42	[illegible]	[illegible]	[illegible]
4	1.5	"	[illegible]	40	38	38	38	38	39	[illegible]	38	[illegible]	[illegible]	[illegible]	[illegible]	42	42	42	[illegible]	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	[illegible]	[illegible]	42
5	2.3	"	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42	[illegible]	[illegible]	42	42	[illegible]	42	42	42	[illegible]	42	[illegible]	42	42	42	42
6	3.2	"	42	42	42	42	42	42	42	42	[illegible]	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
7	4.5	"	44	44	44	44	44	44	44	44	43	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	43
8	5.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	7.2	"	48	48	48	48	48	48	48	48	48	[illegible]	48	48	48	48	48	48	48	48	48	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			33	[illegible]	[illegible]	85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55	[illegible]	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	[illegible]	Clear	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear	Clear	[illegible]	Clear	[illegible]
Wind (Beaufort Scale)			SW5	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	[illegible]	None	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None	None	[illegible]	SE2	SE2

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																								
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
			[illegible]	1345	[illegible]	[illegible]	[illegible]	1430	[illegible]	1400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1415	[illegible]	1415	[illegible]	1415	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.2	Bit. Conc.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	45	58	35	33	44	51	63	47	[illegible]	44	[illegible]	[illegible]	61	47	65	33	46	[illegible]	37	46
2	0.3	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	45	39	[illegible]	[illegible]	44	38	40	[illegible]	43	33	43	56	48	[illegible]	43	43	[illegible]	[illegible]	[illegible]
3	0.8	Silty Clay	[illegible]	47	41	44	41	46	43	43	41	46	41	46	43	41	41	41	46	45	47	[illegible]	[illegible]	41	46	[illegible]	46	46
4	1.5	"	[illegible]	[illegible]	45	44	45	44	45	43	[illegible]	45	45	44	44	33	43	46	46	45	46	46	[illegible]	47	47	46	47	46
5	2.3	"	[illegible]	[illegible]	45	45	45	[illegible]	[illegible]	45	[illegible]	[illegible]	45	45	[illegible]	[illegible]	45	43	43	[illegible]	45	[illegible]	[illegible]	46	46	[illegible]	47	[illegible]
6	3.2	"	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4.5	"	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	5.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	47	47	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	47
9	7.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	[illegible]	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
Surface Temperature			[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			Clear	Cloudy	[illegible]	[illegible]	Clear	Cloudy	Cloudy	Cloudy	[illegible]	Cloudy	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	Cloudy	Cloudy	Cloudy	[illegible]	[illegible]	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				SE2	NE2	[illegible]	S2	[illegible]	NW2	[illegible]	[illegible]	[illegible]	NW2	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	NE1	[illegible]	[illegible]	[illegible]	[illegible]

AND TIME

28	30	30	31	31	2	2	3	3	4	4	7	7	8	9	9	10	10	11	11	13	13	14	14	15	15	16	16	17	17	18
					JANUARY 1947																									
1000	0925	1515	0945	1410	0925	1605	0950	1635	0855	1515	0855	1625	1120	0925	1515	0945	1530	0930	1420	0955	1520	0845	1415	0945	1545	0930	1615	0845	1545	0945
16	28	24	12	22	20	24	26	24	18	30	18	30	30	10	20	4	13	8	13	7	26	11	28	30	24	31	32	28	31	24
21	29	29	18	24	23	25	28	27	22	29	21	30	28	15	22	12	28	12	16	14	25	16	25	28	31	28	31	30	31	26
21	30	30	26	25	27	28	30	30	27	28	26	29	29	25	26	22	23	21	21	22	24	23	24	23	28	30	30	30	31	29
28	37	37	37	35	26	36	35	35	35	35	35	35	34	35	34	34	34	33	33	32	32	32	31	31	31	32	32	32	32	32
45	43	42	41	47	43	43	42	42	41	41	41	44	40	40	40	40	40	40	40	38	38	38	38	38	37	38	37	38	37	37
52	48	48	48	48	47	47	47	47	46	46	45	45	45	45	45	45	45	44	45	44	42	42	42	42	43	43	44	42	42	42
55	58	54	58	54	58	52	52	52	52	52	52	52	51	51	51	51	51	50	57	50	50	50	49	49	49	49	49	48	49	48
58	58	58	57	59	58	57	58	57	57	57	56	56	56	56	56	55	56	55	55	55	55	54	54	54	54	54	54	57	57	57
61	60	60	60	60	60	60	60	60	57	58	57	58	58	59	58	58	57	58	58	57	57	57	57	57	57	51	57	53	57	57
-4	22	18	4	12	8	17	22	18	9	24	24	23	24	-4	11	-8	6	-5	7	0	20	7	23	24	26	32	35	25	32	30
6	20	17	11	12	16	20	23	22	12	21	21	23	27	1	8	-3	5	0	6	7	15	6	26	23	25	35	32	25	31	26
Snow	Clear	Clear	Cloudy	Cloudy	Snow	Snow	Snow	Snow	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Snow	Clear	Clear	Clear	Cloudy	Rain	Rain	Clear	Cloudy	Clear	Clear	Clear
NE2	N3	NW3	SE1	NE1	NE1	NE1	NE1	NE2	N1	W2	SW2	SW2	NW3	N3	NW4	NW2	NW3	N2	N2	NW1	NW2	NE1	NE1	None	NE1	SE1	SE1	W2	W2	SW2

3	4	4	5	5	6	6	7	7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20
												FEBRUARY 1947																		
1535	0905	1415	0850	1540	0845	1420	0830	1815	0915	1420	0900	1430	0740	1440	0730	1430	0730	1400	0840	1330	0940	1415	0845	1130	0845	1400	0845	1520	0845	1420
35	26	37	39	33	26	33	27	31	31	32	25	33	22	37	16	35	15	38	23	35	34	39	10	34	31	44	29	35	17	37
30	27	31	33	32	31	32	32	31	36	32	26	31	25	31	21	31	30	30	24	30	31	32	32	32	31	32	31	33	31	31
25	29	30	31	32	32	32	32	32	36	32	27	31	25	30	35	29	26	25	27	29	31	31	32	31	32	32	31	33	26	29
31	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	34	33	33	33	32	33	33	33	33	33	33	33	34	33	33
37	37	37	37	37	37	37	37	33	37	37	37	37	31	37	33	37	37	37	37	36	37	37	37	37	37	37	36	38	37	37
41	41	41	41	41	41	41	40	45	41	42	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	37	40	40	40
46	46	46	46	46	46	46	46	45	45	45	45	45	45	45	45	45	45	45	45	44	45	45	45	45	45	45	44	45	44	44
52	50	50	50	50	50	[illegible]	50	50	50	50	47	49	49	47	47	47	49	47	47	45	49	49	49	49	49	48	48	49	48	48
53	54	53	53	53	52	52	53	51	53	53	53	56	52	58	52	52	52	52	52	51	52	52	52	51	51	51	51	52	51	51
32	29	42	41	36	[illegible]	27	20	35	36	35	22	27	21	27	11	26	13	30	23	36	35	42	25	33	27	37	20	17	6	21
[illegible]	27	41	45	35	[illegible]	29	20	32	35	36	25	30	20	36	11	25	13	31	25	37	35	44	25	34	27	44	19	21	7	24
Snow	Clear	Clear	Rain	Clear	Clear	Clear	Snow	Snow	Rain	Rain	Clear	Snow	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear
[illegible]	None	SW2	W3	SW2		NW3	NE1	E2	None	None	W3	NW3		NW4	NW3	NW4	NW4	NW3	NW1	NW2	None	SW1	NE2	NE4	NW2	NW2	NW3	NW1	NW2	NW1

7	8	8	10	10	11	11	12	12	13	13	14	14	15	15	17	17	18	18	19	19	20	20	21	21	22	22	24	24	25	26
									MARCH 1947																					
1450	0700	1420	0900	1410	0735	1455	0830	1435	0830	1445	0720	1420	0720	1410	0130	1430	0820	1515	0735	1520	0720	1430	0700	1150	0900	1415	0900	1550	0830	1130
47	33	35	32	41	31	51	35	62	36	60	35	42	36	54	33	52	36	54	30	60	31	61	33	60	36	57	47	56	42	44
40	33	32	32	37	32	42	32	46	33	41	35	38	36	41	33	45	32	45	32	48	32	47	35	47	34	47	43	52	42	39
36	32	32	32	33	32	33	32	36	33	36	35	36	37	37	38	37	35	37	35	38	36	39	37	40	37	39	42	46	41	39
33	33	33	33	34	34	34	34	33	34	34	35	35	36	36	38	37	38	37	38	37	38	38	39	39	40	39	41	42	42	41
33	36	36	36	37	36	36	37	36	37	36	36	36	37	37	39	38	39	39	39	37	38	39	39	39	40	40	40	41	41	42
39	39	39	39	40	39	39	39	38	40	33	39	39	39	39	40	39	40	40	40	40	40	40	41	41	41	40	41	42	41	42
43	43	43	43	44	43	43	43	42	43	43	43	43	43	43	43	42	43	42	42	43	43	43	43	43	43	43	43	44	43	44
47	47	47	47	47	47	47	47	46	47	46	46	46	46	46	46	45	46	46	46	46	46	46	46	46	46	46	46	46	46	46
[illegible]	49	49	49	50	49	49	49	49	49	49	49	49	49	49	48	48	49	48	49	48	48	48	48	48	48	48	48	48	48	48
31	32	37	33	35	27	39	39	41	37	51	37	44	38	47	29	36	28	39	26	41	22	47	30	47	36	47	45	56	41	28
[illegible]	33	40	34	36	26	42	33	55	39	60	38	45	38	55	31	47	34	41	37	50	30	56	32	48	35	48	51	52	42	38
Clear	Snow	Snow	Snow	Rain	Clear	Clear	Clear	Clear	Clear	Clear	Rain	Rain	Clear	Clear	Cloudy	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Rain	Cloudy
NW3	NW2	NE2	N1	NE2	N2	NE2	None	E1	SW1	SW1	S3	S3	W2	W2			W3	N2	NW3	NW2	None	S2	N3	NW3	NW1	NW2	E1	None	NE1	SW4

5	5	5	5	5	7	7	8	8	9	9	10	10	11	11	12	12	12	12	12	12	14	14	15	15	15	15	15	15	15	15
										APRIL 1947																				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0725	1410	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46	46	46	[illegible]	[illegible]	[illegible]
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Clear	[illegible]	Clear	Cloudy	Cloudy	Cloudy	Clear	Cloudy	Clear	Cloudy	Rain	Clear	Clear	Cloudy	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Clear	Clear	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear
None	[illegible]	SE2	SE2	[illegible]	[illegible]	[illegible]	SW2	[illegible]	SE2	SW2	SW2	SW2	SW2	SW2	SW2	SW2	SW2	SW1	SE2		SE2	SE2	None	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

26	28	28
[illegible]	[illegible]	1400
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

NOTES

Air temperatures obtained from thermograph record.

Surface temperatures obtained from mercury thermometer laid on the surface of the pavement.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF TEST ELEMENT P

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG 1947

TABLE 16

D-15

DATE AND TIM

Thermocouple No.	Depth in feet	Type of material	OCTOBER 1946 11 1533	16 1125	20 1233	22 1025	31 1343	NOVEMBER 1946 7 1415	15 0835	19 0905	21 0941	23	25 1110	27 0940	29 1400	DECEMBER 1946 3	7	10	12	14	16	24	26	27	27	28	30	30
1	0.5	Sand & Gravel	60	60	50	50	61	58	49	43	46	46	41	41	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	1.3	Sawdust	61	50	74	77	96	98	51	60	66	57	65	61	65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	2.2	"	69	76	80	83	97	102	52	66	66	68	66	61	71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	3.0	"	77	81	82	84	93	97	50	66	69	67	70	72	78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.8	"	65	76	76	77	83	86	54	64	61	61	70	71	76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	4.7	"	53	63	67	68	72	74	50	63	60	67	68	62	69	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.5	Sand & Gravel	35	61	63	63	67	69	54	64	66	[illegible]	63	66	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8																												
9																												
Air Temperature			66	66	53	50	67	53	40	[illegible]	[illegible]	[illegible]	53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature				64	58	33	37	30	41	37	[illegible]	[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				SW1			WSW1	NW2	N3	N2	[illegible]	[illegible]	S2	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermocouple No.	Depth in feet	Type of material	JANUARY 1947 18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
1	0.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	1.3	Sawdust	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	2.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	3.0	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	4.7	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8																										
9																										
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	Clear	Cloudy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermocouple No.	Depth in feet	Type of material	FEBRUARY 1947 21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
1	0.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	1.3	Sawdust	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	2.2	"	45	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	3.0	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	4.7	"	[illegible]	53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8																										
9																										
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermocouple No.	Depth in feet	Type of material	MARCH 1947 26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5
1	0.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	1.3	Sawdust	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	2.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	3.0	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	4.7	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8																									
9																									
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Thermocouple No.	Depth in feet	Type of material	APRIL 1947 16	16	17	17	18	18	19	19	21	21	21	21	22	22	23	23	24	24	25	25	26	26	28	28
1	0.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	1.3	Sawdust	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	2.2	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	3.0	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3.8	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	4.7	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	5.5	Sand & Gravel	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8																								
9																								
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

A

AND TIME

JANUARY 1947

[illegible]	[illegible]	[illegible]	[illegible]

FEBRUARY 1947

[illegible]	[illegible]	[illegible]	[illegible]

MARCH 1947

[illegible]	[illegible]	[illegible]	[illegible]

APRIL 1947

[illegible]	[illegible]	[illegible]	[illegible]

NOTES

Air temperatures obtained from thermograph record.
Surface temperatures obtained from mercury thermometer laid on the surface of the embankment.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF EMBANKMENT R

SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE 18

B-16

DATE AND TIM

Thermo-couple No.	Depth in feet	Type of material	OCTOBER 1946					NOVEMBER 1946								DECEMBER 1946												
			11	16	20	22	31	7	15	19	21	23	25	27	29	3	7	10	12	14	16	24	26	27	27	28	30	30
			1530	1545	1030	1015	1400	1400	0840	0900	0910	0835	1110	0415	1430	1455	0850	0905	0900	0830	1120	0925	1035	0840	1510	1010	0930	1520
1	0.5	Sand & Gravel	61	64	78	75	75	65	57	53	53	40	47	47	44	47	40	44	42	42	42	41	40	40	41	40	38	38
2	1.3	Sawdust	61	87	89	88	84	73	67	62	62	51	53	53	55	50	54	52	51	50	50	44	49	49	48	49	51	51
3	2.2	"	61	88	94	93	83	84	78	69	69	56	58	59	61	62	62	60	59	58	56	55	55	54	54	54	53	53
4	3.0	"	61	82	92	91	88	84	79	74	73	65	65	64	66	66	67	64	64	63	62	60	60	60	59	59	58	58
5	3.8	"	60	71	81	81	81	75	75	73	71	66	66	66	68	68	67	66	65	65	64	63	62	62	62	62	61	61
6	4.7	"	57	62		60	69	69	69	68	64	63	64	64		65	65	63	64	63	63	62	61	61	61	61	61	61
7	5.5	Sand & Gravel	58	60	63	63	65	66	66	66	60	62	63	63	64	63	64	62	62	63	62	61	61	61	61	61	60	60
8																												
9																												
Air Temperature			65	57	50	50	67	53	41	34	35	35	53	40	33	14	29	25	26	23	3	35	24	-6	10	-4	23	18
Surface Temperature				65	57	55	52	54	43	30	34	32	43	44	35	27	32	38	30	23	23	35	25	2	10	6	20	17
Weather			Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear	Cloudy	Cloudy	Clear	Cloudy	Clear	Cloudy	Snow	Clear	Clear	Snow	Clear	Clear
Wind (Beaufort Scale)				SW1			WSW2	NW2	N3	N2	E1	NW3	S2	NW2		W2	SW1	NE1	SW1	NW3	NW3	W1	S1	NW3	W2	NE3	N3	NW3

Thermo-couple No.	Depth in feet	Type of material	JANUARY 1947																									
			18	20	20	21	21	22	22	23	23	25	25	27	27	28	28	29	30	30	31	31	1	1	3	3	4	4
			1020	0955	1050	0915	1440	0930	1550	0930	1510	0715	1430	0945	1450	0950	1425	0845	0910	1445	0855	1425	0800	1430	0825	1505	0845	1415
1	0.5	Sand & Gravel	32	30	30	31	31	31	31	30	24	28	28	31	31	32	32	32	32	32	31	32	32	32	30	30	30	30
2	1.3	Sawdust	42	44	40	41	41	34	40	41	40	41	41	41	38	38	38	39	38	38	38	38	39	39	39	39	39	38
3	2.2	"	40	40	40	43	45	45	45	45	45	44	44	44	44	43	43	43	43	43	43	43	43	43	43	43	43	43
4	3.0	"	53	52	52	51	51	51	51	51	51	50	50	50	50	50	49	49	49	49	49	49	49	49	48	48	48	48
5	3.8	"	56	56	56	55	55	55	55	55	55	54	54	54	54	54	54	54	53	53	53	53	53	53	53	52	53	52
6	4.7	"	58	57	57	56	56	56	56	56	56	56	56	55	55	55	55	55	55	55	55	55	55	55	54	54	54	54
7	5.5	Sand & Gravel	58	57	57	57	57	57	57	57	56	56	56	56	56	56	56	56	55	55	55	55	55	55	55	55	55	55
8																												
9																												
Air Temperature			28	13	40	40	33	6	3	-1	12	31	34	35	36	31	34	27	26	28	32	38	26	27	10	32	24	42
Surface Temperature			25	15	38	34	31	10	0	1	13	27	36	32	30	31	35	28	25	27	35	36	23	27	15	30	24	40
Weather			Cloudy	Cloudy	Rain	Clear	Cloudy	Clear	Clear	Clear	Clear	Cloudy	Rain	Rain	Rain	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy
Wind (Beaufort Scale)			W4	E1	E1	SW2	W3	NW2	NW3	W2	W3	None	SE1	None	NE1	None	None	NW1	None	NE1		None	NW4	NW3	NW2	NE2	SW2	SW3

Thermo-couple No.	Depth in feet	Type of material	FEBRUARY 1947																									
			21	21	22	22	24	24	25	25	26	27	27	28	28	1	1	3	4	4	5	5	6	6	7	7	8	8
			0935	1430	0815	1305	0900	1030	0825	1400	1445	0845	1415	0815	1515	0935	1425	1345	0810	1515	0845	1520	0820	1410	0840	1450	0750	1420
1	0.5	Sand & Gravel	30	30	27	27	30	31	31	30	30	31	32	31	31	31	30	31	31	31	32	32	32	31	32	32	32	32
2	1.3	Sawdust	30	30	30	30	30	36	30	30	30	30	37	37	36	36	36	35	35	35	36	35	36	35	36	36	38	36
3	2.2	"	41	41	41	41	41	41	41	41	41	40	41	40	41	40	40	40	41	40	40	40	40	40	40	40	40	40
4	3.0	"	46	46	46	46	46	46	46	46	46	45	46	45	45	46	45	45	45	45	45	45	45	45	45	45	45	45
5	3.8	"	50	44	44	49	49	49	49	49	47	48	47	47	49	50	49	49	49	49	49	49	49	49	48	49	49	49
6	4.7	"	52	52	52	52	52	52	52	52	51	51	52	51	51	51	51	51	51	51	51	51	51	51	50	51	51	51
7	5.5	Sand & Gravel	53	53	53	52	52	53	52	52	52	52	53	52	51	52	52	52	52	52	52	51	52	51	51	51	51	51
8																												
9																												
Air Temperature			7	13	20	28	[illegible]	27	12	30	30	44		23	29	20	[illegible]	31	27	13	23	16	26	40	16	41	32	31
Surface Temperature			7	13			20	30	23		35	34	32	26	31	35	36	25	36	37	33	36	35	42	37	42	34	34
Weather			Cloudy	Snow	Snow	Snow	Clear	Clear	Snow	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Cloudy	Cloudy	Snow	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Snow	Snow
Wind (Beaufort Scale)			W3	W4	NE3	SW3	None	SW2	None	W2	NW2	None	W3	None	W2	None	W1	S3	None	NE1	W2	E2		NW3	NW3	NW3	NW2	NE2

Thermo-couple No.	Depth in feet	Type of material	MARCH 1947																									
			26	27	27	28	28	29	29	31	31	1	1	2	2	3	3	4	4	4	4	4	4	4	4	5	5	5
			1500	0910	1440	[illegible]	1400	0900	1420	0915	1415	0820	1330	0815	1445	0800	1330	0510	0705	0420	1125	[illegible]	1520	1720	1410	0520	0725	0920
1	0.5	Sand & Gravel	32	32	32	32	32	32	32	32	31	32	32	32	32	32	32	32	32	32	32		32	32	32	32	32	32
2	1.3	Sawdust	30	30	30	30	30	30	30	30	33	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
3	2.2	"	40	40	37	37	40	40	40	40	37	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
4	3.0	"	44	42	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	42	44
5	3.8	"	47	47	47	47	47	47	47	47	47	47	47	47	47	41	[illegible]	47	47	47	47	47	41	47	47	47	47	47
6	4.7	"	47	47	47	47	47	47	47	47	47	47	49	49	44	49	42	49	49	47	49	49	47	47	47	49	49	47
7	5.5	Sand & Gravel	50	50	50	50	50	50	50	50	49	50	49	50	49	50	[illegible]	50	50	47	50	50	50	50	50	50	50	49
8																												
9																												
Air Temperature			47	33	30	40	30	40	42	40	42	42	32	4	32	31	43	43	29	21	43	44	50	48	40	40	31	41
Surface Temperature			30	40	24	44	42	30	42	30	40	30	34	41	37	34	50	23	23	61	49	14	34	47	40	48	32	48
Weather			Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Wind (Beaufort Scale)			SW1	W2	W2	None	NE2	None	NW2	NW2	NW2	NW1	W2	SW1	SW1	NW3	N3	None	None	N3	N3	N3	N3	SW2	None	None	S1	SE2

Thermo-couple No.	Depth in feet	Type of material	APRIL 1947																									
			16	16	17	17	18	18	19	19	21	21	21	21	21	22	22	23	23	24	24	25	25	26	26	26	28	28
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1115	[illegible]	[illegible]	1415	[illegible]	1415	[illegible]	1415	[illegible]	[illegible]	[illegible]	[illegible]	1345	[illegible]	[illegible]
1	0.5	Sand & Gravel	32	32	32	30	32	32	32	32	32	32	32	32	32	32	32	32	32	32	31	32	32	30	30	32	33	33
2	1.3	Sawdust	33	33	33	33	33	33	33	33	38	38	38	38	38	38	37	37	37	37	37	37	38	37	37	37	40	41
3	2.2	"	40	40	41	40	41	41	41	41	41	41	41	41	41	41	41	42	42	42	41	42	41	42	43	42	43	43
4	3.0	"	43	40	45	42	40	45	45	45	45	40	45	45	45	45	45	45	46	46	45	45	46	46	46	46	46	47
5	3.8	"	45	45	45	45	45	44	41	41	45	46	46	46	46	46	45	46	46	46	47	46	46	46	46	46	47	47
6	4.7	"	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	46	46	47	47	47	47	47	47
7	5.5	Sand & Gravel	49	49	49	50	50	49	50	49	49	49	49	49	49	49	49	49	49	47	49	47	47	51	46	49	51	53
8																												
9																												
Air Temperature			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Surface Temperature			[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weather			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wind (Beaufort Scale)				[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

AND TIME

Date	Time										Weather	Wind
28	1010	40	49	54	59	62	61	61	-4	6	Snow	NE3
30	0930	38	51	53	58	61	61	60	23	20	Clear	N3
30	1520	38	51	53	58	61	61	60	18	17	Clear	NW3
31	0405	34	50	53	58	61	61	60	-4	11	Cloudy	SW1
31	0955	38	48	53	58	61	61	60	12	12	Cloudy	NE1

JANUARY 1947

Date	Time										Weather	Wind
2	0935	37	52	53	59	61	60	60	8	13	Snow	NE1
2	1615	37	51	53	58	61	60	60	17	17	Snow	NE1
3	0950	36	46	53	58	60	60	60	22	21	Snow	NE1
3	1635	36	46	52	57	60	60	60	18	22	Snow	NE2
4	0855	36	49	52	57	60	60	60	9	12	Clear	N1
4	1515	36	49	52	57	60	60	60	24	20	Clear	W3
7	0855	34	46	51	56	59	59	59	24	20	Clear	SW2
7	1625	34	45	50	56	59	59	59	29	29	Cloudy	SW2
8	1120	34	45	50	56	59	59	59	24	27	Clear	NW7
9	0925	34	45	50	56	59	59	59	-1	4	Clear	N3
9	1515	34	44	50	56	59	59	54	11	11	Clear	NW4
10	0845	33	44	50	55	58	59	59	-5	-8	Clear	NW2
10	1530	33	44	50	55	58	59	59	6	2	Clear	NW3
11	0730	33	45	49	55	58	59	59	-5	0	Cloudy	N2
11	1420	32	45	49	55	58	59	59	7	6	Snow	N2
13	0755	31	43	48	54	58	58	53	1	0	Clear	NW1
13	1520	31	43	43	54	58	58	58	20	15	Clear	NW2
14	0925	30	42	43	54	57	58	58	-1	5	Clear	NE1
14	1415	30	42	43	54	57	58	58	23	14	Cloudy	NE1
15	0945	30	41	47	54	57	58	58	34	34	Rain	None
15	1545	30	41	47	53	57	58	58	30	33	Rain	NE1
16	0930	31	40	43	47	53	58	58	32	32	Clear	SE1
16	1615	31	40	47	53	57	58	58	35	32	Cloudy	SE1
17	0845	32	44	47	53	56	57	57	23	28	Clear	W2
17	1545	32	43	47	53	51	57	57	32	29	Clear	W2
18	0745	32	42	46	53	56	58	58	30	26	Clear	SW3

FEBRUARY 1947

Date	Time										Weather	Wind
3	1505	30	39	43	48	52	54	55	32	30	Clear	NE2
4	0845	30	39	43	48	53	54	55	24	24	Clear	SW2
4	1415	30	38	43	48	52	54	55	42	40	Cloudy	SW3
5	0850	31	41	43	48	52	54	55	47	45	Rain	SW3
5	1540	31	39	42	48	52	53	[illegible]	36	35	Clear	SW2
6	0845	32	40	42	48	52	52	53	15	17	Clear	
6	1420	32	39	42	48	52	52	53	27	24	Clear	NW3
7	0830	32	39	42	47	51	52	53	20	19	Snow	NE3
7	1415	32	39	42	47	51	52	53	33	32	Snow	E2
8	0915	32	39	42	47	51	52	53	36	35	Rain	None
8	1440	32	39	42	47	51	52	53	35	32	Rain	None
10	0900	32	38	41	47	53	5[illegible]	53	22	24	Clear	SW3
10	1430	32	39	41	47	51	53	53	27	28	Snow	NW3
11	0740	31	43	41	47	50	53	53	21	20	Clear	
11	1440	31	42	41	46	50	53	53	27	29	Clear	NW4
12	0730	31	41	41	46	50	53	53	11	10	Clear	NW3
12	1430	31	37	41	46	50	53	53	26	29	Clear	NW4
13	0730	30	36	41	46	50	53	53	13	12	Clear	NW4
13	1430	30	36	41	46	50	53	53	30	30	Clear	NW4
14	0840	30	36	41	46	50	52	53	23	25	Cloudy	NW1
14	1510	29	36	40	46	50	52	53	36	35	Clear	NW2
15	0930	31	38	41	46	50	52	53	35	35	Clear	None
15	1415	31	36	41	46	50	52	53	42	38	Clear	SW1
17	0945	31	36	41	46	50	52	53	25	27	Cloudy	NE2
17	1440	31	36	41	46	50	52	53	33	23	Cloudy	NE4
18	0745	32	36	41	46	50	52	53	27	24	Cloudy	[illegible]
18	1400	32	36	41	46	50	52	53	34	34	Clear	NW2
19	0945	31	35	40	45	50	51	52	20	20	Clear	NW3
19	1520	32	37	42	46	50	52	53	19	22	Clear	NW3
20	0845	31	36	41	46	50	52	53	0	7	Clear	NW3
20	1415	30	36	41	46	50	52	53	23	24	Clear	NW3

MARCH 1947

Date	Time										Weather	Wind
7	[illegible]50	32	[illegible]	[illegible]	45	44	51	51	[illegible]	[illegible]	Clear	[illegible]3
8	0750	32	38	40	45	44	51	51	32	34	Snow	NW2
8	1420	32	36	40	45	44	51	51	37	34	Snow	NE2
10	0900	32	36	40	45	44	50	51	33	35	Snow	N1
10	1410	32	36	41	45	44	51	52	35	36	Rain	NE2
11	0735	32	36	40	45	44	50	51	27	24	Clear	N2
11	1455	32	35	40	45	50	50	51	39	38	Clear	NE2
12	0830	32	36	40	45	48	[illegible]	[illegible]	24	30	Clear	None
12	1435	31	35	40	44	48	50	51	44	51	Clear	E1
13	0830	33	36	40	45	49	50	51	35	33	Clear	SW1
13	1440	32	36	40	45	48	50	51	51	52	Clear	SW1
14	0720	32	36	40	45	48	50	51	37	37	Rain	S3
14	1420	32	36	40	45	48	50	51	44	45	Rain	S3
15	0720	32	35	40	44	48	50	51	38	38	Clear	W2
15	1410	32	35	40	44	48	50	51	47	50	Clear	W2
17	0830	32	35	39	44	47	49	50	24	32	Cloudy	
17	1415	31	34	38	43	47	49	50	36	41	Cloudy	
18	0820	32	35	39	43	47	49	50	20	31	Clear	W3
18	1515	31	35	39	43	47	49	50	34	34	Clear	N2
19	0735	32	35	39	43	47	49	50	27	27	Clear	NW3
19	1520	32	35	39	43	47	49	50	43	42	Clear	NW2
20	0720	32	33	39	43	47	49	50	27	31	Clear	None
20	1420	32	35	39	43	47	49	50	47	51	Clear	S2
21	0740	32	35	39	43	47	49	50	30	30	Clear	N3
21	1350	32	35	39	43	47	49	50	41	50	Clear	NW3
22	0845	32	35	39	43	47	49	50	32	34	Clear	NW2
22	1415	31	35	38	43	47	49	50	41	41	Clear	NW3
24	0900	32	35	39	43	47	49	50	43	30	Cloudy	E1
24	1550	33	36	40	44	48	49	50	32	47	[illegible]	None
25	0845	32	35	39	43	47	49	50	41	41	Rain	NE1
26	1130	32	36	40	44	47	49	50	28	37	Cloudy	SW[illegible]

APRIL 1947

Date	Time										Weather	Wind
5	[illegible]20	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	0725	32	36	40	44	47	49	50	31	32	Clear	S1
5	0920	32	36	40	44	47	49	49	41	48	Clear	NE2
5	1120	32	36	40	44	47	49	49	45	52	Cloudy	SE3
5	1325	32	36	40	44	47	49	49	43	[illegible]	Cloudy	S3
7	0925	32	36	[illegible]	43	47	49	49	49	46	Cloudy	W1
7	1445	32	36	40	44	47	49	49	49	49	Clear	W0
8	0735	32	37	40	45	47	49	49	32	33	Cloudy	NW3
8	1410	32	36	40	45	48	41	49	45	30	Clear	NW4
9	0805	32	37	40	45	47	49	49	33	32	Cloudy	SE1
9	1300	32	36	40	45	47	49	50	30	41	Rain	SW2
10	0815	32	37	41	45	47	49	49	34	40	Clear	SW2
10	1320	32	37	40	45	47	49	49	30	34	Clear	SW2
11	0735	32	37	41	45	48	49	49	44	45	Cloudy	SW2
11	1355	32	37	41	45	48	49	49	48	47	Cloudy	SW2
12	0540	32	37	41	45	48	49	49	55	54	Rain	SW2
12	0720	32	37	40	45	49	49	49	54	54	Rain	SW2
12	0915	32	37	40	45	48	49	49	55	57	Rain	SW2
12	1115	32	37	40	45	48	49	49	54	65	Cloudy	SW1
12	1320	32	37	41	45	48	49	49	[illegible]	[illegible]	Cloudy	SW2
12	1520	32	37	41	45	48	49	49	49	12	Clear	
14	1010	32	37	41	45	47	49	49	35	38	Cloudy	SE2
14	1400	32	37	41	41	47	49	49	32	37	Rain	SE2
15	0310	32	37	40	44	47	49	49	32	35	Cloudy	None
15	0720	32	[illegible]	[illegible]	[illegible]	[illegible]	49	49	34	42	[illegible]	NW1
15	0920	32	37	40	45	47	49	49	47	50	Clear	NW3
15	1115	32	37	40	40	47	49	49	32	57	Clear	[illegible]
15	1320	32	37	40	45	47	49	49	38		Clear	NW3
15	1515	32	37	40	45	47	49	49	35	36	Clear	NE3
15	1710	32	39	4[illegible]	42	47	49	49	56	55	Clear	NW2
15	1910	32	37	41	41	47	49	49	41	36	Clear	W1

Date	Time										Weather	Wind
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	33	40	43	40	44	44	50	[illegible]	[illegible]	[illegible]	[illegible]
28	14[illegible]	33	41	43	47	47	46	50	60	33	[illegible]	[illegible]

NOTES

Air temperatures obtained from thermograph record.

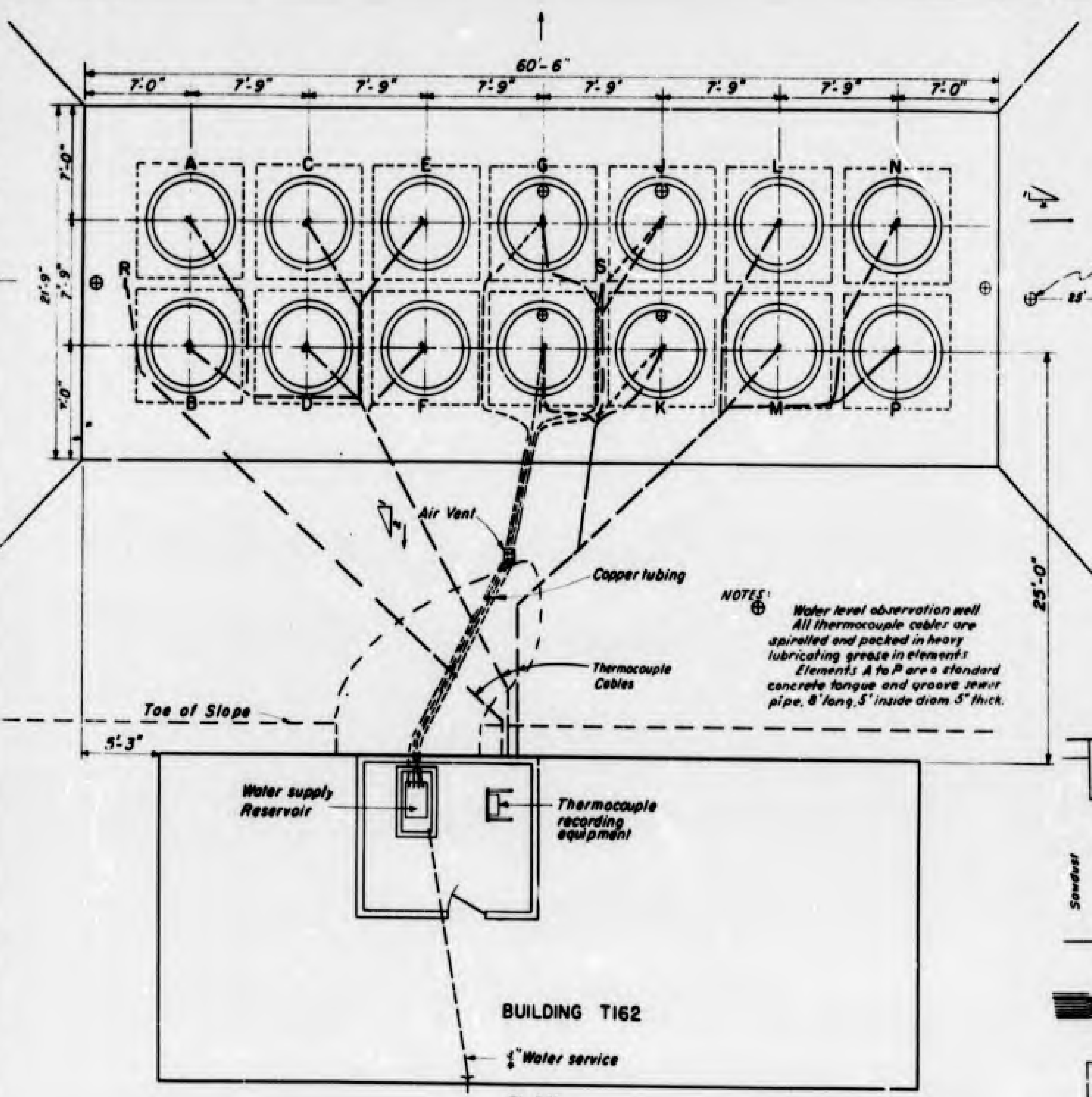
Surface temperature obtained from mercury thermometer laid on the surface of the embankment.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURE RECORD OF EMBANKMENT S

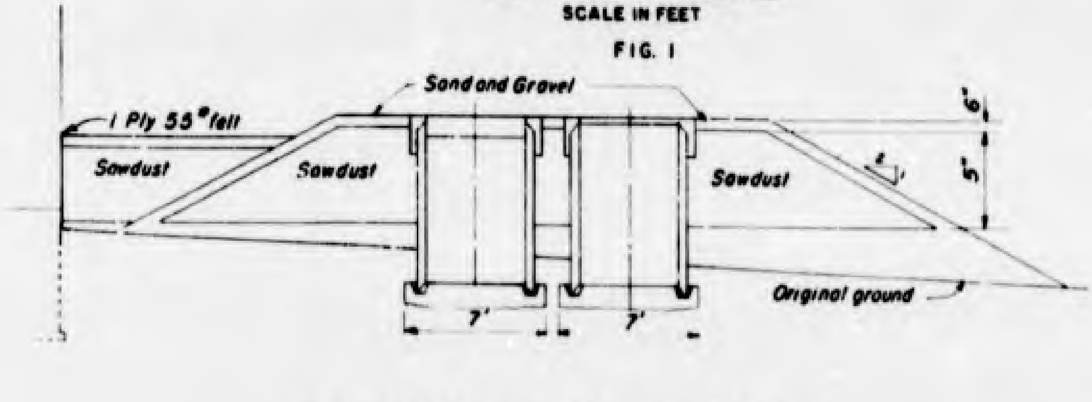
SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG. 1947

TABLE 17



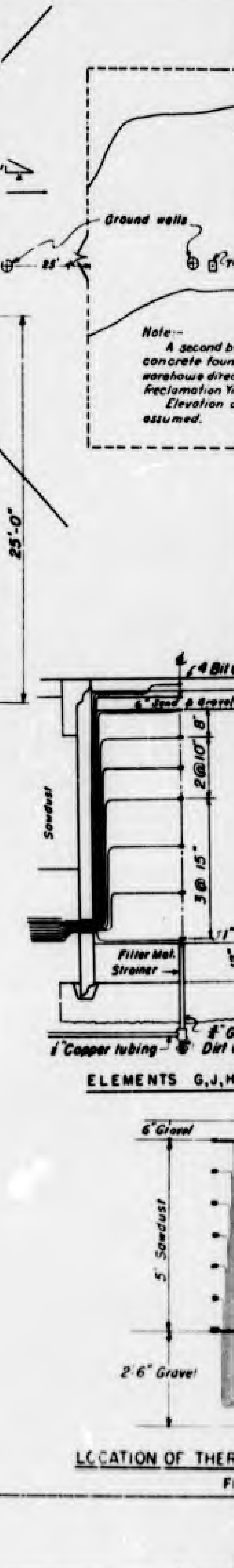
PLAN

FIG. 1



TYPICAL SECTION OF EMBANKMENT

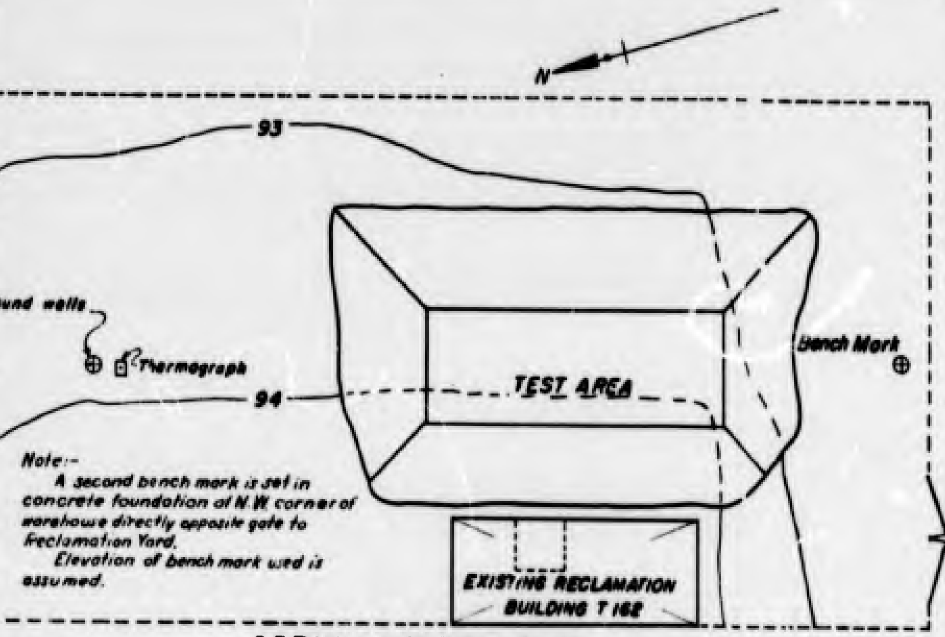
FIG. 3



ELEMENTS G,J,H

LOCATION OF THER

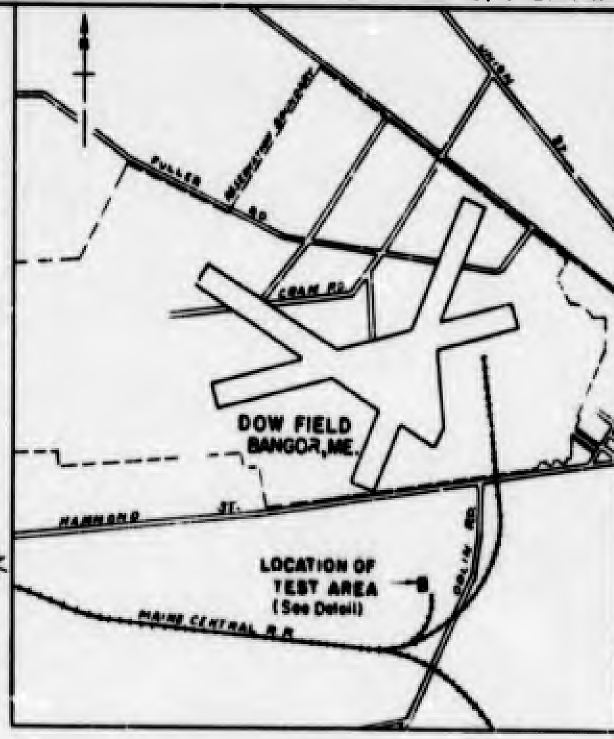
FI



DETAIL LOCATION PLAN

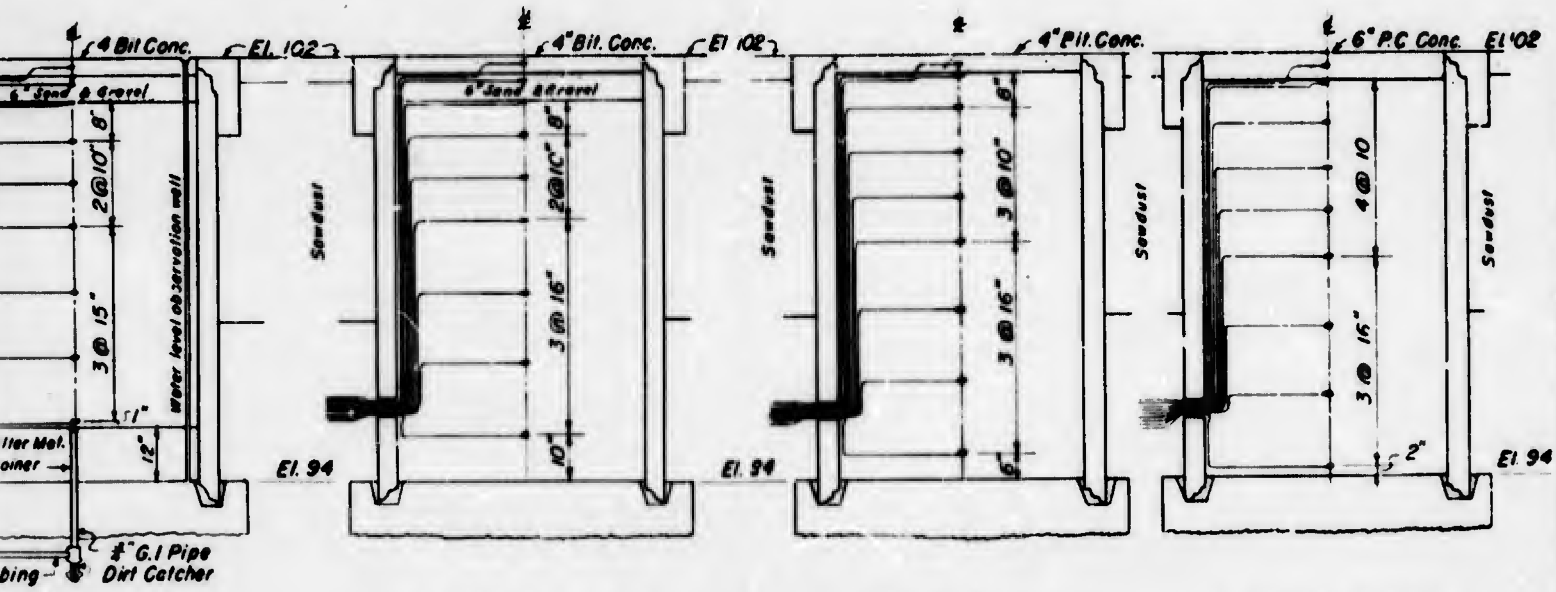
20 0 20 40
SCALE IN FEET

FIG. 2



SITE PLAN

1000 0 2000
SCALE IN FEET



ELEMENTS G,J,H & K

ELEMENTS L,N,M & P

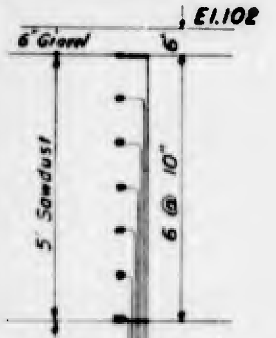
ELEMENTS A,C & E

ELEMENTS B,D & F

TYPICAL SECTIONS

2 0 2 4
SCALE IN FEET

FIG. 4



ION OF THERMOCOUPLES AT R & S

FIG. 5

NOTES:-

For gradation of materials in test elements see PLATE ~~2~~ D-3

Densities and water contents shown PLATE ~~2~~ D-2

Further test section details shown PLATE ~~2~~ D-2

FROST INVESTIGATION
DOW FIELD, BANGOR ME.

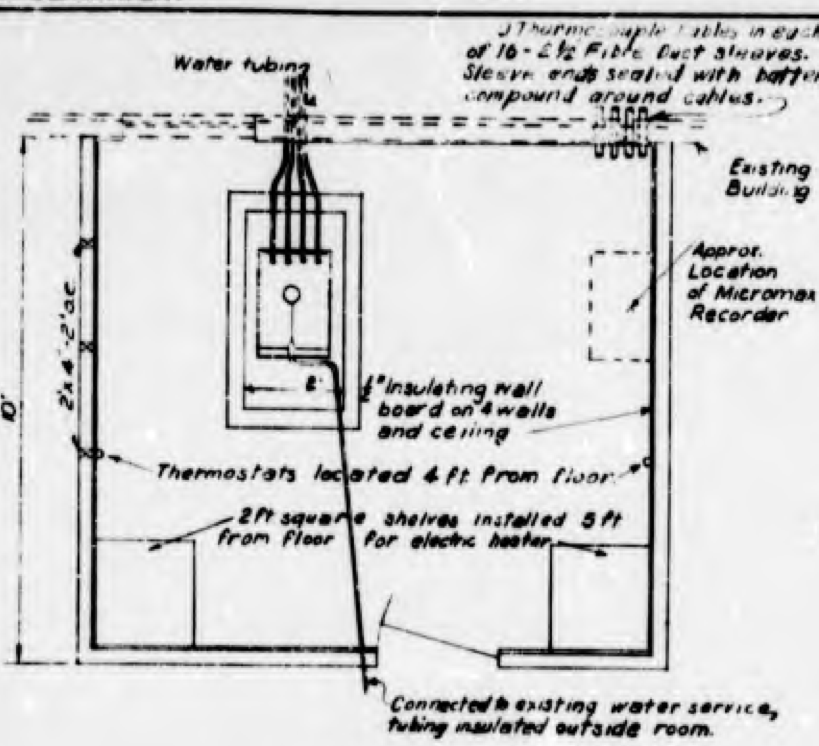
TEST SECTION

SCALES AS SHOWN
SOILS LABORATORY
NEW ENGLAND DIVISION BOSTON, MASS. AUG 1947

(B)

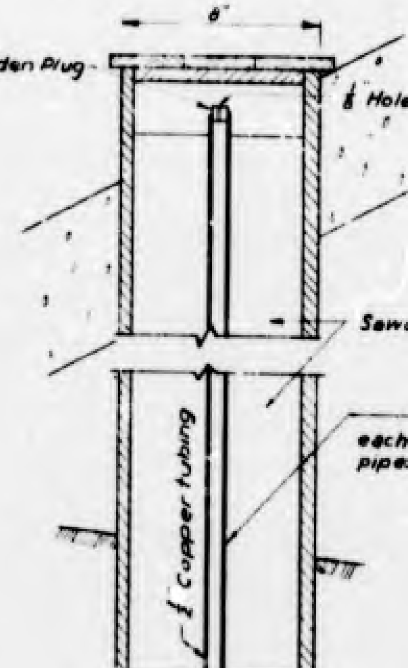
PLATE I

D-1



ROOM PLAN

FIG. 1

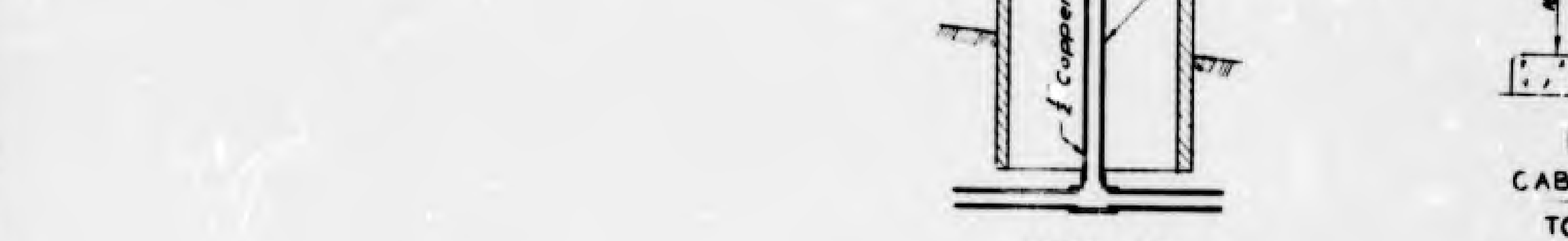


DETAIL OF AIR VENT

FIG. 2

DETAI
CABLE EN
TO ELE

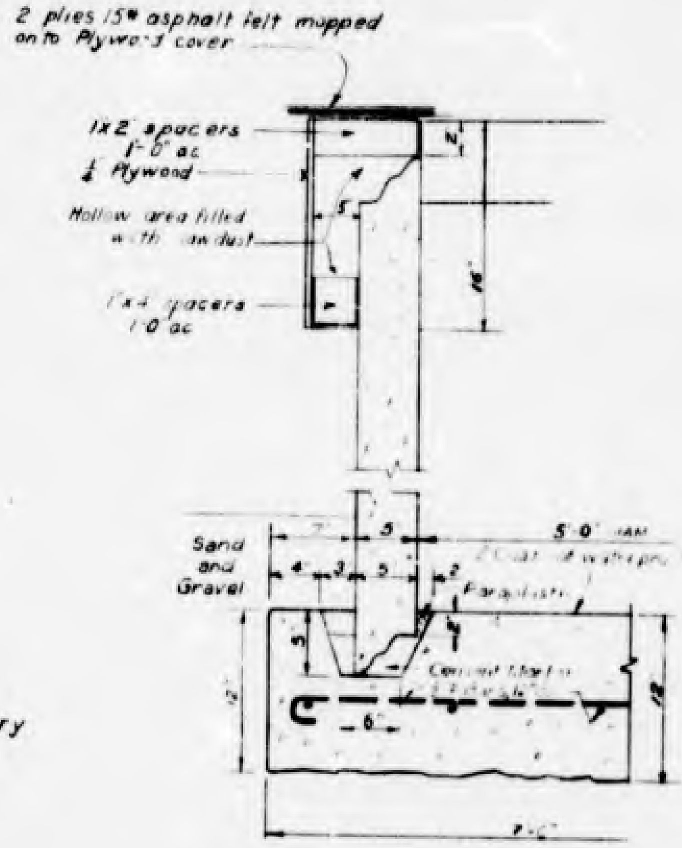
FIG



SECTION - WATER SUPPLY INSTALLATION TO ELEMENTS G,H,J & K

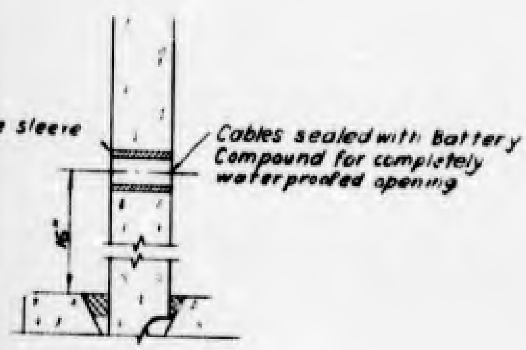
FIG. 5

A



DETAIL OF BASE & TOP

FIG. 4



DETAIL OF CABLE ENTRANCE TO ELEMENT

FIG. 3

Element	Specimen Material	Pavement	Density as Placed in PCF Dry Wt	Water Content for Required % Saturation	% Saturation at Start of Tests
A	Cinders	4" Bit Conc	53 - 68	1 to 2	
B	Cinders	6" P.C. Conc	60 - 64	1 to 3	
C	Sand & Gravel	4" Bit Conc	127 - 131	6 to 8	
D	Sand & Gravel	6" P.C. Conc	128 131	6 to 9	
E	Cr Rock	4" Bit Conc	110	4 to 6	
F	Cr Rock	6" P.C. Conc	107 - 112	4 to 6	
G	Silty Clay	4" Bit Conc	102 105	11 to 28	80 - 90
H	Silty Clay	4" Bit Conc	92 - 98	25 to 29	80 - 90
J	Silty Clay	4" Bit Conc	102 107	15 to 19	60 - 70
K	Silty Clay	4" Bit Conc	90 95	15 to 24	60 - 70
L	Silty Clay	4" Bit Conc	104 - 107	19 to 19	80 - 90
M	Silty Clay	4" Bit Conc	92 - 94	25 to 30	80 - 90
N	Silty Clay	4" Bit Conc	101 105	11 to 19	60 - 70
P	Silty Clay	4" Bit Conc	90 93	18 to 23	60 - 70

TABLE - ELEMENT VARIABLES

Note
For gradation of materials see Plate D-3

FROST INVESTIGATION
DOW FIELD, BANGOR, ME.

DETAILS OF TEST SECTION

SCALES AS SHOWN
SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

B

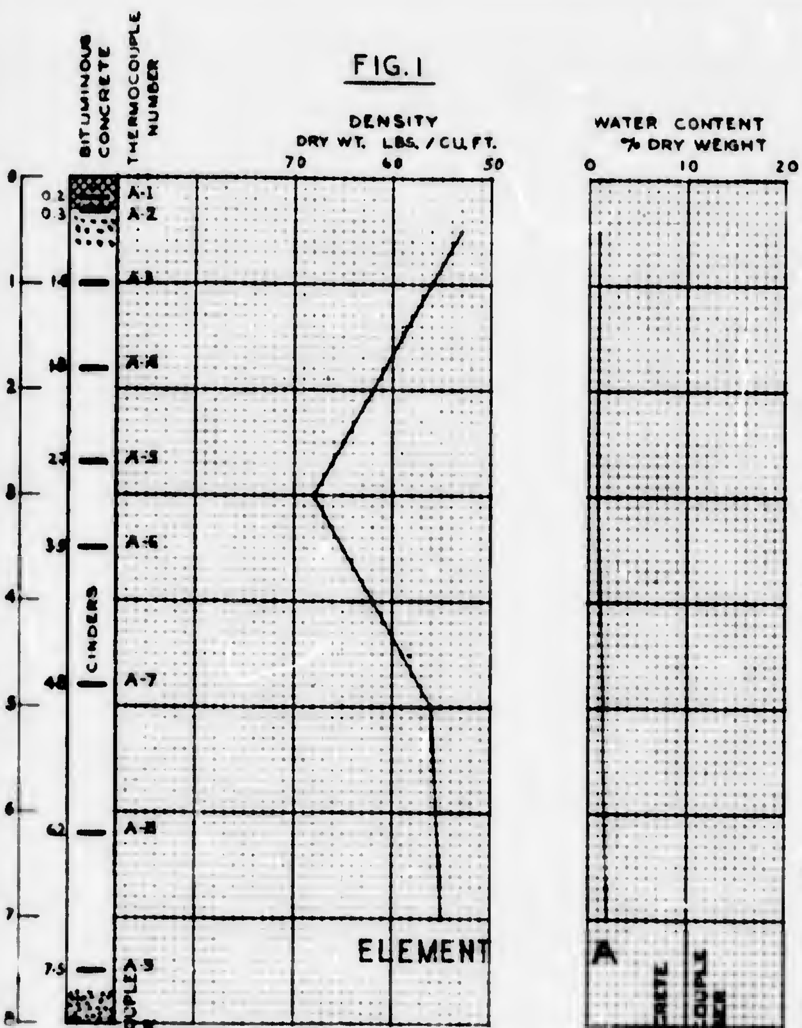
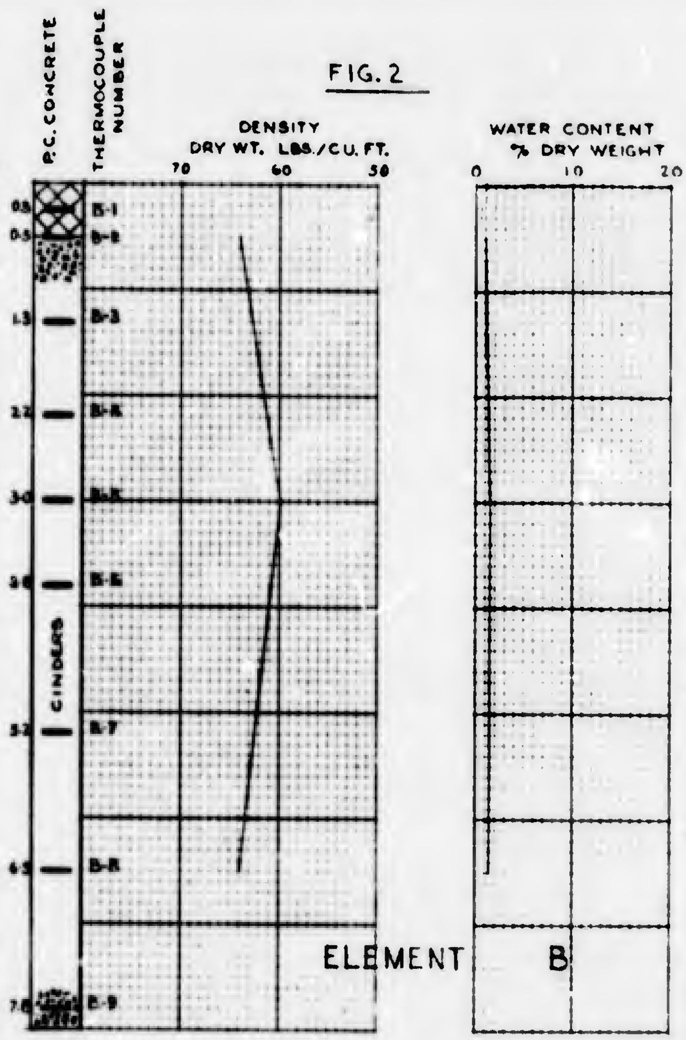
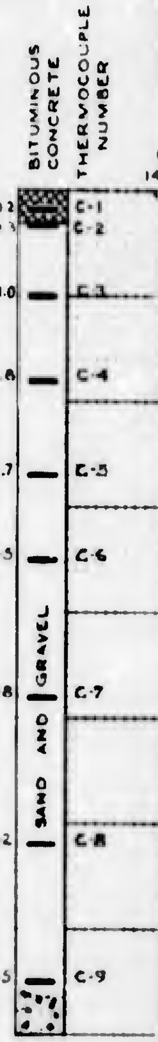


FIG. 1
BITUMINOUS CONCRETE
THERMOCOUPLE NUMBER
DENSITY
DRY WT. LBS./CU. FT.
70 60 50
WATER CONTENT
% DRY WEIGHT
0 10 20
A-1
A-2
A-3
A-4
A-5
A-6
CINDERS
A-7
A-8
A-9
THERMOCOUPLES
ELEMENT A


P.C. CONCRETE
THERMOCOUPLE NUMBER
FIG. 2
DENSITY
DRY WT. LBS./CU. FT.
70 60 50
WATER CONTENT
% DRY WEIGHT
0 10 20
B-1
B-3
B-7
CINDERS
ELEMENT B


BITUMINOUS CONCRETE
THERMOCOUPLE NUMBER
C-1
C-2
C-3
C-4
C-5
C-6
C-7
C-9
SAND AND GRAVEL

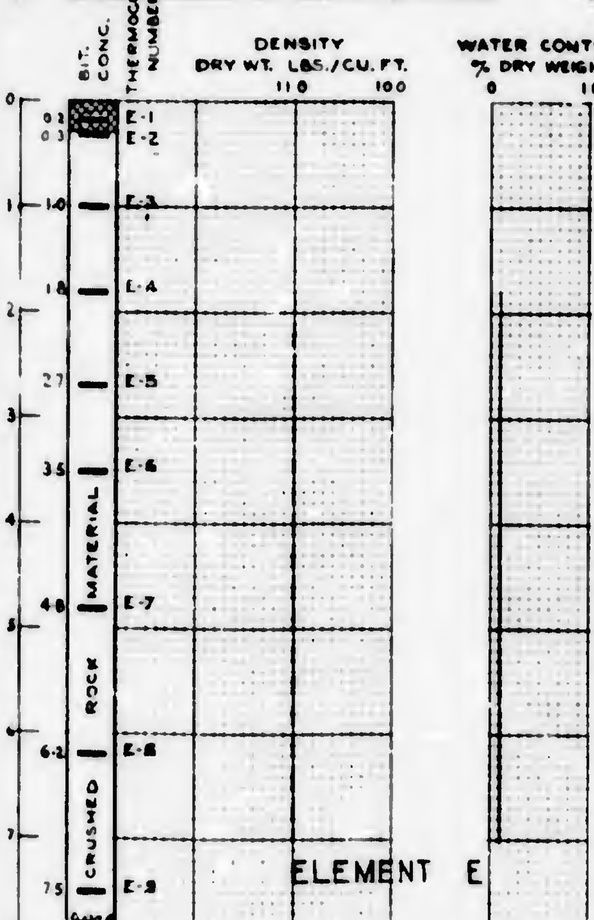

BIT. CONC.
THERMOCOUPLE NUMBER
DENSITY
DRY WT. LBS./CU. FT.
110 100
WATER CONTENT
% DRY WEIGHT
0 10
E-1
E-2
E-3
E-4
E-5
E-6
E-7
E-8
E-9
CRUSHED ROCK MATERIAL
ELEMENT E

FIG 5

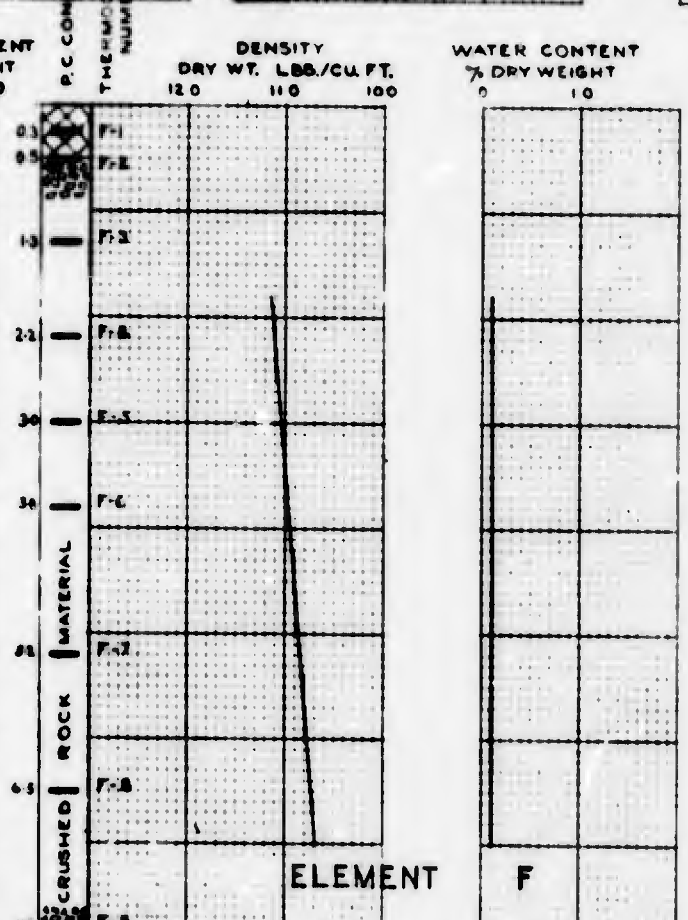

P.C. CONCRETE
THERMOCOUPLE NUMBER
DENSITY
DRY WT. LBS./CU. FT.
120 110 100
WATER CONTENT
% DRY WEIGHT
0 10
F-1
F-2
F-3
F-5
F-6
F-7
F-8
F-9
CRUSHED ROCK MATERIAL
ELEMENT F

FIG 6

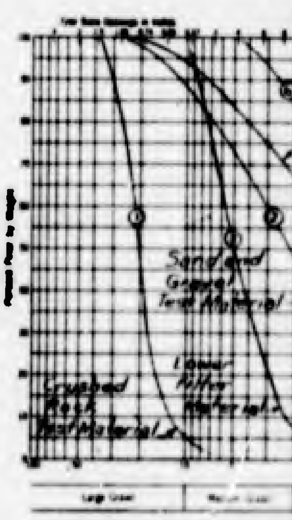

Sand and Gravel Test Material
Crushed Rock Test Material

FIG. 3

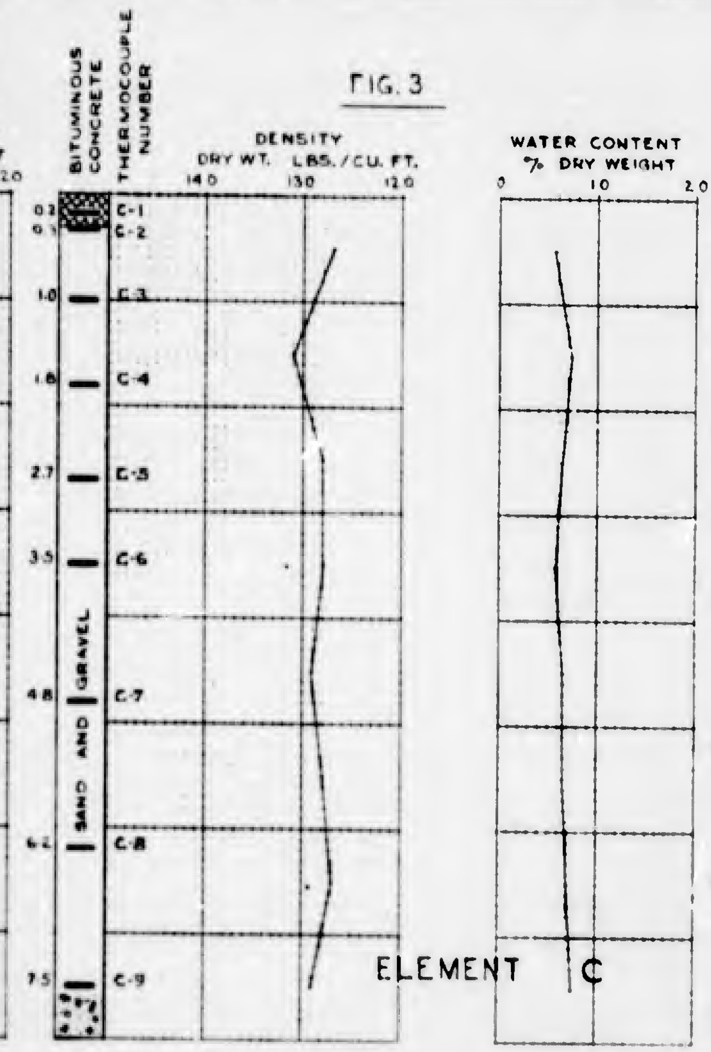
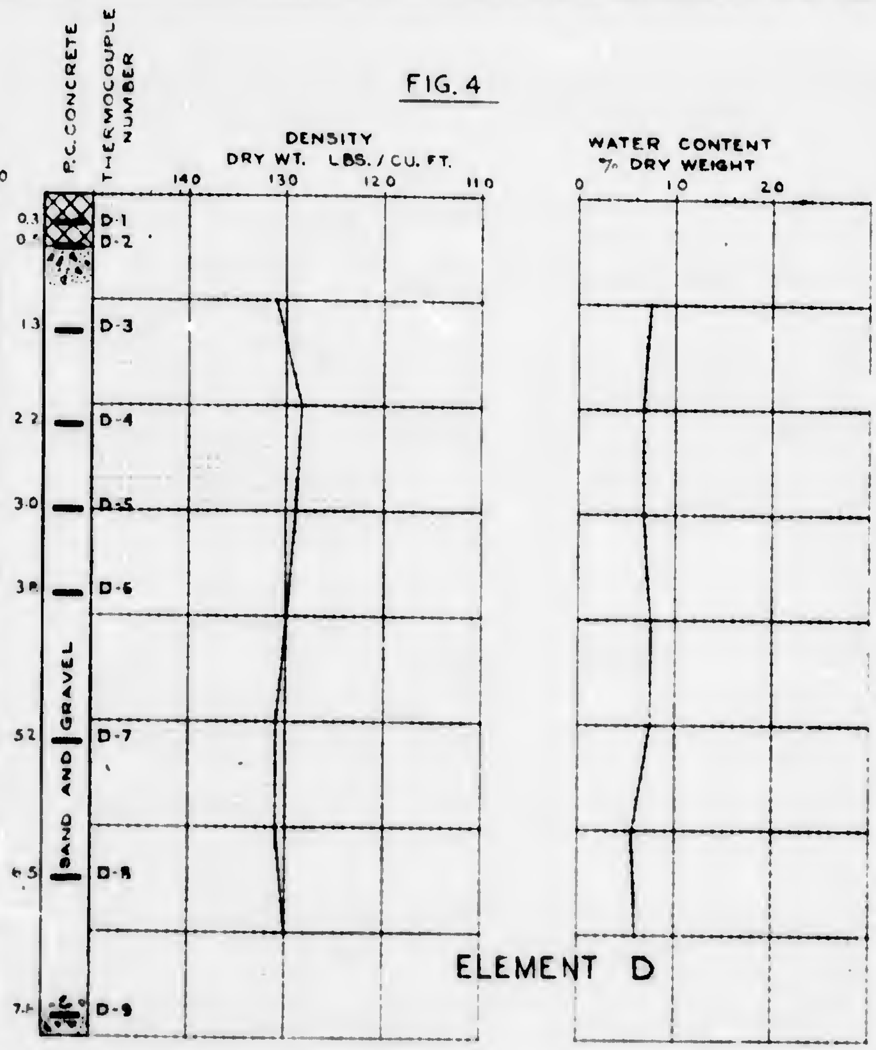


FIG. 4



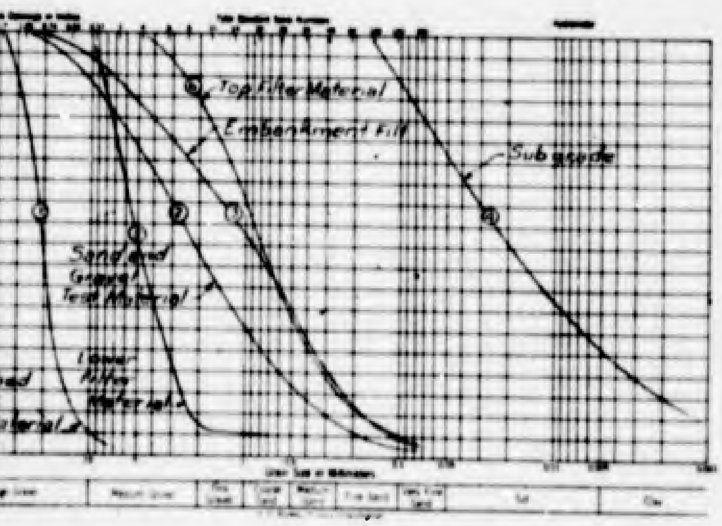


FIG 7

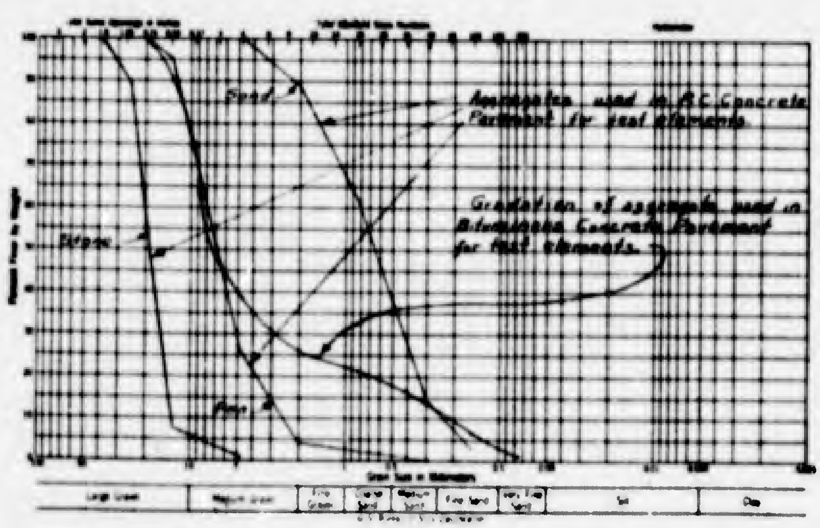


FIG 8

NOTE :-

Density of crushed rock in element E determined by pre-weighing material before compacting in place in layers of predetermined thickness.

FROST INVESTIGATION
TEST SECTION DOW FIELD, BANGOR, ME.

DENSITY AND WATER CONTENT
IN TEST ELEMENTS
WITH LOCATION OF THERMOCOUPLES
SOIL CLASSIFICATION DATA

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS AUG 1947

FIG. 1

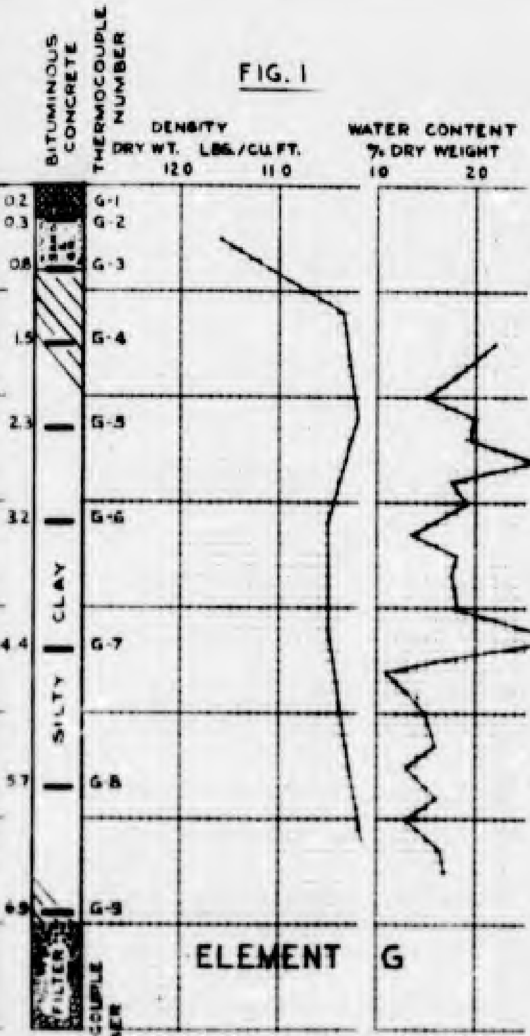


FIG. 2

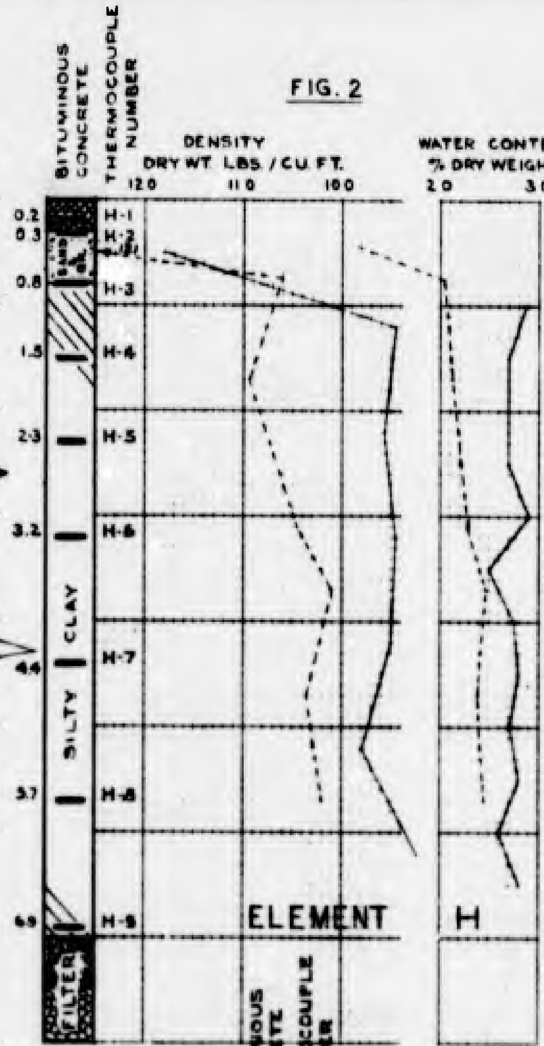
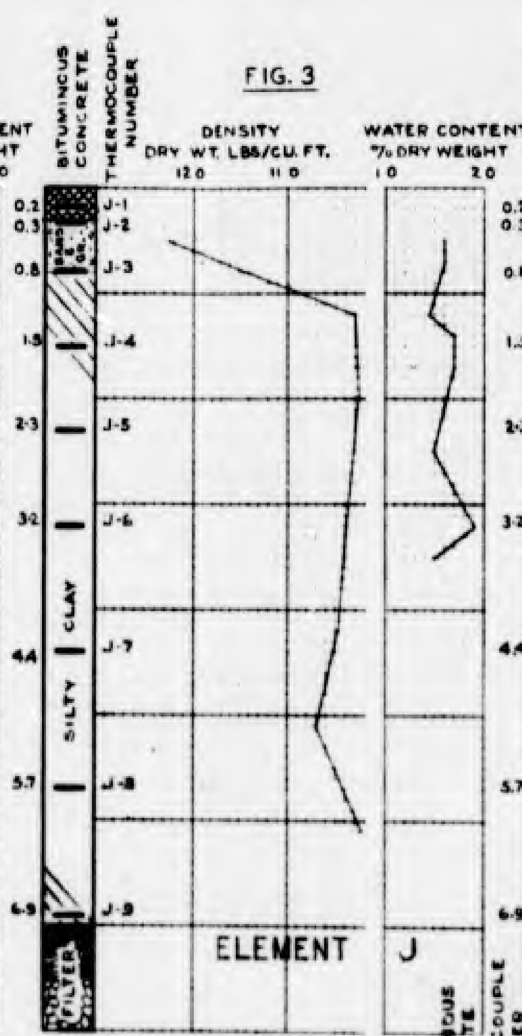
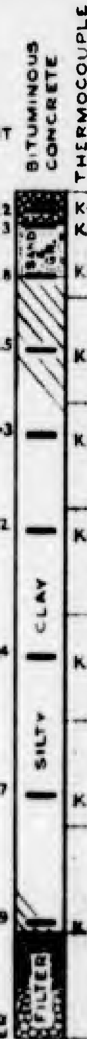


FIG. 3





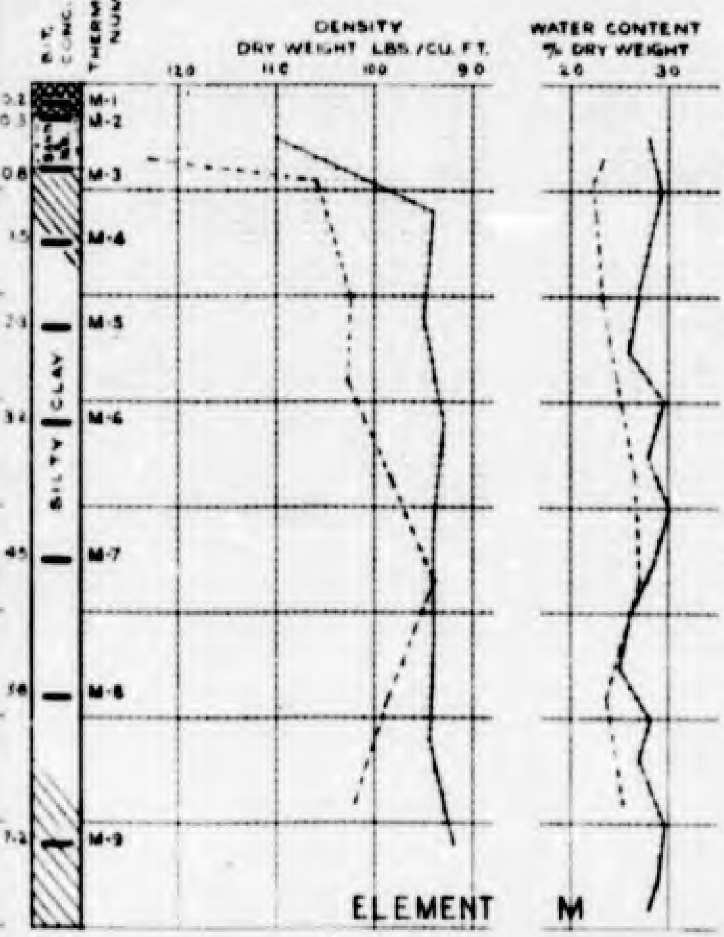


FIG. 6

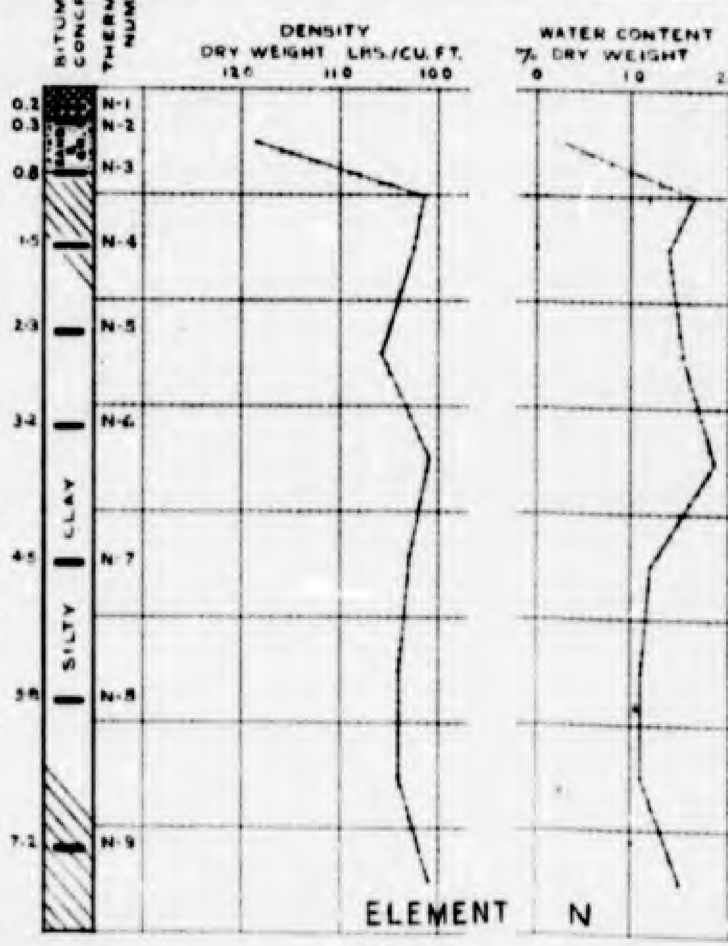


FIG. 7

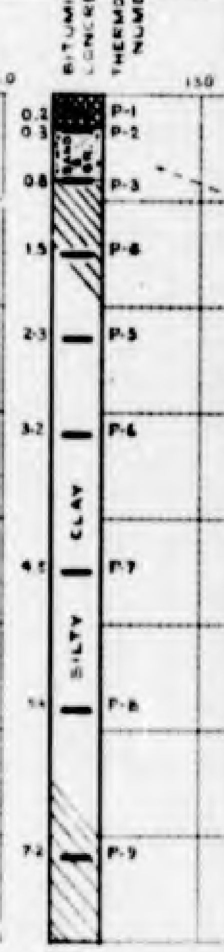


FIG. 4

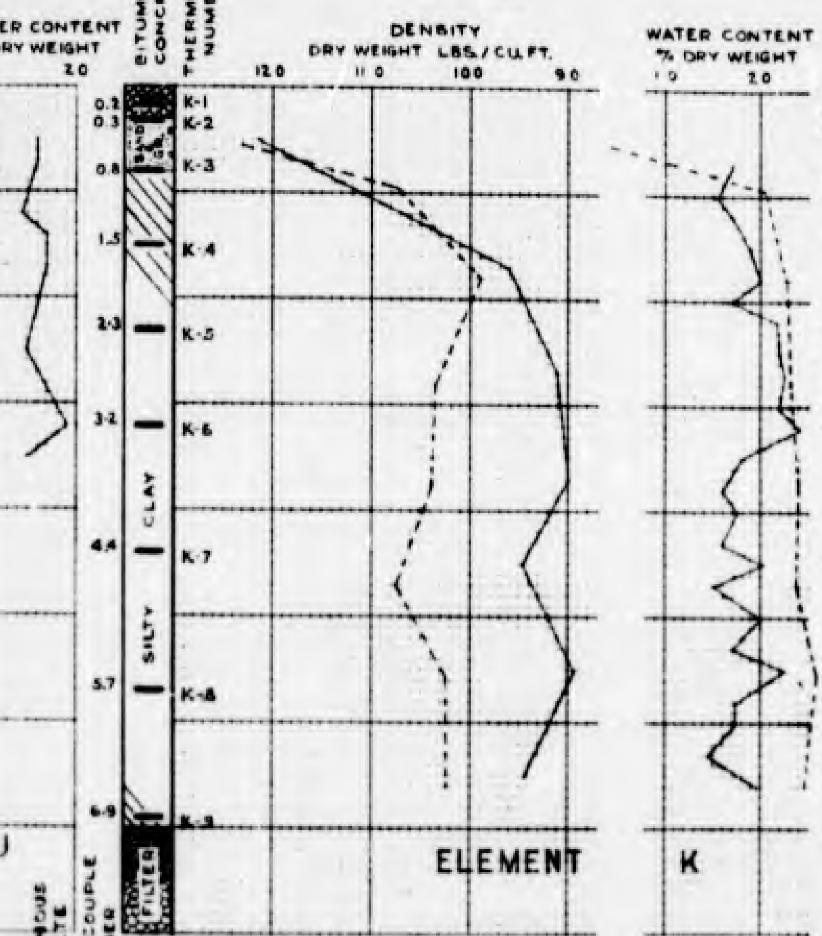
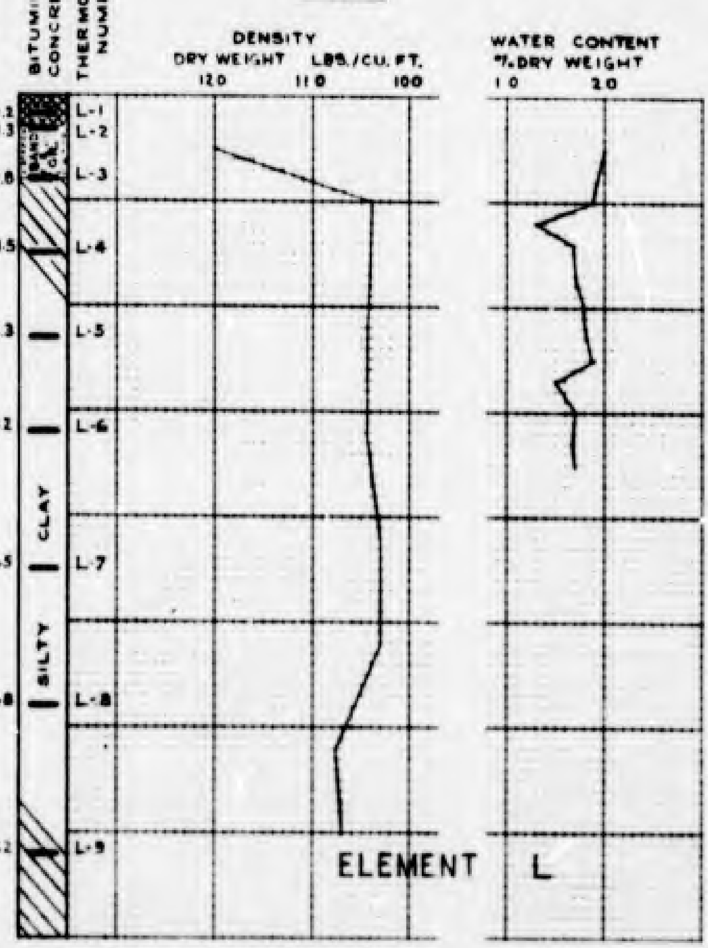


FIG. 5



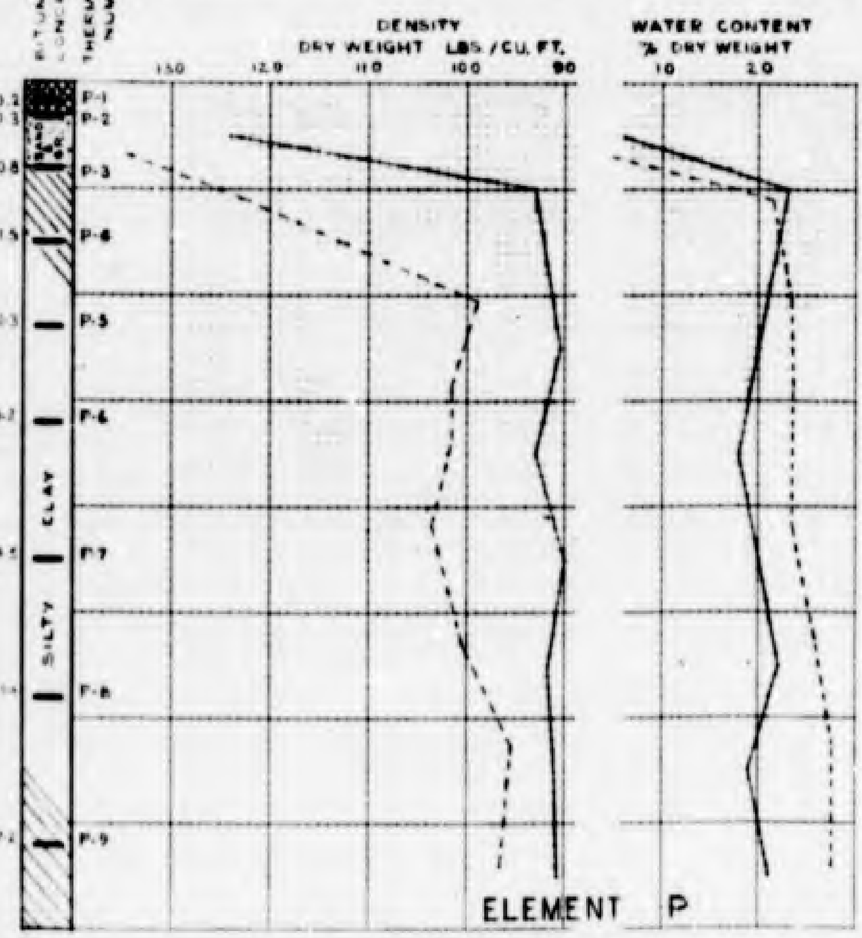


FIG. 8

NOTES -

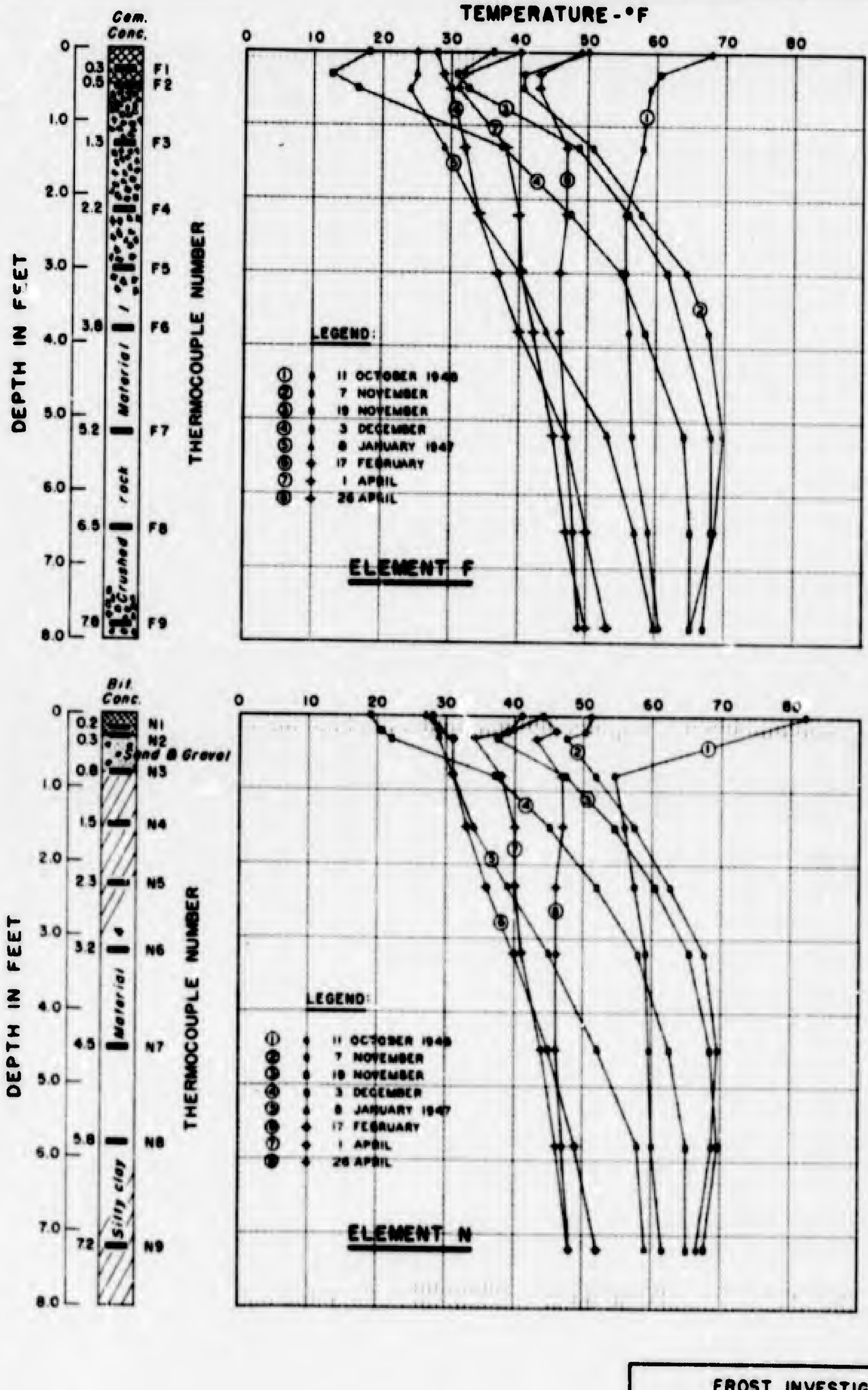
Density and water content in test elements as originally built shown thus ———

Density and water content in test elements rebuilt from June 23 to June 30, 1947 due to subsidence of loosely placed materials shown thus ------

FROST INVESTIGATION
TEST SECTION, DOW FIELD, BANGOR, ME.

DENSITY AND WATER CONTENT IN TEST ELEMENTS WITH LOCATION OF THERMOCOUPLES

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

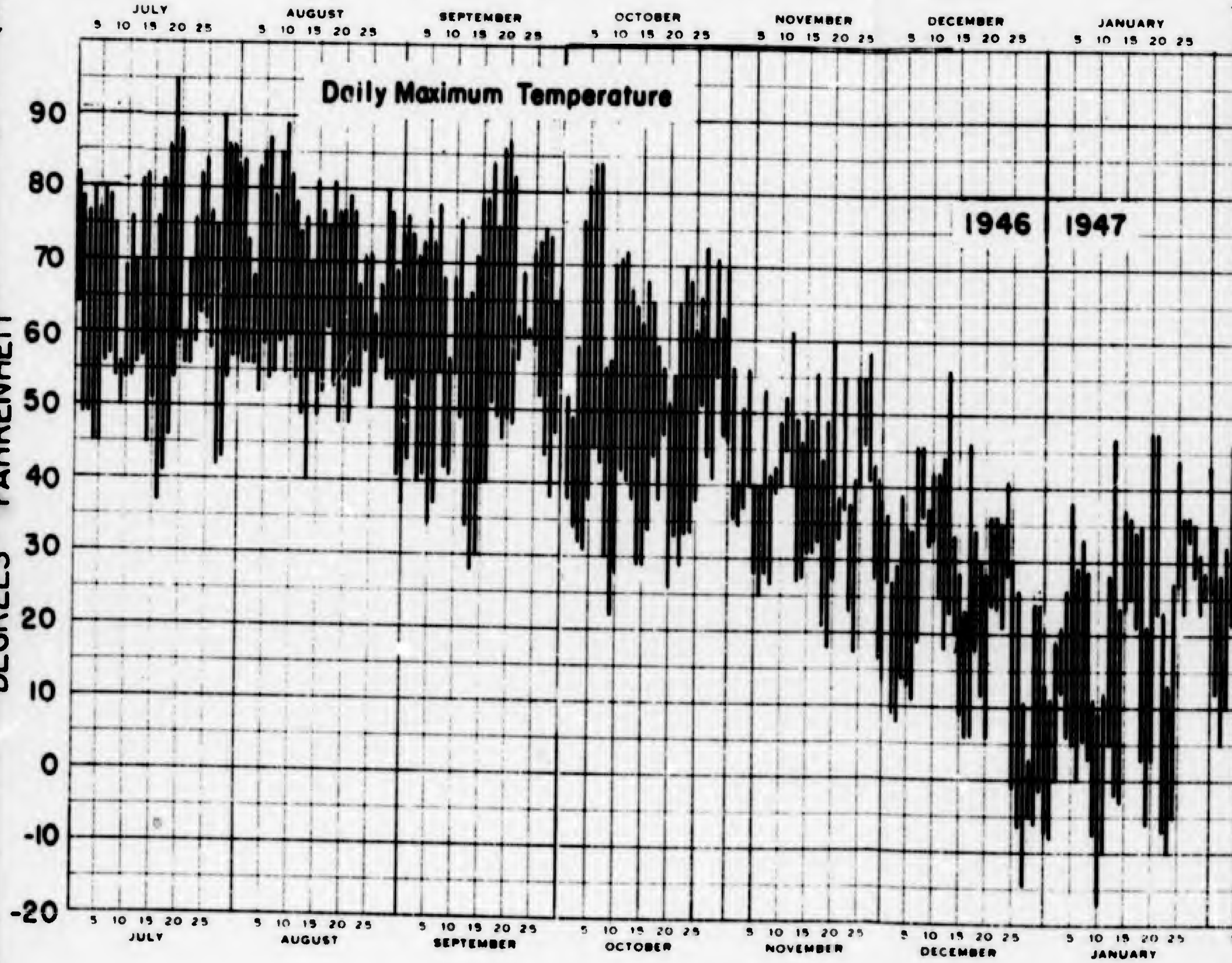


FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEST SECTION
TYPICAL SUBSURFACE TEMPERATURES

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

PLATE 5
D-5

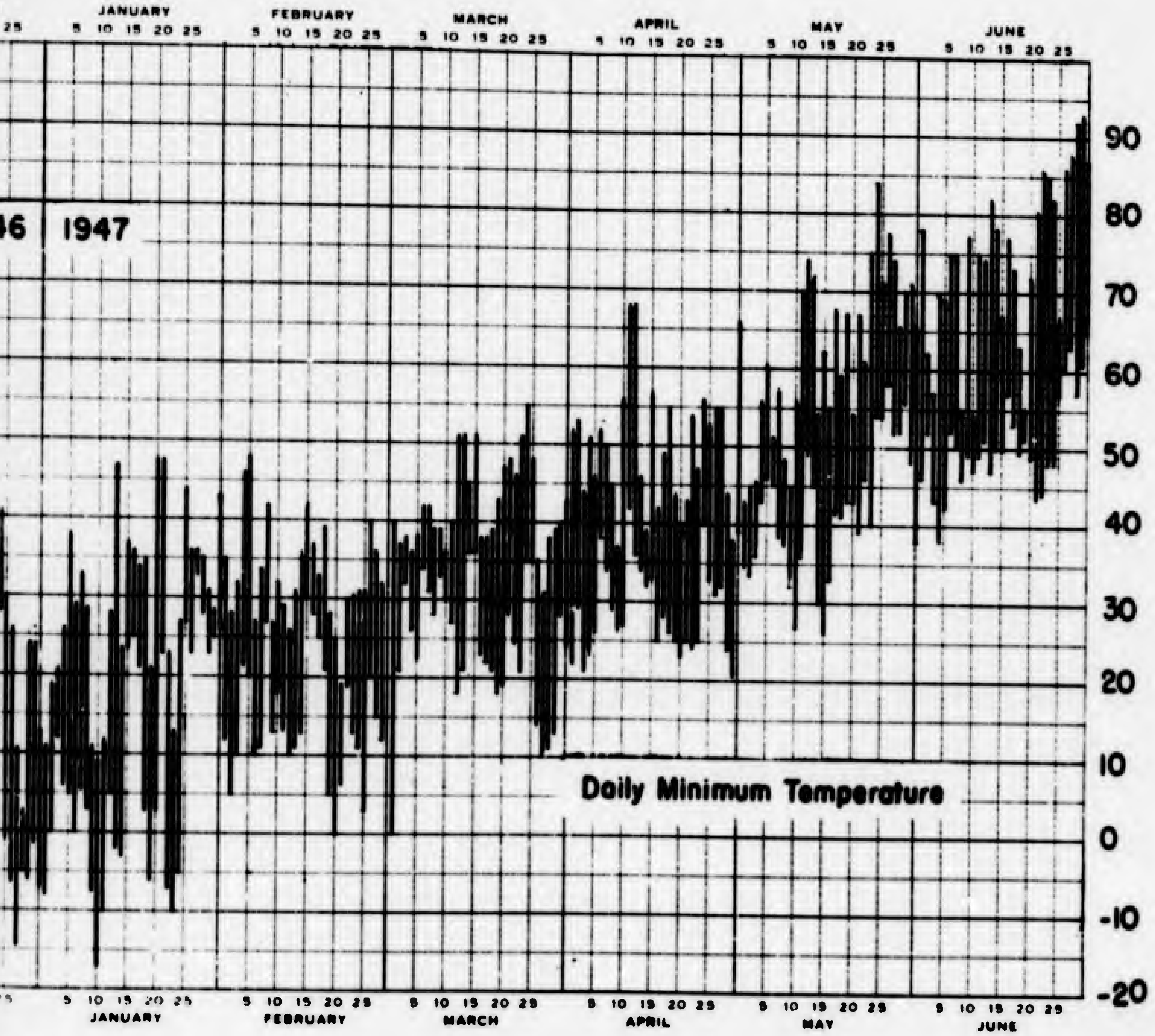


NOTES:

SOURCE OF DATA

U.S. Weather Bureau (Bangor Hydro-Electric Company) 1 July–10 October, 1946.

New England Division Thermograph, continuous record, 11 October, 1946 – 1 July, 1947.

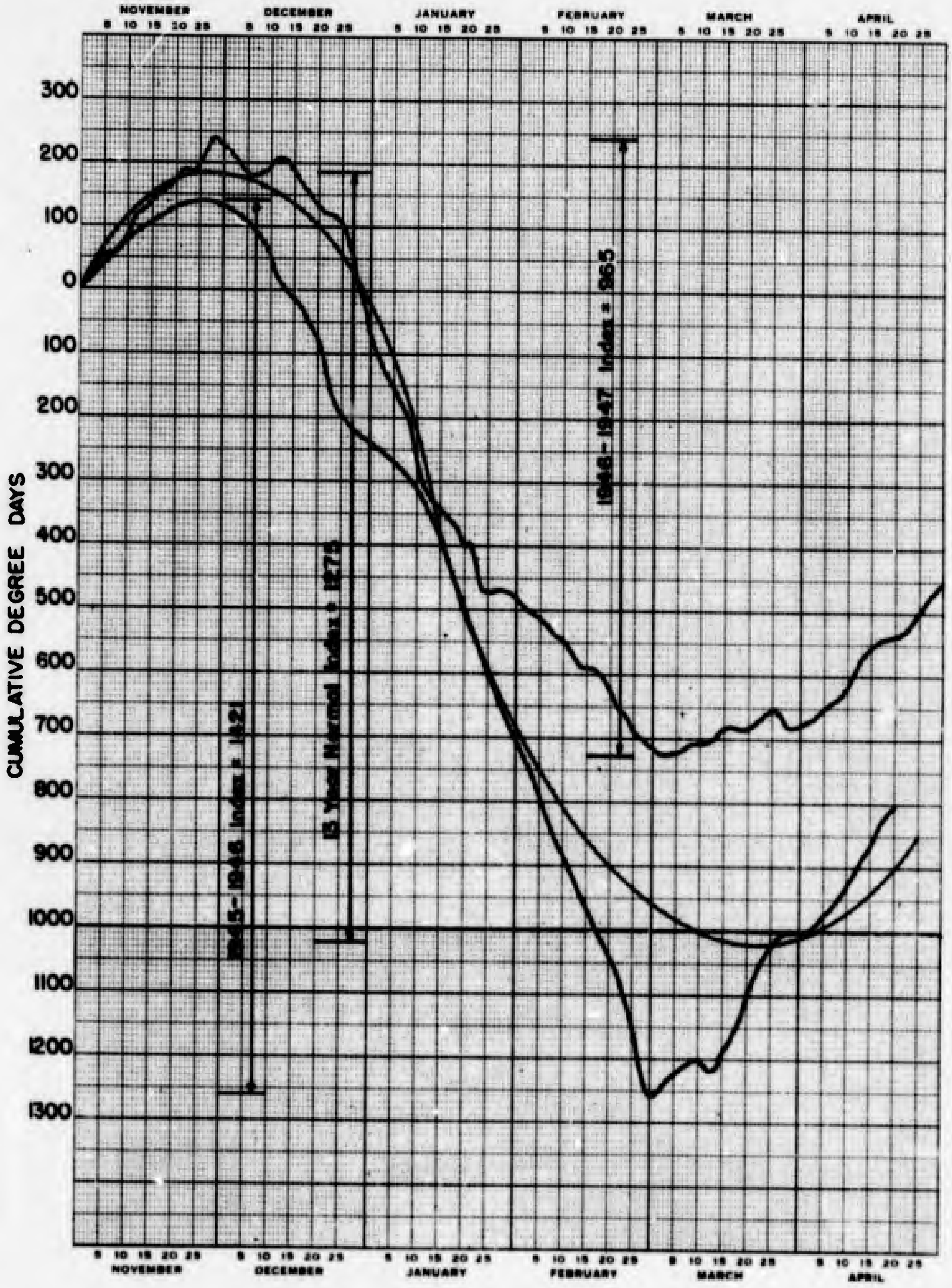


FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

MAXIMUM AND MINIMUM
DAILY TEMPERATURES

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUGUST 1947

PLATE D-6

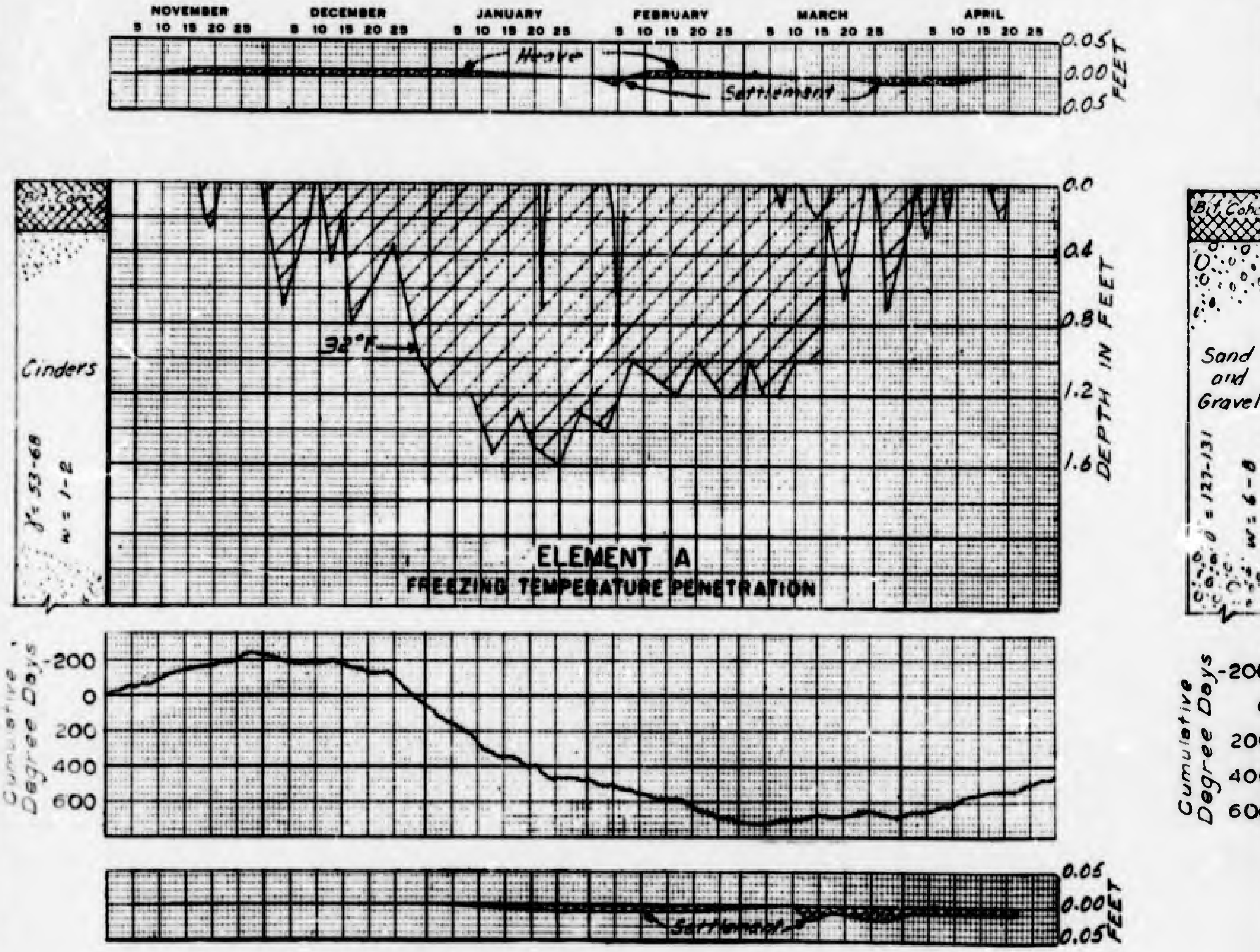


FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

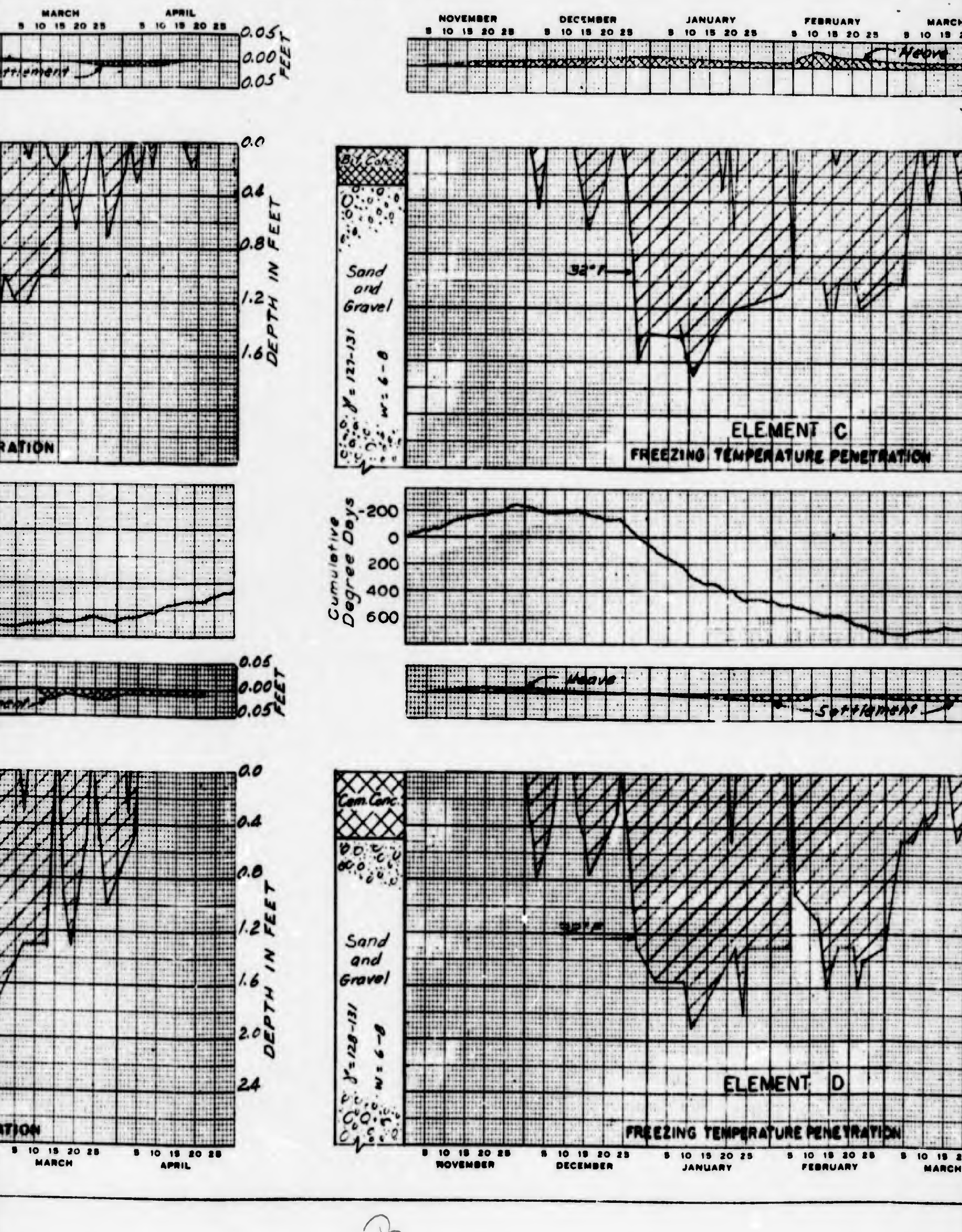
FREEZING INDEX

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUGUST 1947

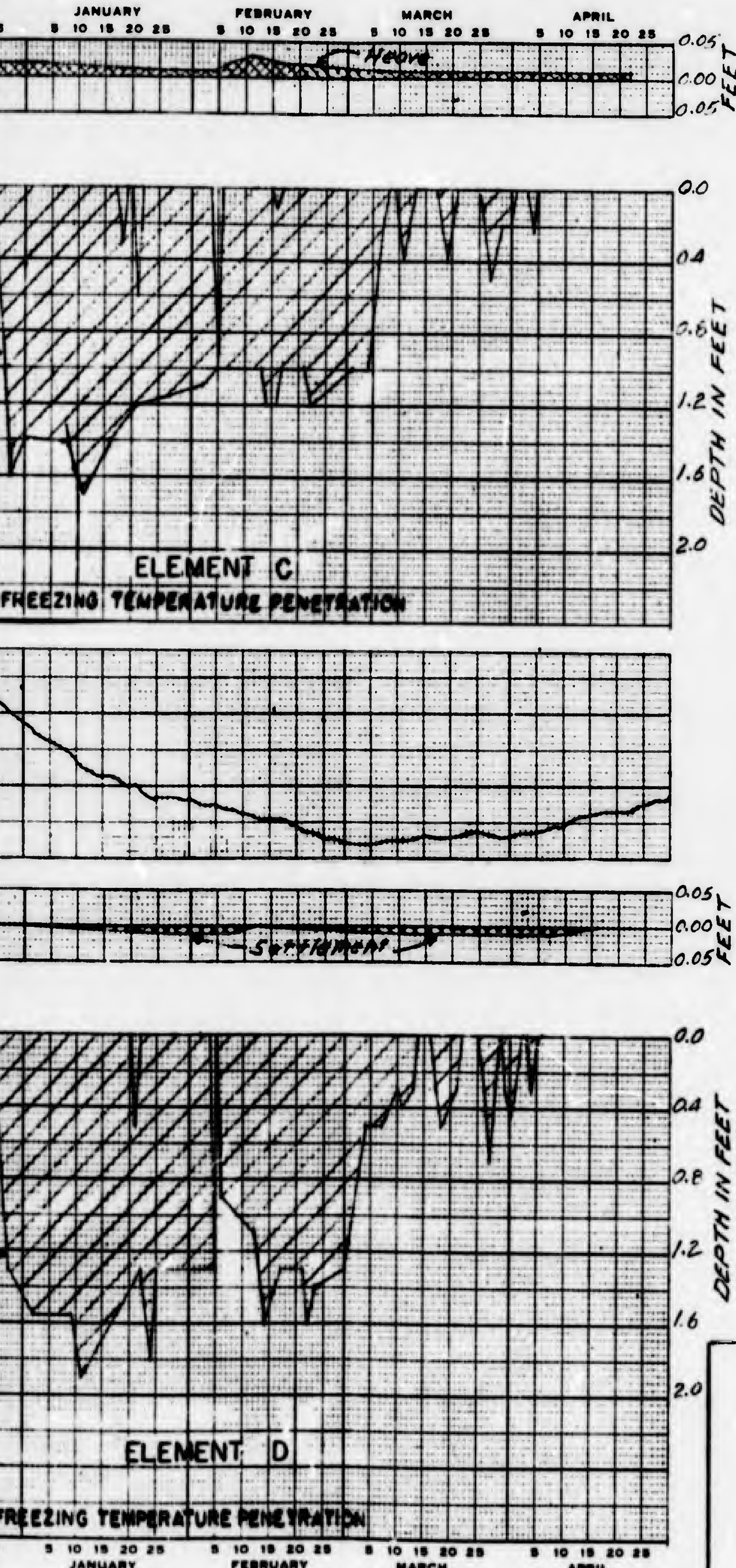
PLATE D-7



NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
Heave
Settlement
0.05
0.00
0.05
FEET
Bit Conc
Cinders
γ = 53-68
w = 1-2
32°F
0.0
0.4
0.8
1.2
1.6
DEPTH IN FEET
ELEMENT A
FREEZING TEMPERATURE PENETRATION
Sand and Gravel
γ = 127-131
w = 6-8
Cumulative Degree Days
-200
0
200
400
600
Settlement
Cem Conc
Cinders
γ = 60-68
w = 1-2
32°F
0.0
0.4
0.8
1.2
1.6
2.0
2.4
DEPTH IN FEET
ELEMENT B
FREEZING TEMPERATURE PENETRATION
Sand and Gravel
γ = 128-131
w = 6-8



MARCH
APRIL
5 10 15 20 25
0.05
0.00
0.05
FEET
Settlement
0.0
0.4
0.8
1.2
1.6
DEPTH IN FEET
RATION
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
Heave
Bit. Conc.
Sand and Gravel
γ = 127-131
w: 6-8
32°F
ELEMENT C
FREEZING TEMPERATURE PENETRATION
Cumulative Degree Days
-200
0
200
400
600
Heave
Settlement
2.0
2.4
Cem. Conc.
γ = 128-131
w: 6-8
ELEMENT D
FREEZING TEMPERATURE PENETRATION
B



NOTE
Effect of air temperature on Elements modified by heat generated by sawdust insulation around element.

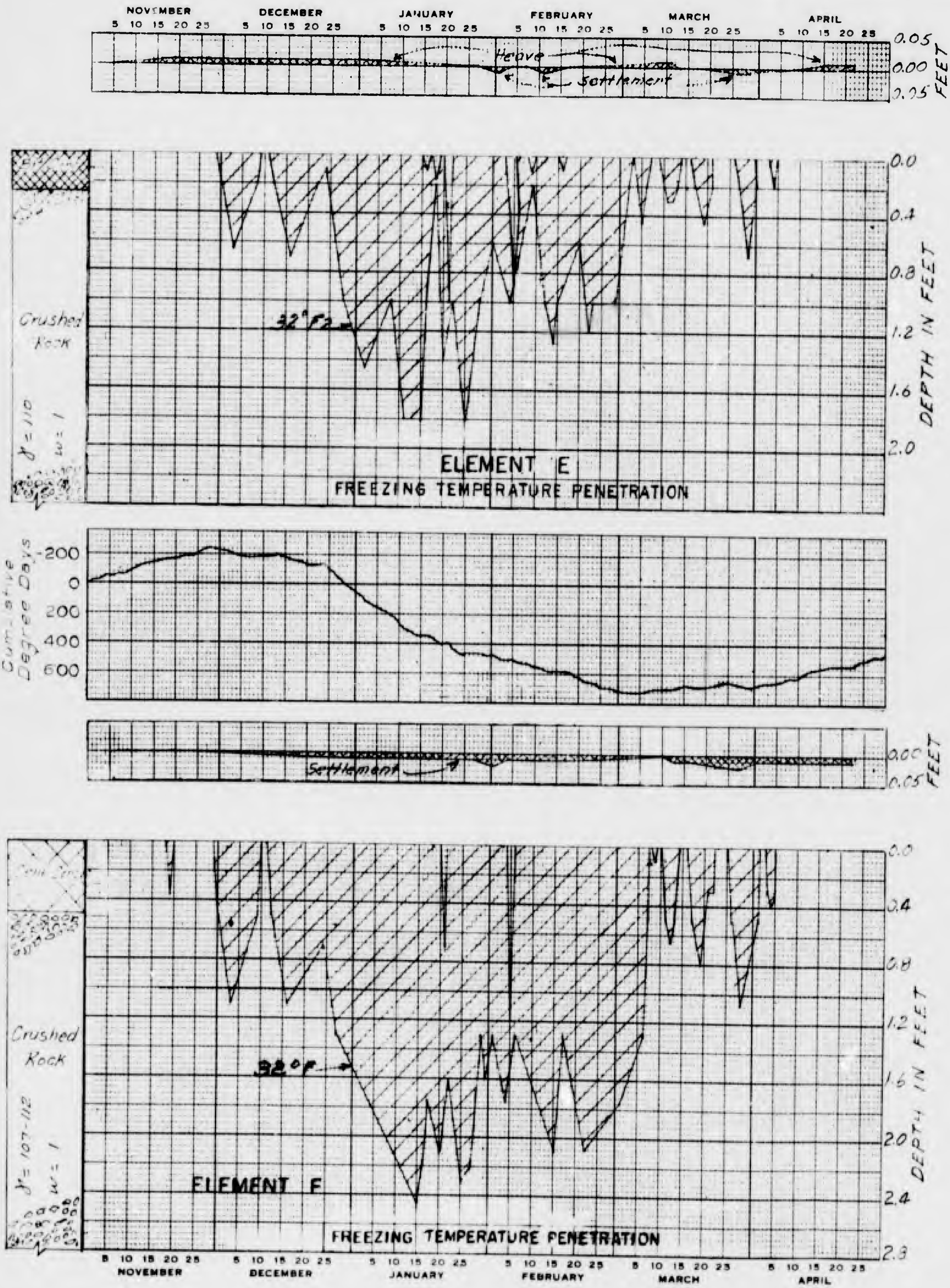
FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

FREEZING TEMPERATURE AND PAVEMENT HEAVE VS TIME

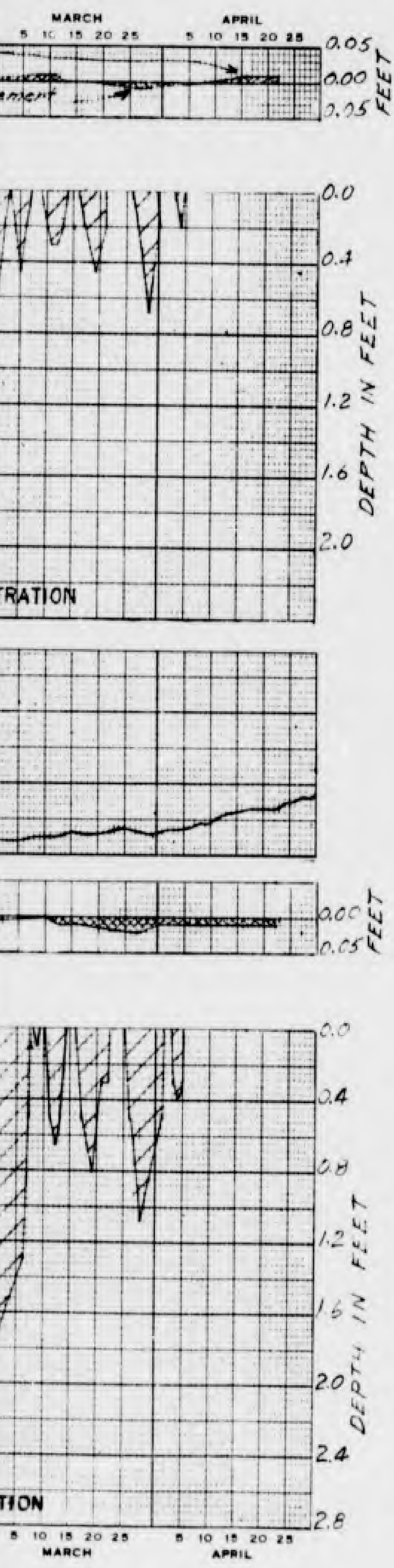
ELEMENTS A, B, C, D.

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

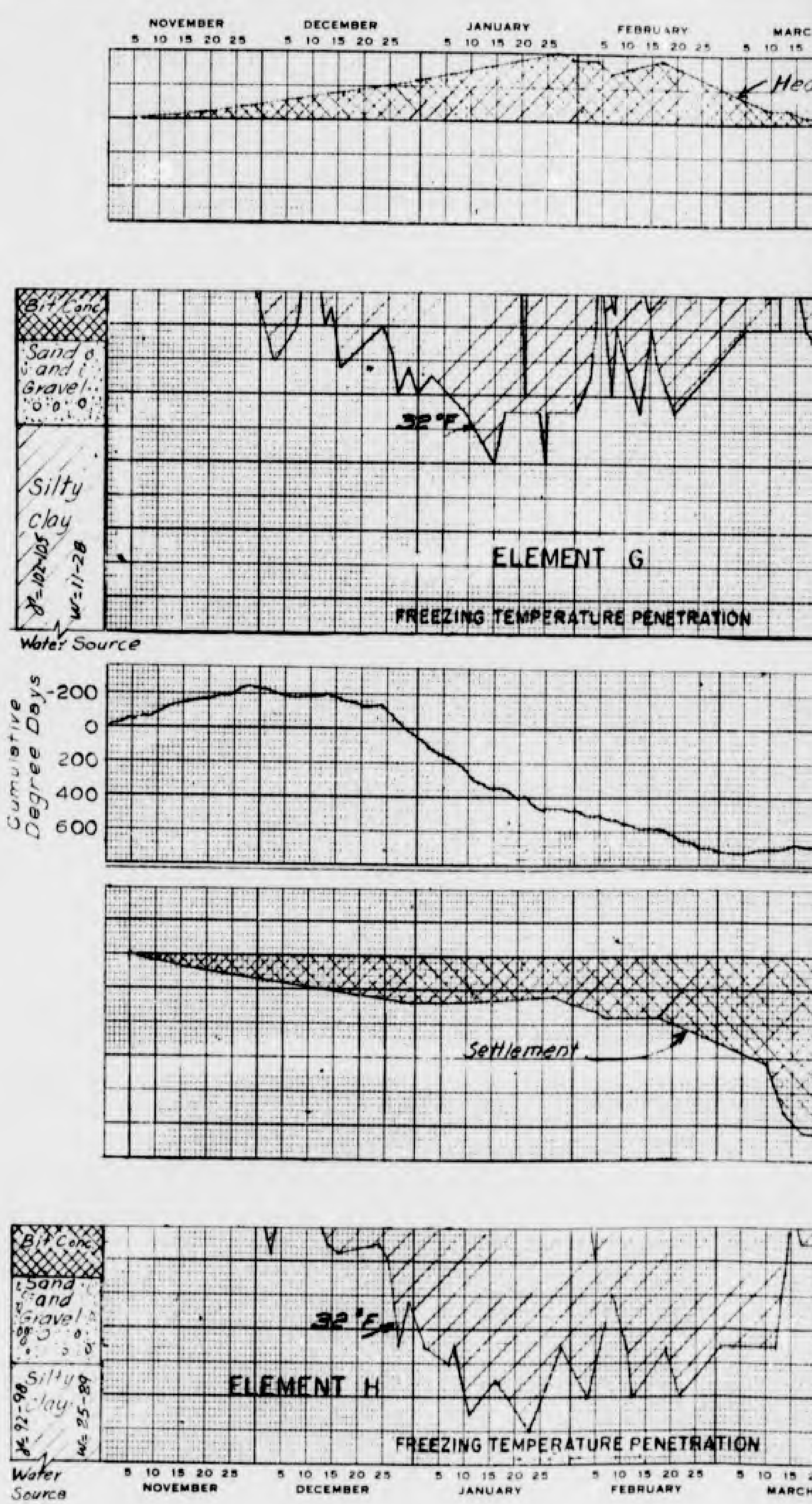
PLATE 8
D-8



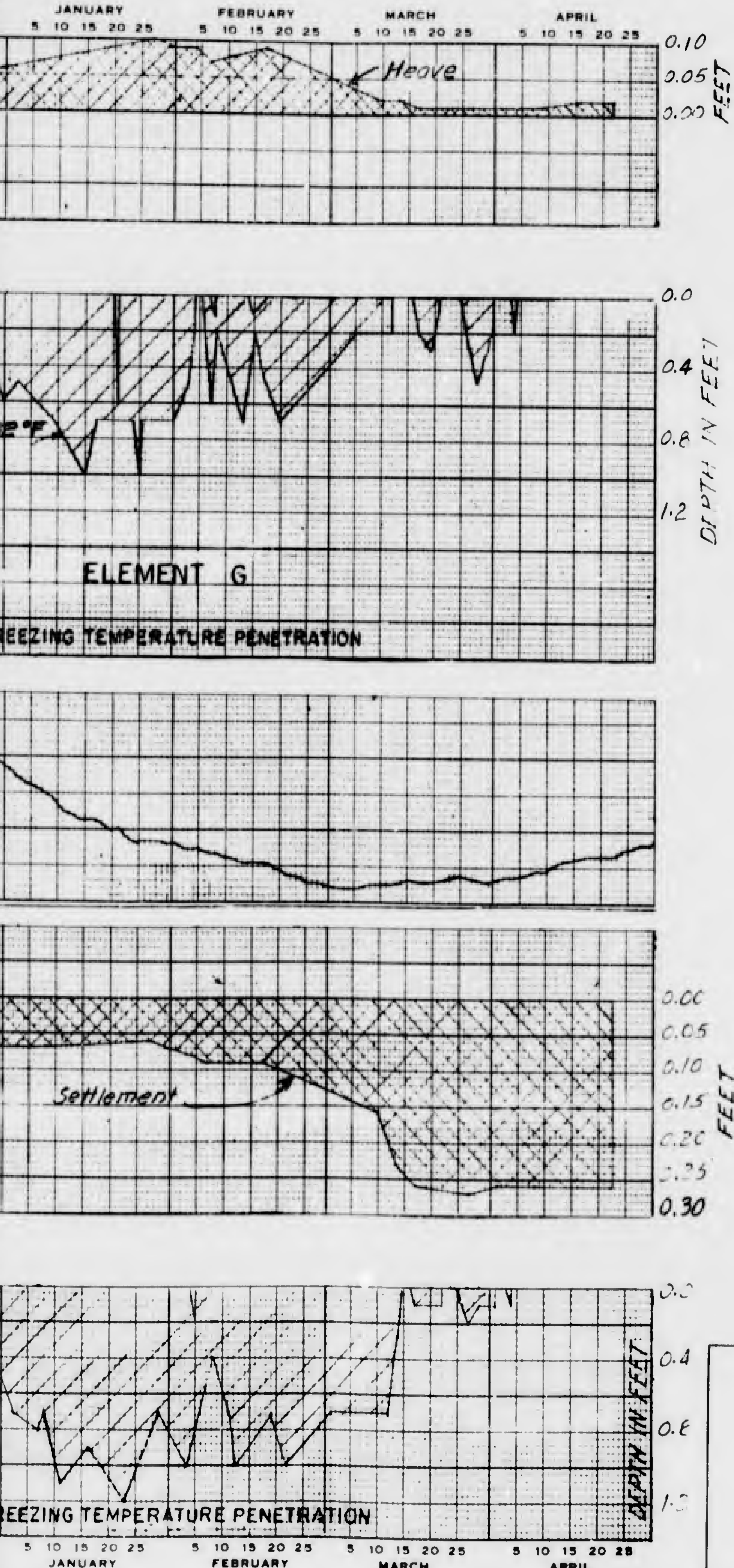
NOVEMBER DECEMBER JANUARY FEBRUARY MARCH APRIL
5 10 15 20 25
Heave
Settlement
0.05
0.00
0.05
FEET
Crushed Rock
γ = 110
w = 1
32°F
0.0
0.4
0.8
1.2
1.6
2.0
DEPTH IN FEET
ELEMENT E
FREEZING TEMPERATURE PENETRATION
Cumulative Degree Days
-200
0
200
400
600
Settlement
0.00
0.05
FEET
Crushed Rock
γ = 107-112
w = 1
32°F
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
DEPTH IN FEET
ELEMENT F
FREEZING TEMPERATURE PENETRATION
5 10 15 20 25
NOVEMBER DECEMBER JANUARY FEBRUARY MARCH APRIL



MARCH
APRIL
5 10 15 20 25
0.05
0.00
0.05
FEET
ement
0.0
0.4
0.8
1.2
1.6
2.0
DEPTH IN FEET
RATION
0.00
0.05
FEET
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
DEPTH IN FEET
TION
5 10 15 20 25
MARCH
APRIL



NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARC
5 10 15 20 25
Hea
Bit Conc
Sand and Gravel
Silty clay
γ=102-105
w=11-28
32°F
ELEMENT G
FREEZING TEMPERATURE PENETRATION
Water Source
Cumulative Degree Days
-200
0
200
400
600
Settlement
Bit Conc
Sand and Gravel
Silty clay
γ=92-98
w=25-89
32°F
ELEMENT H
FREEZING TEMPERATURE PENETRATION
Water Source
5 10 15 20 25
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH



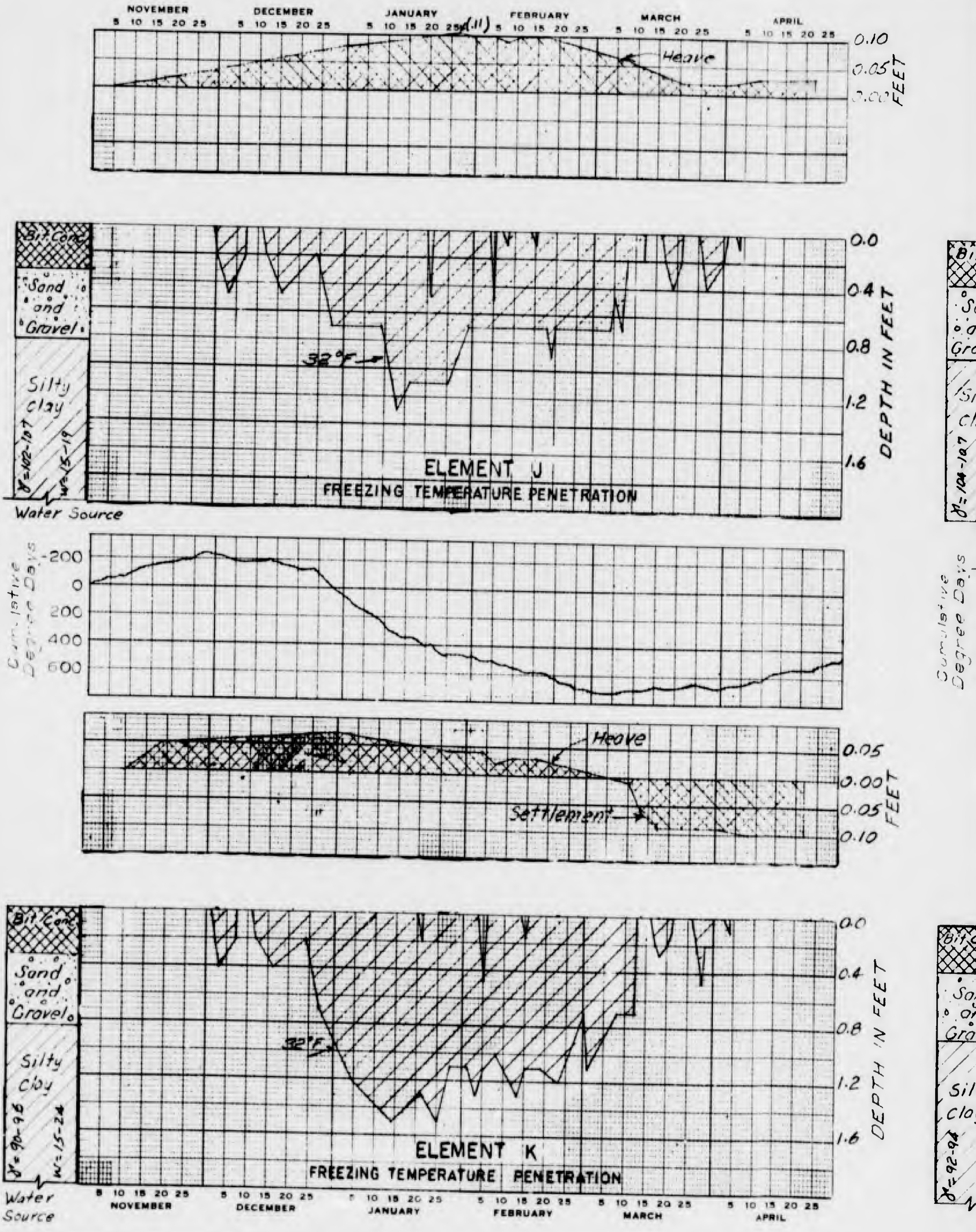
NOTE
Effect of air temperature on Elements modified by heat generated by sawdust insulation around element.

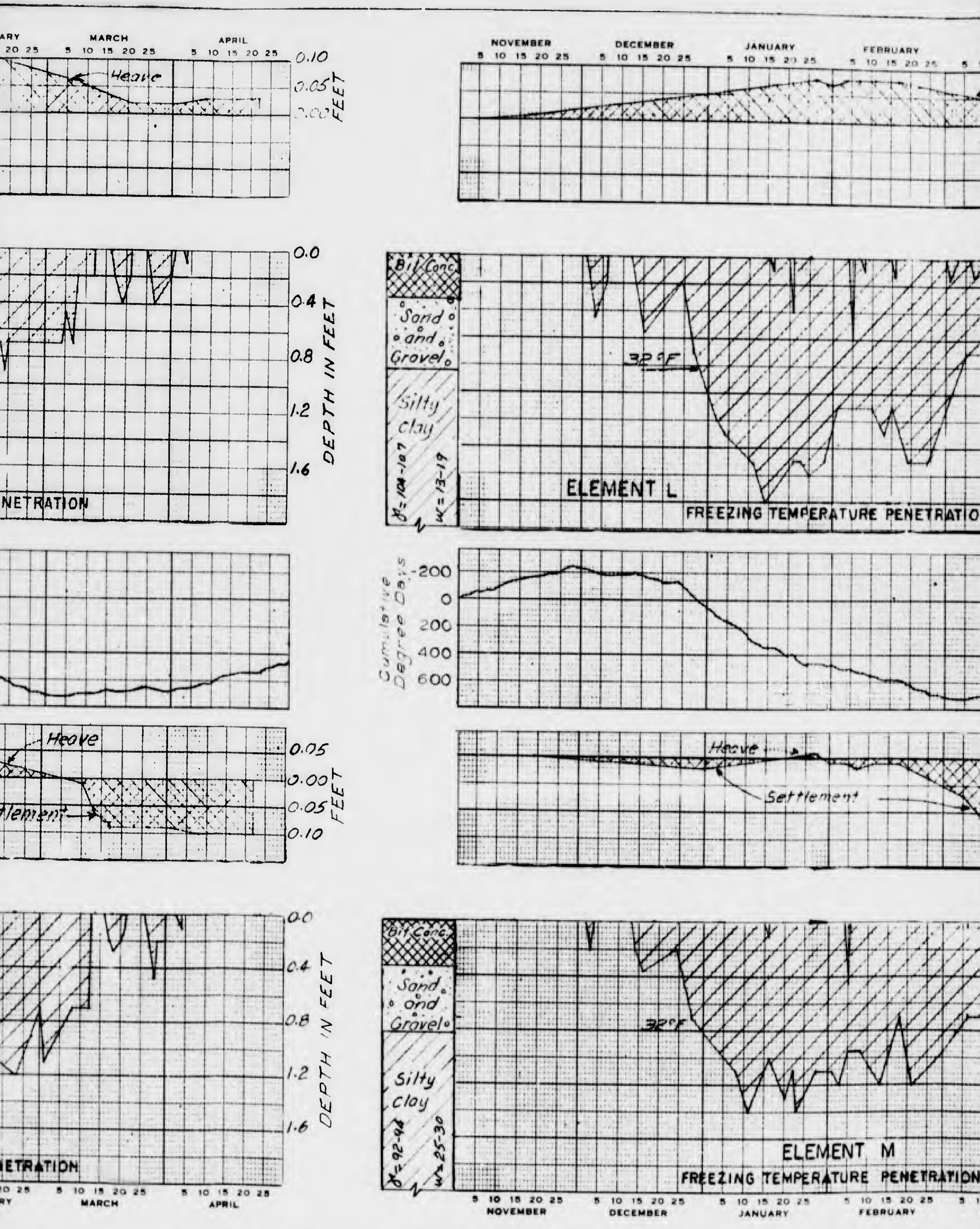
FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

FREEZING TEMPERATURE
AND PAVEMENT HEAVE
VS TIME
ELEMENTS E, F, G, H.

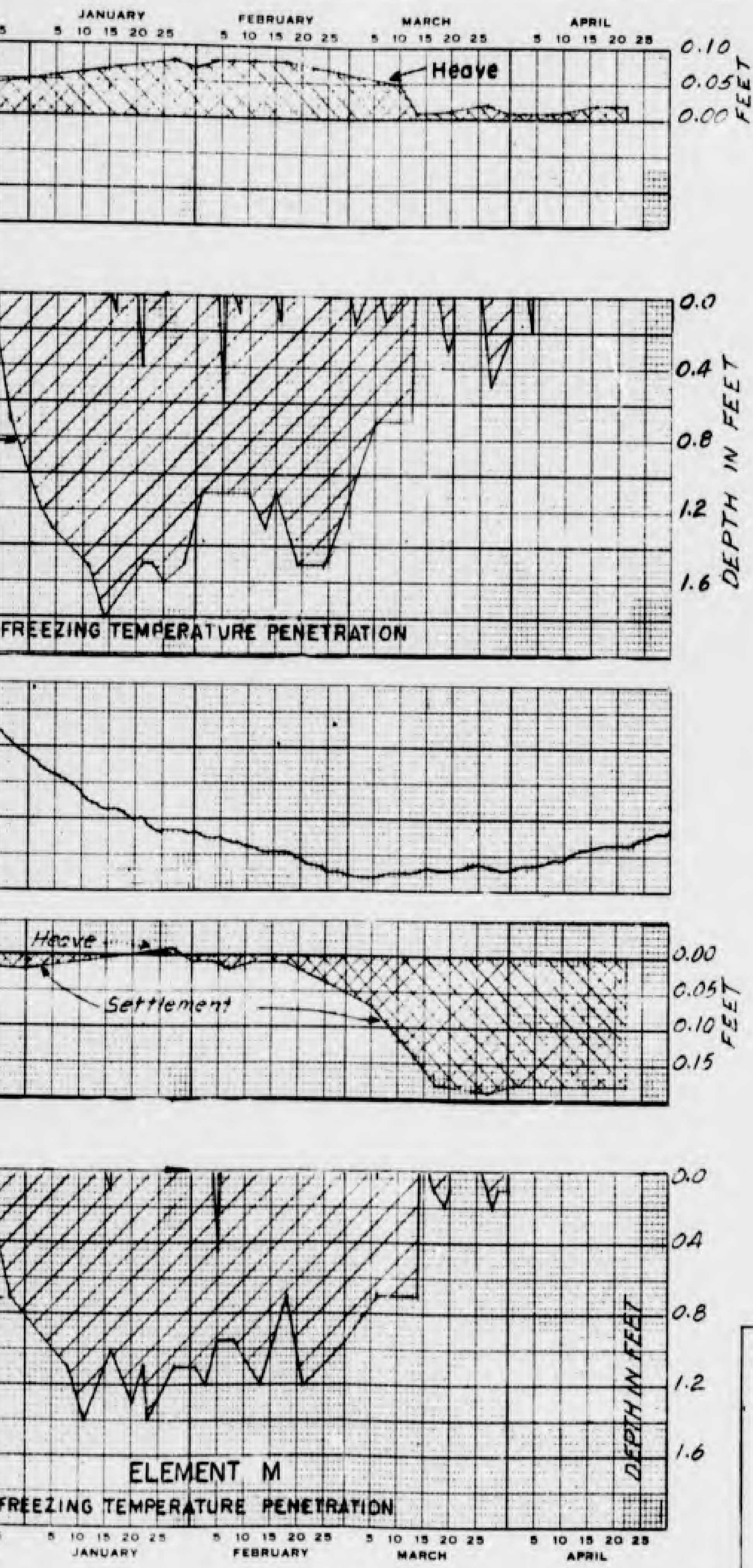
SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUGUST 1947

PLATE D-9


NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
(.11)
Heave
0.10
0.05
0.00
FEET
Bit.Conc.
Sand and Gravel
Silty clay
γ=102-107
w=15-19
Water Source
32°F
0.0
0.4
0.8
1.2
1.6
DEPTH IN FEET
ELEMENT J
FREEZING TEMPERATURE PENETRATION
Cumulative Degree Days
-200
0
200
400
600
Heave
Settlement
0.05
0.00
0.05
0.10
FEET
Bit.Conc.
Sand and Gravel
Silty Clay
γ=90-96
w=15-24
Water Source
32°F
0.0
0.4
0.8
1.2
1.6
DEPTH IN FEET
ELEMENT K
FREEZING TEMPERATURE PENETRATION
γ=104-107
γ=92-94



MARCH
APRIL
Heave
0.10
0.05
0.00
FEET
0.0
0.4
0.8
1.2
1.6
DEPTH IN FEET
NETRATION
Heave
Settlement
0.05
0.00
0.05
0.10
FEET
0.0
0.4
0.8
1.2
1.6
DEPTH IN FEET
ETRATION
MARCH
APRIL
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
5 10 15 20 25
Bit Conc.
Sand and Gravel
Silty clay
32°F
γ = 104-107
w = 13-19
ELEMENT L
FREEZING TEMPERATURE PENETRATIO
Cumulative Degree Days
-200
0
200
400
600
Heave
Settlement
Bit Conc.
Sand and Gravel
Silty clay
32°F
γ = 92-94
w = 25-30
ELEMENT M
FREEZING TEMPERATURE PENETRATION
NOVEMBER
DECEMBER
JANUARY
FEBRUARY



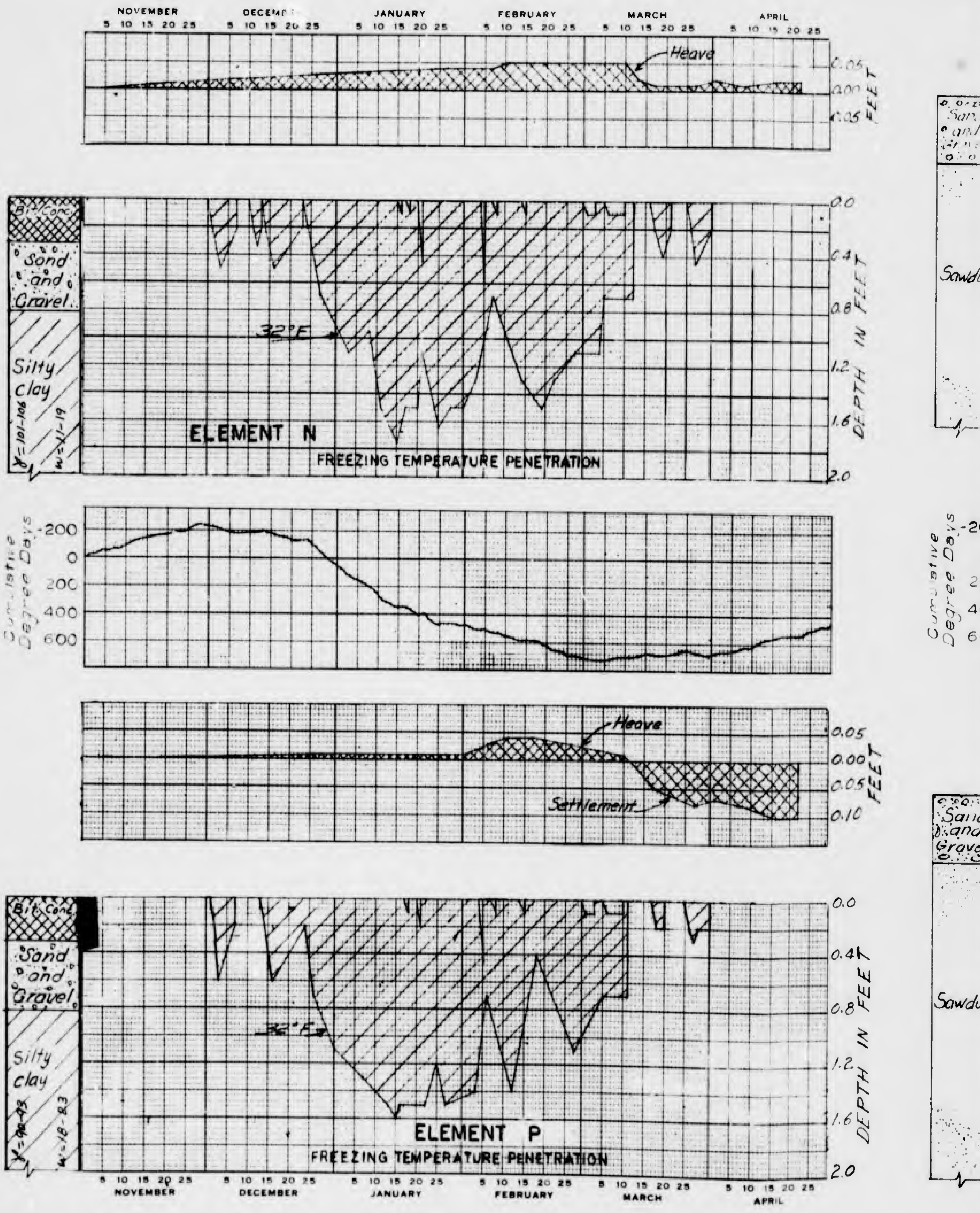
NOTE
Effect of air temperature on Elements modified by heat generated by sawdust insulation around element.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE.

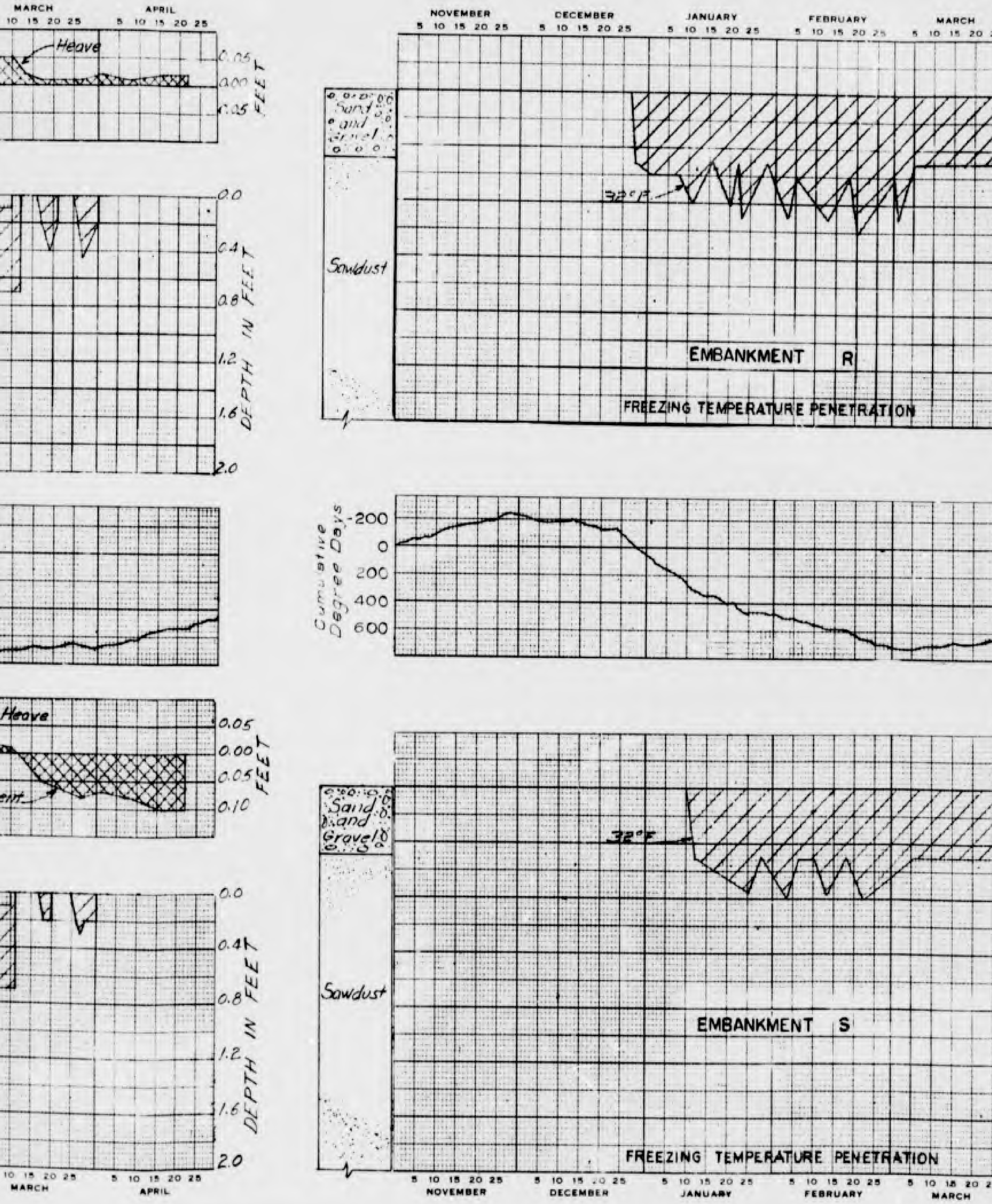
FREEZING TEMPERATURE AND PAVEMENT HEAVE VS TIME
ELEMENTS J,K,L,M

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

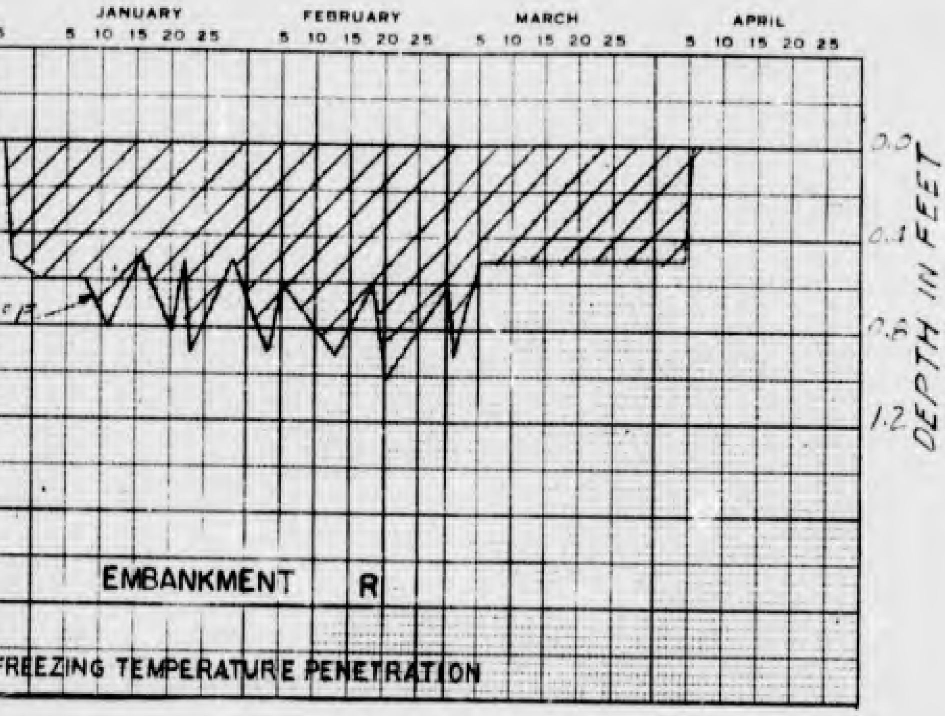
PLATE ~~10~~
D-10

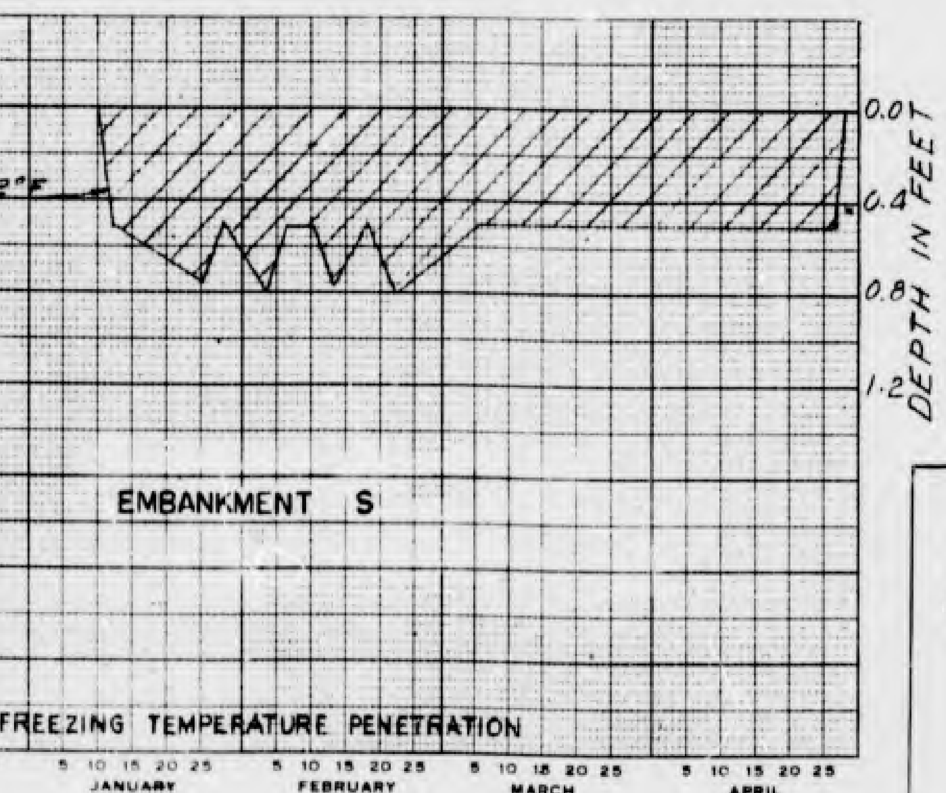


NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
5 10 15 20 25
Heave
0.05
0.00
0.05
FEET
Bit Conc
Sand and Gravel
Silty clay
γ=101-106
w=11-19
32°F
ELEMENT N
FREEZING TEMPERATURE PENETRATION
0.0
0.4
0.8
1.2
1.6
2.0
DEPTH IN FEET
Cumulative Degree Days
-200
0
200
400
600
Heave
Settlement
0.05
0.00
0.05
0.10
FEET
Bit Conc
Sand and Gravel
Silty clay
32°F
ELEMENT P
FREEZING TEMPERATURE PENETRATION
0.0
0.4
0.8
1.2
1.6
2.0
DEPTH IN FEET
Sawdu



MARCH
APRIL
Heave
FEET
DEPTH IN FEET
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
Sand and Gravel
Sawdust
32°F
EMBANKMENT R
FREEZING TEMPERATURE PENETRATION
Cumulative Degree Days
Heave
EMBANKMENT S
FREEZING TEMPERATURE PENETRATION





NOTE
Effect of air temperature on Elements modified by heat generated by sawdust insulation around element.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

FREEZING TEMPERATURE
AND PAVEMENT HEAVE VS TIME

ELEMENTS N, P
EMBANKMENTS R , S

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

PLATE H
D-11

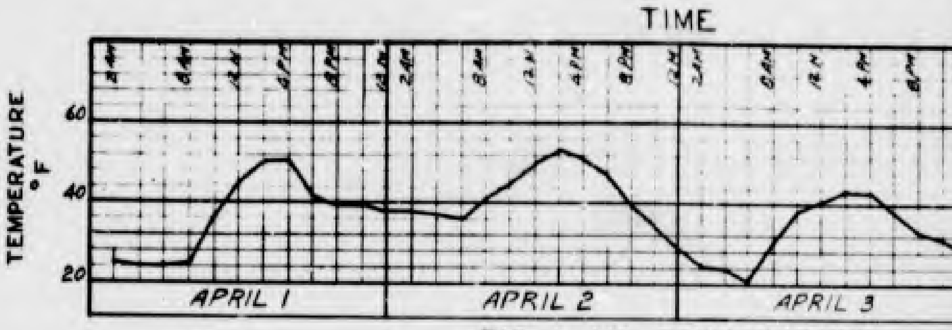


FIG. 1 - AIR TEMPERATURE

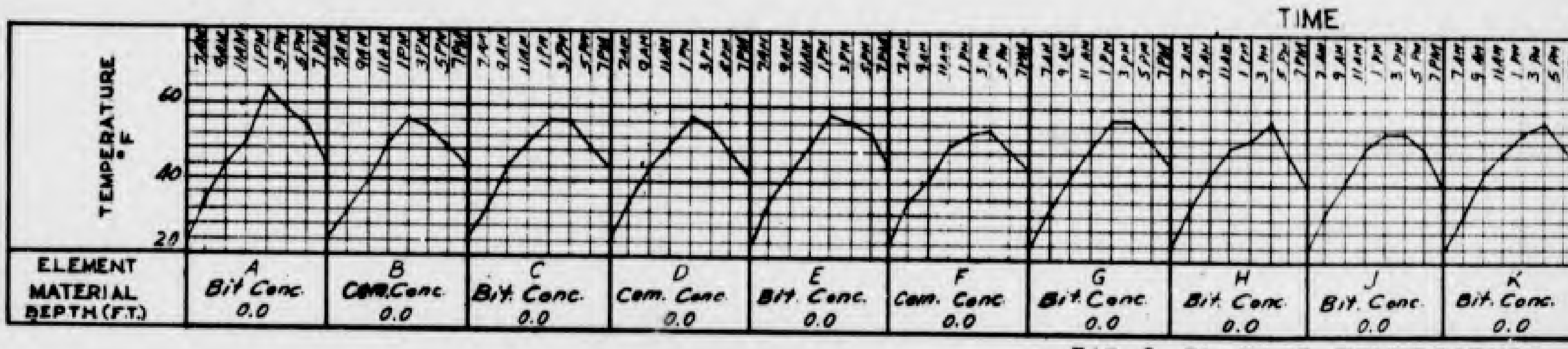


FIG. 2 - SURFACE TEMPERATURE

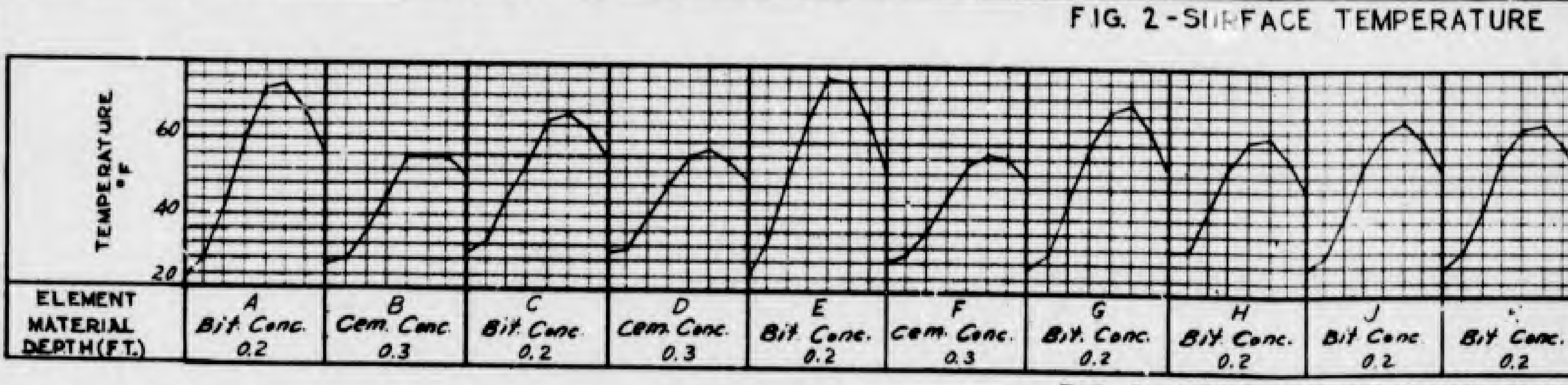


FIG. 3 - MID-POINT OF PAVEMENT

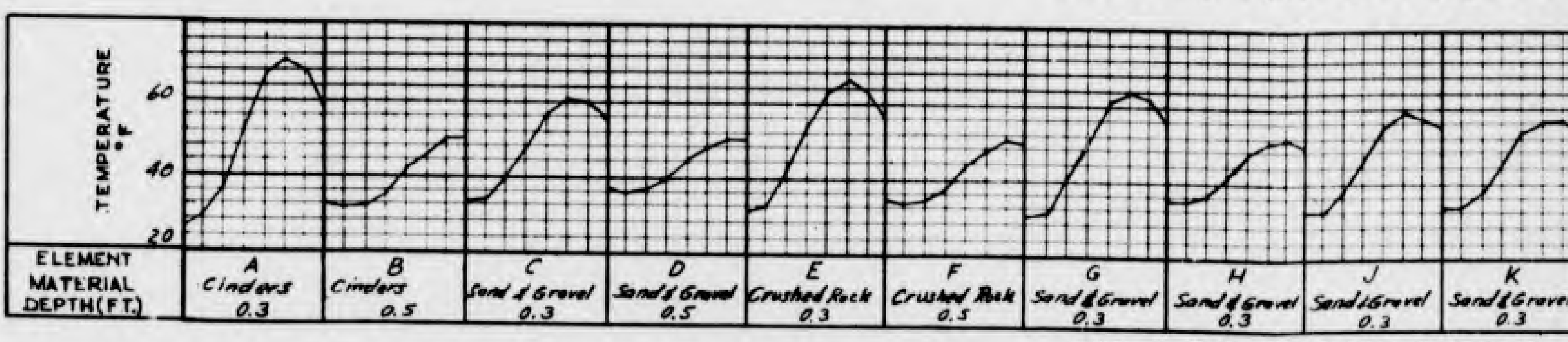


FIG. 4 - TOP OF BASE COURSE

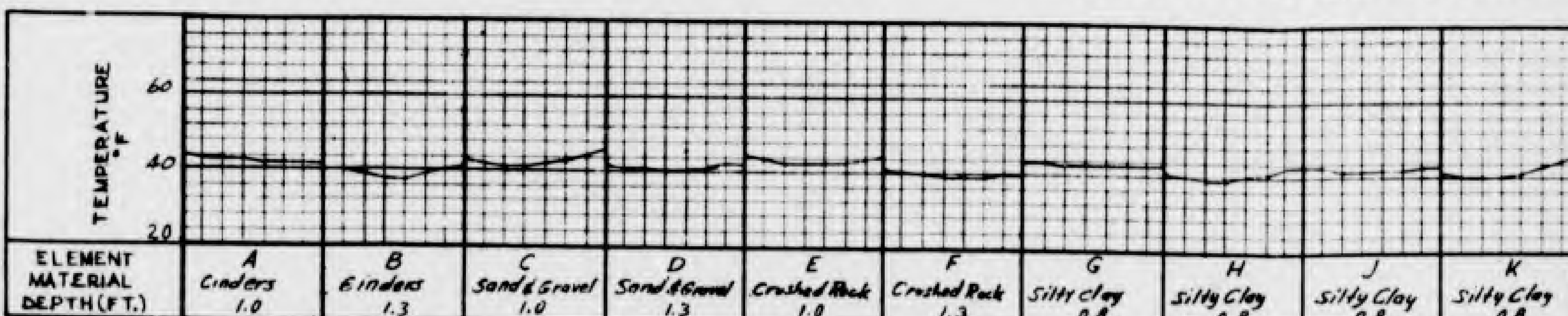


FIG. 5 - BASE COURSE OR SUBGRADE

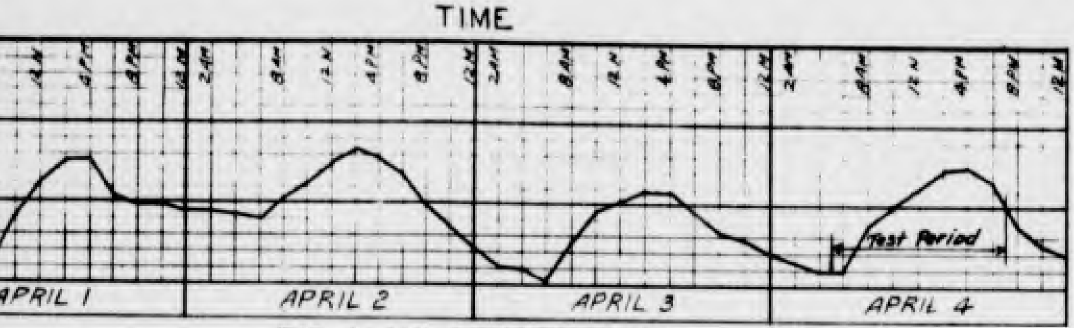


FIG. 1 - AIR TEMPERATURE

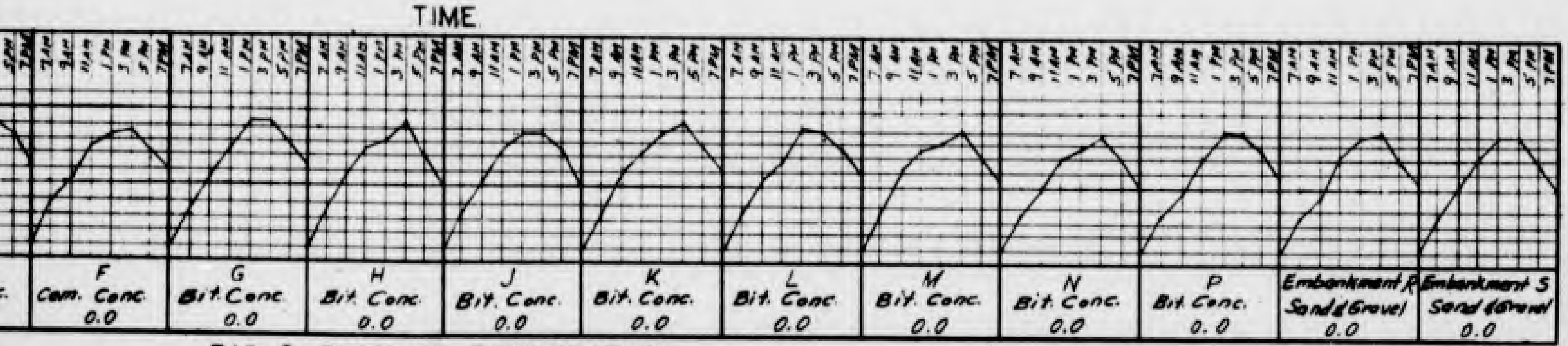


FIG. 2 - SURFACE TEMPERATURE

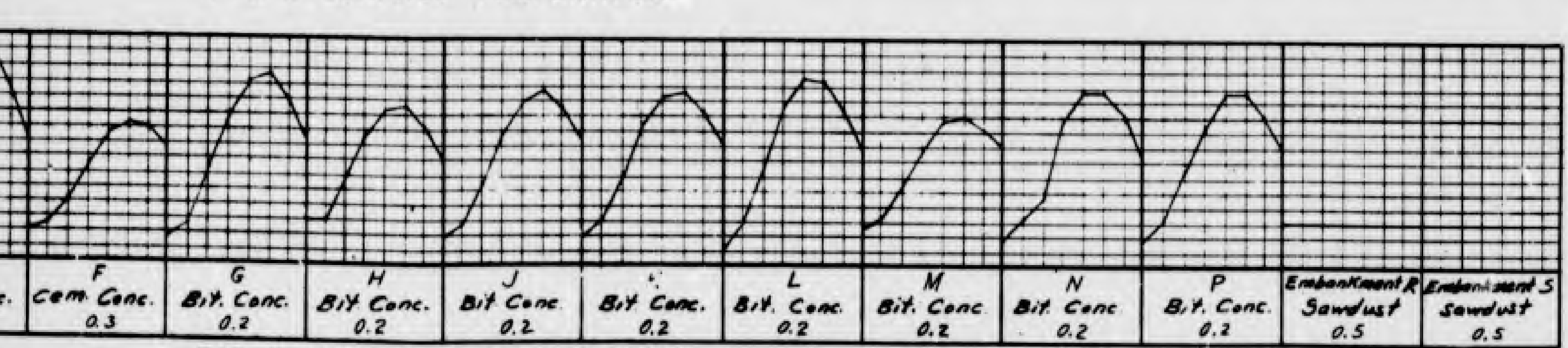


FIG. 3 - MID-POINT OF PAVEMENT

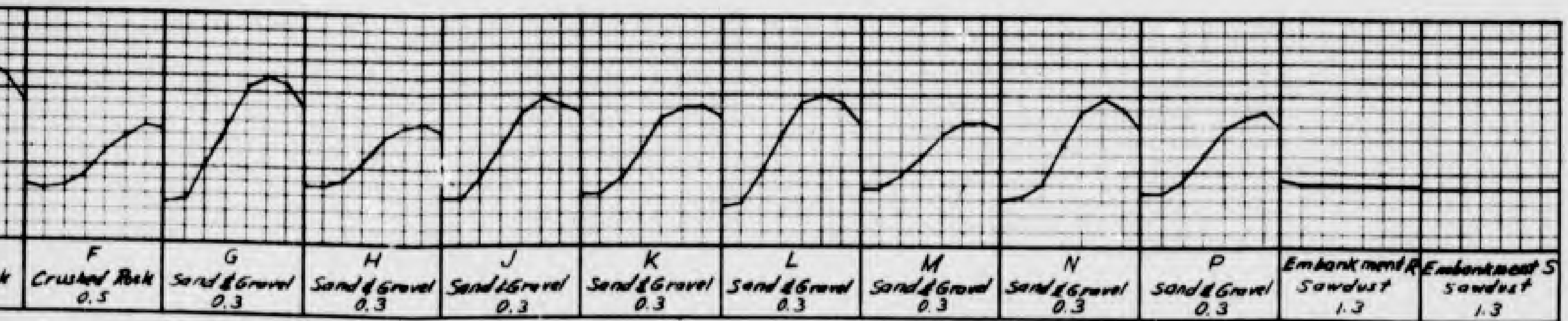


FIG. 4 - TOP OF BASE COURSE

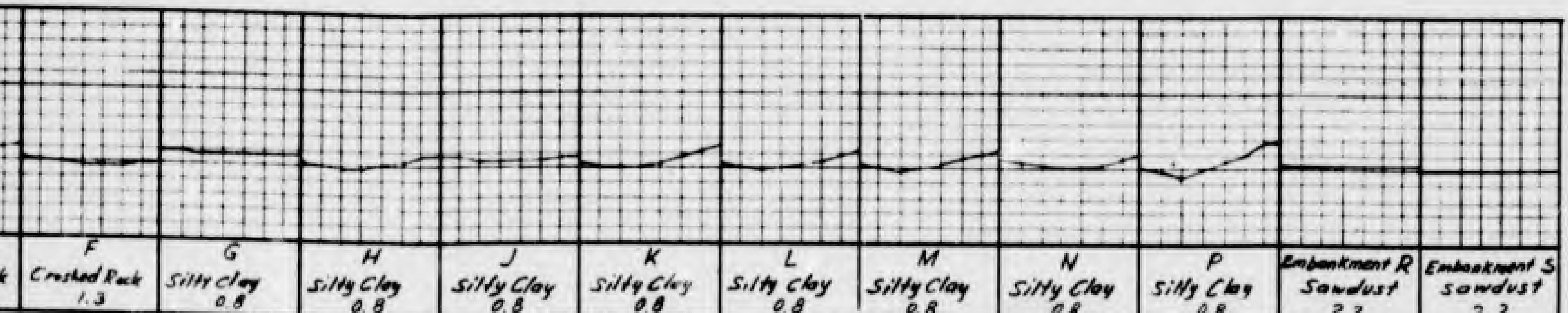
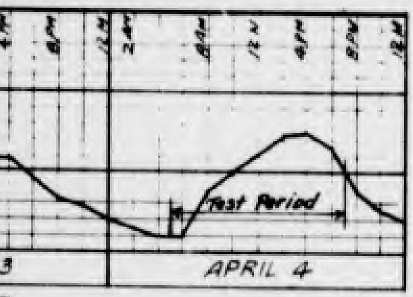


FIG. 5 - BASE COURSE OR SUBGRADE



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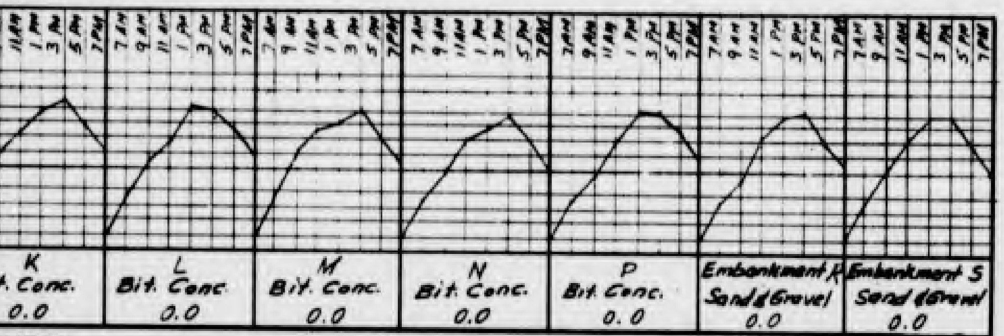

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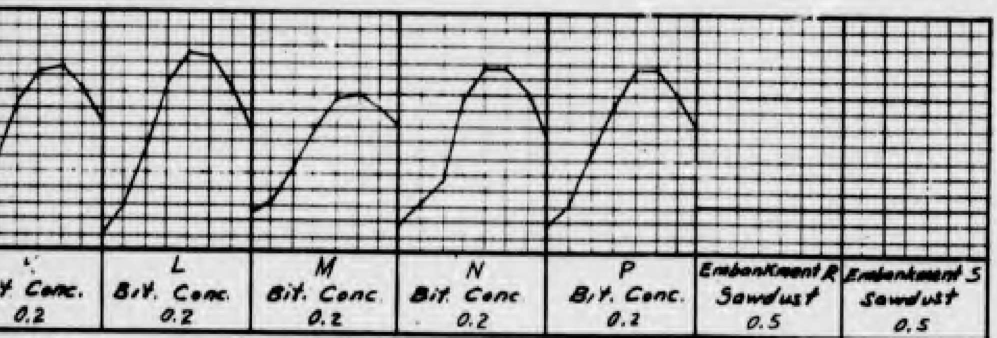
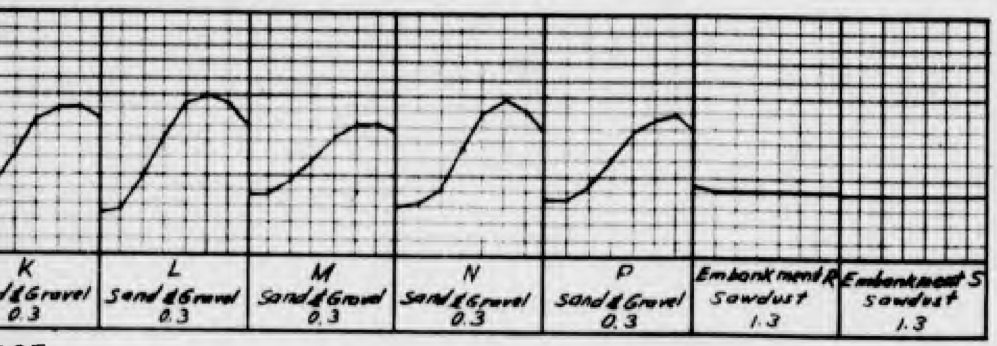
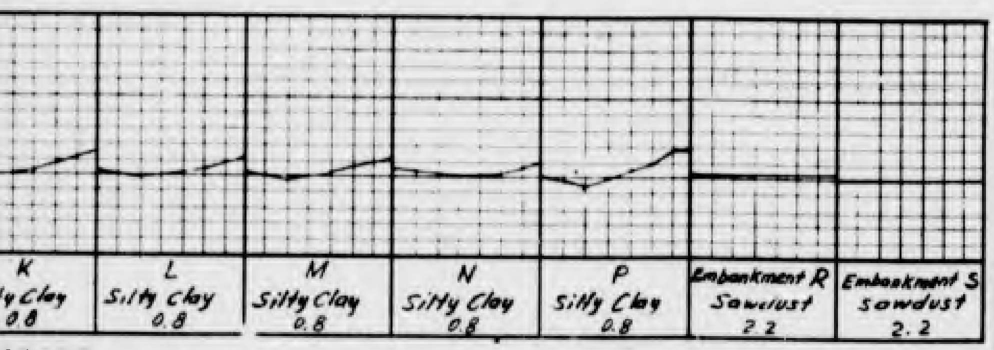


MENT



RSE



GRADE

Notes:-

Weather: Clear, northerly wind, gentle breeze.
Air temperatures, Fig 1, taken from thermograph records.
Surface temperatures, Fig 2, made by mercury thermometer placed on pavement surface and shielded from the sun.
Subsurface temperatures, Figs. 3, 4, 5, made by thermocouple installations.
Readings made every two hours, beginning at 5 A.M. and ending at 7 P.M. 4 April 1947.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TEMPERATURES
AT TWO HOUR INTERVALS
ON 4 APRIL 1947

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

PLATE D-12

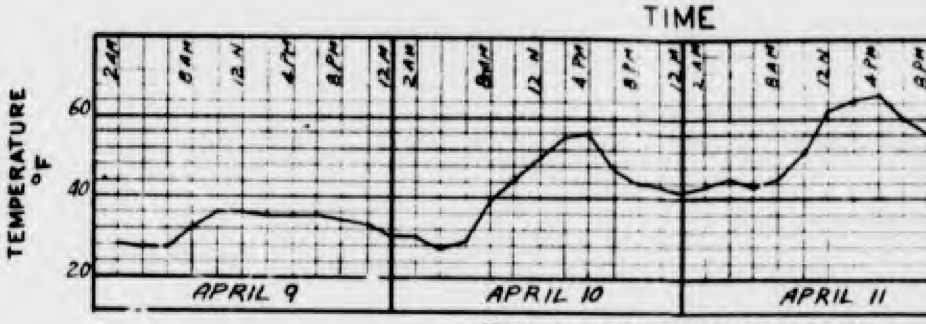


FIG. 1 - AIR TEMPERATURE

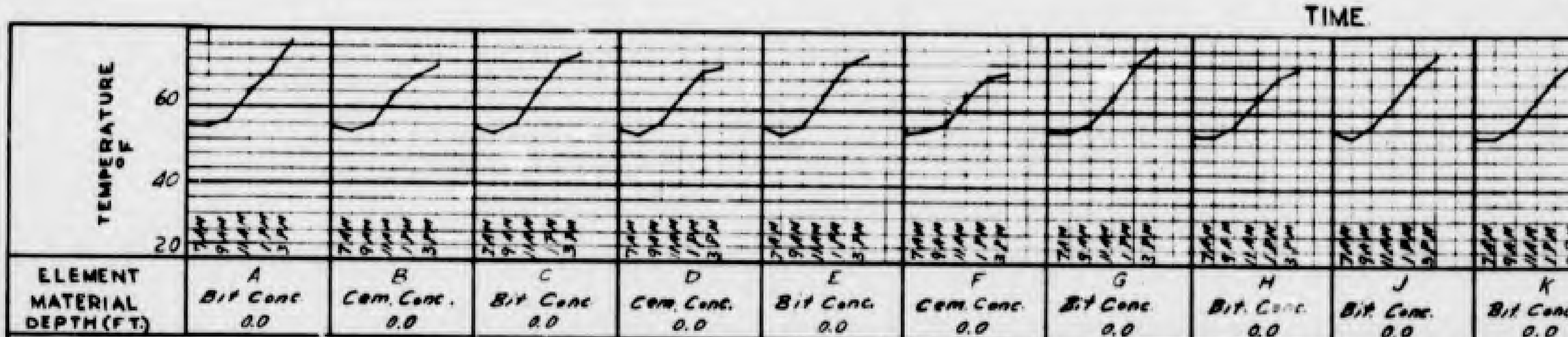


FIG. 2 - SURFACE TEMPERATURE

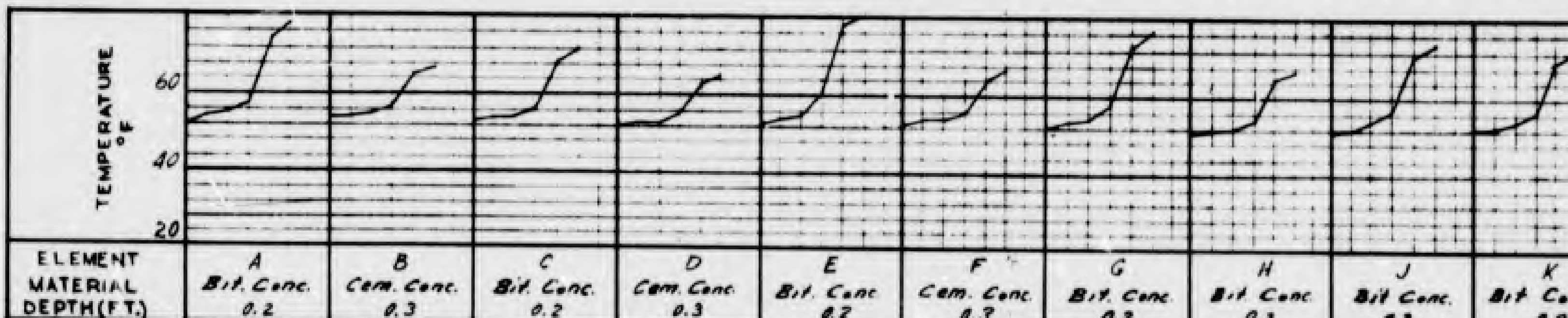


FIG. 3 - MID-POINT OF PAVEMEN

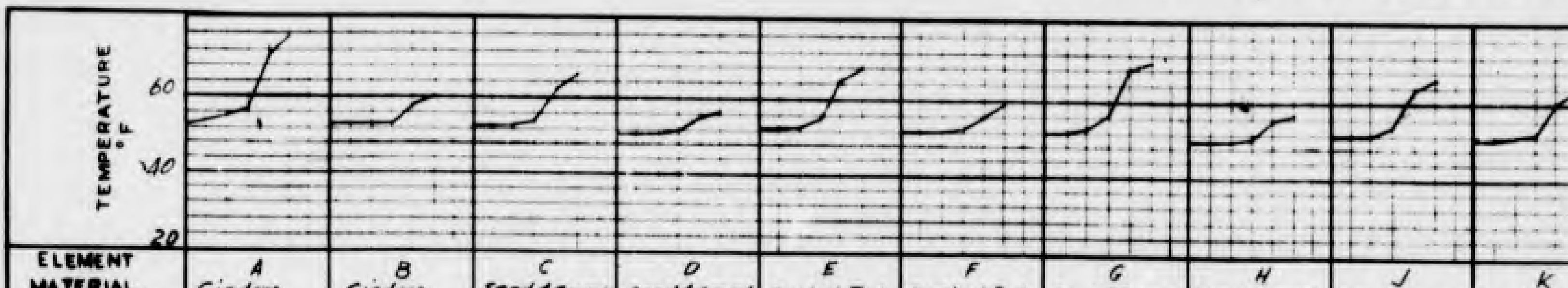


FIG. 4 - TOP OF BASE COURSE

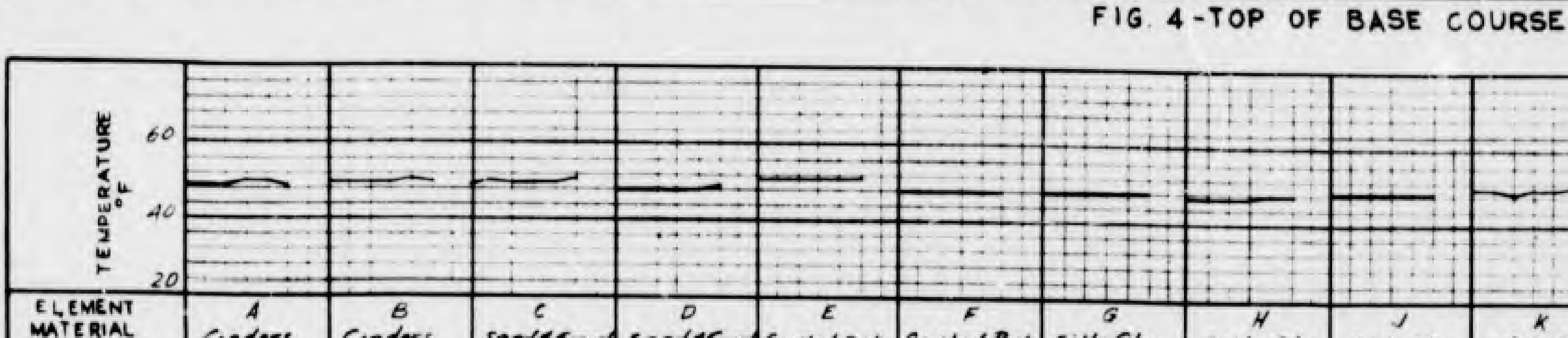


FIG. 5 - BASE COURSE OR SUBGRA

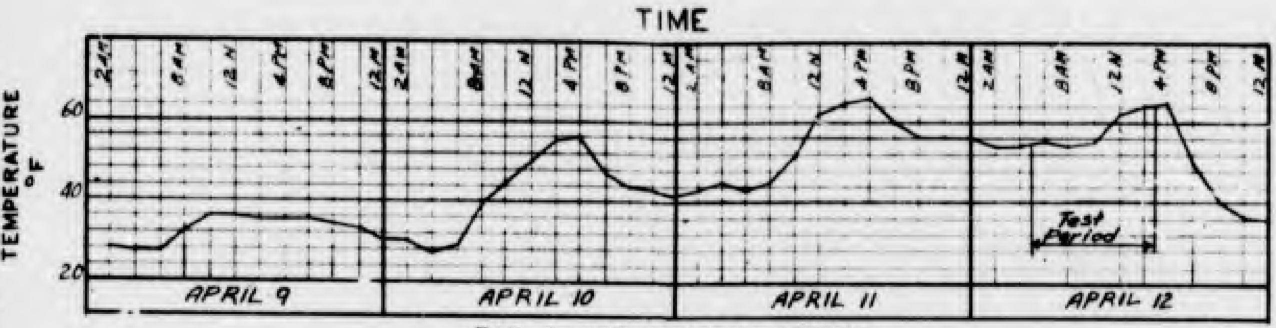


FIG. 1 - AIR TEMPERATURE

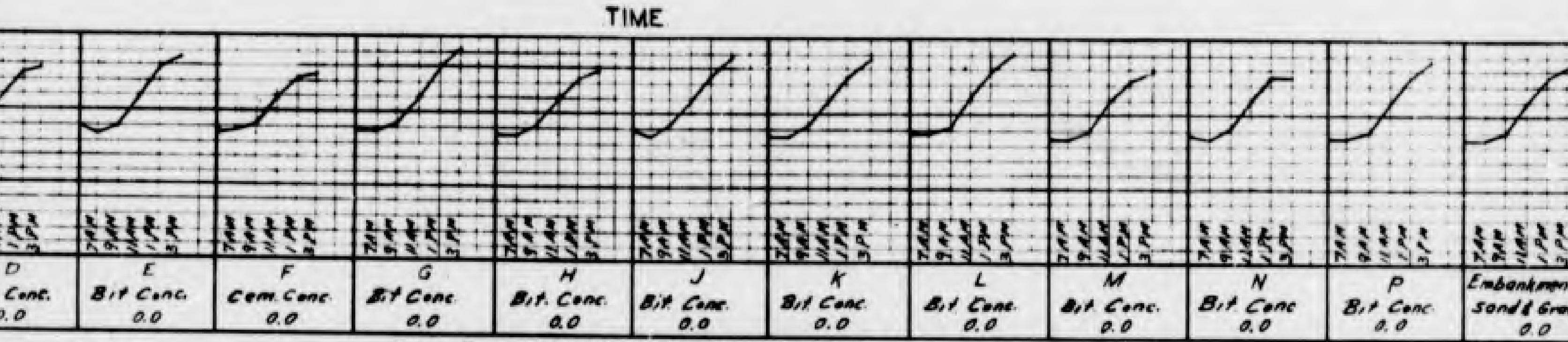


FIG. 2 - SURFACE TEMPERATURE

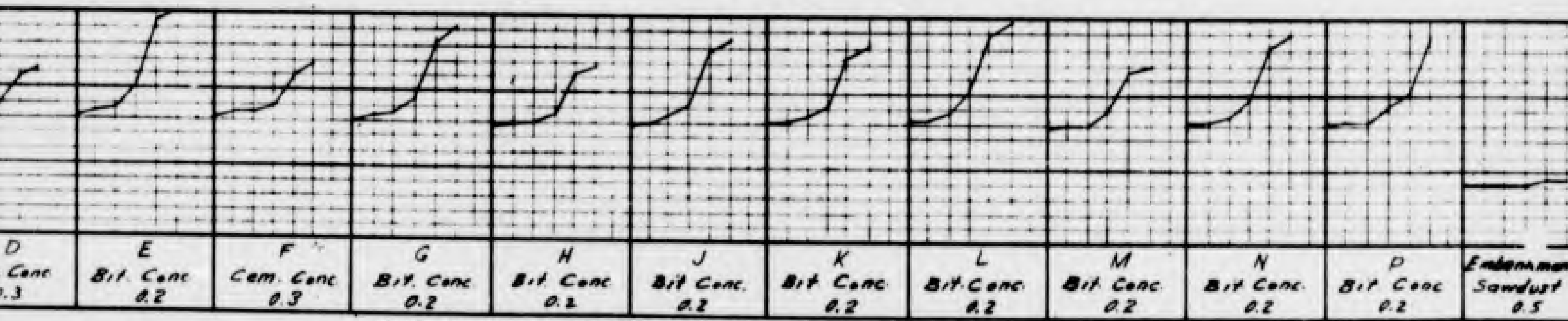


FIG. 3 - MID-POINT OF PAVEMENT

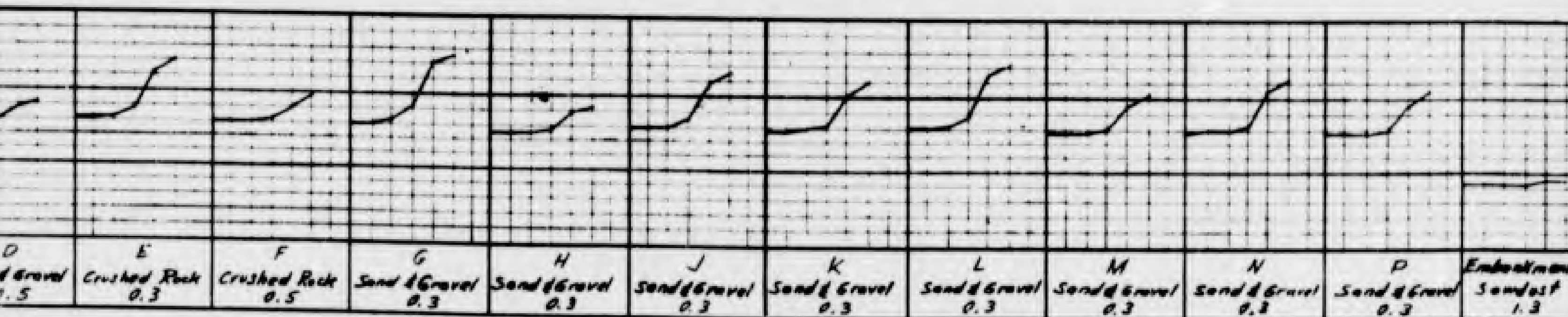


FIG 4 - TOP OF BASE COURSE

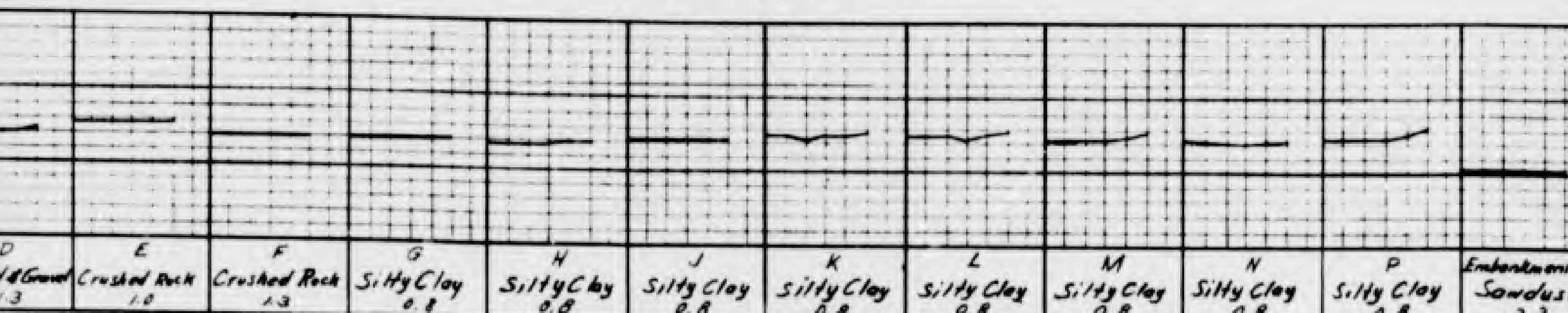


FIG. 5 - BASE COURSE OR SUBGRADE

Notes:-

Weather: Southwesterly wind, gentle breeze. Cloudy from 5 A.M. to 7 A.M. Rain from 7 A.M. to 11 A.M. Clearing at 2 P.M.

Air temperatures, Fig 1 taken from thermograph records

Surface temperatures Fig 2 made by mercury thermometer placed on pavement surface and shielded from the sun.

Subsurface temperatures. Figs 3, 4, 5 made by thermo-couple installations.

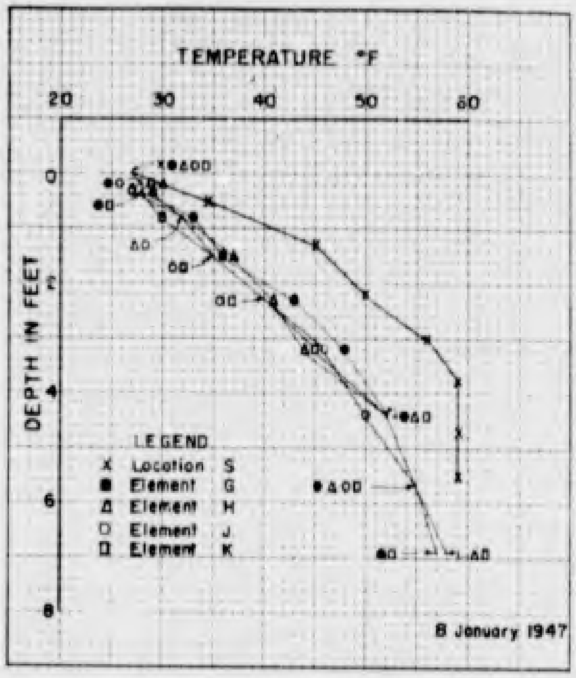
Readings made every two hours, beginning at 5 AM and ending at 3 PM 12 April 1947

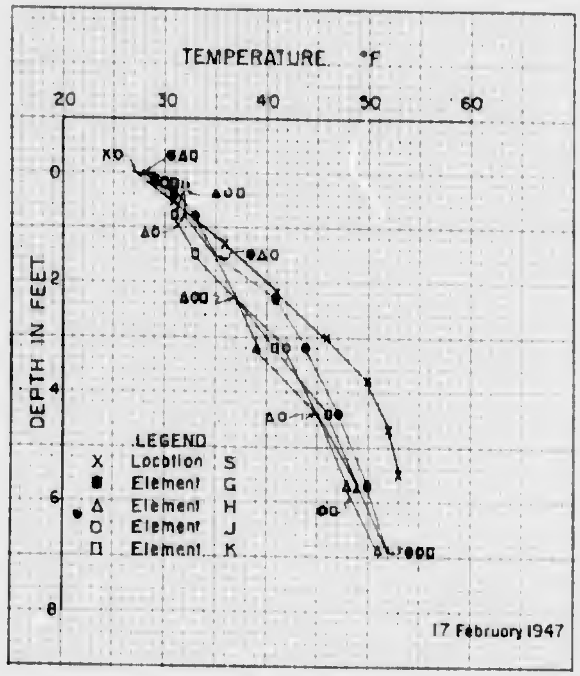
FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

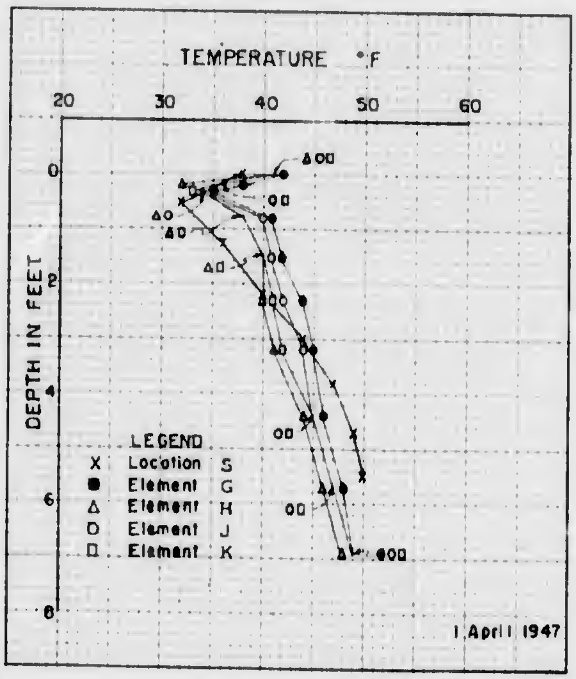
TEMPERATURES
AT TWO HOUR INTERVALS
ON 12 APRIL 1947

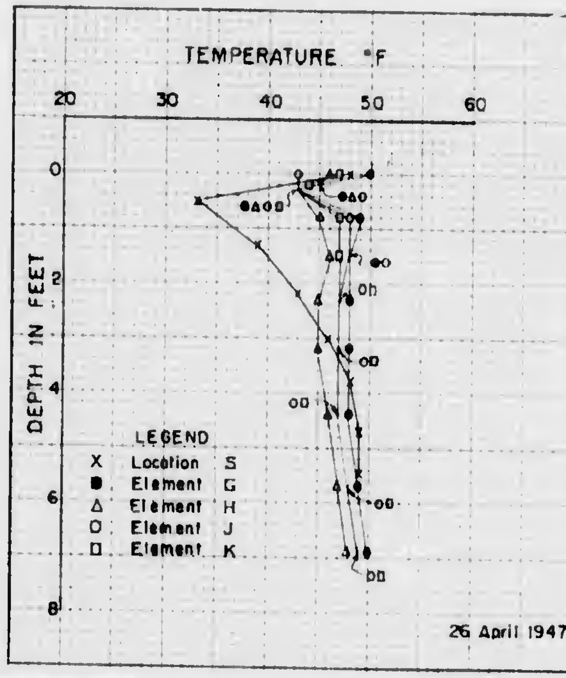
SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON MASS AUG 1947

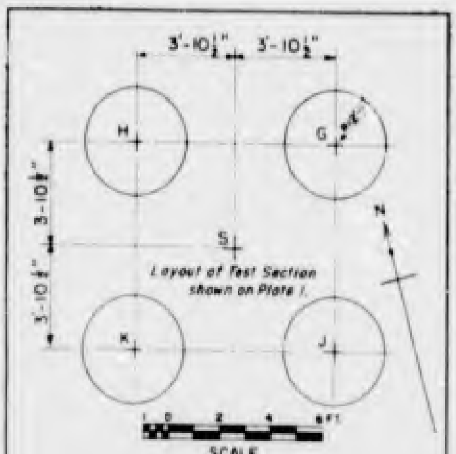
PLATE D-13



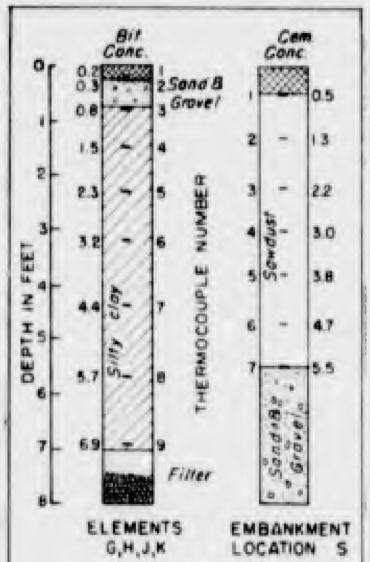








PLAN
THERMOCOUPLE INSTALLATIONS IN ELEMENTS AND EMBANKMENTS



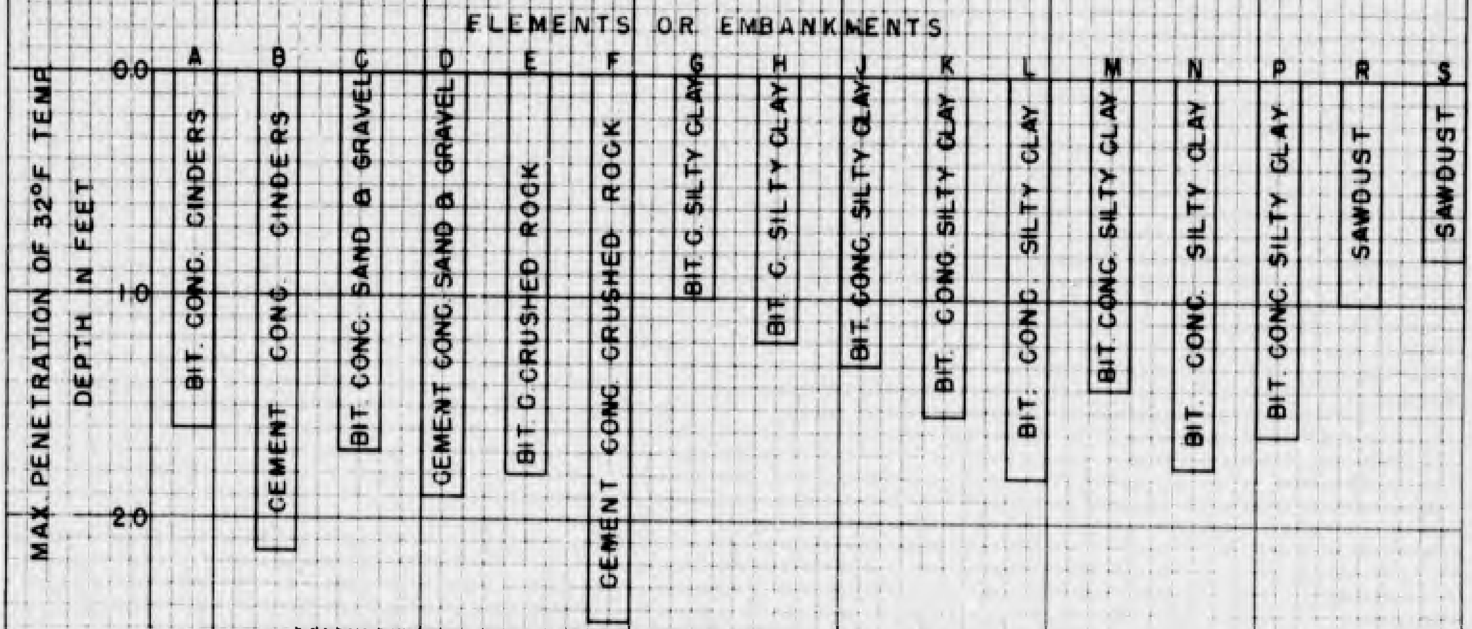
LOG OF ELEMENTS AND EMBANKMENT

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

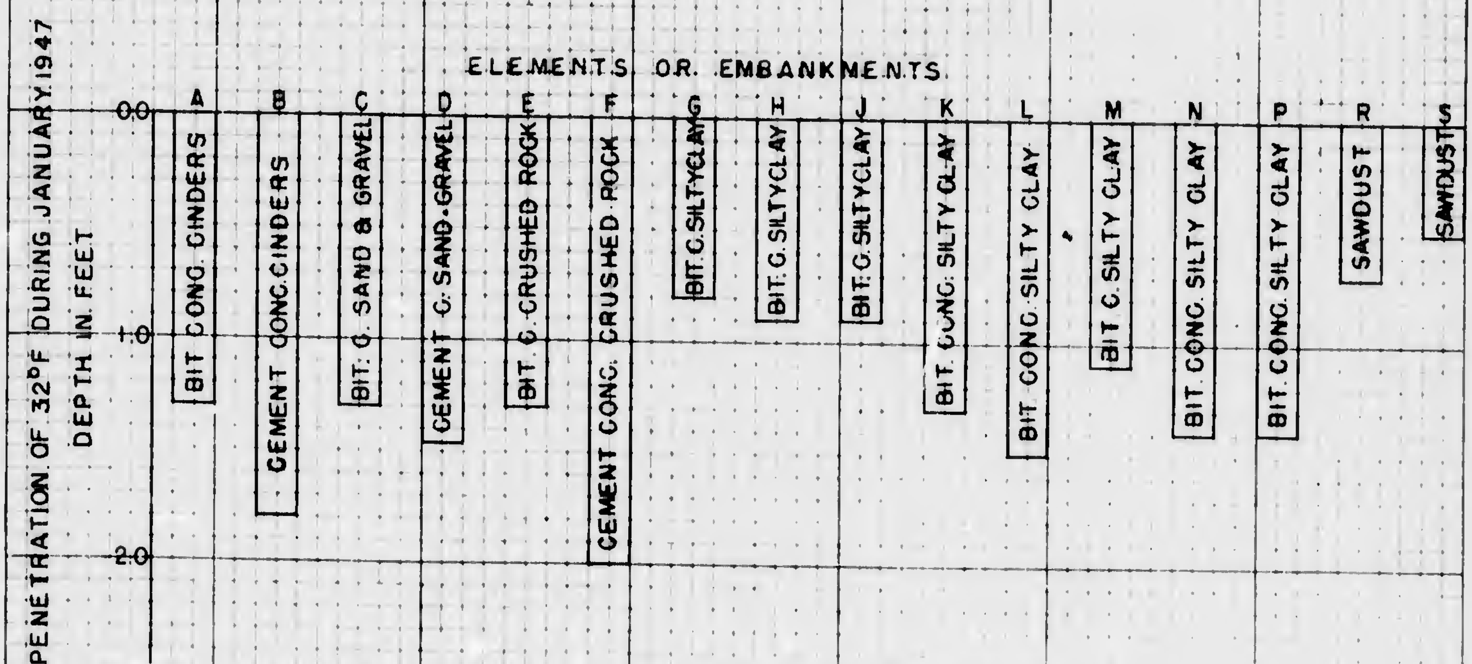
COMPARATIVE TEMPERATURE GRADIENTS IN ELEMENTS AND EMBANKMENT

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS., AUG. 1947

PLATE 14
D-14



MAXIMUM FREEZING TEMPERATURE PENETRATION
DURING THE WINTER
FIG 1



MEAN FREEZING TEMPERATURE PENETRATION
DURING JANUARY 1947
FIG 2

NOTE:

Elements G, H, J, K, L, M, N and P had a six inch layer of sand and gravel between the pavement and silty clay subgrade.

Embankments R and S had a six inch layer of sand and gravel overlying a five foot layer of sawdust.

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

DEPTH OF FREEZING
TEMPERATURE PENETRATION

SOILS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. AUG. 1947

Figure 1. Detail of concrete foundation for Element A

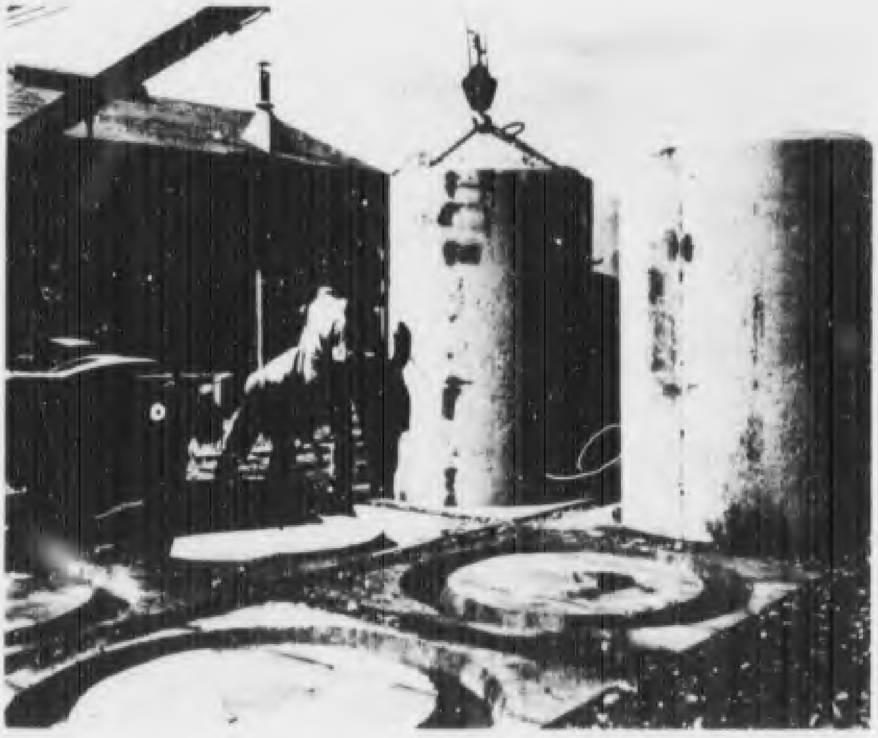


Figure 2. Placing a concrete cylinder during test section construction

DOW FIELD TEST SECTION
DETAILS OF CONSTRUCTION

Figure 1. All concrete cylinders and gravel backfill in place

Figure 2. General view of test section prior to placing sawdust insulation backfill

DOW FIELD TEST SECTION
GENERAL VIEW OF TEST ELEMENTS DURING CONSTRUCTION

Figure 1. Subgrade material in element M, placed at density of 90 PCF and at water content of 28 per cent

Figure 2. Subgrade material in element P, placed at density of 90 PCF and at water content of 22 percent

DOW FIELD TEST SECTION
SUBGRADE MATERIAL IN ELEMENTS

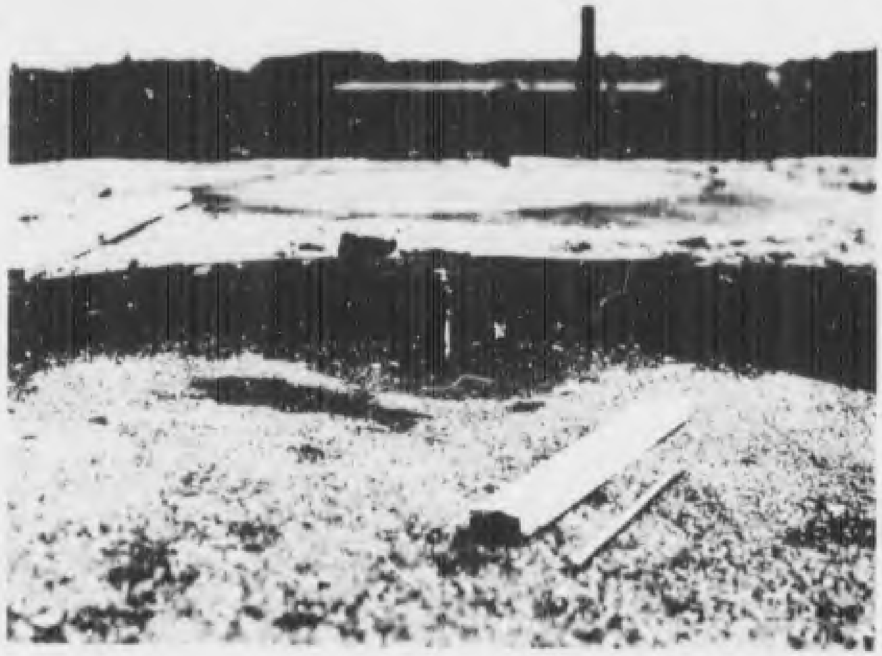


Figure 1. Settlement of pavement in Element H on 11 April 1947

Figure 2. Settlement of pavement in Element W on 11 April 1947

DOW FIELD TEST SECTION
TEST ELEMENTS SHOWING PAVEMENT SETTLEMENT

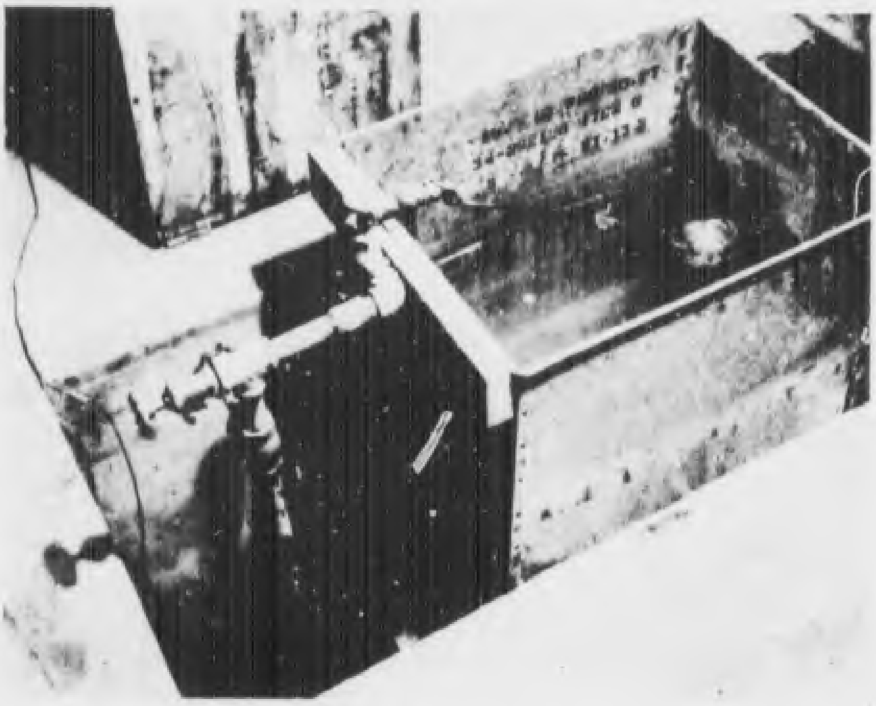


Figure 1. Ball and cork valve control for constant ground water level in Elements G, H, J, and K

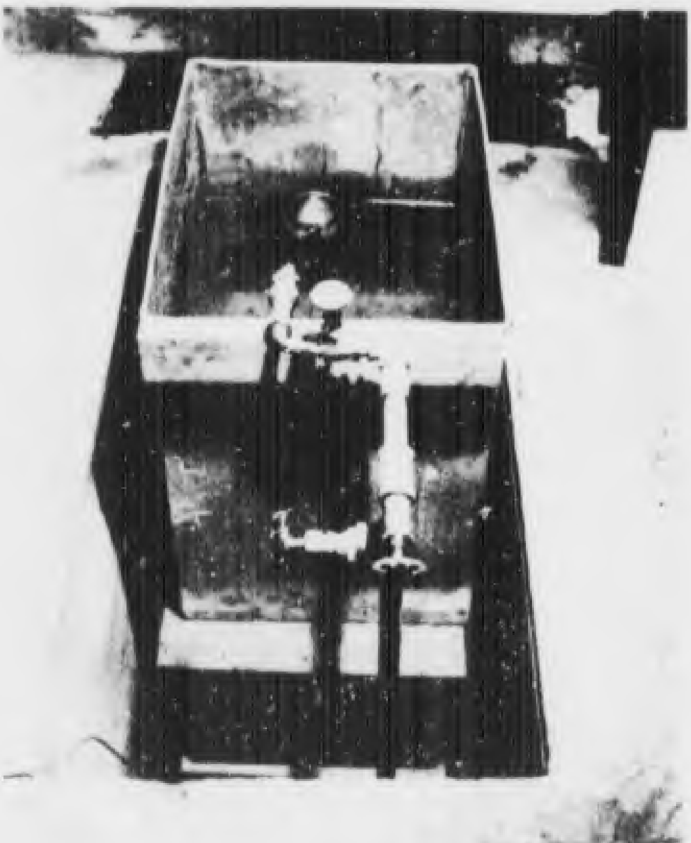


Figure 2. Ball and cork valve control for constant ground water level in Elements G, H, J, and K

DOW FIELD TEST SECTION
WATER SUPPLY TANK

Figure 1. Thermocouples in element prior to placing soil

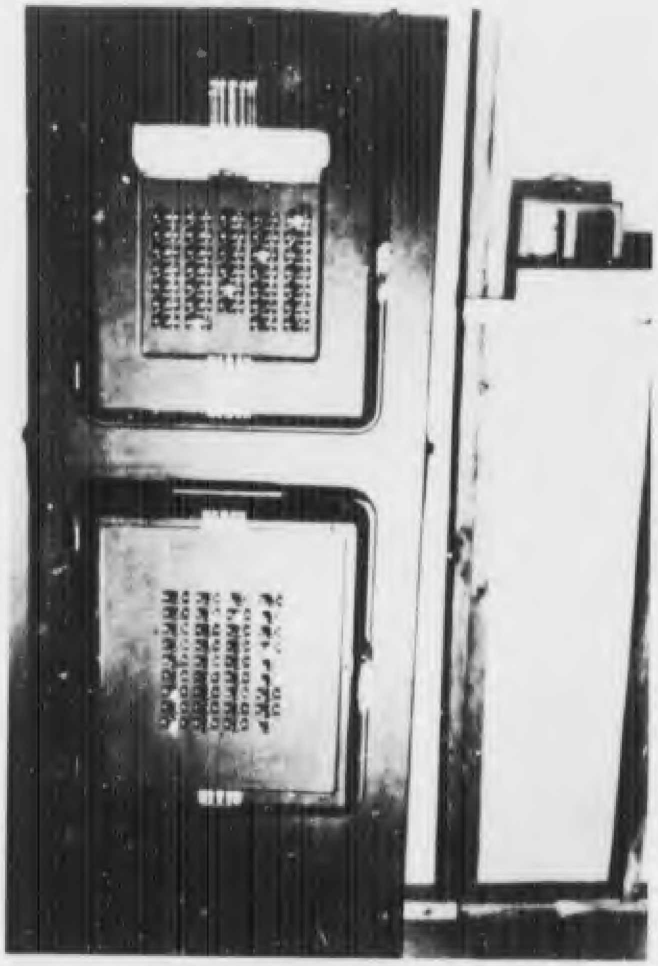
Figure 2. Thermocouple leads in trench from elements to instrument room

DOW FIELD TEST SECTION
THERMOCOUPLES AND THERMOCOUPLE LEADS

Figure 1. Entrance of thermocouple leads to instrument room

Figure 2. Thermocouple leads to instrument

DOW FIELD TEST SECTION
THERMOCOUPLE LEADS TO INSTRUMENT ROOM



DOW FIELD TEST SECTION
THERMOCOUPLE SWITCHING PANEL AND TEMPERATURE
INDICATING SCALE

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U. S. ARMY
BOSTON, MASSACHUSETTS

DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

APPENDIX E

LABORATORY AND FIELD TEST PROCEDURES
1944 - 1945

Part 1, MISSOURI RIVER DIVISION
Part 2, GREAT LAKES DIVISION
Part 3, NEW ENGLAND DIVISION

FROST EFFECTS LABORATORY

JUNE 1949

DATA REPORT OF FROST INVESTIGATIONS

FISCAL YEARS 1943 - 1949

APPENDIX E

Part 1

LABORATORY AND FIELD TEST PROCEDURES
FOR
MISSOURI RIVER DIVISION
1944 - 1945

APPENDIX E

Part 1

LABORATORY AND FIELD TEST PROCEDURES

MISSOURI RIVER DIVISION

TABLE OF CONTENTS

APPENDIX E

Part 1

LABORATORY AND FIELD TEST PROCEDURES

MISSOURI RIVER DIVISION

1. Introduction.

The methods and procedures given herein have been used in connection with the investigation of frost action beneath airfield pavements as authorized by the letter dated 7 July 1944 from the Office, Chief of Engineers, to the Division Engineer, New England Division, subject: "Frost Investigation," and by the letter dated 28 August 1944, from the District Engineer, Boston District, to the Division Engineer, Missouri River Division, subject: "Frost Investigation".

2. Test Methods.

The test methods given herein are those established and standardized by the American Society for Testing Materials, hereinafter referred to as A.S.T.M. Standard Methods; and the methods established by the Chief of Engineers, U.S. Engineer Department as given in the Engineering Manual, and the amendments thereto, hereinafter referred to as the Engineer Manual Method, and referred to by paragraph and chapter, or as amendments thereto.

3. Plate Load Bearing Tests.

Plate load bearing tests, using steel plates varying from 24 to 30 inches in diameter, were made on the surfaces of both rigid and flexible pavements and on the surfaces of base courses, subbases, and subgrades to determine the load-deformation characteristics of those surfaces under relatively large areas of loading. Plate load bearing tests are divided into the following groups:

a. Pavement Surface Tests.

(1) Concrete Pavement Tests.

(a) Method.

The concrete pavement load bearing test procedures used in determining the load-deformation characteristics of the surfaces of concrete pavements, were established by the Missouri River Division.

(b) Equipment.

Two semi-trailer rigs were used to supply the static loads necessary to perform the surface tests. One rig was loaded with sand or gravel, giving a load in excess of 75,000 pounds on the bearing plate. The second rig, loaded by means of an 11,000-gallon water tank, gave static loads in excess of 100,000 pounds. Loads were applied with a hydraulic jack arrangement, using 30 or 50-ton capacity jacks. A 24-inch diameter circular steel bearing plate, approximately 3/4 inches in thickness, was used for the loading tests. Approximately 3 smaller plates were stacked above the bearing plate in order to secure greater stiffness and rigidity in the larger plate.

(c) Procedure.

The surface tests were generally made in the corners of concrete slabs, adjacent to construction, contraction or transverse expansion joints, in order to test the pavement at its weakest point. The steel bearing plate was seated on the surface of the pavement with a thin layer of plaster of Paris, the plate being placed before setting of the plaster occurred. The hydraulic jack was placed over the center of the bearing plate, reacting against a central point on the loaded semi-trailer. Deformations were obtained from two oppositely mounted extensometers, the pins of the extensometers resting on the plate, while the extensometers were mounted on a beam supported by rods driven through holes in the concrete pavement. The rods supporting the beam were greater than 8 feet distand from the edge of the plate, and were supported entirely by the soil beneath the pavement. Loadings were applied in increments of 18,000 pounds, each load being held constant until a movement of less than 0.01 inches per minute was obtained before an additional increment was applied. Extensometer readings were recorded at the end-point of each increment of load. Repeated increments of loading were added until either cracking of the pavement occurred, or the maximum loading of the test rig was obtained. After completion of the first cycle, if cracking did not occur, 9 additional cycles of loading and unloading were made, unless failure of the pavement occurred in less than this number of cycles. Repeated loadings were made by rapidly loading the plate to the maximum loading permitted by the rig, and then unloading rapidly, recording only the zero and maximum load deformations.

(2) Flexible Pavement Tests.

(a) Method.

The methods used in obtaining single and repeated cycle loadings on flexible pavements were established at a conference held on 10 March 1945 at Pierre, South Dakota, between representatives of the Boston District and the Missouri River Division.

(b) Equipment.

The equipment used in the flexible pavement tests is the same as that described in Paragraph 3a(1) (b) above, with the exception that a 24-inch diameter bearing plate was used for repeated loading tests, and a 30-inch diameter bearing plate was used for the single cycle loading tests.

(c) Procedure.

1. Single Cycle Tests.

A 30-inch diameter bearing plate was used for a single cycle loading, the plate being seated on the surface of the pavement by means of plaster of Paris. Loading increments of 18,000 pounds were applied. Each increment was held constant until the rate of deformation was less than 0.001 inches per minute. Loadings were applied to the maximum of the testing equipment. Deformations were measured by means of extensometers, mounted on a beam which was in turn supported on rods driven into the subgrade through holes bored in the pavement at a distance of not less than 8 feet from the edge of the bearing plate. Extensometer readings were obtained prior to loading and at the end-point of each load increment. Readings were also obtained after removal of the load, in order to secure permanent deformation data.

2. Repeated Cycle Tests.

The repeated cycle tests were made with a 24-inch diameter bearing plate. The plates were seated on the surface of the pavement and the extensometers were mounted in the manner described in Paragraph 3a(2) (c)1 above. A total load of 25,000 pounds was used in the repeated loading tests, the load being rapidly applied in one increment, and then held constant for ten minutes before releasing. The loads were released rapidly and extensometer readings were then obtained at the end of a ten minute period. The cycle was then repeated, ten cycles of loading and unloading being used in the repeated cycle test. Permanent deformations were determined from extensometer readings obtained ten minutes after completion of the final cycle of loading.

b. Subgrade Moduli Tests.

Subgrade moduli tests are made to determine the pavement supporting properties of subgrades or base courses under rigid pavements.

(1) Method.

Subgrade moduli tests were made in accordance with

Paragraph 41, Chapter 20 of the Engineering Manual, titled: "Evaluation of Subgrade Reaction," and as amended by a teletype dated 22 January 1944, from the Office, Chief of Engineers, to the Missouri River Division, a copy of which is included in the letter appendix to this report.

(2) Equipment.

Equipment used to obtain subgrade moduli was similar to the equipment described in Paragraph 3a(1) (b) above except that a 30-inch diameter plate was used for all subgrade moduli tests.

(3) Procedure.

The surface of the pavement supporting medium was carefully leveled and a thin layer of fine, dry sand, all of which passed the 40-mesh sieve, was used to seat the bearing plate. A load equivalent to five (5) pounds per square inch, rapidly applied and instantaneously released, was used to obtain additional seating of the plate before beginning the test. Deformations were measured by two extensometers bearing on opposite sides of the bearing plate, the extensometers being mounted on a beam supported by rods driven into the subgrade holes bored in the surface of the pavement. The rods supporting the beam were located at a minimum distance of 8 feet from the edge of the plate. Load increments were applied at the rate of 5 pounds per square inch, each increment being held constant until the increase in deformation for that increment of loading, during a five minute period, was less than 3% of the total deformation for that increment. Loadings were applied until either a total deformation of 0.3 inches was obtained or the capacity of the loading equipment reached. Only single cycle loadings were used to determine subgrade moduli. The load-deformation data obtained from the field moduli test were used to determine subgrade moduli by means of the formula $K_u = \frac{P}{0.05}$; where "K_u" is the subgrade modulus and "P" is equal to the pressure in pounds per square inch required to give a vertical deformation of 0.05 inches in the plate load bearing test. The subgrade moduli obtained from field bearing tests were further modified to compensate for the effect of saturation by the methods hereinafter described under consolidation tests.

4. Consolidation Tests.

Consolidation test data are used for the purpose of correcting the subgrade moduli obtained from field tests for the effects of saturation. The tests consist essentially of recording the load-deformation characteristics of an undistrubed specimen at field moisture content, and the load-deformation characteristics of an undisturbed saturated specimen of the same material. The deformation in the undisturbed unsoaked specimen, produced by a unit loading corresponding to the unit loading used to obtain a deformation of 0.05 inches in the original field test, is used to determine the pressure required to produce a similar deformation in the saturated sample. The unit pressure required to give the required deformation in the saturated sample divided by the unit pressure required to give the same deformation in the undisturbed sample at field moisture content is used as a ratio to modify the field bearing modulus in the formula: $K = K_u \frac{P_s}{P}$, where K is the saturation corrected modulus, K_u is the field modulus, P_s is the saturated specimen unit pressure, and P is the unit pressure required to give a deformation of 0.05 inches in the 30-inch diameter plate bearing test.

a. Method.

Consolidation tests were performed in accordance with Paragraph 41c, Chapter 20 of the Engineering Manual.

b. Equipment.

Tests were conducted in Zanesville type consolidation apparatus. The test specimen was $4\frac{1}{4}$ inches in diameter and $1\frac{1}{4}$ inches thick. The ring assembly was placed in a water tight pan to saturate the specimens. Consolidation was measured by extensometers reading to 0.0001 inch.

c. Procedure.

(1) Consolidation of Unsoaked Specimen.

The unsoaked specimen was placed under a load corresponding to the pavement load over the sample for a period of 30 minutes. The sample was then consolidated by adding increments of load. Each increment of load was impressed for 30 minutes and the resulting consolidation was recorded. Sufficient increments of loading were added to define a consolidation curve from zero load to a unit load greater than the unit load producing a 0.05 inch deflection in the field bearing test. The initial pavement load was taken as zero load in plotting the consolidation curve.

d. Consolidation of Soaked Specimen.

The specimen was placed under a load corresponding to the pavement load over the sample, and soaked. Water was then introduced into the specimen from the bottom only, under a head of approximately 2 inches, in order to facilitate the excape of air and to decrease the soaking time. The specimen was allowed to stand until swelling was completed. Swelling was considered completed when the vertical movement was less than 0.001 inches in 30 minutes. Approximately 2 days soaking time was required for typical soils. The thickness of the specimen at the end of the soaking period was taken as the initial condition and the specimen was consolidated in a manner similar to that used for the unsoaked specimen.

5. Concrete Flexural Strength Tests.

Concrete flexural strength tests were made on beams, sawed from slabs removed from the concrete pavement. Concrete flexural strengths were determined to supply data for the calculation of the load carrying capacities of the pavements.

a. Method.

Concrete flexural strength tests were performed in accordance with A.S.T.M. Standard Method C78-39, as amended by Paragraph 6 of the letter dated 10 January 1944, from the Office, Chief of Engineers, to the Division Engineer, Missouri River Division, subject: "Airfield Pavement Evaluation," a copy of which is included in the letter appendix to this report.

b. Equipment.

Concrete flexural strength tests were made in a government laboratory equipped with a diamond saw and a hydraulic compression machine.

c. Procedure.

Beams were sawed to a 6-inch width, the depth corresponding to the original pavement depth, and to a length meeting the requirements of the test. The beams were immersed in water for 24 hours prior to testing. The beams were tested with the original surface in the "up" position.

6. Density Tests.

a. Laboratory Maximum Density Tests.

Laboratory maximum density tests are made for the purpose of determining the maximum densities of soils or aggregate mixtures obtainable under standard compaction conditions in the laboratory.

(1) Method.

Maximum density tests were made in accordance with the methods given in Paragraph 14, Chapter 20, of the Engineering Manual, and as amended by the letter dated 12 May 1944, from the Office, Chief of Engineers, to the Division Engineer, Missouri River Division, subject: "California Bearing Ratio Procedure," a copy of which is included in the letter appendix to this report.

(2) Equipment.

The equipment used for the determination of the laboratory maximum density, consisted of a 6-inch diameter mold, 5 inches high and fitted with a 2-inch removable extension. The metal tamper weighed 10 pounds, and a tamper drop of 18 inches was used. The sample was compacted in 5 approximately equal layers to a height of approximately 5 inches, with 55 blows per layer.

(3) Procedure.

The test procedures used were those given in the letter referenced in Paragraph 6a(1) above.

b. Field Density Tests.

Field density tests were made to determine the density of "in-place" materials in the field.

(1) Method.

A sand-density method was used to determine the field density of the "in-place" materials.

(2) Equipment.

The equipment used in the test consisted of a glass jar filled with a volume-weight calibrated sand, and fitted with a special funnel and cut-off.

(3) Procedure.

Material was carefully removed from the element to be tested, forming a hole approximately 4 inches in diameter and 6 inches deep in the upper 6 inches of the pavement element. The material removed from the hole was carefully weighed and the moisture content and weight of dry soil determined. The volume of the hole was determined by weighing the quantity of dry sand required to exactly replace the material excavated, this volume being determined by the prior volume-weight calibration of the sand used. With the weight of dry material removed from the hole, and the volume of hole, as data, the dry density of the element was then calculated.

7. California Bearing Ratio Tests.

California Bearing Ratio Test Data are used for the design of flexible type pavements. The method was originally developed and used by the California State Highway Department. The test methods described herein are based on the original methods and revisions thereto made by the U. S. Engineer Department as hereinafter listed.

a. Laboratory Tests.

(1) Undisturbed Specimens.

(a) Source

Laboratory California Bearing Ratio Tests are made in accordance with the procedures and methods given in Paragraph 18, Chapter 20, of the Engineering Manual, and by the revised methods set forth in the letter dated 12 May 1944, from the Chief of Engineers to the Division Engineer, Missouri River Division, subject: "California Bearing Ratio Procedure," a copy of which is included in the letter appendix to this report.

(b) Equipment.

The equipment used for the California Bearing Ratio Tests, conforms to the equipment described in Paragraph 18, Chapter 20, of the Engineering Manual.

(c) Procedure.

Cohesive subgrade materials are obtained as undisturbed samples by incasing the "in-place" soil in 6-inch diameter, 7-inch high steel cylinders. The cylinders are provided with a cutting shoe on the lower edge and a compression head at the upper end. A rough pillar of "in-place" soil is first formed by cutting away exterior portions. The steel sampling cylinder, with cutting edge and compression head "in-place," is then placed on the soil pillar and light pressure applied to the cylinder by a hydraulic jack operating against a truck bumper. The soil is cut away from the cylinder edge by a trowel or knife to allow inclosure of the specimen without exertion of large pressures or disturbance of the specimen. After inclosure of the specimen, the ends are trimmed, capped with Masonite disks and sealed with paraffin for shipment to the laboratory. Undisturbed specimens received in the laboratory are uncapped and immersed until saturated. The upper surfaces of the specimens are surcharged during immersion by circular weights, giving pressures calculated to be equal to the unit pressure exerted on the surfaces by the unloaded pavement in the field, or to a minimum unit load of ten (10) pounds total load on the specimen. The bottoms of the immersed specimens rest on perforated plates which also admit water to the lower portions of the specimens. Swell of the immersed specimens is measured by initial, daily and final extensometer readings; cessation of swell generally being used as an indication of saturation. The specimens are tested for bearing ratio after they are completely saturated.

(2) Disturbed Specimens.

Disturbed specimens are recompacted in the laboratory for bearing ratio tests in accordance with the methods and procedures outlined under Paragraph 7a(3) given below.

(3) Compaction Studies.

Compaction-bearing ratio studies were made to determine the effect of density and various water contents for various compaction on the bearing ratio values of given materials. The studies consist of a series of bearing ratio tests made with materials compacted to various densities at a given water content by varying the work input into the compaction procedure, and other similar series of tests with other moisture contents,

(a) Source.

Compaction studies were performed in accordance with instructions given in the letter dated 12 May 1944, from the Chief of Engineers, to the Division Engineer, Missouri River Division, subject: "California Bearing Ratio Procedure," a copy of which is included in the letter appendix to this report.

b. Field "In-place" Bearing Ratio Tests.

Field "in-place" bearing ratio tests were made in the field on the freshly exposed base, subbase and various subgrade element surfaces to determine the actual existing bearing ratio of the material "in-place".

(1) Source.

"In-place" field bearing ratio tests were performed in accordance with instructions given in Paragraph 18, Chapter 20, of the Engineering Manual.

(2) Equipment.

The equipment used in performing field "in-place" bearing ratio tests consisted of a 7-ton hydraulic jack, gages for the measurement of the load, the piston movement and a 3-square inch circular vertical piston together with the necessary attachments for use under the rear end of a heavily loaded truck, A special spring device was used to measure loads of less than 200 pounds.

(3) Procedure.

The circular piston was seated with a load of 10 pounds. Loading was applied by means of a hydraulic jack, the loads being applied at a rate giving a rate of penetration to the piston of approximately 0.05 inches per minute. Readings were taken of the loadings giving deformations of 0.025 inches, 0.050 inches, 0.075 inches, 0.100 inches, 0.200 inches, 0.300 inches, 0.400 inches, and 0.500 inches. In accordance with the procedures described in Chapter 20 of the Engineering Manual, the bearing ratio was taken to be the ratio of the pressure required to give a penetration of 0.10 inches divided by 1000.

8. Soil Tests.

a. Liquid Limit.

Liquid limit tests were performed in accordance with the procedures and equipment given in A.S.T.M. Standard Method D423-39.

b. Plastic Limit.

Plastic limit tests were performed in accordance with the procedures and equipment given in A.S.T.M. Standard Method D424-39.

c. Mechanical Analysis.

(1) Sieve Analysis.

Sieve analysis tests were performed in accordance with the procedures and equipment given in A.S.T.M. Standard Method D422-39.

(2) Hydrometer Analysis.

Hydrometer analysis tests were performed in accordance with the procedures and equipment given in A.S.T.M. Standard Method D422-39.

d. Classification of Soils.

Soils were classified in accordance with the method described in Paragraph 11, Part 2, Chapter 20, of the Engineering Manual, and as further described in Exhibit 1, Part 2, Chapter 20, of the Engineering Manual.

LETTER APPENDIX

tc

APPENDIX E

Part 2

LABORATORY AND FIELD TEST PROCEDURES

COPY

CONF WA 500 OCE REFERENCE SPENM 104

FROM ROBINS ACTING CHIEF OF ENGRS WASH DC 221850Z Jan 1944

CONF TO GLD MAD MRD NED NAD ORD PD SAD AND SWD

Reference made to paragraph twenty--four one six four Engineering Manual. To be certain that practically complete deformation occurs, loading for each increment should remain until deformation change in five minute period is less than three percent of the total change for load increment. Reference made to paragraph 5, letter dated five August 1943, subject: "Airfield Pavement Evaluation." Tests should be made in strict accordance with paragraph. CBR tests on remolded samples of cohesive type soils should be made for correlation purposes only.

END

SPENM 104

Letter Appendix

COPY

MESSAGEFORM

Date 5 August 1943

File No, CE SPENO 686.61 (Miss. Riv. Div.)

Office of Origin: War Department, Office, Chief of Engineers

Address: Washington, D. C.

To:		Precedence
The Division Engineer Missouri River Division Farm Credit Building 19th & Douglas Omaha (1), Nebraska	Wire or Radio Urgent Priority Routine Deferred	Essential Mil. Mail Airmail x Spec. Delivery x Ordinary Registered

Message:

1. A field survey and an investigation will be made by the Division Engineer at each airfield within the Division and under the jurisdiction of the Army Air Forces to determine the maximum gross weight of airplane that can operate at capacity operation and limited operation at the field without overstressing the pavements. In view of the increasing weights of planes and the necessity for designating fields to be used by certain type of aircraft in the program of the Army Air Forces, it is essential to obtain a record of the evaluation of each field based on the carrying capacities of the pavement as actually constructed. The evaluation of each field will be supplied to the Army Air Forces to serve as a basis for determining the type of aircraft to be assigned thereto. The survey and investigation will be in conformance with the instructions in the following paragraphs.

2. Field Evaluation. Each airfield will be evaluated based on the carrying capacities of the controlling pavements or sections of pavements. The evaluations will be stated as the gross weight of the airplanes that can satisfactorily operate at the field and should not be limited to the standard loadings given in the Engineering Manual. In making the over-all evaluation, consideration must be given to the probable frequency of operation on the various parts of the field as such operation may be controlled by the wind-rose or by other conditions peculiar to the field. For example, let it be assumed that all runways of a particular field are satisfactory for capacity operation of 80,000 pound planes except one runway which is rated as satisfactory for limited operation of such planes only. If, because of the wind-rose or other local conditions, the weak runway will in fact only be used for limited operation, then the proper over-all rating for capacity operation of the field is 80,000 pounds regardless of the weakness of the one runway. Consideration should also be given to the fact that weak sections of pavements of limited extent need not control the overall evaluation of the field. It may be more economical to accept excessive maintenance or reconstruction of a limited pavement area than to abandon a portion of the investment in the greater part of the field.

3. Standards for Evaluation. To evaluate a field will involve the following.

Letter Appendix

a. Determine the controlling pavements.

b. Determine the carrying capacity of the controlling pavements.

To determine the controlling pavements or sections of pavements, the study will include a review of all existing records and data, a review of the construction methods and conditions, and if not available, a complete soil survey of the subgrade conditions, and tests on the subgrades, base courses and paving materials. After the controlling pavements are determined, they will be evaluated in accordance with the design methods described in Chapter XX of the Engineering Manual. To determine the carrying capacity of the controlling pavements at many airfields will require complete field and laboratory investigations. At some fields, sufficient data has been obtained during design and construction to determine the carrying capacity of the controlling pavements. Complete physical tests as described in paragraphs 4 and 5 of "in-place conditions" will not be required if construction control data, inspection of existing conditions and necessary check tests support the validity of the design assumptions and providing the designs were in accordance with the methods described in the Engineering Manual.

4. Evaluation of Flexible Pavements. To evaluate flexible pavements, the California Method of accelerated traffic tests will be used. Accelerated traffic tests as described in Chapter XX, Engineering Manual, should be used only after approval is obtained from the Office, Chief of Engineers. Since the adoption of the California Method of Design, several changes in testing technique of the CBR test procedure have been made. These changes have been incorporated in paragraph 20-18 of Chapter XX, E. M. (March 1943). The revised CBR test procedure described in paragraph 20-18 of Chapter XX, will be used to evaluate flexible pavements in all cases where tests in addition to those for design must be made in compliance with this Circular Letter. It has come to the attention of this office that certain offices have adopted CBR testing procedures at variance with that prescribed in Chapter XX. Although it is not desired to stifle improvement in the CBR test, and Districts and Divisions are urged to investigate all possible improvements, it is apparent that correlation of pavement performance with the purely empirical CBR procedure can only be accomplished by uniform methods of testing. Changes in CBR test procedure where found advisable as a result of this or other investigations will be referred to the Engineering Division, Office, Chief of Engineer, for investigation with the view to incorporation in Chapter XX, E.M.

5. CBR tests should be on remolded samples, undisturbed samples, or on soils in place (see paragraph 20-18, Chapter XX, E.M.) according to the type and moisture condition of the soil. Field tests on cohesive soils in place are considered the most satisfactory if the soil is at or near saturation, but, in all other cases, tests should be made on soaked undistrubed samples. Experience has shown that cohesionless soil will compact under traffic. If the cohesionless soil in place has a unit weight equal to or greater than the density stated in paragraph 20-18, b, 4, Chapter XX, E.M., CBR tests may be conducted with field equipment.

6. Evaluation of Rigid Pavements. For the evaluation of concrete pavements, portions of the pavements shall be removed and the modulus of soil reaction for a saturated condition beneath the pavement will be determined by field plate bearing tests in accordance with paragraph 20-41 and 20-45, Chapter XX, E.M. If the 28-day flexural strength of the concrete as placed

and cured in actual construction was not determined by the A.S.T.M. Test C-78-39, beams should be taken from the pavement for tests. The flexural strength at the time of evaluation should be adjusted according to the characteristics of the concrete to account for the increase in strength that has developed after the 28-day period. A Circular Letter will be issued in the immediate future giving data for the determination of the 28-day flexural strength.

7. Frost and Other Special Features. Consideration should be given to the reduction in load carrying capacity by reason of probable frost action when determining the carrying capacity of both flexible and rigid pavement.

8. Report. A report for each airfield will be prepared, describing in complete detail, the investigation and tests, character of materials involved, method of evaluation, construction features affecting the carrying capacity, and giving test results, justification for selection of controlling pavement conclusions, and all other pertinent information necessary for a complete review of the report. Data and information contained in design analyses and specifications, which are considered pertinent to the evaluations, may be referred to, and these documents or sections of them should be included as appendices to the required report. The report should also include the following plates:

a. A historical and data summary sheet similar to Figure 1 attached.

b. A plan (18 x 21) of the airfield, summarizing the carrying capacity and showing the paved areas similar to Figure 2 attached.

9. Data Summary Sheet. The data summary sheet (Figure 1) should include a maximum of information on a minimum of space. Notes regarding special conditions of subgrade, type of pavement surface, pavement conditions, traffic history, and any item of special interest will be recorded. An unusual maintenance should be described and recorded on the data summary sheet. All reconstruction and resurfacing are to be recorded on separate lines of the data sheet.

10. Summary Plan. The plan (Figure 2) should outline the limits of pavements and show the recommended maximum gross weight of plane that may be used at each airfield. If pavement areas of limited extent (see paragraph 2 above) are not satisfactory for the specified weight of plane, a note will be placed on the plan stating pertinent facts similar to the note on Figure 2. The symbols and colors shown on Figure 2 will be used. If necessary, additional pavement symbols will be used. It is not intended for the pavement symbols to indicate the specific type of pavement but to indicate the general type (such as bituminous treatment, bituminous pavement and concrete pavement). All pertinent dimensions such as length and width of runways, width of major taxiways, width of shoulders, deemed necessary should be shown on the layout plan.

11. Distribution of Report. It is requested that four copies of the detailed report for each field, five additional copies of data summary sheet, Figure 1, and six additional copies of the summary plan, Figure 2, be submitted to this office as soon as the report is prepared. Prior to submittal, each report shall be reviewed and approved by the Division Engineer. For the

duration of the war, all reports shall be marked "Restricted". Although copies will be forwarded to this office, one copy of the report shall be marked for the Embankment, Foundation and Pavement Division, U. S. Waterways Experiment Station, Vicksburg, Mississippi. Copies of the summary plan will be submitted to the Army Air Forces by this office.

12. Order of Evaluation. To establish the order in which fields in each Division should be evaluated, it is requested that Division Engineers confer with the Commanding Officers of the Army Air Force Commands. In general, airfields should first be evaluated for which the construction directive specified the design of pavements for planes weighing in excess of 50,000 pounds or fields designed for lesser loads, but believed to be capable of supporting plans weighing more than 50,000 pounds. It is requested that the Division Engineer submit to this office not later than 10 September 1943, a report stating the estimated dates of completion of investigations for each airfield.

13. Addenda. It is desired that the reports required herein be maintained current. To this end, addenda to the present report will be submitted as future changes in physical characteristics of the airfield or additional information require.

14. Work will be initiated from funds locally available. Request for authorization for use of funds will be made to the Chief of Engineers, attention SPEKM, at such time as sufficient data are available to permit an estimate of cost.

By order of the Chief of Engineers:

/s/ JAMES H. STRATTON
Colonel, Corps of Engineers
Chief, Engineering Division

2 Incls. -
#1 - Historical Data & Record Sheet (Figure No. 1)
#2 - Map - Evaluation of Typical Airfield (Figure No. 2)

Letter Appendix

COPY

MESSAGEFORM

10 January 1944

File No. CE SPENM 686.61 (Missouri River Division)

Office of Origin: War Department, Office, Chief of Engineers

Address: Washington, D. C.

To:	Wire or Radio	Precedence
The Division Engineer	Urgent	Essential Mil. Mail
Missouri River Division	Priority	Airmail x
Farm Credit Building	Routine	Spec. Delivery x
19th & Douglas	Deferred	Ordinary
Omaha (1), Nebraska	Week end	Registered

Subject: Airfield Pavement Evaluation.

1. Reference is made to previous letters of same subject, dated 5 August and 20 August 1943. The evaluation program must be considered as a War Emergency Program and the final evaluation should be submitted with the least possible delay. The Army Air Forces have immediate need for the information in order to properly prosecute the War Training and Transport Program. Every effort should be made to obtain maximum use of all available qualified personnel and suitable testing equipment.

2. To obtain the final results as soon aspossible, it is requested that:

a. Final detailed studies be made only on controlling pavements for runway and all-over field evaluations (see paragraph 3 below). Carrying capacities of pavements other than controlling pavements shown on the "Data Summary Sheet" of the final report should be based on present existing factual data. All values estimated should be noted.

b. Further tests should not be made at field where existing data or observations definitely show that the carrying capacity of the runways for limited operation is less than a gross load of 20,000 pounds.

Many offices desire to make detailed studies of every pavement at a field. The program should be curtailed as above until the present evaluation program is completed. Data and results of additional detailed studies should be submitted in supplementary reports to the final report if such detailed studies are made.

3. The letters referred to in paragraph 1 requested that the program be conducted to determine the "field evaluation". In many cases the field evaluation is controlled by a taxiway or apron. Since repairs or reconstruction of a taxiway or apron will not bar operation at the field, it is considered advisable to also submit to the Army Air Forces the "runway evaluation" which will be controlled by the critical runway. Therefore, it is requested that all reports and summary plans show two evaluations; one as "field evaluation" and the other as "runway evaluation". It is requested that all evaluation values

Letter Appendix

be shown in near the upper right hand corner of the summary plan, in a tubular form as follows:

	GROSS WEIGHT OF PLANES IN POUNDS	
	Capacity Operation	Limited Operation
Field Evaluation	- - - - -	- - - - -
Runway Evaluation	- - - - -	- - - - -

4. Recent traffic tests and observations have shown that many flexible pavements will settle due to traffic compaction. In new construction, subgrade and base materials should be compacted by heavy compaction equipment to insure that settlement due to traffic compaction will be less than 1 or 2 inches. However, no criteria limiting the permissible settlement due to traffic compaction will be established for the present evaluation program. The Army Air Forces have been advised (see attached letter) that flexible pavements will roughen and settle due to traffic compaction and that maintenance in many cases will be considerable. If, subsequent to the present evaluation program, it is considered desirable to conduct accelerated traffic tests on certain pavements to determine the effect of traffic compaction, requests should be submitted to this office in each particular case.

5. Attached is a copy of a letter, subject: "Airfield Pavement Evaluation," dated 5 January 1944, from this office, to the Commanding General, Army Air Forces, defining the terms and meaning of criteria used in the evaluation program. It is requested that the information contained in this letter be forwarded to interested personnel and the definitions stated in paragraph 2 be inserted in final reports. In addition, the final reports should include very detailed description of the procedures of the tests used. Reference to the Engineering Manual is not considered sufficient.

6. To obtain comparable flexural strength results, it is requested that concrete beams sawed from pavement slabs be tested after immersion for a period of at least 24 hours and with the wearing face up. The testing machine should be equipped with a swivel edge to prevent torsion of the beam. Beams should be kept moist until tested. Many offices are "capping" the underside of the beam in the area of the knife edges to produce a smooth surface. To compute the flexural strength, the usual formulas, although not strictly valid for non-uniform concrete, should be used.

7. The evaluation program affords an excellent opportunity to obtain data regarding the moisture conditions below concrete and flexible pavements. It is suggested that such data be obtained at locations which do not interfere with the evaluation program, and special reports be prepared. For the data to be useful, complete information regarding previous weather conditions, densities, water table, construction history, soil characteristics, etc., is required.

By order of the Chief of Engineers:

/s/ E. R. O'BRIEN
Lt. Colonel, Corps of Engineers
Chief, Troop Facilities Branch
Military Construction Division

1 Incl.
Cy. ltr to AAF dated 5 Jan. 44

Letter Appendix,

COPY

WAR DEPARTMENT
Office of the Chief of Engineers
Washington

CE (12 May 44) SPENM

12 May 1944

Subject: California Bearing Ratio Procedure

To: The Division Engineer
Missouri River Division
P. O. Box 1216
Omaha (1) Nebraska

1. Reference is made to Paragraph 20-18b, Chapter XX, Engineering Manual, March 1943 revision. It is requested that the following changes be made in the California Bearing Test Procedure:

Step 2. Conduct all compaction tests in the 6-inch diameter CBR mold. To avoid correcting the density and optimum moisture for stones, the total sample should be used. Soil should not be reused. A sufficient number of specimens should be compacted to definitely establish optimum moisture. Four (4) or five (5) specimens should be compacted with moisture contents with ±2% of optimum moisture for all except cohesionless soils and high swelling clays. In the Modified A.A.S.H.O. test, the height of fall of the hammer must be carefully controlled and the blows must be uniformly distributed. The optimum condition must be rigidly established.

Step 4. When results are required for a soil at 95% Modified A.A.S.H.O. density, compact three (3) specimens at optimum moisture for 100% Modified A.A.S.H.O. compaction using a different number of blows for each specimen, i.e., at 55, 25 and 10 blows per layer. The maximum allowable variation in the molding water content shall be ±0.5% of Modified A.A.S.H.O. optimum moisture. Any specimens not falling within this range shall be discarded and a new specimen compacted that does meet this requirement.

Step 8. Increase the moisture of the specimen, by immersion, to a maximum that might be obtained in the field (porous openings on top and bottom) for a period of four (4) days. The immersion period for previous soils may be less if it is apparent that maximum moisture content is obtained. If the surface of the specimen becomes so soft by immersion that the test results would be unrepresentative of the sample, this method should not be used but the moisture of the specimen should be increased to a maximum by permitting the water to rise upward through the specimen by capillarity until free water appears on the surface.

Step 10. Apply a penetration surcharge weight on all soils equal to the soaking surcharge weight, except that the penetration surcharge weight should not exceed 30 pounds.

Letter Appendix

Step 15. When three (3) specimens are prepared as described above under revision for "Step 4", the results of tests on all samples should be plotted to show the relation between density and CBR. For design purposes, the CBR for 95% Modified A.A.S.H.O. density should be used. (See Fig. 1)

2. CBR test results are affected by the density and molding moisture content of the soil specimen. The effects are great for some low plastic soils. It is desired that the variation of test results with molding moisture and density be determined for at least one typical specimen of each soil encountered, except soils which readily compact under traffic. (See Step 4 in Par. 20-18b, E.M.). The following procedure is recommended:

a. Perform the penetration test, after increasing moisture, on each specimen used to develop the compaction curves for the following compactive efforts; 55, 25 and 10 blows per layer on each of 5 layers using the 10-pound hammer with 18-inch drop and the CBR mold. In many cases, tests on three (3) or four (4) specimens prepared by each compaction effort will be sufficient.

b. Plot the data from these tests as shown on Figure 2. The above procedure is valuable to obtain test results on soils which are greatly affected by small changes in density and molding moisture content and gives a picture of the CBR characteristics, within the range of the expected field control, which will be useful in establishing the limiting CBR values. The test results, as obtained by the above method, should be used in connection with the design curves with the full understanding that the variations obtained may be only qualitatively valid.

3. The above changes will be incorporated in the next revision of Chapter XX of the Engineering Manual. The changes are based on the results of investigations conducted by various laboratories and on information obtained by discussions and conferences in various offices. An extensive investigation of the effect of all factors in the CBR tests and of the method of preparation of specimens for the design test has been made at the U. S. Waterways Experiment Station. A report of this investigation will be prepared for publication in the near future.

4. Due to the difficulties of preparing the sample for the design test to simulate the moisture, density, and structure of the prototype, CBR tests during construction should be made on undisturbed soils, except in the case of those soils which will compact readily under traffic. (See Step 4 in Par. 20-18b, E.M.). If the tests on undisturbed samples do not check the design tests, changes should be made either in the construction methods or design.

5. The present CBR test procedure has not proven entirely satisfactory for testing samples containing particles larger than 1/4 inch in size. It had been found necessary to conduct a great number of tests in order to determine the most reasonable value. This method should be followed until a more satisfactory procedure is developed. However, in some cases, inconsistent results can be avoided by removing the stones which do not affect the stability of the soil.

Letter Appendix

6. The procedure for taking undisturbed samples, outlined in Paragraph 20-18c, Engineering Manual, has not been found satisfactory for all soils. Several Districts have adopted the method generally used to obtain undisturbed samples for shear and consolidation tests. In this method a soil pedestal about 6 inches in diameter and 6 inches high is formed by excavating the surrounding material, an expandable sheet metal cylinder about 7 inches in diameter is placed around the pedestal and paraffin or other suitable material is poured around the sample. The ends are sealed with about 1 inch of paraffin. In the laboratory, the paraffin coat and metal cylinder serve as the sample container during the penetration test.

7. Test results submitted to this office in the past have not always included complete data. Because of minor differences in laboratory technique employed by different divisions soils laboratories for preparing samples for the design tests, it has been extremely difficult to analyze and correlate these results. During the development of any test, the effect of all factors must be studied, and until these are determined, an entirely satisfactory procedure cannot be established. To aid in the development and to maintain a complete record, it is requested that detailed data and a complete description of test procedure be recorded and submitted with all test results.

By order of the Chief of Engineers:

2 Incls
#1- Fig. 1 (In quint.)
#2- Fig. 2 (in quint.)

/s/ HIBBERT HILL
Lt. Colonel, Corps of Engineers
Deputy Chief, Engineering & Development Div.

DATA REPORT OF FROST INVESTIGATIONS

FISCAL YEARS 1943 - 1949

APPENDIX E

Part 2

LABORATORY AND FIELD TEST PROCEDURES
FOR
GREAT LAKES DIVISION
1944 - 1945

APPENDIX E

Part 2

LABORATORY AND FIELD TEST PROCEDURES

GREAT LAKES DIVISION

TABLE OF CONTENTS

APPENDIX E

Part 2

LABORATORY AND FIELD TEST PROCEDURES

GREAT LAKES DIVISION

1. Introduction. - It is the purpose of this appendix to describe the test methods which were used to obtain the results presented in the Data Report of Frost Investigations, Volume III, for investigations conducted at Truax Field, Madison, Wisconsin, and Selfridge Field, Mt. Clemens, Michigan. The following tests were performed on the pavement, base, subbase, and subgrade materials.

Field Tests:

(1) Plate Bearing Tests
  (a) Static Load
  (b) Repeating Load
(2) California Bearing Ratio (CBR)
(3) Water Content
(4) Density

Laboratory Tests:

(1) Classification Tests
  (a) Sieve analysis
  (b) Hydrometer analysis
  (c) Atterberg limits
  (d) Specific gravity
(2) CBR
(3) Pavement Tests
  (a) Extraction of bitumen for bituminous concrete
  (b) Gradation of aggregate in bituminous concrete
  (c) Modulus of Rupture for cement concrete
(4) Soil Compaction Test

Where the procedure followed is a standard of the Engineering Manual or the American Society for Testing Materials (A.S.T.M.), the reference or test number will be given, followed by a description of deviations from the standard, if any.

2. Field Tests.

a. Plate Bearing Test - Static Load.- Engineering Manual, Chapter XX, Paragraph 20-41. In this test, care was taken that loading for each increment remained until deformation change in five minute period was less than 3 per cent of the total change for the load increment. The standard procedure was followed to determine the modulus of soil reaction "k_u" of the base material under the cement concrete pavement in Test Area C. The equipment shown in photographs, Plate 186, Volume III, was used, arranged in the manner shown except that the 30-inch diameter plate was placed directly on the base material.

(1) Application of test to flexible pavement.- Pavement bearing tests on bituminous concrete pavements were made in the manner described in the Engineering Manual, except that the 30-inch diameter plate was placed directly on top of the pavement. A thin layer of plaster of paris was used to seat the plate to insure uniform bearing. One arrangement of the apparatus using soil anchors is shown in Figure 1, Plate 186, Volume III. Another arrangement employing a loaded trailer for reaction was also used, and is shown in Figure 2 on same plate.

(2) Application of Test to corner of rigid pavement slabs.- The standard procedure was used in attempting to determine the load required to fracture corners of cement concrete pavement slabs, with the exception that a plate 24 inches in diameter was used. The plate was seated with a thin layer of plaster of paris on the corner of the slab, one inch from each edge. Three extensometers were placed equidistant around the circumference of the bearing plate and arranged so that one was at a point nearest the corner of the slab. The load was applied in increments of 10 pounds per square inch, except the first which was 20, 25, or 30 pounds per square inch. As the available load was not sufficient to cause failure, the loading was released in decrements of the same magnitude as the corresponding increments. The equipment for this test was assembled as shown in Figure 3, Plate 186, Volume III.

b. Plate Bearing Test - Repeating Load.- The same type and arrangement of testing apparatus as required for the standard Static Load Test described in the Engineering Manual, Chapter XX, Paragraph 20-41 was used. A 24-inch diameter bearing plate was placed on top of the bituminous concrete pavement. To insure uniform bearing, plaster of paris was used to seat the plate. The test was conducted in the following manner: A seating load of 3500 pounds was applied for five minutes and released. A load of 20,000 pounds was then applied and the deformation measured. The load was maintained for ten minutes during which the deformation was measured at the end of the first, fourth, and seventh and tenth minute. The load was then released for a period of five minutes, and the deformation readings taken immediately after release of the load, and after the first and fifth minutes had elapsed. The foregoing procedure was then repeated until ten repetitions had been made. The results of the test were shown graphically by plotting a continuous graph of the deformation measurements taken at the end of the five minute period under no load and at the end of the ten minute period under 20,000 pound load, the deformations being shown as ordinates and the load as abscissae.

c. CBR Test.- Engineering Manual, Chapter XX, Paragraph 20-18d, "CBR Test on Soils in Place". The standard CBR piston was secured to the base of an 8-ton hydraulic jack equipped with gage having a large dial. The load was applied through a swivel head and adjustable column against a steel beam secured to the back end of a light truck. When the spring tests were made, the size of the annular plate through which the penetration surcharge is applied was increased from 6 inches to 12 inches, outside diameter. At each location in the soil profile where the test was conducted, the water content and density tests were also made.

d. Water Content.- The quantity of water contained in the soil was determined by weighing a small representative sample of the soil (50 to 100 grams) before and after drying it in an oven at a temperature of about 110°C. Four ounce ointment tins, a balance sensitive to 0.01 gram, and a small electric thermostatically controlled oven was used. When it was not practical to weigh the samples immediately, the tins were sealed with scotch cellulose tape. Stones larger than 3/4-inch in diameter were not included in the samples. The water content was reported as a per cent of the dry weight of the soil.

e. Density of Soil in Place.- The unit weight of the soil was determined by weighing the soil removed from a hole, about 3 inches in diameter and 3 inches deep, and measuring the volume of the hole from which the soil was dug. The procedure is as follows: A trowel was used to cut away enough of the undisturbed soil to provide a horizontal area four or five inches in diameter. A pan, 24 inches square and 2 inches deep, with a 4-inch diameter hole cut out of the center, was next placed over the spot previously prepared. By means of the trowel and spoon (an ordinary table spoon) the soil was removed and placed in the pan. In digging, care was exercised to cut toward the center of the hole and to avoid compressing the sides of the hole. When enough soil had been removed to provide a hole of the desired size, the pan and soil removed was weighed on a scale sensitive to one gram. To find the volume of the soil thus removed, the hole was filled level full with Ottawa sand of known density, and the weight of container plus Ottawa sand before filling the hole and the weight of container plus Ottawa sand after filling the hole. The unit weight of the Ottawa sand was frequently determined by weighing a known volume of the sand which had been poured in the same manner as employed when pouring the sand into the hole in the soil. Stones larger than 3/4-inch in diameter encountered when digging the hole were set aside and returned to the hole as the sand was poured into the hole. A representative portion of the soil removed from the hole was used for determining the water content as explained in Paragraph 2d above.

f. Density of Frozen Soil.- The density of frozen soil was found by weighing a representative sample and measuring the volume of Ottawa sand displaced by the sample from a container of the sand. The sample weighing about 3 kilograms was broken or cut from a large piece of frozen soil, care being taken to disturb the soil mass as little as possible. The sample was weighed and then placed in a container of known volume, 6 inches in diameter and 8 inches deep, partly filled with Ottawa sand. Ottawa sand was then poured around the sample until the container was full. The container was then rapped with a hammer 10 blows on each side. A small amount of sand was then added and struck off with a straight edge. The container with sand and sample was weighed on a scale sensitive to one gram. Before each series of density determinations were made, the container was filled with Ottawa sand and rapped in the same manner as described above in order to obtain the density of sand required to fill the known volume. The weight of the sand displaced by the sample was calculated by adding the weight of the soil sample, to the weight of a full container of sand (previously determined) and subtracting from this quantity the weight of the sample and sand filling the container. Knowing the density and weight of the sand displaced, its volume was then computed. A portion of the frozen sample, about 100 grams was used for determining the water content as described in Paragraph 2d above.

3. Laboratory Tests.

a. Classification Tests.- All soil samples used in the classification tests were first air dried, and then dried in an oven at 110°C. The sand and clay samples were divided into fractions by quartering until the desired size of sample necessary for the tests was obtained. Each of these selected samples was then ground in a mortar by means of a pestle until all aggregations had been broken down into particles.

(1) Sieve Analysis.- The sand-clay-gravel samples were screened on 1 1/2, 3/4, 3/8 inch and No. 4 sieves and the amount retained on each noted. In all screening operations, all lumps of soil were broken down. The material passing the No. 4 screen was quartered until desired size of sample required for the remaining tests was obtained. Each sample was split into two portions which were sieved on a No. 10 screen. The material passing the No. 10 screen was ground in a mortar to break down all remaining lumps. The percentages of soil particles passing screens having openings of 0.84, 0.43, 0.25, 0.147, and 0.074 millimeters was obtained by following the standard A.S.T.M. test D422-39. The test was performed on both portions of each sample. Sieve analyses of two portions of each sand and clay sample were also made according to the standard test.

(2) Hydrometer Analysis.- A.S.T.M. D422-39. Two tests were performed on each sample of soil submitted to the laboratory. In the case of samples taken from test areas B and C, one test was run using 20 cc of 4% sodium silicate solution, specified in the standard procedure, and in the other test 5 cc of the same solution was added. Apparently, as complete dispersion was obtained in one test as in the other, as no appreciable difference between the results of the two tests could be noted. In reporting the final results, a mean of the two tests was taken. Since no constant temperature bath was available, the temperatures were noted and corrections for temperature applied.

(3) Atterberg Limits.- A.S.T.M. D423-39 and D424-39. Each value reported is the average of at least two tests.

(4) Specific Gravity.- This test was performed by placing between 10 and 20 grams of over-dried soil, passing the No. 10 sieve, in a pycnometer. After weighing and adding some distilled water to the sample, it was de-aerated. The pycnometer was then completely filled with water and its weight and the temperature of the water were recorded. The specific gravity was calculated by dividing the weight of the soil in grams by the volume of the soil in cc. The values reported are a mean of at least two tests.

b. CBR Test.- The procedure for this test is that given in the Engineering Manual, Chapter XX, Paragraph 20-18, as revised by letter from O. C. of E. dated 12 May 1944 (CE-12 May 44-SPENM). A 12 pound soaking surcharge was used on granular soil samples and a 24 pound surcharge on clay. The penetration surcharge was 24 pounds. Stone not passing the 3/4-inch sieve was replaced with similar stone passing the 3/4 inch sieve and retained on a 1/4 inch sieve. The water content of each compacted specimen containing gravel depends on the mean result of tests on four 75-gram samples. When compacting sand and clay specimens, the mean of two tests for water content was used.

c. Pavement Tests.

(1) Extraction and Recovery of Bitumen.- A.S.T.M. D762-44T.

(2) Gradation of Aggregate (extracted from bituminous concrete).- A.S.T.M. C 136-39

(3) Modulus of Rupture for Cement Concrete.- A.S.T.M. C 78-39.

d. Compaction Test.- Engineering Manual, Chapter XX, Paragraph 20-14a (1). This test, called the "Modified AASHO Compaction Test," is performed in the same manner as that portion of the CBR test procedure specified for determination of maximum density and optimum water content. The soil was compacted into a standard CBR mold in five layers, each approximately one inch in thickness under fifty-five blows of the 10 pound hammer dropped from a height of eighteen inches.

DATA REPORT OF FROST INVESTIGATIONS

FISCAL YEARS 1943 - 1949

APPENDIX E

Part 3

LABORATORY AND FIELD TEST PROCEDURES
FOR
NEW ENGLAND DIVISION
1944 - 1945

APPENDIX E

Part 3

LABORATORY AND FIELD TEST PROCEDURES

NEW ENGLAND DIVISION

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APPENDIX E

Part 3

LABORATORY AND FIELD TEST PROCEDURES

NEW ENGLAND DIVISION

1. Introduction. It is the purpose of this appendix to describe the test methods which were used to obtain the results presented in the Report on Frost Investigation where applicable at Dow Field, Bangor, Maine, Presque Isle Airfield, Presque Isle, Maine, Otis Field, Sandwich, Mass., and Houlton Airfield, Houlton, Maine. The following tests were performed:

Field Tests:

(1) Plate Bearing Tests
 (a) Static Load
 (b) Repeating Load
(2) California Bearing Ratio (CBR)
(3) Water Content
(4) Density (Unit dry weight)

Laboratory Tests:

(1) Classification Tests
 (a) Sieve analysis
 (b) Hydrometer analysis
 (c) Atterberg limits
 (d) Specific gravity

(2) California Bearing Ratio (CBR)

(3) Pavement Tests
 (a) Extraction of bitumen for bituminous concrete
 (b) Gradation of aggregate in bituminous concrete
 (c) Modulus of Rupture for cement concrete
 (d) Compressive Strength

(4) Soil Compaction Test (Moisture - Density)

Where the procedure followed is a standard of the Engineering Manual or the American Society for Testing Materials (A.S.T.M.), the reference or test number will be given, followed by a description of deviations from the standard, if any.

2. Field Tests.

a. Plate Bearing Test - Static Load. - Engineering Manual, Chapter XX, paragraph 20-41. The load for each increment was maintained constant until deformation change in five minute period was less than 3 percent of the total change for the load increment. For each increment of load, deflection readings were taken at time intervals 1/4, 1, 3, 5, 7, 9, 10, 12, 14, 15, 17, 19, 20, 22, 24, 25, 27, 29 and 30 minutes. The equipment illustrated in Photographs on Plate 3E-1 in this appendix.

(1) Subgrade Modulus Test.- Tests were performed on top of the gravel base directly beneath the rigid pavement using a 30-inch diameter plate as outlined above.

(2) Application of test to flexible pavement.- Pavement bearing tests on bituminous concrete pavement were made in the manner described in the Engineering Manual, except that the 30-inch diameter plate was placed directly on top of the pavement. A thin layer of sand was used to seat the plate to insure uniform bearing.

(3) Application of test to corner of rigid pavement slab.- The standard procedure was used to determine the load required to fracture corners of cement concrete pavement slabs, with the exception that a plate 24 inches in diameter was used. The plate was seated on a thin layer of sand at the corner of the slab. The edge of the plate was 3 inches from the slab edges. Two extensometers were placed in a line bisecting the right angle formed by the pavement joints. The load was applied in increments of 20, 30, 35, 40, 45, 50, 55 and 60 thousand pounds. If the available load was not sufficient to cause failure, the loading was released in one decrement and reloaded by increments to the maximum total load. This procedure was repeated until rupture occurred or for a total of 5 repetitions.

b. Plate Bearing Test - Repeating Load.- The same type and arrangement of testing apparatus as required for the static load test described in paragraph 2a above was used. A 24-inch diameter bearing plate was placed on top of the bituminous pavement. To insure uniform bearing, a thin layer of sand was used to seat the plate. The test was conducted in the following manner: A seating load of 3500 pounds was applied for five minutes and released. A load of 20,000 pounds was then rapidly applied in one increment. The load was maintained for ten minutes during which the deformation was measured at the end 1/4, 1, $2\frac{1}{4}$, $6\frac{1}{4}$, and 10 minutes. The load was rapidly released and deformation readings taken at the end of a 5-minute period. The foregoing procedure was then repeated until ten load repetitions had been made. The results of the test were shown graphically by plotting a continuous graph of the deformation measurements taken at the end of the five minute period under no load and at the end of the ten minute period under 20,000 pound load, the deformations being shown as ordinates and the load as abscissae.

c. Field-in-Place CBR Test.- The method described in Engineering Manual, Chapter XX, paragraph 20-18d,"CBR Test on Soils in Place" was used. The standard CBR test head was secured to the piston of a 10-ton hydraulic jack equipped with 3 pressure gages for low, medium and high pressure. The reaction was furnished by two 6-foot lengths of 80-lb. steel rail bolted together and weighted by the front wheels of a $2\frac{1}{2}$ ton truck. The surcharge weights consisted of thin annular lead plates 6 inches in diameter with 2-inch diameter hole in center. At each location in the soil profile where a Field CBR test was conducted, water content and density of the soil were also determined.

d. Water Content.- The quantity of water contained in the soil was determined by weighing a small representative sample of the soil (200 to 300 grams) before and after drying it in an oven at a temperature of about 110°C. Eight ounce ointment tins, a scale sensitive to 0.01 gram and an electric oven were used. Stones larger than $\frac{1}{4}$ inch in diameter were not included in the samples. The water content was reported as a percent of the dry weight of the soil.

e. Density of Soil in Place.- Density of a soil is defined as its unit dry weight. The density of the soil was determined by weighing the soil removed from a hole, 6 to 8 inches in diameter and 6 to 8 inches deep, and measuring the volume of the hole from which the soil was removed. The procedure used is as follows: The surface of the undisturbed soil was leveled using a trowel to provide a horizontal area about 12 inches in diameter. By means of a trowel and spoon, a hole was excavated and the soil was removed and placed in gallon size cardboard cartons. In digging, care was exercised to cut toward the center of the hole and to avoid compressing or loosening the sides of the hole. When enough soil had been removed to provide a hole of the desired size, the soil removed was weighed on a scale sensitive to 0.01 gram. The volume of the soil thus removed, was determined from the weight of beach sand of known density required to completely fill the hole. The density of the beach sand was frequently determined by weighing a known volume of the sand which had been poured in the same manner as employed when pouring the sand into the hole in the soil. A representative portion of the soil removed from the hole was used for determining the water content using the procedure described in paragraph 2d above.

3. Laboratory Tests

a. Sieve Analysis.- Coarse material was separated from fine on 1/4-inch sieve. Material passing 1/4-inch sieve was quartered to 100 grams and washed on No. 100 (Tyler) sieve using not more than 1000 C.C. of water. The portion retained in wash water was used for hydrometer analysis. Material 1/4-inch to No. 100 (Tyler) was dried and sieved in mechanical shaker. Material retained on 1/4-inch sieve was sieved by hand. The complete sieve analysis was computed and plotted.

b. Hydrometer Analysis.- The dry weight of sample contained in wash water described in above Paragraph 3 (a) was determined by the pycnometer method. The total dry weight was computed and grain size and percent finer of material passing No. 100 mesh sieve was determined as described in "Notes on Soil Testing for Engineering Purposes" by A. Casagrande and R.E. Fadum, Harvard University, 1940.

c. Atterberg Limits.- Procedure described in "Notes on Soil Testing for Engineering purposes" by A. Casagrande and R.E. Fadum, Harvard University, 1940 was followed. Each value reported is the average of at least two tests.

d. Specific Gravity.-

(1) Material Passing 1/4" Screen. Approximately one hundred grams of material were placed in calibrated volumetric flask approximately two-thirds full of water and the mixture boiled for ten minutes to remove air. The flask was cooled and water was added to bring contents to calibration mark. Outside of the volumetric flask and the inside of the neck was thoroughly dried and weighted to .01 gram and temperature determined. Weight of bottle and water was determined from calibration curve. Dry weight of soil determined and specific gravity computed.

(2) Material Retained on 1/4" Screen.- The specific gravity was determined in accordance with A.S.T.M. Designation C-127-42.

e. CBR Test.- The procedure for this test is that given in the Engineering Manual, Chapter XX, paragraph 20-18, as revised by letter from O.C. of E. dated 12 May 1944 (CE-12 May 44-SPENM). Weight of surcharge during soaking and penetration was equivalent to the weight of overlying materials in situ, except that during penetration the surcharge weight was not greater than 30 lbs. or less than 10 lbs. Stone not passing the 3/4-inch sieve was replaced with similar stone passing the 3/4-inch sieve and retained on a 1/4 inch sieve. The water content of each compacted specimen is the average determined in the bottom, center and top.

f. Pavement Tests.-

(1) Extraction and Recovery of Bitumen. - A.S.T.M. D762-44T.

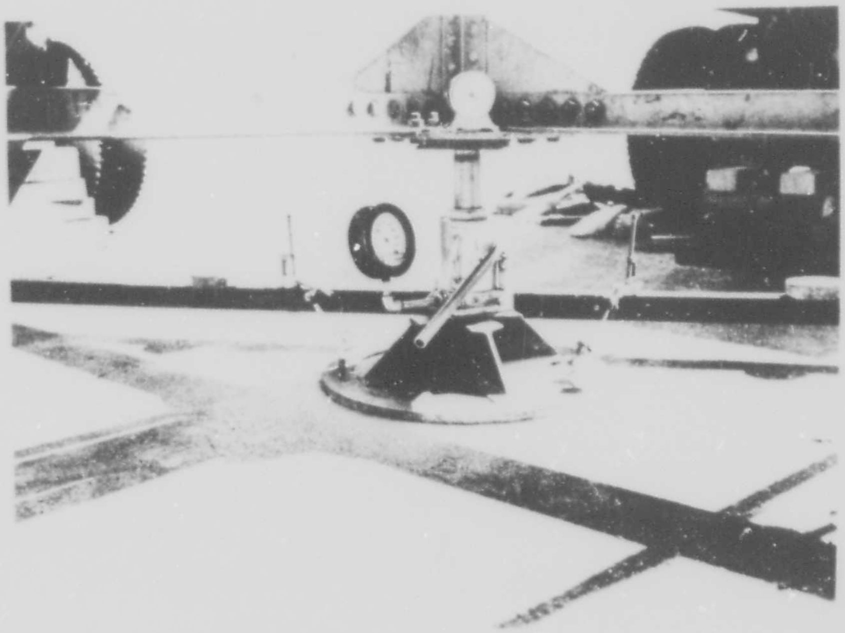
(2) Gradation of Aggregate (extracted from bituminous concrete). - A.S.T.M. C 136-39.

(3) Modulus of Rupture for Cement Concrete. - A.S.T.M. C 78-39.

(4) Compressive strength of modified cubes tested in accordance with A.S.T.M. Designation C 116-39 and cores in accordance with A.S.T.M. C 39-42.

g. Soil Compaction Test.- The procedure is described in Engineering Manual, Chapter XX, paragraph 20-14a (1). This test, called the "Modified AASHO Compaction Test", is performed in the same manner as that portion of the CBR test procedure specified for determination of maximum density and optimum water content. The soil was compacted into a standard CBR mold in five layers, each approximately one inch in thickness under fifty-five blows of the 10 pound rammer dropped from a height of eighteen inches.

General View of Pavement Bearing Test



Close Up View of Pavement Bearing Test

PLATE 3E-1

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U. S. ARMY
BOSTON, MASSACHUSETTS

DATA REPORT OF FROST INVESTIGATIONS
FISCAL YEARS 1943 - 1949

APPENDIX F

BIBLIOGRAPHY
(REVISED JUNE 1949)

FROST EFFECTS LABORATORY

JUNE 1949

FOREWORD

The following bibliography contains references to published articles on subject matter related to frost phenomena. It is limited only to those articles which deal with seasonal frost and its effect on soils. Publications or articles dealing with permanently frozen ground or "Permafrost" are not within the scope of this bibliography.

This bibliography originally appeared as Appendix 15 to Comprehensive Report on Frost Investigation 1944-1945, dated June 1945. It has been augmented since then by the addition of references taken from a bibliography on frost action prepared by the Highway Research Board and from a bibliography on frost and permafrost prepared by the Documentary Research Division, Air University Libraries, Maxwell Field, Alabama, and other sources.

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* MERSMAN, W. A., BERGGREN, W. P., BOELTER, L. M. K. "The Conduction of Heat in Composite Infinite Solids". University of California Publications in Engineering - Vol. 5, No. 1, pp. 1-22, Dec. 15, 1942.

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* MULLIS, I. B. "Illustrations of Frost and Ice Phenomena." Public Roads, Vol. 11, No. 4, pp. 61-79, June, 1930.

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NATIONAL RESEARCH COUNCIL OF CANADA. "Technical Memo. No. 2," National Research Council of Canada.

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NATIONAL RESEARCH COUNCIL OF CANADA. "Soil Temperatures in Canada - Observations of Soil Temperatures," February 1937, Ottawa, National Research Council of Canada.

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NIEDERLANDER, D. B., "Army Cantonment Built in Sub Zero Weather," Civil Engineering, Volume 12 (April 1942), pp. 187-190.
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* NORGAARD, H. "Long-Distance Heating Systems Insulated with Cell Concrete". 25 Years of Civil Engineering, Christiani and Nielsen, 1904-1929, pp. 154-169.

NORTON, C. D. "Water Expansion in Ground Cause of Heaving in Winter." Engineering News-Record, Vol. 80, No. 22, p. 1058, May 30, 1918.
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Brief description of the use of calcium chloride to prevent freezing of the subgrade in winter construction.

O'ROURKE, C. E. "General Engineering Handbook." 2nd Ed., pp. 836, 1913, 1914, N. Y.: McGraw-Hill Book Co., 1940.
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* OSTERBERG, J. O. "A Survey of the Frost Heaving Problem". Civil Engineering, Vol. 10, No. 2, pp. 100-102, Feb. 1940.

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* PARADIS, A. "Foundations and Protection Against Frost Heaving". The Canadian Engineer, Vol. 67, pp. 21-24, Oct. 16, 1934.

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* PATTEN, H. E. "Heat Transference in Soils." U. S. Department of Agriculture, Bulletin No. 59, Sept. 1909.

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PORSILD, A. E., "Earth Mounds in Unglaciated North-Western America." Geographical Review, Volume 28 (1938) pp. 46-58.

POWERS, T. C. "Working Hypothesis for Further Studies of Frost Resistance of Concrete," Journal of the American Concrete Institute, Vol. 16, (February 1945), pp. 245-272.

PRATT, F. R. "Depth of Frost Under Pavement." Engineering News-Record, Vol. 125, No. 25, p. 67, Dec. 19, 1940.
Record of observed temperatures and epth of frost penetration under portland cement concrete pavement.

PRYOR, W. T. and EAGER, W. L. "Ice Formation on Alaska Highway," Public Roads, Volume 24, No. 3 (January, February, and March 1945) pp. 55-74, 82. See also-Engineering and Contract Record, Vol. 58, No. 12 (December 1946). pp. 38-9, 98, 100, 102, 104-6.
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PUBLIC WORKS MAGAZINE. "Minimizing Spring Thaw Damage." Public Works Magazine. Vol. 78, No. 6, pp. 55-56, June 1947.
This appears to be the answers to Better Roads Forum Question in Better Roads, Vol. 17, No. 4, pp. 32-34, April, 1947.

RAVN, H. H. "Frost Damage on Roads" Dansk Vejtidsskr. 1939, 16 (4), pp. 142-148. Road Abstracts. Vol. 7, No. 3, Abst. No. 81, pp. 37-38, April, 1940.

A general review of the theory of frost action and the many and varied means of preventing damage due to frost. Some of the means of prevention mentioned are (1) replacement with coarser soil (2) use of protective courses (3) use of insulating courses of brushwood, straw or hay (4) permitting rapid freezing by immediate removal of snow (5) the use of admixtures, and (6) drainage.

RAVN, H. H. "The Origin of Frost Damage and Methods of Combating It." Dansk Vejtidsskr, 1940, 17 (2), pp. 40-52, (3) 90-97, (5) 151-171. Road Abstracts, Vol. 14, No. 4, Abst. No. 262, p. 48, April 1, 1947, Highway Research Abstracts, No. 141, p. 6, May 1947.

A discussion on the mechanics of frost heaving; depth of frost penetration; amount of heaving; effect of surface loading, grain size of soil, and temperature on heaving; laboratory and field tests, effectiveness of granular bases, insulation (brushwood, moss, etc.); drainage and chemical treatment of soils.

RIIS, AXEL, "Frost Damage to Roads in Denmark", Proceedings, 2nd International Conference on Soil Mechanics, Vol. II, Rotterdam 1948.

ROADS AND BRIDGES. "How can Frost Boils be Prevented." Roads and Bridges (Canada), Vol. 80, No. 11, pp. 26-46, Nov., 1942

Discussion on the use of calcium chloride as a means of preventing frost action in soils.

ROADS AND BRIDGES. "Mechanics of Frost Heaving." Roads and Bridges, (Canada), Vol. 81, No. 5, pp. 84-85, May, 1943.

Review of means of preventing of frost heave, with emphasis on application and effectiveness of calcium chloride.

ROADS AND BRIDGES. "Effect of Freezing and Thawing on Concrete Pavements." Roads and Bridges., Vol. 84 (January 1946), pp. 65-68.

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ROADS AND STREETS. "Tile Drains Solve Frost-Boil Problem". Roads and Streets, Vol. 71, pp. 257-258, July 1931.

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ROADS AND STREETS. "Simple Method of Preventing Spring Breakup of Roads." Roads and Streets. Vol. 87, No. 10, p. 81, Oct., 1944.

Description of method of introducing calcium chloride and pea gravel in holes in subgrade to prevent spring breakup.

ROAD RESEARCH LABORATORY, LONDON ENGLAND "Ice Formation on Roads". Road Research Laboratory, London, England. Department of Scientific and Industrial Research.

ROBERTS, M. "Notes on the Action of Frost on Soil." Journal of Geology, Vol. 11, No. 3, pp. 314-317, April-May, 1903.
Description of ground surface hoar frost (needle ice, Swedish "pipkrake") formed in the Puget Sound area from Feb. 10 to 18, 1903 with ground temperatures as low as 24°F. Includes four photos showing ice formed in six layers ranging in height from 3/8 to 1 in.

ROMONOV, V. V. "Physical Properties of Seasonably Frozen Ground in Marshes," Translated from Russian by V. V. Romonov and Rogantskaia.
Same data on density, per cent of organic, per cent moisture, stability, heat conductivity and flexural strength of frozen soils. Wide variation in test results.

ROOT, W. H. "Vertical Drainage" from Highway Maintenance Performance Items - Summer 1947. An unpublished report of highway maintenance items assembled by Public Roads Administration.
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ROWAT, R. M. "Control of Frost Heave." Proceedings, Highway Research Board, Vol. 19, pp. 464-466, 1939.
A brief statement on the magnitude of subgrade soil temperatures and a description of four methods by which common salt has been applied to prevent frost heave. The author suggests that salt be used to prevert frost heave. (The salt dissolves in the ground water and lowers the freezing point) if the average temperature is known, enough salt should be added to the soil to lower the freezing point to guard against minimum temperatures. This practice was followed on railway grades in Canada.

RUCKLI, ROB. F. X. "Two and Three Dimensional Ground Water Flow Towards the Ice Lenses Formed in the Freezing Ground". Proceedings, 2nd International Conference on Soil Mechanics, Volume II, Rotterdam 1948.

* RUCKLI, R. "Die Frostgefährlichkeit des Strassenuntergrundes" (Frost Damage in Highway Subgrades). Strasse und Verkehr, Vol. 29, No. 19, pp. 311-318, No. 20, pp. 332-9; No. 21, pp. 343-353; No. 22, pp. 357-64; No. 24, pp. 388-96; No. 25, pp. 397-403, Sept. 17 - Dec. 10, 1943. (Translated by H. B. Edwards, Engineer Dept. Research Centers, U. S. Waterways Exp. Sta., Vicksburg, Miss., Aug., 1944). Note: This article is itself a German translation of a French article "Gelivite des Sols et Fondation des Routes" by Dr. A. Stucky of Lausanne University. Published in book form by the Societe du Bulletin Technique de la Suiss Romande).
A long and informative article arranged in seven parts: 1. Types of ice in soil. 2. The mechanics of frost heaving. 3. Frost conditions in Switzerland. 4. Temperature conditions in the soil. 5. Frost penetration in the soil. 6. Theory of Frost heaving. 7. Field experiments.

* SCHAIBLE, L. "The Repair of Frost Damage". Highway Research Abstracts, No. 118, Page 4, March 1945. (Abstract of article in "Strasse" 1942 9(17/18), pp. 173-176).

SEMIAKIN, F. M. and MIKHALEV, P. F. "Formation of Periodic Ice Streaks During Soil Freezing." Comptes Rendus (Doklady) de l'Academie des Sciences, U.S.S.R., 1937, 17 (8) 405-7 (In English). Science Abstracts, 1938, 41 (484), 356. Road Abstracts, Vol. 5, No. 7, Abst. No. 388, p. 110, Oct., 1938.
By using an analogy between the differential equations of diffusion and heat conduction, a law has been obtained giving the spacings between ice-streaks in frost heaving. The law is said to be in accordance with the observations of Taber.

* SHANKLIN, G. B. "The Effects of Moisture on the Thermal Conductivity of Soils". Journal American Institute of Electrical Engineers, Vol. 41, pp. 92-98, Feb. 1922.

* SHANNON, W. L. "Frost Investigations at Dow Field, Bangor, Me.". Proc. Highway Research Board. Vol. 24, pp. 71-86, 1944.

* SHANNON, W. L. "Prediction of Frost Penetration." Journal, New England Water Works Association, Vol. 59, No. 4, pp. 356-363, Dec., 1945.
Data on and discussion of factors influencing frost penetration; the freezing index (with an approximate formula for computing F.I.); thermal properties of soils; depth of frost penetration and means of computing it; correlation between depth of frost penetration and freezing index; and freezing index frequency.

* SHANNON, W. L. and WELLS, W. A. "Tests for Thermal Diffusivity of Granular Materials." Presented at the 50th Annual Meeting of the American Society for Testing Materials, June 16-20, 1947.
Description of apparatus and test methods, analyses, and results of tests to determine thermal diffusivity of a number of different granular materials.

SHIMANOVSKII, S. V., "Thermal Constants of Ground", (Teplovye Konstanty gruntov.)

* SLATE, F. O. "Use of Calcium Chloride in Subgrade Soils for Frost Prevention". Proc. Highway Research Board, pp. 422-441, 1942.

SLESSER, CHARLES. "Field Studies of Migration of Calcium Chloride and Sodium Chloride in Soil." Thesis. Purdue University, 1940.
The essential data in this thesis are given in the following: Slesser, C. "The Migration and Effect on Frost Heave of Calcium Chloride and Sodium Chloride in Soil." Purdue University, Engineering Bul., Vol. 27, No. 4, (Research Ser. No. 89, Highway Research Bul. No. 11), July 1943, 168 pp.

* SMIRNOFF, A. "Soil Temperatures and Cable Rating". Electrical World, Vol. 82, pp. 438-439, Sept. 1, 1923.

SMITH A. "A Contribution to the Study of Interrelations between the Temperature of Soil and the Atmosphere and a New Type of Thermometer for such Study". Soil Science, Vol. 22, pp. 447, 1926.

SMITH A. "Seasonal Subsoil Temperature Variations." Journal of Agricultural Research, Vol. 44, No. 5, pp. 421-428, March 1, 1932.
Includes soil and air temperature data taken at Davis, California, and a discussion of the range of soil temperatures of various depths and the geometric progression low of daily temperature fluctuations.

SMITH, A. "Daily and Seasonal Air and Soil Temperatures at Davis, California." Hilgardia, Vol. 4, No. 3, pp. 77-112, May, 1929.
Observed air and soil temperatures at Davis, California. This reference is given because it describes the installation of thermometers. Winter temperatures of the soil did not fall below freezing.

SMITH, ALFRED. "Effect of Paper Mulches on Soil Temperature, Soil Moisture, and Yields of Certain Crops," Hilgardia, Vol. 6, No. 6, November 1931.

SMITH, H. W. "Frost Damage to Sealed Surfaces in Southland." Proceedings, New Zealand Institution of Engineers, Vol. 32, pp. 570-594, 1945-1946. Highway Research Abstracts, No. 138, pp. 2-4, Feb., 1947.
Description of road surface failures due to frost action; mineralogical description of aggregates used; specific heat and thermal conductivity of various materials; soil temperatures and computation of time required for frost to penetrate bases of various materials and thickness.

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