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FROST INVESTIGATIONS: COLD ROOM
STUDIES. THIRD INTERIM REPORT OF
INVESTIGATIONS

T. W. Lambe

Arctic Construction and Frost Effects
Laboratory
Waltham, Massachusetts

October 1958

OFFICE OF RESEARCH AND DEVELOPMENT

PHYSICS INVESTIGATIONS

COLD ROOM STUDIES
THIRD INTERIM REPORT
OF
INVESTIGATIONS

GENERAL AND CHEMICAL STUDIES

by

L. W. BROWN, JR.

APPENDIX D. ANALYTICAL PROCEDURES AND DATA FOR
GENERAL AND CHEMICAL STUDIES

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CORPS OF ENGINEERS, U. S. ARMY

FROST INVESTIGATIONS

COLD ROOM STUDIES
THIRD INTERIM REPORT OF INVESTIGATIONS

APPENDIX C: MINERAL AND CHEMICAL STUDIES
by
T. William Lambe

APPENDIX D: ACEFEL TEST PROCEDURES AND INVESTIGATIONAL
DATA FOR MINERAL AND CHEMICAL STUDIES

TECHNICAL REPORT NO. 43

PREPARED BY
ARCTIC CONSTRUCTION AND FROST EFFECTS LABORATORY
U. S. ARMY ENGINEER DIVISION, NEW ENGLAND
WALTHAM, MASSACHUSETTS
FOR
OFFICE OF THE CHIEF OF ENGINEERS
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CORPS OF ENGINEERS, U. S. ARMY

FROST INVESTIGATIONS

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APPENDIX C: MINERAL AND CHEMICAL STUDIES

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T. William Lambe

ARCTIC CONSTRUCTION

AND

FROST EFFECTS LABORATORY

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FOREWORD TO APPENDIX C

The following report was submitted by Dr. T. William Lambe, of the Massachusetts Institute of Technology, Cambridge, Massachusetts, who was engaged as a consultant on studies to determine the effect of mineral composition of soil fines and investigations of admixtures to prevent or minimize frost action in soils.

The studies reported herein were carried out in Fiscal Years 1952 and 1953 under a contractual agreement with Dr. Lambe.

The contractor obtained, prepared, and furnished the Arctic Construction and Frost Effects Laboratory the mineral fines, chemicals, and other admixtures for cold room tests and also performed necessary chemical and mineralogical tests for the studies. The results of the freezing tests were tabulated, summarized, and submitted to the contractor by the Laboratory for interpretation and recommendation for further testing.

This report was written by Dr. Lambe in fulfillment of Fiscal Year 1952 contract and was reviewed and processed for reproduction by the Laboratory. The investigations are being continued by Dr. Lambe.

FROST INVESTIGATIONS
COLD ROOM STUDIES
THIRD INTERIM REPORT OF INVESTIGATION
APPENDIX C: MINERAL AND CHEMICAL STUDIES

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SYNOPSIS

This report describes research aimed at: (a) determining the effect of composition of soil fines on the frost susceptibility of the soil, and (b) finding admixtures which can in trace amounts reduce the frost susceptibility of soil. Freezing tests were run on a clean sand to which various monomineral fines had been added. The data, which in most cases are explained in terms of the mineral structure, show that the composition of soil fines has a tremendous influence on the frost behavior of the soil. The nature of the exchangeable ion has a pronounced effect on the frost-heave-producing ability of montmorillonoid fines.

A theoretical discussion shows how trace chemicals can reduce frost susceptibility of a soil by one or more of three mechanisms, namely: (a) alter soil structure, (b) waterproof, and (c) alter permeability. Limited tests show that dispersants, which alter soil structure, have considerable promise as frost modifiers. For example, a one percent treatment of sodium tetraphosphate reduced the rate of heave of a sandy clay from an average of 1.7 mm/day to 0.08 mm/day, a reduction of about 95 percent. Several waterprooferers also showed promise.

PART I - INTRODUCTION

1-01. Background and Purpose. Previous studies by the Arctic Construction and Frost Effects Laboratory and others have shown that the frost susceptibility of a soil depends not only on the amount of fines in the soil but also on the nature of these fines. In an attempt to correlate frost behavior and soil composition, the Arctic Construction and Frost Effects Laboratory¹ determined the mineral constituents of the fines for thirteen soils of known frost behavior. These soils, however, were too heterogeneous for any correlations to be drawn. It was decided that more progress on the effect of soil composition on frost susceptibility could be made by subjecting to freezing tests a non-heaving soil to which had been added various concentrations of different monomineral fines.

The search for an admixture which will minimize, or, better still, prevent frost heave in a soil is not new. While admixtures such as asphalt will successfully prevent frost heave, the level of treatment required is of the order of magnitude normally used in a pavement. Recent advances in the knowledge of the surface characteristics of soil colloids and the increasing availability of chemicals which can alter these surface characteristics offer hope that admixtures can significantly reduce frost heave in a soil by altering the surface characteristics of the soil at treatment levels of one percent or less of the soil dry weight. The second purpose of the work described in this report was, therefore, to search for admixtures which in trace quantities would reduce the frost susceptibility of soil.

1-02. Authorization. The work described in the report was done during the period between the spring of 1952 and 1 June 1953. It was authorized by Contract No. DA-19-016-Eng-1979, dated 29 April 1952, and Contract No. DA-19-016-Eng-2328, dated 27 June 1952.

1-03. Scope of Studies Presented in this Report. The scope of the work described in this report has been very extensive; many mineral fines and many admixtures have been tried. The results obtained present a good perspective on the two problems and suggest the most promising areas for future research. Many of the inconclusive trends observed in the studies will be investigated in future work so that most of them may be resolved.

¹Raised figures refer to bibliography at the end of this report.

1-04. Acknowledgments. The Contractor (and writer of this report), obtained, prepared and furnished to the Arctic Construction and Frost Effects Laboratory the fines, chemicals, and other admixtures for the freezing tests. The frost tests were run and the test data summarized at the Frost Laboratory by personnel of the Laboratory. The Contractor interpreted the data and recommended further tests. He also performed incidental chemical and mineralogical tests and furnished technical assistance to the Frost Laboratory during the test program.

The Contractor used the services of Professor Alan S. Michaels, an industrial chemist, Dr. George E. Murray, an organic chemist, and Dr. Robert T. Martin, a clay mineralogist, all on the staff of the Massachusetts Institute of Technology. The laboratory preparation of the various samples furnished the Frost Laboratory was done by Mr. James K. Mitchell and Mr. Clyde N. Baker of the M. I. T. Soil Stabilization Laboratory. The Contractor discussed possible chemical additives to reduce frost heave with various chemical company representatives; he obtained a number of experimental products from these companies.

PART II - EFFECT OF COMPOSITION OF SOIL FINES

2-01. Soil Composition. Soil components are either organic or inorganic. Knowledge of the nature of soil organic matter and its effect on soil properties is general and limited. The influence of natural organic matter on the frost behavior of soil was not studied in the research included in this report.

The components of inorganic soil materials can have either an orderly atomic arrangement, and thus be crystalline, or have a random atomic arrangement, and thus be amorphous. Until recently, it was thought that the finest particles in soil were amorphous; the inquiring eyes of the electron microscope and the x-ray have shown this thought to be incorrect. The amount of amorphous material in soils is very small⁶. Although freezing tests were not performed on soils with selected amorphous material in this study, the frost susceptibility of an amorphous silica, diatomaceous earth, was determined by the Frost Effects Laboratory during Fiscal Year 1951.

The crystalline, inorganic parts of soil are minerals. In this report, the minerals have been divided into two groups, non-clay minerals and clay minerals. Grim⁴ has defined clay as a natural material that has: (a) plasticity, (b) very small particles, and (c) hydrous aluminum silicates or occasionally hydrous magnesium silicates. Because of the exceptions to Grim's definition and because this definition is not universally accepted, there is considerable confusion as to the definition of a "clay mineral." All minerals which are not "clay minerals" are considered as "non-clay minerals".

The most abundant non-clay minerals in soils are the silicates, oxides, and carbonates. The typical and very common minerals of the abundant non-clay mineral group which were selected for frost tests are listed in Table C1. These minerals exist in particle sizes both larger and smaller than 0.02 mm. The clay minerals used as monomineral fines for frost tests, listed in Table C2, may be classified into four groups; the kaolins, montmorillonoids, illites and a miscellaneous group.*

*The structure of the clay minerals have been discussed in detail in Minerals of the Montmorillonite Group by C.S. Ross and S.B. Hendricks, Prof. Paper 205-B, pp. 23-77, U.S. Geological Survey, Dept. of the Interior, 1945; X-Ray Identification and Crystal Structure of Clay Minerals, edited by G.W. Brindley, the Mineralogical Society, London, 1951; and in Reference Clay Minerals, A.P.I. Research Project 49, American Petroleum Institute, Columbia University, New York, 1951.

The kaolins include minerals consisting of a gibbsite-silica sandwich and the structure is usually termed a 1:1 type structure. Of the three kaolins studied, their order of abundance as soil components increases in the order: dickite, halloysite and kaolinite. There is a little, if any, isomorphous substitution in the lattice of the kaolins, and the linkage of ultimate platelets in the kaolins is a very strong one. The lack of isomorphous substitution results in a very low ion exchange capacity and general low activity of the kaolins; the strong intersheet linkage prevents the kaolin minerals from swelling in the presence of water. In general, therefore, the kaolins can be considered as inactive clay minerals. An exception to this statement is the mineral halloysite, which has a structure similar to that of kaolinite but with considerably more bound water in it. Halloysite can be a very plastic material⁶ and experience has shown that this mineral can cause serious engineering problems.

The structure of the montmorillonoids consists of a gibbsite unit between two hydrated silica sheets. It is therefore, referred to as a 2:1 type structure. The minerals of the montmorillonoid group differ from pyrophyllite in the substitution of metallic ions for either aluminum in octahedral coordination and/or silicon in the tetrahedral coordination. For example, in montmorillonite, a magnesium ion is substituted for every sixth aluminum. This substitution of a plus 2 ion for a plus 3 ion gives a net negative charge of minus 1 for each magnesium. The net negative charge which the montmorillonoid sheets carry because of the isomorphous substitution is balanced by exchangeable cations between the sheets. These exchangeable cations serve to link the sheets together; this linkage is aided by secondary valence forces between the polar units. Since this total linkage is a relatively weak one, the montmorillonoid will swell in the presence of water and often disperse into ultimate sheets in dilute water suspensions.

The most common member of the montmorillonoid group is montmorillonite; there is evidence that nontronite may be almost as abundant as montmorillonite. There is a question as to whether beidellite is a mineral or a mixture of minerals, such as an interstratification of montmorillonite and kaolinite. Hectorite is not thought to be a very common montmorillonoid. Pyrophyllite is included in the montmorillonoid group because of the similar structure, it is not normally considered clay mineral.

Illite is a group name proposed by Grim for clay minerals related to mica but more hydrous and lower in alkali content. The members of the group and the variations are not well established, but it is known that the illites vary in properties over a considerable range. The illite structure is thought to be very similar to that of muscovite. In illite, there is replacement of about 15 percent of the silicon with aluminum, which causes the illite sheet to have a net negative charge. This charge is partially balanced by non-exchangeable potassium ions and partially by exchangeable cations. The sheets in an illite crystal are held together by the potassium ion plus secondary valence forces. This combination results in a strong intersheet linkage, with the result that illite is a non-swelling clay mineral.

There are many minerals which are sometimes included under this classification of clay minerals. The chlorites are hydrous silicates of aluminum with ferrous iron and magnesium in their structure. Recent studies suggest that chlorite may be a very common soil component⁷. Attapulgite, sometimes called a fibrous clay mineral, has an amphibole-type structure. Because of the unusual structure, it is able to draw water into itself just like a bundle of straws.

There is considerable evidence to show that soil colloids carry negative charges which are neutralized by exchangeable cations. The electrical charge which a soil colloid carries can come from one of several sources. The isomorphous substitution of an ion for a higher valent ion results in a charge deficiency; for example, Mg^{++} for Al^{+++} in montmorillonite, and Al^{+++} for Si^{++++} in illite. This type of substitution is, most likely, the major source of particle charge in the montmorillonoids and illites. Most of the soil-water systems are acidic in character. This low pH suggests the dissociation of hydrogen from the hydroxyl groups on the mineral surfaces or the removal of exchangeable hydrogen, thereby giving the mineral a negative charge. Since the surfaces, edges, and corners of soil colloids are locations of discontinuity, there are local residual charges there. The heteropolar bonds in the mineral crystal also result in the local regions of electrical charges. Ions can be strongly attracted to the mineral surfaces to satisfy the local charges, and, in effect, become part of the particles.

The electrical charge of the soil colloid is neutralized by counter-ions or exchangeable ions. They are usually termed exchangeable ions, since they

can be replaced by other ions in exchange reactions. Since the size, hydratability, and other properties of cations are markedly different, it is to be expected that the properties of soil colloids depend on the nature of the exchangeable ions that neutralize their charges. In Table C3 are listed some of the properties of four of the minerals used in the frost tests. The data in Table C3 show two significant things, first, the considerable differences in properties among the various minerals; second, that only in montmorillonite is the nature of the ion a critical consideration. Because of the minor effect of exchangeable ions on the kaolins and illites, only the montmorillonite fines were prepared and tested in various homoionic forms.

2-02. Sample Preparation. In nearly all cases, the non-clay mineral fines were prepared by grinding single, large crystals of the mineral involved; this procedure assured a high degree of purity. The various sized fractions of the non-clay minerals were obtained by successive sedimentation or centrifuging.

The clay minerals were, in nearly all cases, selected because of their high purity and the large amount of compositional and other data available on them. Except for the beidellite and illite, they are all of a very high purity. The degree of purity of these two minerals cannot be determined because of the lack of standards for comparison. They are felt to be fairly pure and representative of their group or family.

No selection of size fractions was made with the clay minerals for two reasons; first, all of the clay minerals except dickite are considerably finer than 0.02 mm (20 μ), and second, particle size may have little meaning with the clay minerals. Many of the clay minerals, for example, montmorillonite, and nontronite, can subdivide or disperse into ultimate platelets in the presence of water, the shape of nontronite and, probably, the shape of halloysite can change during the process of measuring their particle size.

The various ionic forms of montmorillonite were prepared by stirring sodium montmorillonite with a 1 N solution of a salt which had the cation desired for the ion exchange and then leaching with 95% ethyl alcohol the excess salt from the sample. In all cases, the acetate salt was used except with iron, where iron chloride was used. After this exchange had been effected, the sample was leached with an amount of water many times in excess of the sample volume. Based on Cornell work³, it is felt that this method of ion exchange

resulted in greater than 85 percent exchange; in other words, 85 percent of the available spots on the montmorillonite are filled with the ion desired.

The various monomineral fines were prepared in the M.I.T. Soil Stabilization Laboratory and were supplied to the Arctic Construction and Frost Effects Laboratory. At the Frost Effects Laboratory, these mineral fines were incorporated into McNamara sand from which all particles finer than .074 mm and greater than 2.0 mm had been removed. The blended soil samples were then compacted, saturated, and subjected to frost tests by the Frost Effects Laboratory, using a standard procedure.

2-03. Analysis of Test Results. Before an analysis of the data is made, it is pointed out again that only one soil, the minus 2.0 mm to plus 0.074 mm of McNamara sand, was mixed with the various monomineral fines and subjected to freezing tests. The number of tests is limited and, in several instances, the scatter is large. The trends observed must be considered tentative, therefore, until considerably more data have been obtained. The test results listed in Table C6, Appendix C, and Tables D1 and D2, Appendix D, have been plotted in Plates C2, C3, and C4. The heaves for the various mineral fines when present in 3 and 12 percent concentrations, shown in Table C4, were taken from Plates C2 - C4. There are a number of interesting and significant trends which are presented and discussed in the following paragraphs.

In general, the clay mineral fines are more frost producing than are the non-clay mineral fines in concentrations of 3 percent or less. There are several exceptions to this statement, which are discussed below. At a fine concentration of 12 percent, the rates of heave of the various non-clay mineral fines are of the same order of magnitude; on the other hand, the rates of heave for the clay mineral fines vary over a tremendous range.

As Plate C2 shows, for the three most common clay minerals at low fine concentration, the order of frost heaving ability is illite > kaolinite > montmorillonite; at higher concentrations, the order is kaolinite > illite > montmorillonite. An exception is the iron form of montmorillonite, which is more frost heave producing than kaolinite. Plate C2 also shows that an increase in fine concentration causes a reduction in frost heave for illite above a concentration of about 6 percent and sodium montmorillonite at a concentration above about 2.5 percent. No reduction in heave with increasing concentration was noticed with kaolinite up to 50%, the highest concentration tested.

The frost heave producing ability of the three kaolins tested is kaolinite > halloysite > dickite (see Plate C2). Since the liquid limit of halloysite is about twice that of kaolinite, it would be expected that halloysite would reduce the permeability of the sand more than would the kaolinite, and therefore would result in less heave at higher concentration. There are too few data available on dickite to warrant an explanation of its behavior.

The frost heave data on the montmorillonoid fines (Plate C2) show that the heave producing ability of the montmorillonoids varies over a very wide range.

The nature of the exchangeable ion on montmorillonite has a tremendous influence on the frost heave producing ability of the montmorillonite fines, as Plate C2 shows. In order of their frost heave producing ability, the ions are iron > magnesium = potassium = lead > calcium > sodium at a concentration of 3 percent fines. This order is approximately the one which would be expected in view of the water pickup and Atterberg limit data given in Table C3. Iron being a trivalent cation, tends to collapse the diffuse double layer, thereby reducing the adsorbed water, which in turn increases the permeability of iron montmorillonite. At the other extreme, sodium, a monovalent, highly hydratable cation causes the montmorillonite colloid to have a large diffuse double layer, large amount of adsorbed water, and therefore, low permeability. As far as frost heaving ability goes, iron is the worst exchangeable cation to have, and sodium is the best. One should, therefore, be suspicious of the frost susceptibility of soils high in iron. The use of an ion exchange reaction in which sodium replaced other ions might be considered for making a soil less frost-susceptible, were it not for the fact that the use of a dispersant as discussed in Part III of this report, accomplished the same result much more effectively.

The data do not substantiate the thought initially held that carbonates were high frost producing fines. Table C4, for example, shows that the frost heave producing abilities of calcite, magnesite and dolomite are less than that of muscovite, labradorite and quartz. Plate C3 shows that the frost heave producing ability of the three carbonates tested are of the same order of magnitude. It shows further that there is no significant difference between the frost heave producing abilities of < 0.1 mm > 20 μ and < 20 μ > 2 μ fractions of calcite.

Plate C4 and Table C4 show that attapulgite is a high frost heave producer. Since attapulgite, with its amphibole-type structure, has a particle which is a

group of hollow tubes, and can therefore serve as a channel through which water can be drawn, it is not surprising that it is a large frost heave producer. Since attapulgite is a non-swelling mineral, it probably is a large heave producer in even high concentration. The data also show that chlorite, like illite, is a relatively high frost heave producer.

The data suggest that the larger the impermeabilizing effect of the fines, the smaller the frost heave they produce. Since the liquid limit is a measure of the impermeabilizing effect under certain conditions, one might expect an inverse relation between liquid limit and ability to produce heave.

PART III - EFFECT OF ADMIXTURES

3-01. General. Studies have been made by the Corps of Engineers and others to determine the effectiveness of salt and bitumen in preventing ice segregation in soils. Salt reduces frostheave by lowering the freezing point of the pore water; since the salt pore water is usually replaced by salt-free ground water, the beneficial effects of salt as a frost inhibitor are temporary. It was found that ice segregation could be prevented by the addition of sufficient bitumen to make the soil impervious; however, the amount required to reduce segregation to a negligible value approached the bitumen content commonly employed for construction of bituminous pavements.

For an admixture to be an economical frost modifier, it must be either a very cheap material or function at a very low treatment level. Since it is difficult to imagine a soil additive which will be radically cheaper than bitumen, the search for low treatment frost modifiers was undertaken. The type of additive which appears to have most promise as a frost modifier when used in trace quantities is one which reacts with the soil; in other words, it considers the soil as a partner in a soil-chemical reaction, rather than as an inert filler.

Three mechanisms with which chemicals can minimize or prevent frost heave in soils when used in trace amounts are: alter soil structure, waterproof, or alter permeability. While there is an overlap among them, these are discussed below separately. A particular chemical might employ more than one of them.

The potentialities of trace chemical frost modifiers appear to be large. The chances for a successful one will improve as more data on soil chemical reactions, and more understanding of soil and the fundamentals of frost behavior become available.

3-02. Soil Structure. The structure of a soil is the manner in which the components are arranged. Structure, therefore, includes the order or orientation of the various units, the forces between the various units, and the forces between the soil particles and soil water. All of the properties of a soil - apparent particle size, plasticity, strength, permeability, compressibility, compaction characteristics, etc., - depend on its structure. Since the frost behavior of a soil depends on these same characteristics, it follows that this behavior depends on soil structure.

An inorganic soil⁵ consists of (a) the ultimate units of a mineral, (b) crystals made up of these basic or ultimate units, and (c) aggregates made up of crystals. The apparent or effective soil particle can be a basic unit, crystal, or aggregate. The forces holding together the units in a crystal and the forces holding together the atoms in a unit are too strong to be of concern to the engineer. An exception is the group of expanding lattice minerals which have weak linkages between the basic sheets, as was pointed out in Part II - Effect of Composition of Soil Fines. The intra-aggregate bonds, that is, the bonds holding the crystals together to form the aggregate, are relatively weak secondary valance bonds and are, therefore, of much concern to the engineer.

The size of the soil aggregate can be altered by either physical or chemical means. Mechanical work, or remolding, can break the linkages holding the crystals together in the soil aggregate, and thereby reduce the effective particle size of the soil as well as alter other characteristics. Chemicals which change the electrical character of the soil particle surfaces alter the intercrystalline forces and thereby can cause a breakdown or buildup of soil aggregates.

The intercrystal attractive force is one or more of the possible linkages and one or more of the possible repulsive forces. Water, with its dipolar structure, enters into several of these possible attractive forces. The dissipation of electrical potential of a soil-colloid with distance from the particle greatly depends on the pore fluid. Any treatise on soil structure must, therefore, include a consideration of soil moisture. In this report, soil moisture is considered to be one of two types: adsorbed water is that soil water which is under the influence of forces from the soil particle strong enough to influence the properties of the water; pore water is that soil water which is essentially free of soil attractive forces and, therefore, able to respond to normal hydrostatic forces.

One can think of the structure of a natural soil as varying between the limits of complete dispersion and complete aggregation. The position of any particular soil between these two limits depends upon its composition and geological history. For example, a marine clay that has been subjected to large consolidating loads (such as Boston blue clay) will be aggregated to a fairly high degree.

Soil structure can be altered by:

a. Remolding. It has been theorized⁵ that remolding pushes particles apart at points of contact, destroys the largest voids, results in an increase of adsorbed water at the expense of pore water, and permits a more orderly arrangement of particles. This action normally results in a loss of strength and permeability of an undisturbed clay upon remolding. For example, the unconfined compressive strength of remolded Boston blue clay is about 1/25 of the undisturbed, and the permeability of remolded about 1/200 of the undisturbed. Since the permeability of the undisturbed soil is greater than that of the remolded, one would expect more frost heave in undisturbed Boston blue clay, which has a supply of water available, because of the greater ease of securing water. This reasoning agrees with the experimental data.

b. Dispersion. Certain chemicals disperse⁸ a soil system, by increasing the interparticle repulsive forces or simply pushing the particles apart by increasing the thickness of the diffuse double layer and therefore the adsorbed water. One group of such dispersants is the sodium salts of certain polyanions, for example, sodium tetraphosphate. If sodium tetraphosphate is added to a wet soil, the polyvalent cations responsible for aggregating the soil can be replaced by sodium ions; the polyvalent cations are removed by a complexing reaction (sequestration) with the polyphosphates. The soil particles are then separated because of the highly hydrated sodium ions increasing the thickness of the diffuse double layer and therefore the thickness of adsorbed water. The phosphate polyanions also react with surface of the soil and the sodium ions attach themselves to the phosphate. Ultimately, each soil particle will be surrounded by a polyanionic layer with its accompanying atmosphere of hydrated sodium ions. This reaction results in a dispersed soil.

As with remolding an undisturbed clay, the dispersion of an aggregated clay permits the particles to arrange themselves in a more orderly fashion. A dispersed soil can, therefore, be compacted to a greater density with a given effort; it has a lower permeability because of more adsorbed water and better particle orientation; it will dry to a much higher density and strength, etc.

Several dispersants have been evaluated as frost modifiers, as the data which are presented in the following pages show. This very promising soil additive will be further evaluated in ensuing studies.

The degree of aggregation of a soil can be increased by the addition of a chemical which increases the interparticle linkages. One way, in effect, of increasing the linkages is by an ion exchange reaction which puts on a higher valent cation. The exchange of a soil cation for one of higher valence tends to collapse the diffuse double layer, and thereby effectively increase the interparticle linkages. A much more effective way of increasing interparticle linkages is by the use of one of the various new synthetic polyelectrolytes. For example, partially hydrolyzed polyacrylonitrile (sodium polyacrylate) has been found to be a very effective soil aggregator. The anionic ends of the long-chain molecules bond to the soil particles through the exchangeable cations and thereby link the particles.

Aggregation does the opposite of dispersion, namely, results in a soil of lower particle order, less adsorbed water, higher permeability, higher void ratio, etc. One would expect a coarse-grained soil with some fines to be made less frost-susceptible by aggregating the fine particles; that is, effectively removing the fine-grained particles. On the other hand, a very fat clay should be more frost-susceptible upon aggregation, since its permeability would be increased so that it could obtain the water it needed for heaving. The first expectation is borne out by the data which follow, and the second expectation is proved true by the data in Part II, which showed that iron montmorillonite is a more frost-producing fine than is sodium montmorillonite.

3-03. Waterproof. Certain chemicals can alter the adsorptive capacity of a soil for water by increasing the contact angle of water with the surface of the soil. Use can be made of this principle to make soils less sensitive to water by:

a. Treating the soil with a substance consisting of molecules one end of which is first preferentially adsorbed on the soil surface and then undergoes an irreversible reaction with the surface; the other end of the molecule is hydrophobic and thus makes the soil non-wettable with water.

b. Treating the soil with non-hydratable cations which are attracted to the negatively charged soil particles. This linkage is ionic in character and usually reversible.

Chemicals which react with soils by the first mechanism that have been tried are the water soluble silicones and the chlorosilanes; another, a water

dispersed polyamide resin, will be tried. Additives employing the second mechanism that have been tried are Volan, Quilon, Hyamines 1622 and 2389, triethylene tetramine, hexamethylene diamine, di-N-butylamine and monoethanol rosin amine. It is planned to study a number of other such waterproofers.

Other additives which employ the second mechanism are salts of lead and mercury. The lead and mercuric ions are highly polarizable and can, therefore, increase the contact angle between the soil and water. It is proposed that soils be treated with dilute aqueous solutions of lead acetate and mercuric chloride and then subjected to frost tests.

3-04. Alter Permeability. While the chemicals which alter soil structure and those which waterproof the soil also alter the soil permeability, there are materials which can alter the permeability of a soil without employing either of the other mechanisms. At first glance, materials which function by this third mechanism alone do not appear as promising as those which operate by the above two mechanisms. They do, however, appear worthy of consideration, particularly since it is not known just how little an alteration in permeability will be necessary.

It has been found² that a soil can be made completely impermeable by the injection of as little as 0.6 percent of the soil dry weight of a swelling polymer. A swelling polymer, such as a copolymer of calcium acrylate and N-methylolacrylamide, acrylamide and methylene-bis-acrylamide or N-methylolacrylamide and methylene-bis-acrylamide can imbibe a weight of water over sixteen times the weight of the polymer. It is planned to investigate the effectiveness of a monomer injection and the effectiveness of the addition of a powdered swelling polymer as frost-action modifiers.

In view of the very low frost susceptibility of a soil with even very small amounts of sodium montmorillonite (see Part II), tests are planned to evaluate the effectiveness of sodium montmorillonite as a frost modifier.

Materials which combine the last two mechanisms, that is, waterproof and alter permeability, appear to have promise and will be studied. The use of pre-treatments or special additives to a bitumen treatment in order that the affinity of the soil for the bitumen will be increased is one example. There are by-products of certain chemical industries which have already incorporated in them materials which increase the affinity of the material for the soil particle. These by-products will be tested during the coming year.

3-05. Laboratory Tests The Contractor incorporated the various admixtures with each of three soils - a sandy clay from Fort Belvoir, Virginia, a silt from Manchester, New Hampshire, and a blue clay from Cambridge, Massachusetts, - shown on Plate C1*. The treated soils were then subjected to frost tests by the Arctic Construction and Frost Effects Laboratory, employing the miniature compaction size sample.

The effects of an aggregant and a dispersant (see Table C5 for the chemical names of the admixtures studied) on the compaction characteristics of the silt and sandy clay were determined; the frost specimens of these treated soils were the large standard ones (6-inch diameter, 6 inches high). While it is realized that moisture-density tests on the soils treated with the other admixtures should have been made in order to determine the optimum molding water content for preparing the frost samples, it is felt that any really promising additive could be detected by the easier procedure used.

3-06. Analysis of Test Results. The laboratory program on chemically treated soils is in too early a stage to per it more than general trends to be noted. As yet little consideration has been given to chemical cost or incorporation with soil. Based on the mechanism of aggregation and dispersion, a dispersant should raise the maximum dry density and lower the optimum water content of a compacted specimen, while an aggregant should do the opposite, namely, decrease the dry density and increase the optimum water content. Numerous tests run in the M.I.T. Soil Stabilization Laboratory have borne out the theorized trend. The moisture-density curves (Plate C5) for the Fort Belvoir sandy clay show that the effects of the aggregant and the dispersant on the compaction characteristics of the clay were as expected. The results of the compaction tests on the treated silt were not, however, expected. It is hoped that the compaction tests on the silt can be checked in order that the unusual results can be explained.

The data in Table D3, Appendix D, show that both the aggregant, sodium polyacrylate, and the dispersant, sodium tetrapiosphate, had a beneficial effect on the frost susceptibility of both the silt and the clay. The aggregant was not as effective in reducing the frost heave of the silt as would

*The latter two soils are described in detail in Reference No. 1 of bibliography. The sandy clay is composed of 25% kaolinite, 40% quartz, and hydrous oxides of iron and aluminum; the limits and other characteristics are shown on Plates C1 and C5.

have been expected. The sodium polyacrylate reduced the rate of heave from 7.9 mm/day to about 1.4 mm/day, or to about 1/6 of its value when untreated. It was thought that the aggregant, by effectively removing the fines of the silt through aggregation, would be a much more efficient frost heave reducer. On the other hand, the dispersant was more beneficial on the silt than was theorized prior to testing.

As had been theorized, the aggregant was not very effective on the sandy clay, while the dispersant was extremely effective. The sodium polyacrylate reduced the rate of frost heave from an average of 1.7 mm/day to approximately 1.0 mm/day, an insignificant reduction. On the other hand, the dispersant reduced the rate of frost heave of the clay from about 1.7 to 0.1 mm/day, or 1/17 of its original value. According to the Corps of Engineers frost susceptibility classification, the dispersant reduced the Fort Belvoir sandy clay from one of low to negligible frost susceptibility.

The effectiveness of the soil aggregant as a frost modifier as evidenced by the tests to date is disappointing. It is planned during the coming fiscal year to try other soil aggregants, since it is still felt that soil aggregation should be an effective means of reducing the frost susceptibility of a silty soil.

The results on the dispersant as a frost modifier are most encouraging. In view of the relatively low cost of the dispersants (six to ten cents a pound) and the relative ease of incorporating dispersants with soils, dispersants appear to have considerable promise for reducing the frost susceptibility of fine-grained soils.

The average rate of heave exhibited by the miniature size samples are summarized in Table C6 of this appendix. Complete test data on all specimens are presented in Table D4 of Appendix D. As an approximate means of evaluation, a rate of heave equal to 1/4 of that of the untreated soil (the maximum blank rate of heave used) has been designated "promising" and starred. Based on this criterium, there are eight promising additives for the New Hampshire silt, eight for Fort Belvoir sandy clay, and two for Boston blue clay. It is felt that the data are too incomplete to attempt to draw any more definite trends at this time.

PART IV - CONCLUSIONS

4-01. Effect of Composition of Soil Fines.

a. The rate of frost heave of the McNamara sand varies over a wide range, depending on the nature of the monomineral fine added.

b. At low concentrations of fines, the clay minerals are higher frost-heave-producers than the non-clay minerals; at higher concentrations, the heave producing effects of the clay minerals vary over a very wide range, bracketing the results produced by the non-clay minerals. There are exceptions to this general statement.

c. If montmorillonite is the soil fine, the rate of heave can range considerably over a hundred-fold depending on the nature of the exchangeable ion.

d. Sodium as an exchangeable ion gives the lowest heave, while ferric iron gives the highest heave.

e. Iron montmorillonite, nontronite, attapulgite and possibly kaolinite are minerals of high frost heave producing ability.

f. The increase of fine concentration above a certain minimum can result in a decrease of frost heave rate for the more plastic clays such as montmorillonite (exceptions are iron and lead montmorillonite), illite and hectorite.

4-02. Effect of Admixtures.

a. Dispersants show considerable promise as additives to reduce the frost susceptibility of soils.

b. Other types of chemicals, especially certain of the water-proofers, show enough promise to warrant further evaluation.

c. The results to date are encouraging enough to warrant continuation of the extensive search for chemicals to reduce the frost susceptibility of soils.

PART V - RECOMMENDATIONS

5-01. Effect of Composition of Soil Fines. The most important trends observed from tests on the McNamara sand should be checked by adding mono-mineral fines to several other soils. This should be done particularly for those minerals which are high frost producers. Natural soils which contain these high frost producing minerals should be subjected to freezing tests to determine if they follow the pattern which would be predicted from the tests on the McNamara sand. Natural soils which are found to be highly frost-susceptible should be analyzed to determine their mineral composition to see if their unusual frost behavior can be explained by the data obtained during this test program.

5-02. Effect of Admixtures. The extensive search should be continued so that all types of materials which are thought to be potential frost modifiers will be evaluated by laboratory tests. Those admixtures which have shown or do show promise should be studied in more detail to determine their optimum concentration and any relation between effectiveness and soil type.

Study should be given to techniques of incorporating dispersants, and any other additive which shows promise, into base and subgrade soils.

It is recommended that a small scale field test of a dispersant and possible of other admixtures be made. Measurements of heave and strength after heaving on treated and untreated sections should be taken.

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TABLE C1
NON-CLAY MINERALS

<u>Mineral</u>	<u>Specific Gravity *</u>
Quartz (a silicate)	2.65
Labradorite (a feldspar)	2.71
Muscovite (a mica)	2.76 - 3.10
Calcite (a carbonate)	2.72
Magnesite (a carbonate)	3.0 - 3.2
Dolomite (a carbonate)	2.85
Limonite (an oxide)	3.6 - 4.0

* Hurlbut, C.S., Dana's Manual of Mineralogy, John Wiley and Sons, New York, 1949.

TABLE C2
CLAY MINERALS

Mineral	Locality	Specific Gravity		Source
		Theoretical ¹	Measured	
<u>Kaolins</u>				
Kaolinite	Murfreesboro, Arkansas	2.609	2.60-2.65	Dana ⁴
Dickite H-16	St. George, Utah	2.589		
Halloysite H-12	Bedford, Indiana		2.95	
<u>Montmorillonoids</u>				
Montmorillonite H-25 ²	Upton, Wyoming			
<u>Beidellite</u>				
Nontronite H-33a	Garfield, Washington	2.2 ⁵		
Hectorite H-34	Hector, California		1.70	M. I. T.
Pyrophyllite H-49	Robbins, No. Carolina	2.844		
<u>Illite H-36</u>	Morris, Illinois		2.77	
<u>Miscellaneous</u>				
Chlorite				
Attapulgite	Attapulgus, Georgia		2.29-2.36	Brindley ³

General Note: The minerals with the H-series numbers are used by the American Petroleum Institute in their Research Project 49, Reference Clay Minerals, New York 1951. The numbers are those given by the A. P. I.

1. From Preliminary Report No. 7, Analytical Data of Reference Clay Minerals, American Petroleum Institute Research Project 49.
2. Samples prepared with the following exchangeable cations: Ca⁺⁺, Mg⁺⁺, Pb⁺⁺, Fe⁺⁺⁺, Na⁺, K⁺.
3. X-ray Identification and Crystal Structure of Clay Minerals, ed. G. W. Brindley, the Mineralogical Society, London, 1951.
4. Hurlbut, C. S., Dana's Manual of Mineralogy, John Wiley and Sons, New York 1949.
5. Not reliable because of fluctuations in the distances between layers, but probably should not be greater than 2.2 for laboratory dry material. (page 21, API Analytical Data on Reference Clay Minerals, Preliminary Report No. 7.)

TABLE C3 •
PROPERTIES OF CLAY MINERALS

<u>Mineral</u>	<u>Ion Exchange Capacity in ME/100</u>	<u>Water Content at 50% Relative Humidity, %</u>	<u>Liquid Limit %</u>	<u>Plastic Limit %</u>	<u>Plasticity Index %</u>	<u>Shrinkage Limit %</u>
Montmorillonite	127					
Na ⁺		11.4	706	54	652	10
K ⁺		8.5	660	98	562	9
Ca ⁺⁺		18.5	508	81	427	11
Mg ⁺⁺		17.7	408	60	348	15
Fe ⁺⁺⁺		-	213	63	150	13
Illite	29					
Na ⁺		4.5	116	53	63	15
K ⁺		4.0	122	60	62	17
Ca ⁺⁺		5.9	105	45	65	17
Mg ⁺⁺		5.9	95	46	49	15
Fe ⁺⁺⁺		-	104	46	58	17
Kaolinite	3					
Na ⁺		-	53	32	21	27
K ⁺		0.6	49	29	20	-
Ca ⁺⁺		1.0	38	27	11	25
Mg ⁺⁺		1.0	54	31	23	29
Fe ⁺⁺⁺		-	52	35	17	29
Attapulgite **	9 †	-	274	148	126	8

• Data from Final Report, Soil Solidification Research, Vol. II, Cornell University, 1951.

** Limits for H⁺ while natural attapulgite is essentially Mg⁺⁺ attapulgite.

TABLE C4
AVERAGE RATES OF HEAVE FOR
CLAY MINERALS WITH MCNAMARA SAND

Mineral	Rate of Heave in mm/day	
	3% Fines	12% Fines
Quartz <20 μ >2 μ	0.33*	-
Labradorite <20 μ >2 μ	0.24	-
Muscovite <20 μ >2 μ	0.40	-
<2 μ	0.44	-
Calcite	0.30	0.35
<0.1 mm>20 μ	0.14	-
<20 μ >2 μ	0.27	-
Magnesite	0.30	0.72
Dolomite	0.31	0.66
Limonite	0.12	0.54
Kaolinite	0.43	0.95
Dickite	0.35	-
Halloysite	0.47	0.59
Montmorillonite		
Na ⁺	0.06	0.14
K ⁺	0.28	0.07
Ca ⁺⁺	0.07	-
Mg ⁺⁺	0.18	0.13
Fe ⁺⁺⁺	0.45	1.42
Pb ⁺⁺	0.18	-
Beidellite	0.14	-
Nontronite	0.83	-
Hectorite	0.27	-
Pyrophyllite	0.64	-
Illite	0.66	0.70
Chlorite <20 μ dispersed with Quadrafos	0.63	-
Attapulgite	0.91	-

* Interpolated

TABLE C5
CHEMICALS TRIED AS FROST MODIFIERS

	<u>Trade Name</u>	<u>Class of Chemical</u>	<u>Chemical Name</u>
I Modifiers of Soil Structure			
A. Dispersants	Quadrafos	Polyphosphrte	Sodium Tetrphosphate
B. Aggregants	Agriilon	Polyacrylate	Sodium Polyacrylate
	Carbowax 200	-	Polyethylene Glycol 200
	Carbowax 6000	-	Polyethylene Glycol 6000
	-	Pyridine	Styrene-N-Methyl-2-Vinylpyridine
	CRD-197	Sodium Salt of a Polymer	-
II Waterproofers	SC-50	Silicone	Sodium Methyl Siliconate
	Hyamine 1622	Quaternary Ammonium salt	Di-isobutyl phenoxy ethoxy dimethyl benzyl ammonium chloride, monohydrate
	Hyamine 2389	Quaternary Ammonium salt	Alkyl tolyl methyl tri-methyl ammonium chloride (alkyl ranges from C ₉ H ₁₉ to C ₁₅ H ₃₁) (50% in H ₂ O)
	Triton K-60	Quaternary Ammonium salt	Stearyl Dimethyl Benzyl Ammonium Chloride
	Primene 81-R	Amine	Tertiary alkyl amine
	Volon	Chrome complex	Methacrylate chromic chloride
	Quilon	Chrome complex Diethanol resin Monoethanol resin Triethylene Tetra- mine Hexamethylene diamine Di-n-butylamine	Stearate chromic chloride

TABLE C6

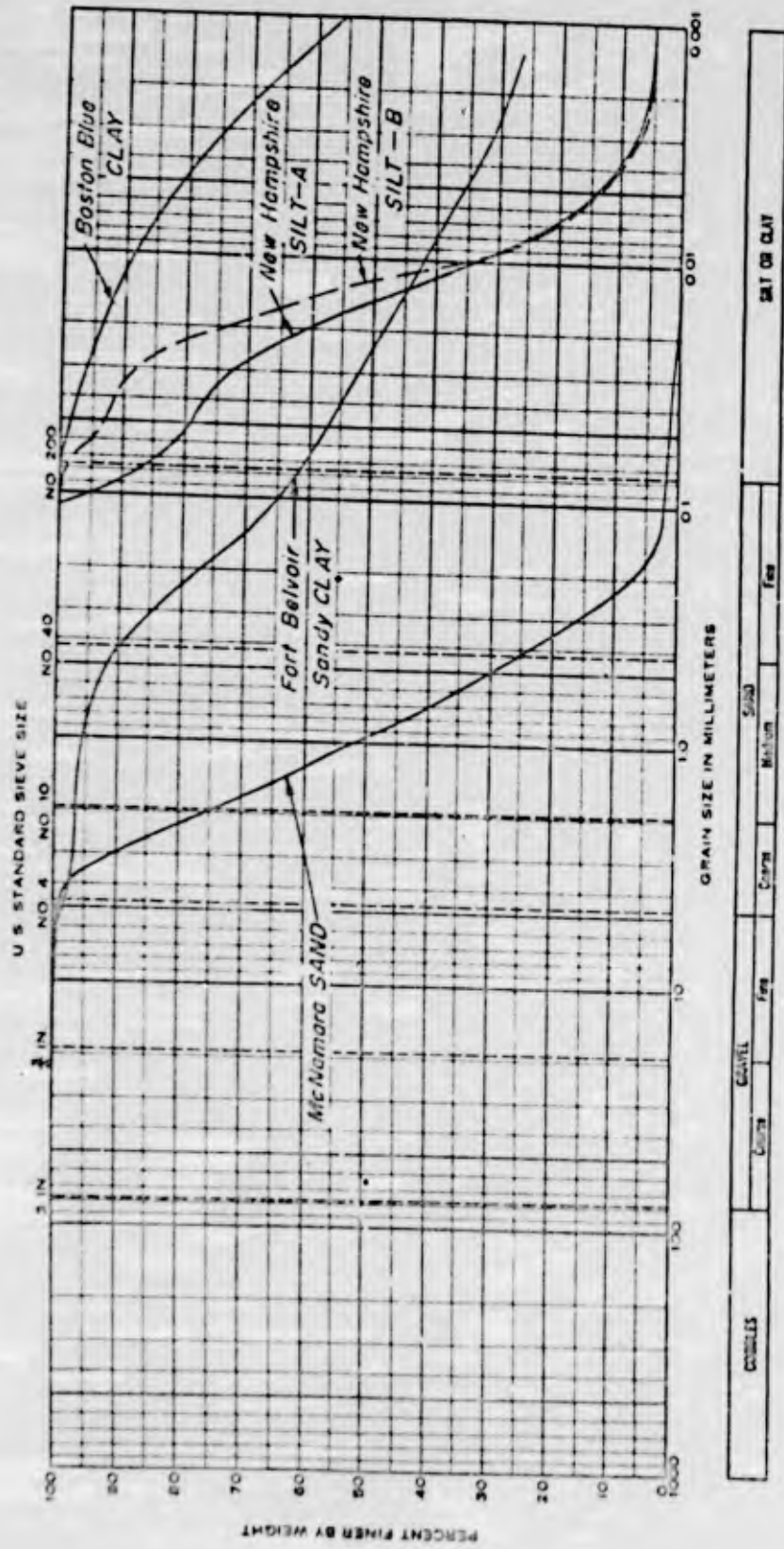
AVERAGE RATE OF HEAVE IN mm/DAY FOR CONCENTRATIONS IN PERCENT

Additive	New Hampshire Silt			Port Belvoir Clay			Boston Blue Clay		
	0.1	0.5	1.0	0.1	0.5	1.0	0.1	0.5	1.0
None	4.50	5.17	0.89	2.29	1.57	1.99	1.47	0.93	1.99
Carbowax 200	2.84	1.67	1.93	1.40	0.32*	0.56*	2.90	1.27	1.12
Carbowax 6000	2.54	2.74	1.08*	1.58	0.51*	0.71	2.44	2.24	0.56
Pyridine	0.15*	0.72*	1.56	1.75	3.25	2.00	1.05	2.11	2.63
CRD-197	0.89*	1.48	1.86	1.11	0.89	0.13*	2.39	4.12	3.40
SC-50	2.10	2.21	1.40	1.08	0.60	0.02*	0.50*	0.11*	0.08*
Hyamine 1662	3.56	2.14	1.88	2.10	0.97	1.38	1.75	2.25	2.17
Hyamine 2389	4.74	2.03	1.44	1.36	0.93	0.97	1.83	2.07	2.13
Triton K-60	2.20	2.84	1.48	1.69	1.21	1.63	1.50	2.00	1.75
Primene 81-R	0.23*	0.10*	0.13*	2.76	2.07	2.38	4.57	6.45	7.11
		0.97*	0.76*						
Volan	1.61	1.09*		0.62	0.54*	0.25*	1.00	0.00*	0.29*
Quilon	1.69	2.50	0.11*	0.91	0.87	0.42*	1.43	0.83	0.95
Diethanol Resin							1.50	1.92	2.18
Monoethanol Resin							1.11	2.12	2.00
Triethylene Tetramine	3.30	1.46	1.04*	0.95	0.97	1.16	1.62	2.00	1.51
Hexamethylene Diamine	0.11*	1.88	1.69	1.13	0.86	0.36*	1.73	3.50	3.43
Di-n-Butylamine	3.50	2.00	2.03	1.00	0.71	0.28*	3.14	1.05	1.18

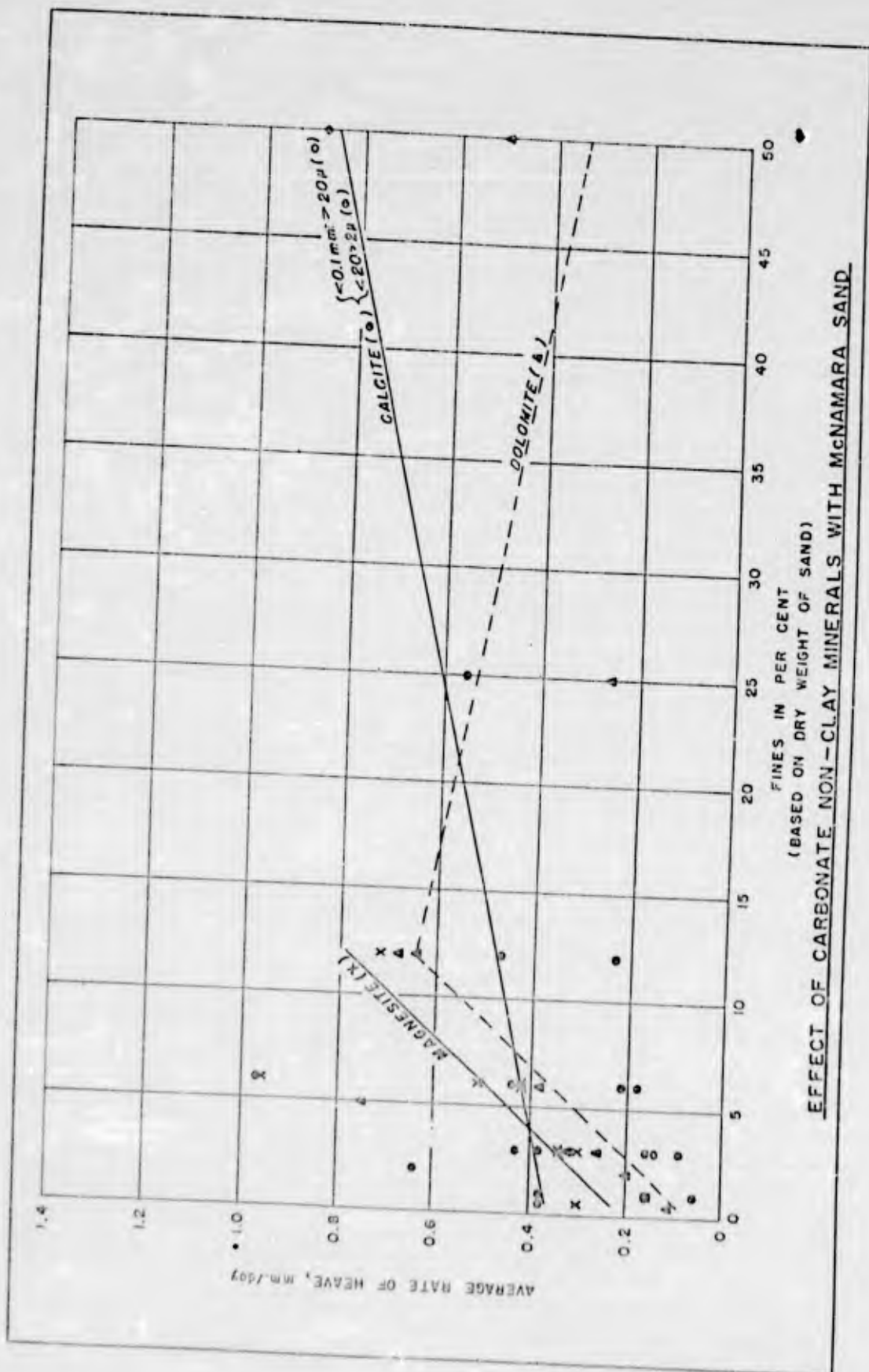
*Promising, < 1.29

*Promising, < 0.57

*Promising, < 0.50



GRADATION CURVES OF SOILS SELECTED FOR TESTS



EFFECT OF CARBONATE NON-CLAY MINERALS WITH McNAMARA SAND

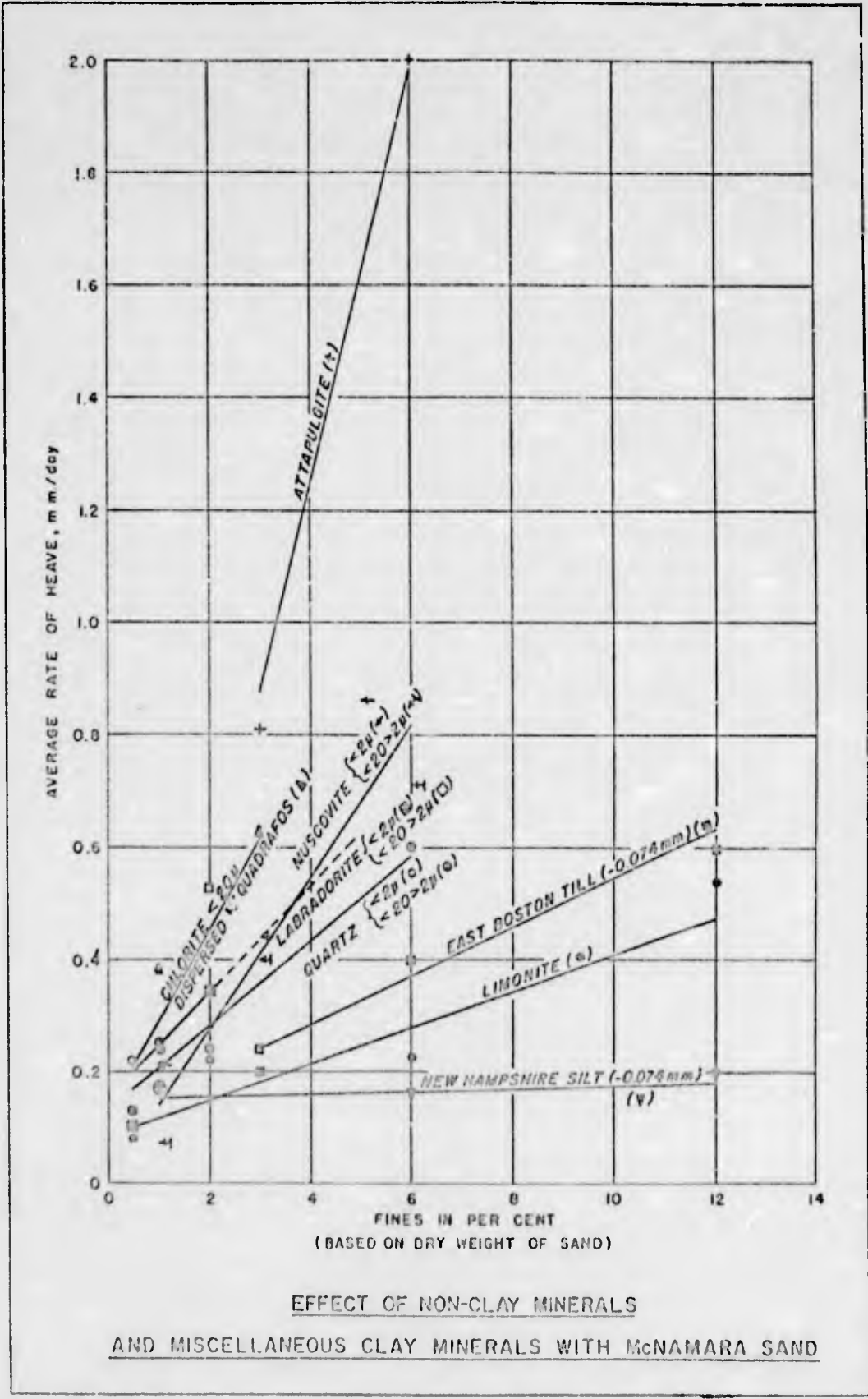
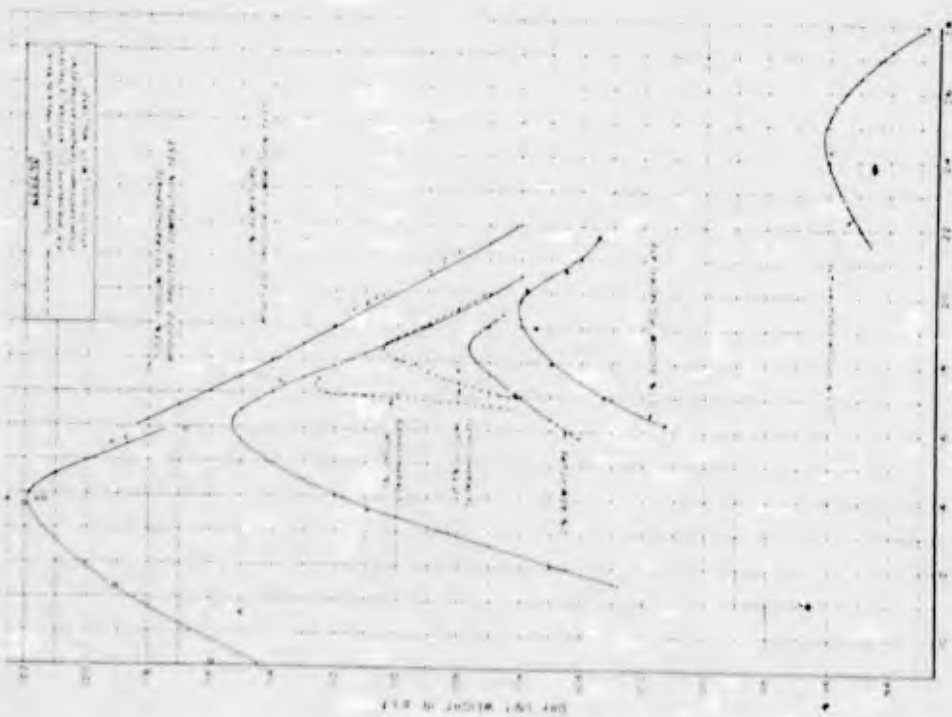
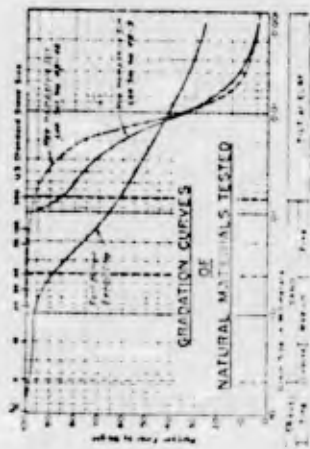


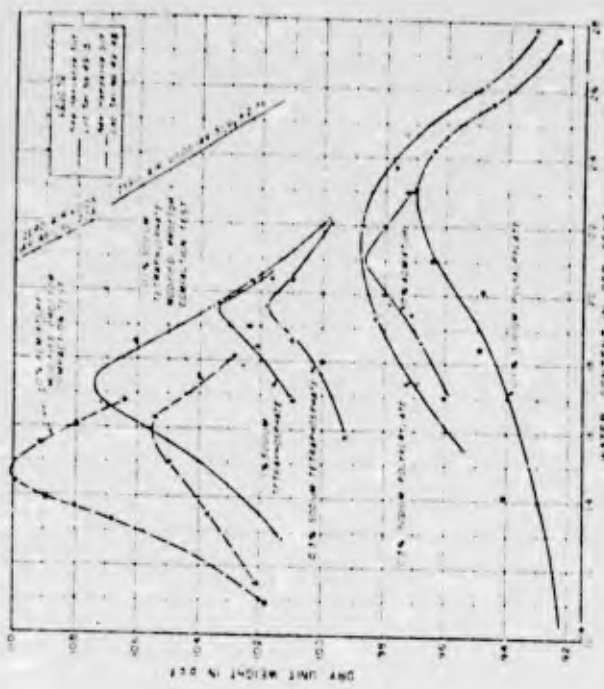
PLATE C4



EFFECT OF VARIOUS ADMIXTURE PERCENTAGES ON THE COMPACTION CHARACTERISTICS OF FORT BELVOIR SANDY CLAY AND NEW HAMPSHIRE SILT



- NOTES
- (1) All tests performed with Harvard Miniature Compaction Apparatus unless otherwise indicated
 - (2) Modified Proctor Compaction Test
 - (a) Volume of mold - 95 cc
 - (b) No. of layers - 5
 - (c) No. of blows per layer - 25
 - (d) 10 pound hammer, 18 inch drop
 - (3) Harvard Miniature Compaction Test
 - (a) Volume of mold - 452 cc
 - (b) No. of layers - 3
 - (c) No. of blows per layer - 25
 - (d) 40 pound prestressed spring hammer



EFFECT OF VARIOUS ADMIXTURE PERCENTAGES ON THE COMPACTION CHARACTERISTICS OF FORT BELVOIR SANDY CLAY AND NEW HAMPSHIRE SILT

CORPS OF ENGINEERS, U. S. ARMY

FROST INVESTIGATIONS

COLD ROOM STUDIES
THIRD INTERIM REPORT OF INVESTIGATIONS

APPENDIX D: ACEL TEST PROCEDURES AND INVESTIGATIONAL
DATA FOR MINERAL AND CHEMICAL STUDIES

ARCTIC CONSTRUCTION

AND

FROST EFFECTS LABORATORY

PREFACE TO APPENDIX D

The following appendix presents the special test procedures employed by the Arctic Construction and Frost Effects Laboratory in the mineral and chemical studies described by Dr. T. William Lambe of Massachusetts Institute of Technology, in Appendix C, together with the detailed test data.

FROST INVESTIGATIONS
COLD ROOM STUDIES
THIRD INTERIM REPORT OF INVESTIGATIONS

APPENDIX D: ACEFEL TEST PROCEDURES AND
INVESTIGATIONAL DATA FOR MINERAL AND CHEMICAL STUDIES

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1-02	Preparation of Mineralogical Specimens	D1
1-03	Preparation of Chemically-treated Specimens	D1
1-04	Molding of Specimens	D2
1-05	Thermocouples in Specimens	D3
1-06	Saturation of Specimens	D3
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APPENDIX D: TABLE OF CONTENTS (CONT'D.)

LIST OF TABLES

<u>TABLE NO.</u>	<u>DESCRIPTION</u>
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D2	Tests for Effect of Clay Minerals with McNamara Sand
D3	Tests for Effect of Additives, Standard Size Specimens
D4	Tests for Effect of Additives, Miniature Size Specimens
D5 thru D23	Water Content Distribution after Freezing

LIST OF PLATES

<u>PLATE NO.</u>	<u>DESCRIPTION</u>
D1	Miniature Sample Freezing Tray
D2	Components of Harvard Miniature Compaction Apparatus
D3 thru D15	Temperature and Heave Data

APPENDIX D: ACFEL TEST PROCEDURES AND INVESTIGATIONAL
DATA FOR MINERAL AND CHEMICAL STUDIES

1-01. Freezing Trays. Two 36-sample freezing trays were constructed especially for this test program to facilitate the freezing of the large number of test specimens. The tray, illustrated on Plate D1, consists of a 15-gauge galvanized metal pan, 17 in. square and 3/4 in. deep (inside dimensions); a 3/8 in. thick lucite base plate 17 in. square with 36 equidistantly spaced holes, 1-3/4 in. in diameter, drilled and tapped to receive the molds; 36 cylindrical lucite sample molds with an inside diameter of 1-1/4 in. and 3.358 in. long, threaded at each end for a distance of 7/16 in. and two filter mats. Along the inside perimeter and the centerline of the pan there is a 1/4 in. by 1/2 in. continuous rubber gasket and a series of machine bolts for attaching the base plate to the pan. Two 1/4 in. brass nipples, 3 in. long, are soldered to the bottom of the pan at the centers of the two sections formed by the centerline gasket.

When the trays are assembled, the filter mats are placed on the bottom of the pan. These mats are built up from 64 by 64 weave muslin (against lucite base plate), 18 by 14 in. bronze screen cloth and 1/2 in. 18-gauge galvanized expanded metal.

1-02. Preparation of Mineralogical Specimens. The mineral fines were initially prepared for blending with the McNamara Sand (between the grain sizes of 2.0 mm and 0.074 mm) by oven drying at 105°C., and then thoroughly pulverizing the fines in a porcelain mortar with a porcelain pestle. Porcelain laboratory equipment was used to prevent ion exchange in the fines. The halloysite fines were oven dried at 32°C. to avert property changes which occur at higher temperatures. The desired percentage of fines, based on the dry weight of the sand phase, was then dispersed in freshly boiled (but cooled) distilled water with a pH of 7.0 and the solution thoroughly blended into the McNamara Sand to give a test sample with a combined dry weight (combined fines and sand) of 116 grams and a degree of saturation of 95%. After molding (Par. 1-04), the blended sample was stabilized in airtight glass containers for a minimum period of 24 hours preparatory to molding.

1-03. Preparation of Chemically-Treated Specimens. The chemically treated New Hampshire silt, Fort Belvoir sandy clay, and Boston blue clay materials were

prepared for freezing tests by oven drying at 105°C., and then pulverizing the soils with a rubber-tipped pestle. Each chemically-treated material was then stabilized at a water content equivalent to the optimum moisture content determined for the untreated soils by the modified AASHTO test procedure for at least 24 hours.

1-04. Molding of Specimens. In placing the soils in the freezing trays, the inside walls of the lucite molds were lubricated with a thin coating of silicone, and a 1/4 in. thick, grade 49, carbon disc and filter paper were inserted at the base of each mold. An extension collar was then screwed to the top of the mold.

The samples were molded by placing several spoonfuls (plastic spoon) of the prepared materials into the mold and then leveled with a wooden plunger. Next, 60 tamps were applied to the material with the 40-lb. prestressed spring tamper of the Harvard Miniature Compaction Apparatus* shown on Plate D2. The tip of the tamper was coated with glyptol to prevent ion exchange in the fines. Each of the first four tamps was applied in separate quadrants and adjacent to the mold edge; the fifth tamp was made in the center of the mold, thereby making a complete coverage. The tamps were applied at a rate of ten tamps per 15 seconds, and each cycle was repeated to attain 60 tamps per layer.

The mineralogical samples were compacted in six layers, whereas the chemically-treated samples were compacted in three layers. The extension collar was then removed and the excess material carefully trimmed from the top of the mold. Since the volume of the mold is 1/454th of a cubic foot, the net weight of the compacted sample in grams is equal to the unit weight in pounds per cubic foot.

The mold was then screwed into the lucite base plate of the freezing tray in the test cabinet, where a constant supply of distilled water was maintained 1/8 in. above the carbon discs at the base of the molds by means of a water connection to the brass nipples. Care was exercised to prevent entrapping air in this process, and the specimens were capped to prevent loss of moisture by evaporation.

*Wilson, S.D., Small Soil Compaction Apparatus Duplicates Field Results Closely. Engineering News Record, Nov. 1950.

1-05. Thermocouples in Specimens. Thermocouples were placed during molding at 1-in. intervals along the central longitudinal axis (including top and bottom faces) of two samples per tray. Thermocouples were also placed at the bottom of four samples and at the top of six additional samples. This provided a means of checking the temperatures within the specimens and observing the initiation and completion of the freezing period.

1-06. Saturation of Specimens. After all specimens were molded and placed in the tray, the constant water level supply was adjusted to the tops of the specimens and the caps were removed. The samples were allowed to absorb water for a minimum period of 48 hours, or until such time that additional water was not taken on by samples. Each sample was then weighed and measured to obtain dry unit weights and degrees of saturation before freezing. Prior to reinserting the molds into the lucite base plate, the threads of each cylinder and base plate were coated with silicone to prevent freezing together of these units. The water level supply was adjusted 1/2 in. above the carbon discs and granulated cork was placed around each sample for the full sample height.

1-07. Freezing of Specimens. Freezing tests were initiated after a 24-hour tempering period at 35°F., by first bringing the tops of the samples to a temperature of 28°F. The tops of the samples were then seeded with ice crystals at a temperature of 28°F., and thin metal plates painted with glyptol were placed on top of each sample. Thereafter, a 1/4 in. per day rate of freezing was maintained until the bottom thermocouples registered 32°F. The cabinet temperature was then lowered until all the bottom thermocouples indicated a temperature of 28°F. The latter temperature change made positive the complete freezing of the samples to facilitate ejection of the samples from the molds.

Heave measurements were made daily for each specimen and were read to the nearest hundredth of an inch. Measurements were obtained with a depth gauge from an extension collar that fitted on top of the specimen molds.

Plots showing the heave, degree-hours, and the penetration of the 32°F. temperature vs time for all samples are shown on Plates D3 through D15. The rate of heaving, in millimeters per day, was determined from these plots (see definition of Rate of Heave on page 4 Volume 1).

1-08. Examination of Specimens. At the completion of freezing, the samples were removed from their molds, weighed to determine the change in water content and then split longitudinally in two sections. Measurements for amount of heave, and observations for the location, distribution, and magnitude of ice lens formation, and water content were made on one-half of each sample. The remaining half of the sample was photographed and water contents were obtained for each quarter of sample. Water content determinations for each sample are tabulated on Tables D5 through D23.

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 AND 1953

TABLE D1
TESTS FOR EFFECT OF NON CLAY MINERALS
WITH
MORANARA SAND
(OPEN SYSTEM)

SAMPLE NUMBER	NON CLAY MINERAL	PER CENT MINERAL	DRY UNIT WEIGHT pcf.	VOID RATIO	DAY START OF TEST (1)	WATER CONTENT		PER CENT HEAVE (2)	AFD. RATE OF HEAVE mm/day	WATER CONTENT DATA TABLE D2	THAW AND FROST DATA TABLE D3
						BEFORE TEST	AFTER TEST				
273	Quartz <20μ>20μ	0.5	111.2	0.537	85.1	16.3	16.3	3.5	0.13	05	
275		1.0	109.4	0.552	81.2	16.6	16.6	4.8	0.25	05	09
276	<20μ	2.0	110.0	0.550	82.6	16.7	16.9	4.8	0.24	05	09
266		6.0	114.9	0.608	96.1	17.1	15.1	9.0	0.60	05	09
267	Labradorite <20μ>20μ	0.5	110.3	0.550	80.0	16.8	16.9	4.8	0.22	05	09
277		1.0	106.2	0.640	73.6	18.3	19.6	3.4	0.17	05	09
278	<20μ	0.5	109.9	0.555	82.9	16.8	16.0	4.5	0.10	06	09
279		2.0	106.2	0.609	79.4	16.9	16.8	4.1	0.53	06	09
280	Muscovite <20μ>20μ	3.0	116.7	0.656	95.1	16.1	13.7	3.2	0.26	06	09
271		1.0	110.5	0.568	76.8	15.3	15.4	5.5	0.36	05	09
272	<20μ	1.0	105.7	0.617	100.0	22.5	17.1	4.4	0.07	05	09
273		3.0	114.1	0.478	86.2	16.1	16.1	6.8	0.40	05	09
274	Calcite	6.0	113.1	0.512	72.2	13.5	16.0	8.9	0.71	07	09
275		1.0	111.1	0.538	82.0	16.1	17.5	6.4	0.21	05	09
276	<0.1mm>20μ	3.0	112.9	0.514	80.6	15.1	15.5	7.4	0.14	05	09
277		5.0	116.8	0.454	83.0	16.1	16.4	14.8	0.66	07	09
278	<20μ>20μ	0.5	113.1	0.511	77.2	14.4	16.0	5.5	0.38	08	09
279		1.0	113.8	0.503	76.4	14.0	16.5	4.8	0.38	08	09
280	<0.1mm>20μ	2.0	115.8	0.477	81.2	14.1	15.2	7.2	0.66	08	09
281		3.0	117.5	0.455	86.8	14.9	17.7	9.7	0.38	09	09
282	Dolomite	3.6	113.1	0.511	86.8	16.2	15.4	4.2	0.09	09	09
283		3.0	115.6	0.479	80.2	14.9	15.0	6.5	0.43	08	09
284	<20μ>20μ	6.0	120.7	0.416	97.3	14.8	16.1	9.9	0.44	09	09
285		6.0	113.9	0.501	81.3	15.0	15.4	4.2	0.21	09	09
286	Muscovite	6.0	117.8	0.451	77.9	17.8	17.1	12.0	0.97	10	09
287		12.0	119.2	0.434	86.9	13.8	14.2	7.3	0.47	09	09
288	<0.1mm>20μ	12.0	115.1	0.486	75.4	13.4	14.6	3.2	0.23	08	09
289		25.0	119.1	0.430	85.5	13.5	14.0	7.3	0.56	08	09
290	<20μ>20μ	50.0	122.6	0.390	85.8	12.3	14.5	9.4	0.88	08	09
291		1.0	106.4	0.605	73.3	16.2	16.6	1.6	0.16	06	09
292	Dolomite	3.0	109.3	0.563	79.7	16.3	16.4	3.5	0.14	06	09
293		6.0	110.9	0.541	82.8	16.3	17.0	3.9	0.16	06	09
294	<20μ>20μ	1.0	102.0	0.678	77.1	16.9	16.9	0.0	0.06	06	09
295		1.0	117.8	0.516	80.2	15.1	15.1	4.5	0.35	07	09
296	Muscovite	3.0	105.5	0.575	78.0	16.3	17.6	8.0	0.16	06	09
297		1.0	112.9	0.514	83.5	15.7	15.1	0.3	0.28	07	09
298	<20μ>20μ	6.0	110.2	0.549	73.3	15.3	17.7	4.9	0.15	06	09
299		6.0	115.9	0.475	90.0	15.6	16.6	2.9	0.22	07	09
300	Dolomite	0.5	119.5	0.548	74.6	14.9	15.4	3.2	0.30	08	09
301		2.0	115.0	0.492	82.9	14.8	15.3	3.8	0.34	08	09
302	<0.1mm>20μ	3.0	113.0	0.517	79.3	14.9	17.5	1.3	0.30	08	09
303		6.0	120.2	0.431	99.4	15.5	19.2	18.0	0.96	09	09
304	Dolomite	6.0	120.1	0.434	90.1	14.2	15.4	5.6	0.42	09	09
305		6.0	114.0	0.511	80.0	14.8	13.1	5.2	0.51	08	09
306	<0.1mm>20μ	12.0	119.2	0.455	85.5	14.0	16.7	11.0	0.72	09	09
307		0.5	106.0	0.613	72.2	16.2	15.6	0.3	0.11	08	09
308	Dolomite	1.0	105.1	0.627	70.1	16.0	17.6	0.6	0.16	08	09
309		2.0	108.0	0.599	76.1	15.5	17.1	1.9	0.20	08	09
310	<0.1mm>20μ	3.0	115.6	0.481	96.6	16.9	16.5	4.9	0.32	09	09
311		3.0	112.4	0.521	87.0	16.5	16.7	5.6	0.34	09	09
312	Dolomite	3.0	108.0	0.583	72.2	15.3	17.3	4.5	0.46	08	09
313		6.0	117.0	0.465	93.5	15.8	17.6	10.6	0.76	09	09
314	<0.1mm>20μ	6.0	114.4	0.509	84.4	15.3	16.6	5.1	0.38	09	09
315		6.0	115.6	0.485	85.6	15.1	15.5	4.5	0.42	09	09
316	Dolomite	12.0	119.2	0.430	77.8	12.1	15.1	7.9	0.44	09	09
317		12.0	118.7	0.466	89.0	14.4	14.5	6.6	0.46	09	09
318	<0.1mm>20μ	25.0	117.6	0.470	83.3	14.1	13.9	1.6	0.26	08	09
319		50.0	119.5	0.462	87.5	14.4	14.3	7.9	0.50	09	09
320	Limonite	0.5	116.1	0.479	86.2	15.0	12.8	2.8	0.08	09	09
321		1.0	112.3	0.529	79.3	15.2	13.7	1.3	0.24	09	09
322	<0.1mm>20μ	2.0	109.5	0.513	79.5	16.5	13.8	1.9	0.22	09	09
323		3.0	112.3	0.539	79.5	15.5	15.6	1.3	0.12	09	09
324	Dolomite	6.0	99.8	0.750	81.4	21.4	21.1	4.4	0.23	09	09
325		12.0	113.4	0.579	72.7	14.7	16.1	4.9	0.54	09	09
326	East Boston Till (-0.075mm)	3.0	116.5	0.470	92.1	15.7	16.0	4.8	0.20	05	09
327		6.0	114.6	0.492	82.7	14.8	15.5	3.5	0.18	05	09
328	Dolomite	12.0	117.8	0.452	88.5	14.5	16.2	9.3	0.60	05	09
329		1.0	114.7	0.491	82.5	14.7	14.9	4.2	0.17	05	09
330	New Hampshire Till (-0.075mm)	3.0	111.4	0.534	77.4	15.0	14.8	2.9	0.11	05	09
331		6.0	115.0	0.486	85.5	14.5	14.5	6.1	0.16	05	09
332	Dolomite	12.0	120.5	0.418	97.3	14.8	13.3	3.5	0.19	05	09

Notes: (1) Degree of saturation in per cent at start of test.
(2) Based on original height of freeze portion.

TABLE D1

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

TABLE D2

TESTS FOR EFFECT OF CLAY MINERALS
WITH
MORAKIRA SAND
(OPEN SYSTEM)

SAMPLE NO.	CLAY MINERAL GROUP	CLAY MINERAL	PER CENT MINERAL	DRY UNIT WEIGHTpcf.	VOID RATIO	CLAY START OF TEST	WATER CONTENT		PER CENT HEAVE (2)	AVG. RATE OF HEAVE mm/day	WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA TABLE NO.		
							BEFORE TEST	AFTER TEST						
CM-280	Kaoline	kaolinite	0.5	107.4	0.991	76.0	16.5	16.4	3.2	0.31	D6	D9		
345			0.5	113.7	0.504	81.4	15.0	15.5	5.5	0.27	D13	D11		
281			1.0	110.9	0.580	96.3	19.0	15.0	2.6	0.12	D6	D9		
346			1.0	179.6	0.561	72.7	14.9	16.2	5.5	0.21	D13	D11		
347			2.0	107.8	0.585	73.0	15.6	16.6	4.2	0.35	D13	D11		
55			3.0	115.1	0.653	84.7	15.0	20.1	12.4	0.69	D9	D3		
252			3.0	110.7	0.584	80.9	15.9	15.9	3.0	0.30	D6	D9		
348			3.0	112.0	0.526	77.5	14.9	17.3	8.4	0.40	D13	D11		
56			6.0	119.3	0.629	93.0	14.6	23.8	23.1	1.24	D9	D3		
227			6.0	115.8	0.476	63.6	14.5	17.6	12.9	0.82	D14	D8		
349			6.0	114.9	0.483	82.9	14.6	17.2	9.7	0.46	D7	D11		
283			9.0	113.8	0.501	81.3	19.3	19.3	10.3	0.90	D6	D9		
228			12.0	119.7	0.418	50.5	13.7	20.3	13.5	1.12	D14	D8		
350			12.0	117.1	0.469	87.6	14.5	16.9	9.2	0.79	D7	D11		
229			25.0	113.2	0.494	80.2	13.7	26.9	34.7	2.29	D14	D8		
351			25.0	120.6	0.402	96.0	14.2	27.0	23.5	1.68	D7	D11		
230			50.0	116.4	0.436	89.9	14.6	29.1	33.1	2.25	D14	D8		
352			50.0	111.0	0.507	80.6	15.2	25.0	24.9	2.37	D7	D11		
69				Dickite	3.0	115.8	0.470	86.1	14.9	15.9	6.5	0.35	D11	D3
70					6.0	113.3	0.504	85.4	15.8	17.5	3.0	0.09	D11	D3
337				Halloysite	0.5	119.3	0.434	71.7	11.4	15.7	1.3	0.23	D13	D11
338					1.0	109.1	0.626	78.7	18.0	16.2	4.2	0.19	D13	D11
339					2.0	110.1	0.550	73.2	14.8	16.4	3.6	0.38	D13	D11
71					3.0	116.6	0.470	87.1	14.9	17.8	6.5	0.31	D11	D3
340					3.0	116.0	0.479	85.1	14.8	14.4	8.8	0.63	D13	D11
72					6.0	119.4	0.439	91.2	14.5	18.3	15.4	0.71	D11	D3
341					6.0	116.4	0.475	84.9	14.7	15.6	6.8	0.61	D13	D11
342					12.0	111.6	0.519	85.9	17.0	17.0	16.5	0.59	D13	D11
343					25.0	115.4	0.509	80.0	15.7	18.6	11.9	0.65	D13	D11
344					50.0	98.9	0.835	86.6	25.4	24.9	11.6	0.16	D13	D11
246			Montmorillonite	Calcium Montmorillonite	0.5	112.2	0.523	83.7	16.0	16.1	2.9	0.66	D10	D8
247					1.0	113.1	0.511	85.1	16.0	15.7	2.3	0.66	D10	D8
248					2.0	115.8	0.477	87.2	15.2	14.1	0.6	0.01	D10	D8
344					2.0	117.3	0.458	85.0	14.2	14.6	5.2	0.40	D12	D10
43					3.0	118.5	0.442	93.7	15.1	13.9	1.1	0.68	D9	D3
249	3.0	114.2			0.497	83.7	16.1	15.6	2.6	0.66	D10	D8		
44	6.0	121.9			0.491	100.0	14.6	15.5	6.6	0.55	D9	D3		
250	6.0	116.4			0.458	92.2	15.8	14.7	3.5	0.03	D10	D8		
315	12.0	116.6			0.461	90.2	15.2	13.2	1.6	-	D12	D10		
321		Iron Montmorillonite			1.0	109.1	0.568	80.2	16.6	17.0	1.3	0.27	D12	D10
322			2.0	111.1	0.525	83.1	16.1	16.6	4.2	0.43	D12	D10		
73			3.0	112.6	0.518	83.1	15.7	19.5	15.2	0.33	D11	D3		
323			3.0	114.3	0.497	85.4	15.5	18.2	8.7	0.58	D12	D10		
74			6.0	120.4	0.419	98.0	15.0	16.1	7.8	0.10	D11	D3		
324			6.0	116.9	0.463	89.6	15.1	18.4	12.8	0.75	D12	D10		
325			12.0	117.4	0.451	88.2	14.6	22.5	18.2	1.42	D12	D10		
65				Lead Montmorillonite	3.0	114.7	0.490	84.4	15.1	16.2	2.9	0.18	D11	D3
66	6.0	115.3			0.482	83.5	14.7	15.6	1.6	0.25	D11	D3		
326		Magnesium Montmorillonite	1.0	114.1	0.490	81.5	14.8	14.9	3.2	0.22	D12	D10		
327			2.0	115.0	0.487	85.8	15.4	14.5	4.2	0.16	D12	D10		
47			3.0	111.8	0.528	80.3	15.5	17.4	6.1	0.16	D11	D3		
328			3.0	112.4	0.521	81.0	15.4	13.6	1.9	0.21	D12	D10		
68			6.0	119.2	0.433	93.0	14.7	14.4	1.9	0.26	D11	D3		
329			6.0	117.0	0.461	93.3	15.7	13.8	1.3	0.68	D12	D10		
330			12.0	115.6	0.478	93.2	16.2	14.1	0.3	0.13	D12	D10		

NOTES: (1) Degree of saturation in per cent at start of test.
(2) Based on original height of frozen portion.

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

TABLE D2

TESTS FOR EFFECT OF CLAY MINERALS
WITH
MONMARA SAND

(OPEN SYSTEM)

SAMPLE NO.	CLAY MINERAL GROUP	CLAY MINERAL	PER CENT MINERAL	DRY UNIT WEIGHT pcf.	VOID RATIO	D AT START OF TEST (1)	WATER CONTENT		PER CENT HEAVE (2)	AVG. RATE OF HEAVE cm/day	WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA PLATE NO.	
							BEFORE TEST	AFTER TEST					
CM-316	Montmorillonoid (continued)	Potassium Montmorillonite	1.0	110.9	0.541	79.6	15.7	20.8	3.5	0.25	D12	D10	
317			2.0	107.7	0.587	78.2	16.8	16.6	0.6	0.10	D12	D10	
59			3.0	118.3	0.645	90.7	14.7	16.1	6.3	0.36	D9	D3	
318			3.0	110.3	0.577	78.5	15.8	14.1	3.5	0.20	D12	D10	
60			6.0	119.4	0.631	84.3	14.8	14.1	7.3	0.22	D9	D3	
319			6.0	114.8	0.659	83.0	14.8	13.5	0.6	0.07	D12	D10	
320		12.0	115.0	0.681	82.0	14.4	13.4	0.3	0.07	D12	D10		
238		Sodium Montmorillonite	Sodium Montmorillonite	0.5	114.1	0.604	88.5	16.0	16.3	4.4	0.22	D14	D6
239				1.0	117.6	0.577	87.4	16.5	17.0	3.9	0.10	D14	D6
240				2.0	115.2	0.634	88.9	15.7	15.6	2.9	0.35	D14	D6
353	2.0			116.7	0.668	86.7	14.7	14.1	1.3	0.19	D7	D11	
47	3.0			115.9	0.674	82.1	14.2	13.6	3.6	0.08	D9	D3	
77	3.0			115.7	0.666	83.5	14.6	13.1	2.3	0.08	D11	D3	
211	3.0			113.8	0.593	79.9	14.7	13.8	1.3	0.01	D10	D6	
48	6.0			117.8	0.650	85.3	14.0	14.5	4.3	0.09	D9	D3	
212	6.0			112.4	0.520	83.2	15.8	15.2	1.6	0.08	D11	D3	
354	6.0			108.9	0.599	81.6	17.0	14.9	1.6	0.01	D10	D6	
243	6.0			111.5	0.575	79.7	15.6	14.3	0.3	-	D7	D11	
355	12.0			109.6	0.553	75.3	15.3	15.8	1.0	0.03	D10	D6	
244	12.0			112.7	0.512	79.3	14.9	12.7	0.0	0.25	D7	D11	
356	25.0			112.4	0.516	81.4	15.4	15.1	0.6	0.01	D10	D6	
245	25.0	113.9	0.466	82.3	14.9	13.6	0.0	-	D7	D11			
357	50.0	97.0	0.752	80.3	22.2	20.9	7.1	0.03	D10	D6			
291	50.0	104.6	0.623	68.9	15.9	15.2	0.0	-	D7	D11			
292	Serpentinite	Serpentinite	0.5	104.2	0.580	88.4	18.7	17.8	3.1	0.02	D6	D9	
293			1.0	106.4	0.606	92.8	20.6	17.6	1.3	0.14	D6	D9	
294			3.0	110.9	0.541	85.6	16.4	16.6	4.5	0.14	D6	D9	
223	Nontronite	Nontronite	6.0	114.4	0.694	97.4	15.3	15.5	3.8	0.25	D6	D9	
224			0.5	112.3	0.522	86.0	16.4	15.6	5.8	0.36	D14	D6	
45			1.0	113.0	0.513	89.5	17.3	17.6	8.4	0.31	D14	D6	
225			3.0	119.4	0.620	95.0	14.8	14.1	18.1	1.35	D9	D3	
16			3.0	117.6	0.649	98.2	16.2	18.4	13.2	0.51	D14	D6	
226	6.0	117.5	0.638	84.5	13.7	19.3	18.0	0.64	D9	D3			
53	Hectorite	Hectorite	6.0	120.1	0.608	94.1	14.2	22.8	24.5	1.43	D14	D6	
54			3.0	120.1	0.623	98.1	15.1	16.1	4.9	0.27	D9	D3	
51	Pyrophyllite	Pyrophyllite	6.0	118.3	0.644	89.5	14.5	14.8	3.6	0.15	D9	D3	
52			3.0	117.3	0.659	86.8	14.5	17.2	10.9	0.64	D9	D3	
231	Illite	Illite	6.0	118.0	0.652	92.1	15.2	16.0	12.8	0.70	D9	D3	
232			0.5	111.2	0.537	76.6	13.0	17.8	4.5	0.26	D14	D6	
40			1.0	112.1	0.525	77.1	13.9	16.6	5.6	0.34	D14	D6	
233			3.0	120.5	0.614	109.0	15.3	17.6	11.2	0.60	D9	D3	
50			3.0	115.3	0.683	87.1	15.3	16.6	5.8	0.72	D14	D6	
234			6.0	118.4	0.645	92.6	15.0	20.4	16.5	1.21	D9	D3	
235			6.0	116.4	0.669	88.6	15.2	16.6	7.4	0.91	D14	D6	
236			9.0	112.4	0.521	78.8	14.9	18.7	7.1	0.51	D6	D9	
237			12.0	121.2	0.610	97.9	14.2	17.2	41.6	0.70	D14	D6	
237			25.0	120.5	0.619	109.0	15.3	16.2	7.7	0.60	D14	D6	
36	Miscellaneous	Chlorite < 20µ dispersed w/ illite	0.5	114.3	0.695	86.2	15.6	15.2	5.2	0.10	D7	D11	
366			1.0	111.2	0.510	82.7	15.4	16.0	5.5	0.38	D7	D11	
365		3.0	114.2	0.697	83.4	15.1	16.9	9.2	0.63	D7	D11		
75		Attapulgite	Attapulgite	3.0	109.6	0.553	81.3	16.5	23.6	16.1	0.91	D11	D3
76	6.0			115.3	0.669	92.2	16.3	31.0	36.4	2.01	D11	D3	

NOTES: (1) Degree of saturation in per cent at start of test.
(2) based on original height of frozen portion.

TABLE D3

SAMPLE NUMBER	MATERIAL	ADDITIVE		GRAIN SIZE			PER CENT HEAVE (1)	AVERAGE RATE OF HEAVE mm./day	CLAY UNIT WEIGHT pcf.	VOID RATIO	PERMEABILITY $k \times 10^{-4}$ cm./sec.	GAT START OF TEST (2)	ATTERBERG LIMITS (3)		WATER CONTENT DATA TABLE NO.	HEAVE AND TEMPERATURE DATA TABLE NO.
		TYPE	PER CENT	2.0	0.42	0.075							L.L.	P.I.		
SB-77-A	New Hampshire Silt	-	-	100	100	85	150.2	7.9	104.8	0.643	0.054	88.0	21.1	5.9	DL5	DL2
SB-10-A	-	Na Polyacrylate	0.05	100	100	85	37.3	1.4	105.0	0.640	0.130	97.1	29.4	13.8	DL5	DL2
SB-11-A	-	Na Tetra-phosphate	0.10	100	100	85	68.8	1.6	104.1	0.654	0.089	100.0	29.4	13.8	DL5	DL2
SB-12-A	-	-	0.10	100	100	85	49.4	1.4	100.3	0.717	0.098	74.8	29.4	13.8	DL5	DL2
SB-13-A	-	-	0.50	100	100	85	32.4	1.2	100.3	0.717	0.098	77.9	29.4	13.8	DL5	DL2
FB-7-A	Fert Pelvoir Sandy CLAY	-	-	97	90	61	18.2	1.5	117.0	0.456	0.098	89.8	43.8	20.3	DL5	DL3
FB-8-A	-	-	-	97	90	61	22.1	1.3	113.3	0.504	0.130	100.0	43.8	20.3	DL5	DL3
FB-9-A	-	-	-	97	90	61	27.5	2.2	118.2	0.441	0.089	100.0	43.8	20.3	DL5	DL3
FB-10-A	Na Polyacrylate	0.10	97	90	61	49	23.0	1.3	112.9	0.508	0.089	94.6	43.4	21.4	DL5	DL4
FB-11-A	-	-	0.10	97	90	61	22.9	1.5	117.8	0.446	0.098	100.0	43.4	21.4	DL5	DL4
FB-12-A	-	-	0.50	97	90	61	16.0	1.0	107.9	0.578	0.098	100.0	40.6	18.2	DL5	DL4
FB-13-A	Na Tetra-phosphate	0.30	97	90	61	49	11.7	0.9	114.8	0.484	0.098	100.0	40.6	18.2	DL5	DL4
FB-14-A	-	-	0.30	97	90	61	5.5	0.3	117.4	0.451	0.098	90.9	40.6	18.2	DL5	DL4
FB-15-A	-	-	0.30	97	90	61	4.9	0.4	106.9	0.594	0.098	84.4	40.6	18.2	DL5	DL4
FB-16-A	-	-	1.00	97	90	61	6.3	0.3	116.8	0.457	0.098	100.0	40.6	18.2	DL5	DL4
FB-17-A	-	-	1.00	97	90	61	3.5	0.1	109.7	0.552	0.098	96.5	40.6	18.2	DL5	DL4
FB-18-A	-	-	1.00	97	90	61	2.6	0.1	120.1	0.418	0.098	100.0	40.6	18.2	DL5	DL4

NOTES:

- (1) Based on original height of frozen portion.
 (2) Degree of saturation in percent at start of test.
 (3) Tests made on material passing the U.S. Standard No. 40 sieve.

SOIL MOON STUDIES OF PEST ACTION IN SOIL
FISCAL YEARS 1952 AND 1953

TABLE 24

TESTS FOR EFFECT OF ADDITIVES
EXTRACTED FROM SPERMINE

(CONT. SYSTEM)

SAMPLE NUMBER	ADDITIVE	PER CENT ADDITIVE	BASIC SOIL	DEG. OF HUMIDITY	WIND SPEED	G AT START OF TEST	WATER CONTENT		PER CENT MOISTURE (2)	ATTACH DATE OF MOISTURE	WATER CONTENT DATA TABLE NO.	DATE AND TEMPERATURE DATA PLATE NO.
							BEFORE TEST	AFTER TEST				
ADDITIVES												
172	Carbon 270	0.1	New Hampshire SILT	95.4	0.20	100.0	39.1	38.4	39.1	7.5	076	06
173		0.5		94.8	0.17	93.5	39.1	38.6	35.0	1.67	076	06
174		1.0	94.2	0.16	93.9	38.5	37.3	30.9	1.93	076	06	
177		0.1	Fort Belvoir Sandy CLAY	107.7	0.46	93.0	37.6	39.8	17.3	1.40	077	09
178		0.5		107.5	0.46	93.2	38.1	36.8	6.6	0.32	077	09
179		1.0	107.4	0.46	93.9	37.6	33.7	7.7	0.56	077	09	
180	0.1	Boston Blue CLAY	97.5	0.33	93.1	37.1	37.9	33.9	2.90	078	09	
181	0.5		94.7	0.32	93.0	37.8	37.4	18.4	1.47	078	09	
182	1.0	94.3	0.30	93.6	37.0	32.1	13.1	1.12	078	09		
175	Carbon 500	0.1	New Hampshire SILT	94.3	0.26	97.8	39.3	41.0	35.9	2.0	076	06
176		0.5		93.3	0.26	97.8	38.5	36.9	29.9	2.75	076	06
183		1.0	90.4	0.23	97.9	39.3	31.2	14.1	1.08	076	06	
184		0.1	Fort Belvoir Sandy CLAY	101.0	0.46	96.9	39.3	33.2	16.1	1.58	079	09
185		0.5		103.2	0.43	97.3	39.3	33.9	15.4	1.59	079	09
186		1.0	100.8	0.40	97.5	39.4	32.4	6.7	0.51	079	09	
187	0.1	Boston Blue CLAY	95.2	0.23	98.5	39.8	35.9	9.4	0.71	079	09	
188	0.5		93.8	0.21	98.0	39.2	34.8	30.3	2.64	079	09	
189	1.0	93.0	0.21	99.8	39.5	34.5	21.2	2.26	079	09		
190	0.1	Pyridine	94.4	0.23	97.8	39.4	39.4	6.0	0.15	076	06	
191	0.5		94.4	0.23	94.7	39.1	37.3	19.4	0.72	076	06	
192	1.0	91.5	0.18	94.8	39.2	33.2	23.2	1.56	076	06		
193	0.1	Fort Belvoir Sandy CLAY	102.4	0.43	97.2	39.7	33.9	20.2	1.75	079	09	
194	0.5		99.3	0.41	97.0	39.7	33.5	13.4	1.45	079	09	
195	1.0	94.7	0.39	95.7	39.7	32.8	17.4	2.03	079	09		
196	0.1	Boston Blue CLAY	98.8	0.20	97.3	39.2	35.6	24.4	1.65	079	09	
197	0.5		95.5	0.17	96.4	39.3	34.5	34.3	3.11	079	09	
198	1.0	91.4	0.14	95.9	39.3	32.4	39.9	4.45	079	09		
199	CDB-17	0.1	New Hampshire SILT	90.9	0.19	96.3	39.0	30.4	9.7	0.09	078	09
200		0.5		92.0	0.17	99.8	39.2	35.7	15.0	1.03	078	09
201		1.0	90.6	0.16	94.9	39.2	35.0	25.5	1.22	078	09	
202		0.1	Fort Belvoir Sandy CLAY	106.4	0.43	96.9	39.1	37.6	15.7	1.11	077	09
203		0.5		104.4	0.42	97.8	39.4	35.2	14.4	0.89	077	09
204		1.0	104.6	0.41	97.7	39.4	33.5	2.6	0.13	077	09	
205	0.1	Boston Blue CLAY	93.6	0.17	95.6	39.0	37.5	21.3	2.09	079	09	
206	0.5		95.0	0.16	100.0	39.0	41.5	40.4	5.13	079	09	
207	1.0	97.4	0.15	93.8	39.6	34.1	39.4	3.49	079	09		
ADDITIVES												
175	CDB-50	0.1	New Hampshire SILT	93.4	0.20	97.9	39.0	40.0	30.1	2.10	076	06
176		0.5		97.0	0.19	98.9	38.5	35.5	25.5	2.11	076	06
177		1.0	97.4	0.18	100.0	37.0	34.6	30.4	1.80	076	06	
178		0.1	Fort Belvoir Sandy CLAY	106.4	0.43	99.4	38.5	33.2	3.2	1.03	078	09
179		0.5		103.2	0.40	99.4	39.0	30.0	1.3	0.08	078	09
180		1.0	104.6	0.39	98.0	39.9	33.0	1.0	0.08	078	09	
181	0.1	Boston Blue CLAY	100.7	0.43	100.0	38.9	32.7	1.5	0.08	078	09	
182	0.5		101.3	0.42	98.4	39.2	34.3	1.2	0.11	078	09	
183	1.0	104.0	0.40	98.5	39.7	37.2	0.3	0.02	078	09		
184	Epsilon 100	0.1	New Hampshire SILT	97.4	0.19	96.0	38.7	40.5	39.7	1.58	077	09
185		0.5		91.8	0.18	94.7	38.9	34.9	27.0	1.24	077	09
186		1.0	89.5	0.17	97.1	39.1	35.0	14.3	1.82	077	09	
187		0.1	Fort Belvoir Sandy CLAY	105.3	0.43	99.9	38.9	34.0	13.0	1.10	077	09
188		0.5		105.0	0.42	99.4	39.0	34.0	13.8	0.97	077	09
189		1.0	102.4	0.42	98.4	38.7	34.0	13.0	1.30	077	09	
190	0.1	Boston Blue CLAY	105.3	0.43	97.2	38.7	36.9	26.4	1.75	077	09	
191	0.5		95.1	0.41	96.9	38.4	37.7	21.5	2.05	077	09	
192	1.0	91.8	0.39	92.8	38.4	39.4	42.2	3.11	077	09		
193	Epsilon 100	0.1	New Hampshire SILT	91.8	0.19	97.3	38.7	31.4	53.2	4.76	078	09
194		0.5		92.0	0.18	94.7	38.9	35.7	25.7	2.03	078	09
195		1.0	92.7	0.18	99.9	37.0	37.0	29.4	1.64	078	09	
196		0.1	Fort Belvoir Sandy CLAY	100.7	0.43	99.9	39.3	36.0	14.0	1.30	078	09
197		0.5		100.4	0.42	98.0	39.0	34.7	11.2	0.93	078	09
198		1.0	103.7	0.43	98.0	39.8	34.3	4.3	0.47	078	09	
199	0.1	Boston Blue CLAY	105.9	0.43	97.4	39.0	39.1	19.4	1.83	078	09	
200	0.5		94.3	0.41	97.0	38.1	37.7	49.0	3.07	078	09	
201	1.0	92.9	0.39	97.8	38.4	47.0	49.3	4.13	078	09		
202	Pyridine 1-00	0.1	New Hampshire SILT	97.1	0.17	95.6	39.1	36.3	17.4	2.70	078	09
203		0.5		97.4	0.16	94.1	39.0	36.9	62.8	2.76	078	09
204		1.0	97.0	0.16	91.1	39.4	36.4	34.4	1.14	078	09	
205		0.1	Fort Belvoir Sandy CLAY	100.4	0.41	97.7	39.6	31.4	29.3	1.69	078	09
206		0.5		104.9	0.40	95.4	39.1	36.1	17.0	1.21	078	09
207		1.0	103.7	0.40	96.3	39.0	37.9	18.7	1.43	078	09	
208	0.1	Boston Blue CLAY	102.0	0.43	94.4	39.0	39.9	15.7	1.53	078	09	
209	0.5		98.0	0.39	96.0	38.0	35.1	24.4	2.08	078	09	
210	1.0	95.5	0.38	91.4	38.5	42.4	39.2	3.75	078	09		

(1) Degree of saturation is per cent on basis of test.
(2) Based on original weight of freeze jacket.

WELD FINE STRUCTURE OF FERRITE IN SOIL
FISCAL YEARS 1958 AND 1959

TABLE 26

TESTS FOR EFFECT OF ADDITIVE
EXTRACTED FROM SOILS

(CONT. TABLE)

SAMPLE NUMBER	ADDITIVE	PER CENT ADDITIVE	BASIC SOIL	WET WEIGHT PERCENT	WET WEIGHT PERCENT	WET WEIGHT PERCENT	WATER CONTENT		PER CENT LOSS	WATER LOSS PER CENT	WATER LOSS PER CENT	WATER LOSS PER CENT	WATER LOSS PER CENT	
							BEFORE TEST	AFTER TEST						
WATERBORNE (CONT'D)														
186-200	Frisman C-2	0.1	See Descriptive FILE	98.7	0.299	98.8	26.1	29.7	11.4	0.25	213	29		
186		0.5		99.2	0.267	99.2	27.1	32.2	14.0	0.9	218	26		
187		0.5		98.3	0.228	98.3	25.0	29.2	7.1	0.10	218	27		
188		1.0		-	-	-	-	-	-	-	-	-	-	
189		1.0		98.9	0.225	97.8	26.3	32.4	13.9	0.76	219	26		
190		0.1		105.4	0.515	101.1	15.6	17.1	13.2	0.15	219	26		
191		0.5		105.4	0.545	79.5	14.8	14.0	13.2	2.76	219	27		
192		1.0		102.1	0.416	75.4	13.4	17.2	12.4	2.07	217	27		
193		0.1		99.8	1.022	10.0	34.4	40.2	35.9	2.58	217	27		
194		0.5		98.2	1.111	37.7	35.1	47.4	19.1	4.57	219	27		
195	1.0	90.1	1.166	73.7	30.9	39.2	72.4	6.45	217	27				
196	Valon	0.1	See Descriptive FILE	98.4	0.548	99.0	26.1	35.9	23.4	1.41	222	26		
196		0.5		99.7	0.490	94.2	27.0	32.4	32.4	1.09	222	26		
197		0.1		105.2	0.609	88.2	19.5	18.9	14.5	0.68	221	26		
198		0.5		113.9	0.600	85.0	18.5	11.2	1.2	0.52	221	26		
199		1.0		105.5	0.615	87.9	17.8	19.9	1.8	0.25	221	26		
200		0.1		102.8	0.680	92.7	22.9	29.4	15.4	1.00	223	26		
201		0.5		101.4	0.711	65.8	21.9	27.3	9.0	0.00	223	26		
202		1.0		109.1	0.683	87.4	21.5	26.1	1.5	0.29	223	26		
203		0.1		98.2	0.815	90.5	26.7	39.4	24.8	1.00	220	26		
204		0.5		99.2	0.717	84.5	25.8	34.9	28.3	2.50	220	26		
205	1.0	100.2	0.719	95.3	24.8	31.7	1.5	0.11	219	26				
206	Park Nitrate Ready CLAY	0.1	105.1	0.462	94.1	20.5	26.5	4.5	0.21	221	25			
207		0.5		102.0	0.407	87.3	20.4	28.4	1.8	0.27	221	25		
208		1.0		100.4	0.725	95.1	23.0	34.1	2.2	0.22	221	25		
209		0.1		98.4	0.705	89.1	24.2	31.4	16.7	1.43	223	25		
210		0.5		99.2	0.811	94.1	27.5	31.5	12.5	0.95	221	25		
211		1.0		95.4	0.833	91.0	27.9	37.9	35.9	1.59	223	25		
212		0.1		91.4	0.897	92.5	30.8	42.0	28.1	1.92	219	25		
213		0.5		85.4	1.031	95.4	35.4	47.7	24.4	2.10	223	25		
214		Hexamethyl Soda		0.1	Jacks Fine CLAY	95.5	0.495	91.8	28.2	39.0	26.0	1.11	222	24
215				0.5		85.5	1.031	92.7	30.4	44.0	27.0	2.12	223	24
216	1.0		83.0	1.029		92.1	35.5	55.0	24.4	2.48	220	24		
217	Tetrapropylene Tetramine	0.1	See Descriptive FILE	91.3	0.478	94.1	29.9	42.7	31.0	3.50	222	24		
218		0.5		91.6	0.430	90.3	27.4	33.0	15.5	1.64	222	24		
219		1.0		90.8	0.481	88.3	27.8	32.7	12.5	1.02	222	24		
220		0.1		105.8	0.521	87.4	19.2	25.4	11.5	0.95	222	24		
221		0.5		104.9	0.483	87.9	19.2	24.4	11.0	0.97	222	24		
222		1.0		101.1	0.492	89.8	21.3	26.5	15.8	1.10	222	24		
223		0.1		97.9	0.770	81.2	28.4	39.7	33.4	1.42	220	24		
224		0.5		97.9	0.777	83.3	23.7	34.4	41.5	2.02	220	24		
225		1.0		98.5	0.876	87.4	27.4	33.4	24.9	1.81	220	24		
226		Hexamethylene Diamine		0.1	See Descriptive FILE	95.1	0.521	90.8	29.0	45.7	34.0	3.43	223	24
227	0.5		-	-		-	-	-	-	-	-	-	-	
228	1.0		94.4	0.525		85.4	24.3	37.2	19.5	1.20	220	24		
229	0.1		104.4	0.602		88.4	29.5	40.2	16.0	1.13	220	24		
230	0.5		104.0	0.605		89.8	19.4	28.6	11.9	0.66	220	24		
231	1.0		105.3	0.617		87.9	17.6	21.7	5.5	0.26	220	24		
232	0.1		101.2	0.609		84.2	29.5	38.4	27.5	1.73	223	24		
233	0.5		97.7	0.770		83.5	24.1	32.4	47.9	3.20	223	24		
234	1.0		83.7	1.072		99.9	34.7	57.4	45.7	3.43	223	24		
235	Di-n-Octylamine		0.1	See Descriptive FILE		91.4	0.575	90.0	28.1	40.5	33.4	3.20	220	24
236		0.5	91.1		0.571	88.2	24.3	31.4	2.4	2.00	220	24		
237		1.0	95.1		0.519	84.2	29.5	37.2	44.7	2.05	220	24		
238		0.1	109.0		0.604	88.4	29.1	38.4	17.1	1.03	220	24		
239		0.5	107.3		0.597	83.2	29.8	33.5	9.0	0.71	220	24		
240		1.0	106.0		0.608	84.4	28.4	34.4	1.5	0.23	220	24		
241		0.1	91.1		0.695	84.1	30.4	47.5	34.2	3.16	223	24		
242		0.5	97.8		0.679	84.4	29.1	41.4	34.4	1.85	223	24		
243		1.0	88.1		0.589	90.4	31.4	41.5	40.9	1.18	223	24		
BASIC SOILS														
244	Fluor	-	See Descriptive FILE	89.2	0.920	70.0	33.8	46.4	31.8	1.50	220	24		
245		-		89.2	0.864	65.8	35.1	50.4	37.0	5.17	220	24		
246		-		89.4	0.880	69.8	29.0	38.4	17.1	0.68	220	24		
247		-		89.2	0.921	69.9	29.4	35.9	14.7	0.50	220	24		
248		-		109.0	0.429	80.4	20.4	27.4	20.5	2.29	220	24		
249		-		107.7	0.411	83.1	19.5	27.7	19.8	1.57	220	24		
250		-		104.7	0.443	82.5	19.4	24.5	26.1	1.99	220	24		
251		-		104.4	0.461	80.0	22.4	31.5	19.9	1.67	220	24		
252		-		104.1	0.465	80.5	21.6	31.0	11.0	0.61	220	24		
253		-		101.5	0.470	85.5	21.7	31.8	20.1	1.99	220	24		

NOTE: (1) Degree of saturation in per cent at start of test.
(2) Based on original weight of freeze portion.

TABLE D4 Sheet 2 of 2

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-259		SAMPLE NUMBER CM-260		SAMPLE NUMBER CM-261		SAMPLE NUMBER CM-262		SAMPLE NUMBER CM-263		SAMPLE NUMBER CM-264	
$H_o = 3.13$	$H_f = 3.28$	$H_o = 3.14$	$H_f = 3.25$	$H_o = 3.13$	$H_f = 3.12$	$H_o = 3.11$	$H_f = 3.24$	$H_o = 3.11$	$H_f = 3.20$	$H_o = 3.11$	$H_f = 3.30$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 15.7$	$W_o = 14.8$	$W_o = 14.5$	$W_o = 14.5$	$W_o = 14.7$	$W_o = 14.5$	$W_o = 15.0$	$W_o = 14.5$	$W_o = 15.0$	$W_o = 14.5$	$W_o = 14.5$	$W_o = 14.5$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	17.1	0.0-1.5	17.4	0.0-1.5	19.5	0.0-1.5	15.5	0.0-1.5	15.6	0.0-1.5	14.5
1.5-3.28	13.7	1.5-3.25	14.0	1.5-3.12	14.6	1.5-3.24	13.8	1.5-3.2	12.7	1.5-3.3	14.5
SAMPLE NUMBER CM-265		SAMPLE NUMBER CM-266		SAMPLE NUMBER CM-267		SAMPLE NUMBER CM-268		SAMPLE NUMBER CM-269		SAMPLE NUMBER CM-270	
$H_o = 3.11$	$H_f = 3.22$	$H_o = 3.11$	$H_f = 3.26$	$H_o = 3.21$	$H_f = 3.32$	$H_o = 3.11$	$H_f = 3.28$	$H_o = 3.11$	$H_f = 3.31$	$H_o = 3.11$	$H_f = 3.34$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 14.8$	$W_o = 14.8$	$W_o = 16.8$	$W_o = 16.8$	$W_o = 18.3$	$W_o = 18.3$	$W_o = 15.3$	$W_o = 15.3$	$W_o = 16.1$	$W_o = 16.1$	$W_o = 15.1$	$W_o = 15.1$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	15.6	0.0-1.5	17.3	0.0-1.5	20.4	0.0-1.5	16.6	0.0-1.5	17.2	0.0-1.5	17.0
1.5-3.22	10.2	1.5-3.26	16.5	1.5-3.32	19.2	1.5-3.28	13.2	1.5-3.31	17.8	1.5-3.34	14.2
SAMPLE NUMBER CM-271		SAMPLE NUMBER CM-272		SAMPLE NUMBER CM-273		SAMPLE NUMBER CM-274		SAMPLE NUMBER CM-275		SAMPLE NUMBER CM-276	
$H_o = 3.16$	$H_f = 3.30$	$H_o = 3.11$	$H_f = 3.32$	$H_o = 3.11$	$H_f = 3.22$	$H_o = 3.11$	$H_f = 3.26$	$H_o = 3.11$	$H_f = 3.26$	$H_o = 3.11$	$H_f = 3.39$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 22.5$	$W_o = 22.5$	$W_o = 15.1$	$W_o = 15.1$	$W_o = 16.3$	$W_o = 16.3$	$W_o = 16.6$	$W_o = 16.6$	$W_o = 16.7$	$W_o = 16.7$	$W_o = 17.1$	$W_o = 17.1$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	18.0	0.0-1.5	18.3	0.0-1.5	18.5	0.0-1.5	17.2	0.0-1.5	16.0	0.0-1.5	15.5
1.5-3.3	15.9	1.5-3.32	14.1	1.5-3.22	14.0	1.5-3.26	15.7	1.5-3.28	14.5	1.5-3.39	14.8

H_o = Original Height in Inches.
 H_f = Final Height in Inches.
 H_u = Thickness of Unfrozen Portion in Inches.
 W_o = Original Water Content in Per Cent.

TABLE 05

COLD ROOM STUDIES OF FAST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-277		SAMPLE NUMBER CM-278		SAMPLE NUMBER CM-279		SAMPLE NUMBER CM-280		SAMPLE NUMBER CM-281		SAMPLE NUMBER CM-282	
$H_o = 3.11$	$H_f = 3.25$	$H_o = 3.16$	$H_f = 3.27$	$H_o = 3.10$	$H_f = 3.20$	$H_o = 3.11$	$H_f = 3.21$	$H_o = 3.11$	$H_f = 3.19$	$H_o = 3.11$	$H_f = 3.23$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 16.9$		$W_o = 16.9$		$W_o = 16.1$		$W_o = 16.5$		$W_o = 19.0$		$W_o = 15.9$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	15.7	0.0-1.5	17.1	0.0-1.5	15.0	0.0-1.5	16.3	0.0-1.5	15.4	0.0-1.5	13.2
1.5-3.25	16.3	1.5-3.29	17.6	1.5-3.2	11.5	1.5-3.21	15.8	1.5-3.29	15.1	1.5-3.23	14.1
SAMPLE NUMBER CM-283		SAMPLE NUMBER CM-284		SAMPLE NUMBER CM-285		SAMPLE NUMBER CM-286		SAMPLE NUMBER CM-287		SAMPLE NUMBER CM-288	
$H_o = 3.11$	$H_f = 3.43$	$H_o = 3.09$	$H_f = 3.30$	$H_o = 3.13$	$H_f = 3.23$	$H_o = 3.11$	$H_f = 3.22$	$H_o = 3.11$	$H_f = 3.23$	$H_o = 3.18$	$H_f = 3.18$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 19.3$		$W_o = 14.9$		$W_o = 16.2$		$W_o = 15.3$		$W_o = 16.3$		$W_o = 15.9$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	23.6	0.0-1.5	22.3	0.0-1.5	15.9	0.0-1.5	16.4	0.0-1.5	17.9	0.0-1.5	17.1
1.5-3.43	15.8	1.5-3.3	17.0	1.5-3.23	17.2	1.5-3.22	15.7	1.5-3.23	15.6	1.5-3.18	16.1
SAMPLE NUMBER CM-289		SAMPLE NUMBER CM-290		SAMPLE NUMBER CM-291		SAMPLE NUMBER CM-292		SAMPLE NUMBER CM-293		SAMPLE NUMBER CM-294	
$H_o = 3.11$	$H_f = 3.26$	$H_o = 3.09$	$H_f = 3.24$	$H_o = 3.18$	$H_f = 3.28$	$H_o = 3.19$	$H_f = 3.23$	$H_o = 3.11$	$H_f = 3.25$	$H_o = 3.18$	$H_f = 3.30$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 15.3$		$W_o = 15.3$		$W_o = 19.7$		$W_o = 20.6$		$W_o = 16.1$		$W_o = 15.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	19.2	0.0-1.5	19.0	0.0-1.5	17.5	0.0-1.5	17.6	0.0-1.5	17.0	0.0-1.5	19.5
1.5-3.26	15.2	1.5-3.24	16.6	1.5-3.28	17.9	1.5-3.23	17.8	1.5-3.25	15.1	1.5-3.3	14.0

H_o = Original Height in Inches.
 H_f = Final Height in Inches.
 H_u = Thickness of Unfrozen Portion in Inches.
 W_o = Original Water Content in Per Cent.

TABLE D6

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-349		SAMPLE NUMBER CM-350		SAMPLE NUMBER CM-351		SAMPLE NUMBER CM-352		SAMPLE NUMBER CM-353		SAMPLE NUMBER CM-354	
$H_o = 3.09$ $H_f = 3.39$ $H_u = 0$ $W_o = 14.6$		$H_o = 3.10$ $H_f = 3.40$ $H_u = 0$ $W_o = 14.5$		$H_o = 3.11$ $H_f = 3.34$ $H_u = 0$ $W_o = 14.2$		$H_o = 3.13$ $H_f = 3.91$ $H_u = 0$ $W_o = 15.2$		$H_o = 3.12$ $H_f = 3.16$ $H_u = 0$ $W_o = 14.7$		$H_o = 3.12$ $H_f = 3.13$ $H_u = 0$ $W_o = 15.6$	
Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %
0.0-1.5	21.1	0.0-1.5	21.5	0.0-1.5	28.1	0.0-0.6	26.5	0.0-1.5	14.4	0.0-1.5	15.0
1.5-3.39	15.0	1.5-3.4	15.4	1.5-3.64	18.4	0.6-1.8	52.1	1.5-3.16	14.0	1.5-3.13	16.4
						1.8-3.91	17.6				
SAMPLE NUMBER CM-355		SAMPLE NUMBER CM-356		SAMPLE NUMBER CM-357		SAMPLE NUMBER CM-358		SAMPLE NUMBER CM-359		SAMPLE NUMBER CM-360	
$H_o = 3.13$ $H_f = 3.13$ $H_u = 0$ $W_o = 14.9$		$H_o = 3.13$ $H_f = 3.13$ $H_u = 0$ $W_o = 14.9$		$H_o = 3.14$ $H_f = 3.14$ $H_u = 0$ $W_o = 15.9$		$H_o = 3.05$ $H_f = 3.50$ $H_u = 0$ $W_o = 14.1$		$H_o = 3.05$ $H_f = 3.32$ $H_u = 0$ $W_o = 13.5$		$H_o = 3.12$ $H_f = 3.26$ $H_u = 0$ $W_o = 15.1$	
Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %
0.0-1.5	10.9	0.0-1.5	10.2	0.0-1.7	10.9	0.0-1.9	29.2	0.0-1.5	20.9	0.0-1.5	17.7
1.5-3.13	13.7	1.5-3.13	16.2	1.7-3.14	19.0	1.9-3.50	12.7	1.5-3.32	16.4	1.5-3.26	13.1
SAMPLE NUMBER CM-361		SAMPLE NUMBER CM-362		SAMPLE NUMBER CM-363		SAMPLE NUMBER CM-364		SAMPLE NUMBER CM-365		SAMPLE NUMBER CM-366	
$H_o = 3.12$ $H_f = 3.13$ $H_u = 0$ $W_o = 15.7$		$H_o = 3.11$ $H_f = 3.20$ $H_u = 0$ $W_o = 15.6$		$H_o = 3.10$ $H_f = 3.26$ $H_u = 0$ $W_o = 15.6$		$H_o = 3.06$ $H_f = 3.34$ $H_u = 0$ $W_o = 15.1$		$H_o = 3.11$ $H_f = 3.28$ $H_u = 0$ $W_o = 15.4$		$H_o =$ $H_f =$ $H_u =$ $W_o =$	
Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %	Depth	W.C., %
0.0-1.5	18.4	0.0-1.5	17.6	0.0-1.5	17.9	0.0-1.5	22.6	0.0-1.5	19.9		
1.5-3.13	15.0	1.5-3.20	11.9	1.5-3.26	13.4	1.5-3.34	15.0	1.5-3.28	15.7		

H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of unfrozen portion in Inches
 W_o = Original Water Content in Per Cent

TABLE 07

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-295		SAMPLE NUMBER CM-296		SAMPLE NUMBER CM-297		SAMPLE NUMBER CM-298		SAMPLE NUMBER CM-299		SAMPLE NUMBER CM-300	
$H_o = 3.13$	$H_f = 3.23$	$H_o = 3.13$	$H_f = 3.25$	$H_o = 3.07$	$H_f = 3.23$	$H_o = 3.12$	$H_f = 3.29$	$H_o = 3.13$	$H_f = 3.28$	$H_o = 3.07$	$H_f = 3.29$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 14.9$	$W_o = 14.8$	$W_o = 14.8$	$W_o = 14.8$	$W_o = 14.8$	$W_o = 14.8$	$W_o = 14.4$	$W_o = 14.4$	$W_o = 14.0$	$W_o = 14.0$	$W_o = 14.1$	$W_o = 14.1$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	17.5	0.0-1.5	17.5	0.0-1.5	18.5	0.0-1.5	17.6	0.0-1.5	18.7	0.0-1.5	19.9
1.5-3.23	15.0	1.5-3.25	13.9	1.5-3.23	9.1	1.5-3.29	14.2	1.5-3.28	14.5	1.5-3.29	13.3
SAMPLE NUMBER CM-301		SAMPLE NUMBER CM-302		SAMPLE NUMBER CM-303		SAMPLE NUMBER CM-304		SAMPLE NUMBER CM-305		SAMPLE NUMBER CM-306	
$H_o = 3.07$	$H_f = 3.27$	$H_o = 3.01$	$H_f = 3.37$	$H_o = 3.10$	$H_f = 3.20$	$H_o = 3.00$	$H_f = 3.22$	$H_o = 2.97$	$H_f = 3.25$	$H_o = 3.17$	$H_f = 3.18$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 14.0$	$W_o = 14.0$	$W_o = 12.8$	$W_o = 12.8$	$W_o = 13.4$	$W_o = 13.4$	$W_o = 13.5$	$W_o = 13.5$	$W_o = 12.3$	$W_o = 12.3$	$W_o = 16.2$	$W_o = 16.2$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	18.9	0.0-1.5	22.6	0.0-1.5	17.5	0.0-1.5	17.8	0.0-1.5	20.0	0.0-1.5	13.0
1.5-3.27	11.4	1.5-3.37	22.7	1.5-3.2	13.2	1.5-3.22	10.9	1.5-3.25	10.3	1.5-3.18	15.4
SAMPLE NUMBER CM-307		SAMPLE NUMBER CM-308		SAMPLE NUMBER CM-309		SAMPLE NUMBER CM-310		SAMPLE NUMBER CM-311		SAMPLE NUMBER CM-312	
$H_o = 3.17$	$H_f = 3.19$	$H_o = 3.14$	$H_f = 3.20$	$H_o = 3.14$	$H_f = 3.28$	$H_o = 3.09$	$H_f = 3.23$	$H_o = 3.03$	$H_f = 3.23$	$H_o = 3.03$	$H_f = 3.17$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 16.0$	$W_o = 16.0$	$W_o = 15.5$	$W_o = 15.5$	$W_o = 15.3$	$W_o = 15.3$	$W_o = 15.1$	$W_o = 15.1$	$W_o = 14.4$	$W_o = 14.4$	$W_o = 14.1$	$W_o = 14.1$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	18.0	0.0-1.5	17.9	0.0-1.5	19.9	0.0-1.5	15.8	0.0-1.5	16.2	0.0-1.5	16.1
1.5-3.19	16.6	1.5-3.2	17.1	1.5-3.28	11.9	1.5-3.23	14.1	1.5-3.23	11.0	1.5-3.17	12.3

H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_o = Original Water Content in Per Cent

TABLE D8

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-43		SAMPLE NUMBER CM-44		SAMPLE NUMBER CM-45		SAMPLE NUMBER CM-46		SAMPLE NUMBER CM-47		SAMPLE NUMBER CM-48	
$H_o = 3.06$	$H_f = 3.10$	$H_o = 3.04$	$H_f = 3.24$	$H_o = 3.06$	$H_f = 3.62$	$H_o = 3.06$	$H_f = 3.61$	$H_o = 3.08$	$H_f = 3.19$	$H_o = 3.04$	$H_f = 3.17$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 15.1$	$W_o = 14.6$	$W_o = 14.6$	$W_o = 14.6$	$W_o = 14.8$	$W_o = 13.7$	$W_o = 13.7$	$W_o = 14.2$	$W_o = 14.2$	$W_o = 14.2$	$W_o = 14.0$	$W_o = 14.0$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	15.2	0.0-0.5	21.5	0.0-0.5	50.9	0.0-0.7	23.5	0.0-0.5	16.9	0.0-0.5	9.3
0.5-1.0	15.9	0.5-1.0	18.3	0.5-1.2	24.6	0.7-1.0	23.8	0.5-1.0	15.0	0.5-1.0	13.3
1.0-1.5	13.6	1.0-1.5	14.5	1.2-2.0	19.3	1.0-1.5	23.1	1.0-1.5	15.6	1.0-1.5	12.5
1.5-2.0	12.4	1.5-2.0	12.9	2.0-2.5	17.2	1.5-2.0	20.0	1.5-2.0	9.8	1.5-2.0	18.8
2.0-2.5	13.1	2.0-2.5	14.6	2.5-3.0	16.3	2.0-2.5	22.3	2.0-2.5	16.1	2.0-2.5	13.2
2.5-3.1	11.2	2.5-3.0	12.6	3.0-3.62	14.3	2.5-3.01	19.5	2.5-3.19	15.0	2.5-3.17	21.0
3.0-3.24	9.2										
SAMPLE NUMBER CM-49		SAMPLE NUMBER CM-50		SAMPLE NUMBER CM-51		SAMPLE NUMBER CM-52		SAMPLE NUMBER CM-53		SAMPLE NUMBER CM-54	
$H_o = 3.04$	$H_f = 3.38$	$H_o = 3.06$	$H_f = 3.57$	$H_o = 3.04$	$H_f = 3.37$	$H_o = 3.04$	$H_f = 3.43$	$H_o = 3.04$	$H_f = 3.19$	$H_o = 3.06$	$H_f = 3.17$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 15.3$	$W_o = 15.3$	$W_o = 15.0$	$W_o = 15.0$	$W_o = 17.2$	$W_o = 17.2$	$W_o = 18.0$	$W_o = 18.0$	$W_o = 16.1$	$W_o = 16.1$	$W_o = 14.6$	$W_o = 14.6$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.6	25.9	0.0-0.5	29.3	0.0-0.2	14.9	0.0-0.2	39.0	0.0-0.5	16.5	0.0-0.5	14.6
0.6-1.0	21.4	0.5-1.0	24.4	0.2-0.5	30.4	0.2-1.0	27.3	0.5-1.0	18.1	0.5-1.0	18.1
1.0-1.5	19.6	1.0-1.5	24.3	0.5-1.0	12.4	1.0-1.5	24.0	1.0-1.5	16.5	1.0-1.5	16.1
1.5-2.0	15.6	1.5-2.0	20.6	1.0-1.5	19.7	1.5-2.0	18.7	1.5-2.0	16.5	1.5-2.0	14.1
2.0-2.5	15.3	2.0-2.5	19.0	1.5-2.0	24.4	2.0-2.5	13.7	2.0-2.5	14.1	2.0-2.5	16.3
2.5-3.38	16.5	2.5-3.0	19.0	2.0-2.5	14.6	2.5-3.0	15.6	2.5-3.0	14.3	2.5-3.17	15.3
		3.0-3.57	16.6	2.5-3.0	15.4	3.0-3.43	12.5	3.0-3.19	13.7		
				3.0-3.37	14.0						
SAMPLE NUMBER CM-55		SAMPLE NUMBER CM-56		SAMPLE NUMBER CM-57		SAMPLE NUMBER CM-58		SAMPLE NUMBER CM-59		SAMPLE NUMBER CM-60	
$H_o = 3.06$	$H_f = 3.44$	$H_o = 3.08$	$H_f = 3.80$	$H_o = 3.08$	$H_f = 3.38$	$H_o = 3.02$	$H_f = 3.32$	$H_o = 3.04$	$H_f = 3.23$	$H_o = 3.06$	$H_f = 3.13$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 20.1$	$W_o = 20.1$	$W_o = 23.6$	$W_o = 23.6$	$W_o = 17.7$	$W_o = 17.7$	$W_o = 16.1$	$W_o = 16.1$	$W_o = 16.1$	$W_o = 16.1$	$W_o = 14.1$	$W_o = 14.1$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	25.8	0.0-0.7	14.9	0.0-0.5	25.4	0.0-0.5	21.0	0.0-0.5	14.5	0.0-0.5	11.1
0.5-1.0	30.4	0.7-1.0	38.1	0.5-1.0	23.8	0.5-1.0	19.5	0.5-1.0	17.7	0.5-1.0	16.3
1.0-1.5	19.1	1.0-1.5	26.1	1.0-1.5	16.9	1.0-1.5	15.1	1.0-1.5	18.1	1.0-1.5	14.5
1.5-2.0	21.2	1.5-2.0	29.5	1.5-2.0	12.0	1.5-2.0	13.3	1.5-2.0	15.6	1.5-2.0	13.6
2.0-2.5	18.3	2.0-2.5	26.1	2.0-2.5	17.1	2.0-2.5	14.9	2.0-2.5	14.6	2.0-2.5	15.2
2.5-3.0	15.8	2.5-3.0	20.4	2.5-3.0	14.2	2.5-3.0	13.9	2.5-3.0	9.1	2.5-3.13	16.1
3.0-3.44	14.5	3.0-3.5	17.8	3.0-3.38	16.6	3.0-3.32	15.5	3.0-3.23	19.6		
		3.5-3.8	17.7								

H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_o = Original Water Content in Per Cent

TABLE D9

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-241		SAMPLE NUMBER CM-242		SAMPLE NUMBER CM-243		SAMPLE NUMBER CM-244		SAMPLE NUMBER CM-245		SAMPLE NUMBER CM-246	
$H_o = 3.11$	$H_f = 3.15$	$H_o = 3.11$	$H_f = 3.17$	$H_o = 3.11$	$H_f = 3.14$	$H_o = 3.11$	$H_f = 3.13$	$H_o = 3.11$	$H_f = 3.33$	$H_o = 3.11$	$H_f = 3.21$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 14.7$		$W_o = 17.0$		$W_o = 15.3$		$W_o = 15.4$		$W_o = 22.2$		$W_o = 16.0$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	11.5	0.0-1.5	13.7	0.0-1.5	10.5	0.0-1.5	12.5	0.0-1.5	13.0	0.0-1.5	14.9
1.5-3.15	15.8	1.5-3.17	19.2	1.5-3.14	21.2	1.5-3.13	17.0	1.5-3.33	28.7	1.5-3.21	15.8

SAMPLE NUMBER CM-247		SAMPLE NUMBER CM-248		SAMPLE NUMBER CM-249		SAMPLE NUMBER CM-250		SAMPLE NUMBER CM-251		SAMPLE NUMBER CM-252	
$H_o = 3.11$	$H_f = 3.19$	$H_o = 3.11$	$H_f = 3.14$	$H_o = 3.11$	$H_f = 3.20$	$H_o = 3.11$	$H_f = 3.22$	$H_o = 3.11$	$H_f = 3.23$	$H_o = 3.11$	$H_f = 3.26$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 16.0$		$W_o = 15.2$		$W_o = 16.1$		$W_o = 15.8$		$W_o = 16.2$		$W_o = 15.0$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	15.5	0.0-1.5	15.3	0.0-1.5	15.6	0.0-1.5	14.7	0.0-1.5	15.9	0.0-1.5	17.3
1.5-3.19	13.7	1.5-3.14	13.0	1.5-3.2	13.1	1.5-3.22	14.7	1.5-3.23	14.4	1.5-3.26	13.6

SAMPLE NUMBER CM-253		SAMPLE NUMBER CM-254		SAMPLE NUMBER CM-255		SAMPLE NUMBER CM-256		SAMPLE NUMBER CM-257		SAMPLE NUMBER CM-258	
$H_o = 3.01$	$H_f = 3.23$	$H_o = 3.04$	$H_f = 3.29$	$H_o = 3.00$	$H_f = 3.24$	$H_o = 3.05$	$H_f = 3.21$	$H_o = 3.11$	$H_f = 3.26$	$H_o = 3.03$	$H_f = 3.29$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 13.8$		$W_o = 11.2$		$W_o = 11.0$		$W_o = 16.5$		$W_o = 15.3$		$W_o = 12.1$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	17.3	0.0-1.5	18.9	0.0-1.5	21.3	0.0-1.5	18.1	0.0-1.5	18.8	0.0-1.5	21.9
1.5-3.23	11.1	1.5-3.29	11.2	1.5-3.24	9.5	1.5-3.21	13.4	1.5-3.26	14.5	1.5-3.29	11.9

H_o = Original Height in Inches.
 H_f = Final Height in Inches.
 H_u = Thickness of Unfrozen Portion in Inches
 W_o = Original Water Content in Per Cent.

TABLE DIO

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-61		SAMPLE NUMBER CM-62		SAMPLE NUMBER CM-63		SAMPLE NUMBER CM-64		SAMPLE NUMBER CM-65		SAMPLE NUMBER CM-66	
$H_0 =$	3.08	$H_0 =$	3.10	$H_0 =$	3.08	$H_0 =$	3.06	$H_0 =$	3.06	$H_0 =$	3.08
$H_f =$	3.23	$H_f =$	3.43	$H_f =$	3.12	$H_f =$	3.55	$H_f =$	3.15	$H_f =$	3.23
$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0
$W_0 =$	16.5	$W_0 =$	17.6	$W_0 =$	17.5	$W_0 =$	19.2	$W_0 =$	16.2	$W_0 =$	15.6
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	21.3	0.0-0.7	28.6	0.0-0.5	26.4	0.0-0.5	28.8	0.0-0.5	19.0	0.0-0.5	28.3
0.5-1.0	21.6	0.7-1.5	22.8	0.5-1.0	24.8	0.5-1.0	23.7	0.5-1.0	22.9	0.5-1.0	15.4
1.0-1.5	22.6	1.5-2.0	15.7	1.0-1.5	17.7	1.0-1.5	29.7	1.0-1.5	14.5	1.0-1.5	15.0
1.5-2.0	16.1	2.0-2.5	13.9	1.5-2.0	15.0	1.5-2.0	25.7	1.5-2.0	14.5	1.5-2.0	14.2
2.0-2.5	15.4	2.5-3.0	13.2	2.0-2.5	16.3	2.0-2.5	13.5	2.0-2.5	13.0	2.0-2.5	14.6
2.5-3.0	10.8	3.0-3.43	16.7	2.5-3.12	13.2	2.5-3.0	10.3	2.5-3.0	13.1	2.5-3.0	16.0
3.0-3.23	13.3					3.0-3.55	13.0	3.0-3.15	15.3	3.0-3.23	13.2

SAMPLE NUMBER CM-67		SAMPLE NUMBER CM-68		SAMPLE NUMBER CM-69		SAMPLE NUMBER CM-70		SAMPLE NUMBER CM-71		SAMPLE NUMBER CM-72	
$H_0 =$	3.10	$H_0 =$	3.10	$H_0 =$	3.10	$H_0 =$	3.04	$H_0 =$	3.06	$H_0 =$	3.06
$H_f =$	3.19	$H_f =$	3.16	$H_f =$	3.30	$H_f =$	3.13	$H_f =$	3.32	$H_f =$	3.53
$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0
$W_0 =$	17.4	$W_0 =$	11.1	$W_0 =$	16.9	$W_0 =$	17.5	$W_0 =$	17.8	$W_0 =$	18.3
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	25.3	0.0-0.5	21.0	0.0-0.5	24.4	0.0-0.5	28.2	0.0-0.5	19.1	0.0-0.5	24.1
0.5-1.0	23.3	0.5-1.0	9.6	0.5-1.0	25.3	0.5-1.0	24.0	0.5-1.0	21.0	0.5-1.0	24.6
1.0-1.5	19.6	1.0-1.5	13.2	1.0-1.5	15.8	1.0-1.5	17.4	1.0-1.5	21.2	1.0-1.5	21.0
1.5-2.0	16.7	1.5-2.0	15.0	1.5-2.0	13.0	1.5-2.0	14.4	1.5-2.0	14.5	1.5-2.0	17.2
2.0-2.5	14.3	2.0-2.5	10.9	2.0-2.5	13.3	2.0-2.5	15.5	2.0-2.5	17.9	2.0-2.5	15.1
2.5-3.0	12.8	2.5-3.16	11.1	2.5-3.0	13.4	2.5-3.13	15.5	2.5-3.0	16.4	2.5-3.0	15.1
3.0-3.19	13.2			3.0-3.3	11.2			3.0-3.32	18.5	3.0-3.53	13.7

SAMPLE NUMBER CM-73		SAMPLE NUMBER CM-74		SAMPLE NUMBER CM-75		SAMPLE NUMBER CM-76		SAMPLE NUMBER CM-77		SAMPLE NUMBER CM-78	
$H_0 =$	3.10	$H_0 =$	3.08	$H_0 =$	3.10	$H_0 =$	3.08	$H_0 =$	3.08	$H_0 =$	3.08
$H_f =$	3.57	$H_f =$	3.32	$H_f =$	3.60	$H_f =$	4.20	$H_f =$	3.15	$H_f =$	3.13
$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0	$H_u =$	0
$W_0 =$	19.5	$W_0 =$	16.1	$W_0 =$	23.4	$W_0 =$	31.0	$W_0 =$	13.1	$W_0 =$	15.2
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	33.9	0.0-0.5	24.5	0.0-0.5	35.2	0.0-0.7	35.4	0.0-0.5	10.1	0.0-0.5	15.2
0.5-1.0	21.1	0.5-1.0	14.3	0.5-1.0	25.2	0.7-1.2	68.9	0.5-1.0	16.9	0.5-1.0	14.2
1.0-1.5	18.2	1.0-1.5	16.2	1.0-1.5	27.5	1.2-2.0	37.5	1.0-1.5	13.6	1.0-1.5	15.7
1.5-2.0	20.8	1.5-2.0	11.3	1.5-2.0	20.9	2.0-2.5	41.4	1.5-2.0	12.2	1.5-2.0	14.8
2.0-2.5	14.3	2.0-2.5	15.1	2.0-2.5	22.4	2.5-3.0	33.5	2.0-2.5	14.9	2.0-2.5	16.6
2.5-3.0	15.8	2.5-3.0	12.5	2.5-3.0	16.4	3.0-3.5	24.9	2.5-3.15	13.0	2.5-3.0	16.6
3.0-3.57	16.8	3.0-3.32	13.2	3.0-3.6	13.8	3.5-4.0	18.3			2.5-3.13	19.0
						4.0-4.2	11.7				

H_0 = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_0 = Original Water Content in Per Cent

TABLE DII

COLD ROOM STUDIES OF FROST ACTION IN SOILS
 PHYSICAL YEARS 1952 AND 1953

WATER CONTENT DISTRIBUTION
 AFTER FREEZING

SAMPLE NUMBER CM-313		SAMPLE NUMBER CM-314		SAMPLE NUMBER CM-315		SAMPLE NUMBER CM-316		SAMPLE NUMBER CM-317		SAMPLE NUMBER CM-318	
$H_o = 3.03$	$H_f = 3.27$	$H_o = 3.09$	$H_f = 3.25$	$H_o = 3.12$	$H_f = 3.17$	$H_o = 3.12$	$H_f = 3.23$	$H_o = 3.16$	$H_f = 3.18$	$H_o = 3.12$	$H_f = 3.23$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 14.4$	$W_o = 14.4$	$W_o = 14.2$	$W_o = 14.2$	$W_o = 15.2$	$W_o = 15.2$	$W_o = 15.7$	$W_o = 15.7$	$W_o = 15.8$	$W_o = 15.8$	$W_o = 15.8$	$W_o = 15.8$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	17.9	0.0-1.5	17.2	0.0-1.5	13.9	0.0-1.5	17.5	0.0-1.5	17.3	0.0-1.5	16.6
1.5-3.27	12.2	1.5-3.25	13.3	1.5-3.17	12.9	1.5-3.23	15.4	1.5-3.18	15.8	1.5-3.23	13.1
SAMPLE NUMBER CM-319		SAMPLE NUMBER CM-320		SAMPLE NUMBER CM-321		SAMPLE NUMBER CM-322		SAMPLE NUMBER CM-323		SAMPLE NUMBER CM-324	
$H_o = 3.12$	$H_f = 3.14$	$H_o = 3.13$	$H_f = 3.14$	$H_o = 3.13$	$H_f = 3.17$	$H_o = 3.11$	$H_f = 3.24$	$H_o = 3.12$	$H_f = 3.39$	$H_o = 3.12$	$H_f = 3.52$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 14.8$	$W_o = 14.8$	$W_o = 14.4$	$W_o = 14.4$	$W_o = 15.6$	$W_o = 15.6$	$W_o = 16.1$	$W_o = 16.1$	$W_o = 15.5$	$W_o = 15.5$	$W_o = 15.1$	$W_o = 15.1$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	14.3	0.0-1.5	12.7	0.0-1.5	19.8	0.0-1.5	19.9	0.0-1.5	20.9	0.0-1.5	20.7
1.5-3.14	14.2	1.5-3.14	13.7	1.5-3.17	14.8	1.5-3.24	15.0	1.5-3.37	15.8	1.5-3.52	16.4
SAMPLE NUMBER CM-325		SAMPLE NUMBER CM-326		SAMPLE NUMBER CM-327		SAMPLE NUMBER CM-328		SAMPLE NUMBER CM-329		SAMPLE NUMBER CM-330	
$H_o = 3.13$	$H_f = 3.70$	$H_o = 3.11$	$H_f = 3.21$	$H_o = 3.10$	$H_f = 3.23$	$H_o = 3.13$	$H_f = 3.19$	$H_o = 3.13$	$H_f = 3.17$	$H_o = 3.13$	$H_f = 3.14$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 14.6$	$W_o = 14.6$	$W_o = 14.8$	$W_o = 14.8$	$W_o = 15.4$	$W_o = 15.4$	$W_o = 15.4$	$W_o = 15.4$	$W_o = 15.7$	$W_o = 15.7$	$W_o = 16.2$	$W_o = 16.2$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-2.0	20.8	0.0-1.5	16.3	0.0-1.5	15.2	0.0-1.5	16.0	0.0-1.5	14.9	0.0-1.5	14.1
2.0-3.2	23.0	1.5-3.21	13.9	1.5-3.23	13.7	1.5-3.19	12.6	1.5-3.17	13.8	1.5-3.14	14.3
3.2-3.7	23.7										

H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_o = Original Water Content in Per Cent

TABLE D12

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FRESHING

SAMPLE NUMBER CM-331		SAMPLE NUMBER CM-332		SAMPLE NUMBER CM-333		SAMPLE NUMBER CM-334		SAMPLE NUMBER CM-335		SAMPLE NUMBER CM-336	
$H_o = 3.12$	$H_f = 3.20$	$H_o = 3.13$	$H_f = 3.17$	$H_o = 3.13$	$H_f = 3.19$	$H_o = 3.15$	$H_f = 3.19$	$H_o = 3.18$	$H_f = 3.32$	$H_o = 3.06$	$H_f = 3.21$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 15.0$	$W_o = 15.0$	$W_o = 15.2$	$W_o = 15.2$	$W_o = 16.5$	$W_o = 16.5$	$W_o = 15.5$	$W_o = 15.5$	$W_o = 21.8$	$W_o = 21.8$	$W_o = 14.7$	$W_o = 14.7$
Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%
0.0-1.5	16.3	0.0-1.5	15.3	0.0-1.5	11.3	0.0-1.5	13.9	0.0-1.5	19.7	0.0-1.5	19.8
1.5-3.2	12.4	1.5-3.17	12.7	1.5-3.19	11.9	1.5-3.19	16.7	1.5-3.32	16.7	1.5-3.21	13.4
SAMPLE NUMBER CM-337		SAMPLE NUMBER CM-338		SAMPLE NUMBER CM-339		SAMPLE NUMBER CM-340		SAMPLE NUMBER CM-341		SAMPLE NUMBER CM-342	
$H_o = 3.09$	$H_f = 3.13$	$H_o = 3.13$	$H_f = 3.26$	$H_o = 3.14$	$H_f = 3.25$	$H_o = 3.08$	$H_f = 3.35$	$H_o = 3.09$	$H_f = 3.50$	$H_o = 3.15$	$H_f = 3.18$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 11.4$	$W_o = 11.4$	$W_o = 18.0$	$W_o = 18.0$	$W_o = 11.8$	$W_o = 11.8$	$W_o = 11.8$	$W_o = 11.8$	$W_o = 11.7$	$W_o = 11.7$	$W_o = 17.0$	$W_o = 17.0$
Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%
0.0-1.5	17.3	0.0-1.5	16.7	0.0-1.5	19.8	0.0-1.5	12.6	0.0-1.5	21.7	0.0-1.5	21.8
1.5-3.13	14.2	1.5-3.26	15.2	1.5-3.25	11.5	1.5-3.35	20.0	1.5-3.30	11.9	1.5-3.18	14.5
SAMPLE NUMBER CM-343		SAMPLE NUMBER CM-344		SAMPLE NUMBER CM-345		SAMPLE NUMBER CM-346		SAMPLE NUMBER CM-347		SAMPLE NUMBER CM-348	
$H_o = 3.10$	$H_f = 3.17$	$H_o = 3.19$	$H_f = 3.56$	$H_o = 3.10$	$H_f = 3.27$	$H_o = 3.10$	$H_f = 3.27$	$H_o = 3.11$	$H_f = 3.24$	$H_o = 3.10$	$H_f = 3.36$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 15.7$	$W_o = 15.7$	$W_o = 25.4$	$W_o = 25.4$	$W_o = 15.0$	$W_o = 15.0$	$W_o = 14.9$	$W_o = 14.9$	$W_o = 15.6$	$W_o = 15.6$	$W_o = 14.9$	$W_o = 14.9$
Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%	Depth	W.C.,%
0.0-1.5	25.8	0.0-1.5	27.8	0.0-1.5	18.2	0.0-1.5	17.5	0.0-1.5	19.0	0.0-1.5	19.7
1.5-3.17	12.6	1.5-3.56	23.5	1.5-3.27	15.8	1.5-3.27	14.2	1.5-3.24	15.7	1.5-3.36	15.6

H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Partion in Inches
 W_o = Original Water Content in Per Cent

TABLE D13

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-223		SAMPLE NUMBER CM-224		SAMPLE NUMBER CM-225		SAMPLE NUMBER CM-226		SAMPLE NUMBER CM-227		SAMPLE NUMBER CM-228	
$H_o = 3.11$	$H_f = 3.31$	$H_o = 3.11$	$H_f = 3.39$	$H_o = 3.11$	$H_f = 3.53$	$H_o = 3.11$	$H_f = 3.89$	$H_o = 3.11$	$H_f = 3.53$	$H_o = 3.11$	$H_f = 3.73$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 16.4$		$W_o = 17.3$		$W_o = 16.2$		$W_o = 14.2$		$W_o = 14.5$		$W_o = 13.7$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	13.9	0.0-1.0	22.2	0.0-1.0	22.9	0.0-0.7	20.0	0.0-1.0	23.6	0.0-1.0	25.4
1.0-2.0	13.2	1.0-2.0	15.6	1.0-2.0	18.5	0.7-2.2	26.3	1.0-2.0	17.2	1.0-2.0	20.1
2.0-3.31	13.4	2.0-3.39	15.0	2.0-3.53	14.8	2.2-3.89	19.7	2.0-3.53	15.8	2.0-3.73	18.7
SAMPLE NUMBER CM-229		SAMPLE NUMBER CM-230		SAMPLE NUMBER CM-231		SAMPLE NUMBER CM-232		SAMPLE NUMBER CM-233		SAMPLE NUMBER CM-234	
$H_o = 3.11$	$H_f = 4.20$	$H_o = 3.11$	$H_f = 4.27$	$H_o = 3.11$	$H_f = 3.34$	$H_o = 3.11$	$H_f = 3.29$	$H_o = 3.11$	$H_f = 3.29$	$H_o = 3.11$	$H_f = 3.36$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 13.7$		$W_o = 14.6$		$W_o = 13.9$		$W_o = 13.9$		$W_o = 15.3$		$W_o = 15.2$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	24.2	0.0-1.4	18.8	0.0-1.0	20.4	0.0-1.5	17.7	0.0-1.5	18.6	0.0-1.5	18.9
1.5-3.5	37.0	1.4-3.1	52.4	1.0-2.0	9.7	1.5-3.29	15.9	1.5-3.29	14.6	1.5-3.36	14.0
3.5-4.2	12.4	3.1-4.29	13.5	2.0-3.34	16.9						
SAMPLE NUMBER CM-235		SAMPLE NUMBER CM-236		SAMPLE NUMBER CM-237		SAMPLE NUMBER CM-238		SAMPLE NUMBER CM-239		SAMPLE NUMBER CM-240	
$H_o = 3.11$	$H_f = 3.48$	$H_o = 3.11$	$H_f = 3.36$	$H_o = 3.11$	$H_f = 3.17$	$H_o = 3.11$	$H_f = 3.27$	$H_o = 3.11$	$H_f = 3.23$	$H_o = 3.11$	$H_f = 3.22$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_o = 14.2$		$W_o = 15.3$		$W_o = 15.0$		$W_o = 16.0$		$W_o = 16.5$		$W_o = 15.7$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	21.1	0.0-1.5	17.8	0.0-1.5	14.6	0.0-1.5	15.9	0.0-1.5	18.0	0.0-1.5	14.0
1.5-3.48	14.1	1.5-2.6	18.9	1.5-3.17	15.2	1.5-3.27	16.6	1.5-3.23	16.0	1.5-3.22	15.7
		2.6-3.36	12.4								

H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_o = Original Water Content in per Cent

TABLE D14

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER FB-7-A		SAMPLE NUMBER FB-8-A		SAMPLE NUMBER FB-9-A		SAMPLE NUMBER FB-10-A		SAMPLE NUMBER FB-11-A		SAMPLE NUMBER FB-12-A	
$H_0 = 6.00$ $H_f = 7.09$ $H_u = 0$ $W_0 = 15.0$		$H_0 = 6.00$ $H_f = 6.33$ $H_u = 0$ $W_0 = 15.0$		$H_0 = 6.00$ $H_f = 7.17$ $H_u = 0.70$ $W_0 = 18.5$		$H_0 = 6.06$ $H_f = 7.34$ $H_u = 0.50$ $W_0 = 17.6$		$H_0 = 6.00$ $H_f = 6.96$ $H_u = 0$ $W_0 = 21.1$		$H_0 = 6.00$ $H_f = 6.24$ $H_u = 1.06$ $W_0 = 18.4$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	13.2	0.0-0.5	17.1	0.0-1.0	25.8	0.0-1.0	14.8	0.0-1.0	20.2	0.0-0.5	30.7
1.0-2.0	21.9	0.5-1.0	17.1	1.0-1.5	23.5	1.0-1.7	20.0	1.0-2.0	24.7	0.5-1.5	21.1
2.0-3.0	21.1	1.0-2.0	21.1	1.5-2.2	28.4	1.7-3.0	23.9	2.0-3.0	26.1	1.5-2.2	20.0
3.0-3.5	27.0	2.0-3.0	16.6	2.2-3.0	23.9	3.0-4.0	24.0	3.0-4.0	30.5	2.2-3.0	17.2
3.5-4.0	27.0	3.0-4.0	13.1	3.0-4.0	20.9	4.0-5.0	25.7	4.0-5.0	30.0	3.0-4.0	15.8
4.0-4.7	20.5	4.0-5.0	14.9	4.0-5.0	25.4	5.0-6.0	39.8	5.0-6.0	35.2	4.0-5.0	15.8
4.7-5.5	22.9	5.0-6.0	12.8	5.0-6.0	36.0	6.0-6.5	37.2	6.0-6.96	36.4	5.0-5.2	16.2
5.5-6.5	19.7	6.0-6.33	17.9	6.0-6.5	28.2	6.5-6.8	27.2			5.2-6.24	17.5
6.5-7.0	96.9			6.5-7.17	19.4	6.8-7.34	18.5				
7.0-7.09	20.3										

SAMPLE NUMBER FB-13-A		SAMPLE NUMBER FB-14-A		SAMPLE NUMBER FB-15-A		SAMPLE NUMBER FB-16-A		SAMPLE NUMBER FB-17-A		SAMPLE NUMBER FB-18-A	
$H_0 = 6.00$ $H_f = 6.13$ $H_u = 0.00$ $W_0 = 19.5$		$H_0 = 6.00$ $H_f = 7.60$ $H_u = 0$ $W_0 = 16.2$		$H_0 = 6.02$ $H_f = 7.40$ $H_u = 0$ $W_0 = 16.4$		$H_0 = 6.00$ $H_f = 6.70$ $H_u = 0$ $W_0 = 17.7$		$H_0 = 6.00$ $H_f = 6.38$ $H_u = 0$ $W_0 = 16.8$		$H_0 = 6.06$ $H_f = 6.22$ $H_u = 0$ $W_0 = 15.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	26.4	0.0-1.0	26.4	0.0-1.0	23.1	0.0-1.0	21.1	0.0-1.1	20.7	0.0-1.0	16.1
1.0-2.0	19.4	1.0-2.0	19.4	1.0-2.0	21.9	1.0-2.0	20.9	1.1-2.2	21.4	1.0-2.0	14.5
2.0-3.0	17.9	2.0-2.7	30.8	2.0-3.0	30.8	2.0-3.0	22.3	2.2-3.2	24.8	2.0-3.0	15.3
3.0-4.0	18.3	2.7-3.4	14.8	3.0-4.0	24.4	3.0-4.0	20.3	3.2-4.5	14.7	3.0-4.0	14.2
4.0-5.0	17.0	3.4-3.9	59.5	4.0-5.0	31.1	4.0-5.0	25.3	4.5-5.5	15.1	4.0-5.0	14.9
5.0-5.4	15.6	3.9-4.9	19.0	5.0-6.0	23.7	5.0-6.0	29.4	5.5-6.58	14.3	5.0-6.22	17.8
5.4-6.16	19.7	4.9-5.0	31.0	6.0-7.4	42.3	6.0-6.7	36.9				
		5.0-6.8	36.0								
		6.8-7.66	19.9								

SAMPLE NUMBER FB-19-A		SAMPLE NUMBER FB-20-A		SAMPLE NUMBER FB-21-A		SAMPLE NUMBER FB-22-A		SAMPLE NUMBER FB-23-A		SAMPLE NUMBER FB-24-A	
$H_0 = 6.00$ $H_f = 12.31$ $H_u = 1.50$ $W_0 = 20.5$		$H_0 = 6.00$ $H_f = 7.96$ $H_u = 0.75$ $W_0 = 23.0$		$H_0 = 6.00$ $H_f = 8.89$ $H_u = 1.00$ $W_0 = 23.7$		$H_0 = 6.00$ $H_f = 7.93$ $H_u = 2.10$ $W_0 = 18.6$		$H_0 = 6.00$ $H_f = 7.70$ $H_u = 0.75$ $W_0 = 20.2$		$H_0 =$ $H_f =$ $H_u =$ $W_0 =$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	63.3	0.0-1.0	65.2	0.0-0.5	38.7	0.0-1.0	33.6	0.0-1.0	50.4		
1.0-2.0	70.5	1.0-2.0	41.1	0.5-2.5	24.4	1.0-2.0	27.1	1.0-2.0	40.0		
2.0-3.0	83.1	2.0-3.0	36.0	2.5-3.0	80.8	2.0-3.0	16.0	2.0-3.0	40.0		
3.0-4.0	100.1	3.0-4.0	49.4	3.0-3.2	131.2	3.0-4.0	68.5	3.0-4.0	39.1		
4.0-6.0	134.9	4.0-5.0	33.1	3.2-4.0	74.6	4.0-5.0	73.4	4.0-5.0	39.6		
6.0-9.0	158.7	5.0-6.0	28.0	4.0-5.5	95.6	5.0-5.8	66.6	5.0-6.0	47.9		
9.0-10.0	35.70	6.0-7.0	27.4	5.5-6.0	57.9	5.8-7.0	20.4	6.0-7.0	37.8		
10.0-10.7	225.8	7.0-7.2	14.4	6.0-7.0	134.3	7.0-7.93	19.2	7.0-7.70	20.9		
10.7-12.31	24.1	7.2-7.96	25.0	7.0-8.89	22.8						

H_0 = Original Height in Inches.
 H_f = Final Height in Inches.
 H_u = Thickness of Unfrozen Portion in Inches.
 W_0 = Original Water Content in Per Cent.

TABLE D 15

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-169		SAMPLE NUMBER CM-170		SAMPLE NUMBER CM-171		SAMPLE NUMBER CM-172		SAMPLE NUMBER CM-173		SAMPLE NUMBER CM-174	
$H_o = 3.06$ $H_f = 3.24$ $H_u = 0$ $W_o = 27.4$		$H_o = 3.11$ $H_f = 3.71$ $H_u = 0$ $W_o = 29.1$		$H_o = 3.07$ $H_f = 3.78$ $H_u = 0$ $W_o = 28.9$		$H_o = 3.02$ $H_f = 3.18$ $H_u = 0$ $W_o = 29.0$		$H_o = 3.04$ $H_f = 3.66$ $H_u = 0$ $W_o = -$		$H_o = 3.11$ $H_f = 3.83$ $H_u = 0$ $W_o = 26.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.7	50.9	0.0-0.9	48.0	0.0-1.0	39.9	0.0-0.2	22.2	0.0-0.5	16.5	0.0-0.5	55.6
0.7-2.0	27.3	0.9-1.1	78.3	1.0-2.0	55.8	0.2-1.0	31.5	0.5-1.0	39.6	0.5-1.5	50.0
2.0-3.24	23.2	1.1-1.4	101.1	2.0-3.2	33.0	1.0-2.0	26.6	1.0-1.7	16.8	1.5-2.5	63.5
		1.4-2.1	35.1	3.2-3.78	24.9	2.0-3.18	25.3	1.7-2.1	26.7	2.5-3.83	24.1
		2.1-3.0	25.1					2.1-3.66	25.7		
		3.0-3.71	26.2								
SAMPLE NUMBER CM-175		SAMPLE NUMBER CM-176		SAMPLE NUMBER CM-177		SAMPLE NUMBER CM-178		SAMPLE NUMBER CM-179		SAMPLE NUMBER CM-180	
$H_o = 3.07$ $H_f = 3.99$ $H_u = 0$ $W_o = 27.0$		$H_o = 3.11$ $H_f = 3.90$ $H_u = 0$ $W_o = 24.5$		$H_o = 3.11$ $H_f = 3.43$ $H_u = 0$ $W_o = 27.6$		$H_o = 3.02$ $H_f = 4.10$ $H_u = 0$ $W_o = 29.3$		$H_o = 3.07$ $H_f = 3.77$ $H_u = 0$ $W_o = 28.5$		$H_o = 3.00$ $H_f = 3.54$ $H_u = 0$ $W_o = 29.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	57.3	0.0-1.1	42.8	0.0-0.5	24.9	0.0-1.0	17.0	0.0-0.8	27.9	0.0-0.5	13.8
0.5-1.3	43.5	1.1-2.0	53.6	0.5-1.7	27.4	1.0-2.0	66.5	0.8-1.6	72.9	0.5-1.8	36.5
1.3-2.3	66.5	2.0-3.9	27.7	1.7-3.43	21.1	2.0-2.3	58.1	1.6-2.1	48.7	1.8-2.8	31.7
2.3-3.99	25.9					2.3-4.1	29.5	2.1-3.77	26.9	2.8-3.54	27.3
SAMPLE NUMBER CM-181		SAMPLE NUMBER CM-182		SAMPLE NUMBER CM-183		SAMPLE NUMBER CM-184		SAMPLE NUMBER CM-185		SAMPLE NUMBER CM-186	
$H_o = 3.00$ $H_f = 4.14$ $H_u = 0$ $W_o = 29.1$		$H_o = 3.01$ $H_f = 3.55$ $H_u = 0$ $W_o = 29.4$		$H_o = 3.02$ $H_f = 3.65$ $H_u = 0$ $W_o = 28.5$		$H_o = 3.11$ $H_f = 3.54$ $H_u = 0$ $W_o = -$		$H_o = 3.08$ $H_f = 3.57$ $H_u = 0$ $W_o = 27.1$		$H_o = 2.97$ $H_f = 3.76$ $H_u = 0$ $W_o = 29.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	53.8	0.0-1.0	39.2	0.0-0.7	39.6	0.0-1.0	19.8	0.0-1.0	52.6	0.0-1.4	42.0
1.0-2.0	102.4	1.0-2.0	39.6	0.7-1.6	41.9	1.0-2.0	42.3	1.0-1.8	36.5	1.4-2.1	70.1
2.0-4.14	28.9	2.0-3.55	27.0	1.6-2.9	37.4	2.0-3.54	24.9	1.8-3.57	25.0	2.1-3.76	25.4
				2.9-3.65	30.0						

H_o = Original Height in Inches.
 H_f = Final Height in Inches.
 H_u = Thickness of Unfrozen Portion in Inches.
 W_o = Original Water Content in Per Cent.

TABLE D16

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FROSTING

SAMPLE NUMBER CM-187		SAMPLE NUMBER CM-188		SAMPLE NUMBER CM-189		SAMPLE NUMBER CM-190		SAMPLE NUMBER CM-191		SAMPLE NUMBER CM-192	
$H_o = 3.12$	$H_f = 3.61$	$H_o = 3.12$	$H_f = 3.63$	$H_o = 3.12$	$H_f = 3.20$	$H_o = 3.13$	$H_f = 4.28$	$H_o = 3.12$	$H_f = 4.13$	$H_o = 3.12$	$H_f = 4.24$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 19.1$	$W_o = 19.4$	$W_o = 19.4$	$W_o = 19.4$	$W_o = 19.4$	$W_o = 19.4$	$W_o = 19.6$	$W_o = 19.6$	$W_o = 19.8$	$W_o = 19.8$	$W_o = 18.6$	$W_o = 18.6$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	34.5	0.0-1.0	21.2	0.0-1.0	22.0	0.0-1.0	80.1	0.0-1.0	20.1	0.0-1.0	30.7
1.0-2.0	33.7	1.0-2.0	34.5	1.0-2.5	25.8	1.0-2.0	60.2	1.0-2.0	39.6	1.0-2.0	51.7
2.0-2.9	32.1	2.0-3.6	23.3	2.5-3.2	19.3	2.0-3.0	26.2	2.0-3.0	56.7	2.0-3.0	66.6
2.9-3.6	25.3					3.0-3.5	46.2	3.0-3.5	22.6	3.0-3.5	22.9
						3.5-4.4	23.0	3.5-4.13		3.4-4.24	
SAMPLE NUMBER CM-193		SAMPLE NUMBER CM-194		SAMPLE NUMBER CM-195		SAMPLE NUMBER CM-196		SAMPLE NUMBER CM-197		SAMPLE NUMBER CM-198	
$H_o = 3.11$	$H_f = 3.59$	$H_o = 3.13$	$H_f = 3.54$	$H_o = 3.12$	$H_f = 3.42$	$H_o = 3.12$	$H_f = 3.64$	$H_o = 3.11$	$H_f = 3.52$	$H_o = 3.13$	$H_f = 3.37$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 19.3$	$W_o = 19.3$	$W_o = 19.5$	$W_o = 19.5$	$W_o = 19.8$	$W_o = 19.8$	$W_o = 19.6$	$W_o = 19.6$	$W_o = 20.1$	$W_o = 20.1$	$W_o = 19.6$	$W_o = 19.6$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.2	29.7	0.0-1.2	27.3	0.0-1.2	30.7	0.0-1.0	26.3	0.0-1.2	21.3	0.0-1.0	21.8
1.2-2.4	18.0	1.2-2.9	30.9	1.2-2.9	32.3	1.0-2.5	43.1	1.2-2.4	30.7	1.0-2.0	26.3
2.4-3.59	25.2	2.9-3.54	22.2	2.9-3.42	23.8	2.5-3.66	23.4	2.4-3.62	23.7	2.0-3.37	24.0
SAMPLE NUMBER CM-199		SAMPLE NUMBER CM-200		SAMPLE NUMBER CM-201		SAMPLE NUMBER CM-202		SAMPLE NUMBER CM-203		SAMPLE NUMBER CM-204	
$H_o = 3.16$	$H_f = 4.15$	$H_o = 3.18$	$H_f = 4.17$	$H_o = 3.16$	$H_f = 4.11$	$H_o = 3.18$	$H_f = 4.74$	$H_o = 3.18$	$H_f = 5.55$	$H_o = 3.18$	$H_f = 5.76$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 27.0$	$W_o = 27.0$	$W_o = 32.0$	$W_o = 32.0$	$W_o = 29.6$	$W_o = 29.6$	$W_o = 32.6$	$W_o = 32.6$	$W_o = 35.1$	$W_o = 35.1$	$W_o = 30.9$	$W_o = 30.9$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	24.2	0.0-2.0	53.8	0.0-1.0	37.0	0.0-1.0	28.3	0.0-1.2	15.0	0.0-1.2	52.6
1.0-2.4	44.5	2.0-3.0	69.9	1.0-2.4	50.0	1.0-2.1	95.8	1.2-1.2	91.6	1.2-3.2	138.5
2.4-3.2	44.5	3.0-4.0	109.9	2.4-2.6	92.7	2.1-3.0	96.5	1.4-2.3	91.2	3.2-4.3	125.4
3.2-4.15	27.9	4.0-4.17	39.7	2.6-3.4	82.0	3.0-4.0	77.2	2.3-3.4	86.8	4.3-5.0	171.5
				3.4-4.41	37.0	4.0-4.74	30.2	3.4-4.4	272.4	5.0-5.76	33.3
								4.4-5.55	44.5		

H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_o = Original Water Content in Per Cent

TABLE D17

COLD ROOM STUDIES OF FROST ACTION IN SOILS
 FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
 AFTER FREEZING

SAMPLE NUMBER CM-205		SAMPLE NUMBER CM-206		SAMPLE NUMBER CM-207		SAMPLE NUMBER CM-208		SAMPLE NUMBER CM-209		SAMPLE NUMBER CM-210	
$H_0 = 3.14$ $H_f = 4.69$ $H_1 = 0$ $W_0 = 27.2$		$H_0 = 3.32$ $H_f = 3.78$ $H_1 = 0$ $W_0 = 27.5$		$H_0 = 3.13$ $H_f = 3.45$ $H_1 = 0$ $W_0 = 23.1$		$H_0 = 3.15$ $H_f = 4.23$ $H_1 = 0$ $W_0 = 28.1$		$H_0 = 3.15$ $H_f = 3.63$ $H_1 = 0$ $W_0 = 27.6$		$H_0 = 3.12$ $H_f = 3.53$ $H_1 = 0$ $W_0 = 23.0$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-2.0	43.2	0.0-2.0	39.6	0.0-1.0	28.3	0.0-2.0	33.1	0.0-1.0	24.7	0.0-1.0	26.1
2.0-2.6	18.2	2.0-3.0	61.7	1.0-2.5	33.4	2.0-3.0	51.9	1.0-2.4	41.1	1.0-2.0	35.2
2.6-3.3	129.3	3.0-3.78	30.7	2.5-3.45	23.4	3.0-3.8	75.5	2.4-3.0	75.9	2.0-3.2	40.7
3.3-4.09	24.4					3.8-4.23	27.6	3.0-3.63	25.7	3.2-3.53	26.6
SAMPLE NUMBER CM-211		SAMPLE NUMBER CM-212		SAMPLE NUMBER CM-213		SAMPLE NUMBER CM-214		SAMPLE NUMBER CM-215		SAMPLE NUMBER CM-216	
$H_0 = 3.12$ $H_f = 3.77$ $H_1 = 0$ $W_0 = 19.3$		$H_0 = 3.14$ $H_f = 3.96$ $H_1 = 0$ $W_0 = 19.4$		$H_0 = 3.13$ $H_f = 3.76$ $H_1 = 0$ $W_0 = 21.7$		$H_0 = 3.14$ $H_f = 3.78$ $H_1 = 0$ $W_0 = 30.2$		$H_0 = 3.11$ $H_f = 3.64$ $H_1 = 0$ $W_0 = 29.8$		$H_0 = 3.11$ $H_f = 3.57$ $H_1 = 0$ $W_0 = 29.6$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.5	26.8	0.0-2.5	31.4	0.0-1.9	36.9	0.0-1.0	20.5	0.0-0.6	33.4	0.0-0.9	51.5
1.5-1.9	12.0	2.5-3.1	53.3	1.9-3.1	18.4	1.0-3.2	44.0	0.6-2.0	18.1	0.9-2.0	41.4
1.9-3.0	40.2	3.1-3.6	38.9	3.1-3.76	22.0	3.2-3.78	21.0	2.0-3.64	30.1	2.0-3.57	28.9
3.0-3.77	21.1	3.6-3.96	27.4								
SAMPLE NUMBER CM-217		SAMPLE NUMBER CM-218		SAMPLE NUMBER CM-219		SAMPLE NUMBER CM-220		SAMPLE NUMBER CM-221		SAMPLE NUMBER CM-222	
$H_0 = 3.11$ $H_f = 3.43$ $H_1 = 0$ $W_0 = 28.0$		$H_0 = 3.11$ $H_f = 3.59$ $H_1 = 0$ $W_0 = 28.2$		$H_0 = 3.11$ $H_f = 3.64$ $H_1 = 0$ $W_0 = 25.2$		$H_0 = 3.11$ $H_f = 3.59$ $H_1 = 0$ $W_0 = 26.4$		$H_0 = 3.11$ $H_f = 3.33$ $H_1 = 0$ $W_0 = 25.0$		$H_0 = 3.11$ $H_f = 3.28$ $H_1 = 0$ $W_0 = 26.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	44.9	0.0-1.3	37.6	0.0-0.7	38.1	0.0-0.5	41.5	0.0-0.5	15.9	0.0-1.0	31.1
1.0-2.0	29.2	1.3-2.2	51.0	0.7-1.7	32.1	0.5-2.5	32.4	0.5-2.0	29.5	1.0-2.0	22.8
2.0-3.43	25.2	2.2-3.59	28.3	1.7-2.7	18.4	2.5-3.5	25.6	2.0-3.33	25.0	2.0-3.28	25.5
				2.7-3.44	20.0						

H_0 = Original Height in Inches.
 H_f = Final Height in Inches.
 H_1 = Thickness of Vicious Portion in Inches.
 W_0 = Original Water Content in Per Cent.

TABLE D18

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-133		SAMPLE NUMBER CM-134		SAMPLE NUMBER CM-135		SAMPLE NUMBER CM-136		SAMPLE NUMBER CM-137		SAMPLE NUMBER CM-138	
$H_o = 3.11$	$H_f = 3.16$	$H_o = 3.12$	$H_f = 3.52$	$H_o = 3.11$	$H_f = 3.60$	$H_o = 3.12$	$H_f = 3.75$	$H_o = 3.12$	$H_f = 4.48$	$H_o = 3.12$	$H_f = 3.67$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 19.9$	$W_o = 19.9$	$W_o = 19.9$	$W_o = 19.9$	$W_o = 21.3$	$W_o = 20.2$	$W_o = 20.2$	$W_o = 20.7$	$W_o = 20.7$	$W_o = 22.0$	$W_o = 22.0$	$W_o = 22.0$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.0	32.1	0.0-0.3	18.3	0.0-1.0	29.9	0.0-0.6	27.3	0.0-1.4	14.2	0.0-1.0	34.5
1.0-2.0	28.2	0.3-1.3	32.2	1.0-2.0	36.2	0.6-1.0	35.0	1.4-2.1	51.3	1.0-2.0	38.5
2.0-2.9	25.9	1.3-2.3	26.2	2.0-3.1	28.3	1.0-1.5	56.9	2.1-2.8	67.1	2.0-2.8	25.7
2.9-3.16	20.1	2.3-3.3	23.8	3.1-3.5	23.8	1.5-2.5	21.5	2.8-3.3	32.2	2.9-3.67	27.3
		3.3-3.52	19.8			2.5-3.0	30.1	3.3-4.48	34.4		
						3.0-3.75	21.6				
SAMPLE NUMBER CM-139		SAMPLE NUMBER CM-140		SAMPLE NUMBER CM-141		SAMPLE NUMBER CM-142		SAMPLE NUMBER CM-143		SAMPLE NUMBER CM-144	
$H_o = 3.12$	$H_f = 3.62$	$H_o = 3.11$	$H_f = 3.1$	$H_o = 3.11$	$H_f = 3.28$	$H_o = 3.11$	$H_f = 3.64$	$H_o = 3.12$	$H_f = 3.12$	$H_o = 3.12$	$H_f = 3.16$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 20.3$	$W_o = 20.3$	$W_o = 1.6$	$W_o = 1.6$	$W_o = 19.6$	$W_o = 19.6$	$W_o = 20.1$	$W_o = 20.1$	$W_o = 19.8$	$W_o = 19.8$	$W_o = 19.4$	$W_o = 19.4$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	32.0	0.0-1.1	30.2	0.0-1.0	21.6	0.0-1.0	29.7	0.0-1.0	27.2	0.0-1.0	21.2
0.5-1.5	29.9	1.1-2.1	26.9	1.0-2.0	21.7	1.0-2.0	27.7	1.0-2.0	23.3	1.0-2.0	18.8
1.5-2.1	33.0	2.1-3.0	29.0	2.0-3.0	23.3	2.0-3.0	26.4	2.0-3.1	21.9	2.0-3.16	18.9
2.1-3.3	28.3	3.0-3.45	20.5	3.0-3.20	20.2	3.0-3.64	20.1	3.1-3.2	17.8		
3.3-3.62	23.7										
SAMPLE NUMBER CM-145		SAMPLE NUMBER CM-146		SAMPLE NUMBER CM-147		SAMPLE NUMBER CM-148		SAMPLE NUMBER CM-149		SAMPLE NUMBER CM-150	
$H_o = 3.12$	$H_f = 4.07$	$H_o = 3.11$	$H_f = 4.22$	$H_o = 3.13$	$H_f = 3.49$	$H_o = 3.28$	$H_f = 4.23$	$H_o = 3.28$	$H_f = 3.37$	$H_o = 3.32$	$H_f = 5.34$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 20.0$	$W_o = 20.0$	$W_o = 35.5$	$W_o = 35.5$	$W_o = 21.6$	$W_o = 21.6$	$W_o = 32.1$	$W_o = 32.1$	$W_o = 32.3$	$W_o = 32.3$	$W_o = 33.3$	$W_o = 33.3$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.8	45.1	0.0-1.0	69.7	0.0-1.0	64.0	0.0-1.0	69.2	0.0-0.7	19.6	0.0-1.0	66.1
0.8-1.7	76.5	1.0-1.6	77.0	1.0-2.0	28.6	1.0-1.9	91.6	0.7-1.7	37.9	1.0-2.3	178.9
1.7-2.7	25.2	1.6-2.6	72.6	2.0-3.0	25.3	1.9-2.3	12.7	1.7-3.37	24.1	2.3-3.3	121.1
2.7-3.2	25.1	2.6-3.0	43.4	3.0-3.49	20.8	2.2-3.2	29.6			3.3-5.3	27.4
3.2-4.77	20.2	3.0-3.3	41.5			3.2-4.21	24.5				
		3.3-4.22	30.9								

H_o = Original Height in Inches.
 H_f = Final Height in Inches.
 H_u = Thickness of Unfrozen Portion in Inches.
 W_o = Original Water Content in Per Cent.

TABLE D19

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-79		SAMPLE NUMBER CM-80		SAMPLE NUMBER CM-81		SAMPLE NUMBER CM-82		SAMPLE NUMBER CM-83		SAMPLE NUMBER CM-84	
$H_0 = 3.11$	$H_f = 3.18$	$H_0 = 3.11$	$H_f = 3.14$	$H_0 = 3.11$	$H_f = 3.12$	$H_0 = 3.11$	$H_f = 3.60$	$H_0 = 3.11$	$H_f = 3.37$	$H_0 = 3.11$	$H_f = 4.33$
$H_u = 1.10$		$H_u = 0.70$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_0 = 26.0$		$W_0 = 15.8$		$W_0 = 13.7$		$W_0 = 21.8$		$W_0 = 21.0$		$W_0 = 24.5$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	21.8	0.0-0.5	13.1	0.0-0.5	11.0	0.0-0.5	22.8	0.0-0.5	30.5	0.0-0.5	18.0
0.5-1.0	25.5	0.5-1.0	14.3	0.5-1.0	14.3	0.5-0.9	14.6	0.5-0.9	34.3	0.5-1.0	14.5
1.0-1.5	19.4	1.0-1.5	16.8	1.0-1.5	15.6	0.9-1.2	33.5	0.9-1.2	36.5	1.0-1.5	38.2
1.5-2.0	23.3	1.5-2.0	16.4	1.5-2.0	15.7	1.2-1.7	30.7	1.2-1.9	10.0	1.5-2.0	55.7
2.0-2.6	23.2	2.0-2.5	17.1	2.0-2.5	20.7	1.7-2.5	26.6	1.9-2.4	25.9	2.0-2.3	70.5
2.6-3.18	17.2	2.5-3.14	20.4	2.5-3.12	22.4	2.3-2.9	38.6	2.4-3.0	17.5	2.3-3.0	39.7
						2.9-3.2	28.9	3.0-3.3	39.5	3.0-3.3	87.3
						3.2-3.6	18.9	3.3-3.87	29.6	3.3-3.5	23.5
										3.5-4.33	25.6

SAMPLE NUMBER CM-85		SAMPLE NUMBER CM-86		SAMPLE NUMBER CM-87		SAMPLE NUMBER CM-88		SAMPLE NUMBER CM-89		SAMPLE NUMBER CM-90	
$H_0 = 3.11$	$H_f = 3.87$	$H_0 = 3.11$	$H_f = 3.98$	$H_0 = 3.11$	$H_f = 3.80$	$H_0 = 3.11$	$H_f = 3.72$	$H_0 = 3.11$	$H_f = 3.98$	$H_0 = 3.11$	$H_f = 1.24$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_0 = 21.7$		$W_0 = 24.8$		$W_0 = 26.4$		$W_0 = 21.0$		$W_0 = 26.1$		$W_0 = 26.4$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	25.1	0.0-0.7	30.3	0.0-0.6	38.6	0.0-0.5	23.7	0.0-0.5	45.3	0.0-0.5	13.5
0.5-1.0	39.8	0.7-1.0	32.0	0.6-1.5	11.4	0.5-1.0	14.6	0.5-1.0	31.2	0.5-2.2	13.5
1.0-1.4	10.8	1.0-1.0	15.8	1.5-2.2	36.6	1.0-1.5	36.6	1.0-1.5	14.4	1.2-1.9	19.1
1.4-2.0	24.2	1.8-2.3	36.4	2.2-2.9	10.9	1.5-2.0	24.7	1.5-2.0	52.8	1.9-2.5	75.4
2.0-2.5	26.4	2.3-2.8	19.6	2.9-3.4	58.8	2.0-2.5	27.3	2.0-2.3	42.0	2.5-2.9	18.1
2.5-3.0	30.7	2.8-3.2	15.5	3.4-3.8	25.0	2.5-3.0	35.0	2.3-3.0	45.3	2.5-3.4	14.7
3.0-3.5	16.2	3.2-3.8	15.5			3.0-3.4	20.7	3.0-3.7	47.5	3.4-3.8	16.5
3.5-3.87	18.5	3.8-3.98	22.0			3.4-3.72	17.4	3.7-3.93	23.6	3.8-4.04	31.3

SAMPLE NUMBER CM-91		SAMPLE NUMBER CM-92		SAMPLE NUMBER CM-93		SAMPLE NUMBER CM-94		SAMPLE NUMBER CM-95		SAMPLE NUMBER CM-96	
$H_0 = 3.11$	$H_f = 4.15$	$H_0 = 3.11$	$H_f = 4.10$	$H_0 = 3.11$	$H_f = 3.88$	$H_0 = 3.11$	$H_f = 3.87$	$H_0 = 3.11$	$H_f = 4.24$	$H_0 = 3.11$	$H_f = 4.35$
$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$		$H_u = 0$	
$W_0 = 22.6$		$W_0 = 23.2$		$W_0 = 27.4$		$W_0 = 24.2$		$W_0 = 26.3$		$W_0 = 29.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	23.1	0.0-0.5	10.4	0.0-1.0	51.0	0.0-0.5	34.4	0.0-0.7	12.3	0.0-1.0	105.2
0.5-1.0	37.8	0.5-1.1	13.5	1.0-1.3	18.8	0.5-1.0	41.3	0.7-1.3	55.6	1.0-2.0	67.3
1.0-1.5	15.2	1.1-1.5	42.3	1.3-2.0	52.8	1.0-1.9	37.4	1.3-2.5	58.2	2.0-3.0	70.0
1.5-2.2	50.3	1.5-1.7	13.1	2.0-2.8	38.4	1.9-2.5	52.9	2.5-2.9	11.3	3.0-3.7	36.6
2.2-2.9	15.8	1.7-1.9	24.8	2.8-3.4	37.1	2.5-3.2	43.4	2.9-3.6	16.5	3.7-4.35	31.7
2.9-3.5	53.5	1.9-2.7	57.3	3.4-3.88	28.0	3.2-3.87	22.3	3.0-4.0	33.9		
3.5-4.15	22.8	2.7-3.3	75.2					4.0-4.24	25.7		
		3.3-4.0	35.2								
		4.0-4.44	30.1								

H_0 = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_0 = Original Water Content in Per Cent

TABLE D20

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-115		SAMPLE NUMBER CM-116		SAMPLE NUMBER CM-117		SAMPLE NUMBER CM-118		SAMPLE NUMBER CM-119		SAMPLE NUMBER CM-120	
$H_o = 3.11$ $H_f = 4.02$ $H_u = 0$ $W_o = 19.6$		$H_o = 3.12$ $H_f = 3.52$ $H_u = 0$ $W_o = 20.2$		$H_o = 3.12$ $H_f = 3.71$ $H_u = 0$ $W_o = 19.8$		$H_o = 3.11$ $H_f = 3.21$ $H_u = 0$ $W_o = 20.5$		$H_o = 3.11$ $H_f = 3.15$ $H_u = 0$ $W_o = 19.9$		$H_o = 3.13$ $H_f = 3.16$ $H_u = 0$ $W_o = 19.9$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	39.5	0.0-1.0	23.9	0.0-0.7	27.5	0.0-0.4	20.4	0.0-0.5	18.1	0.0-1.0	15.2
0.5-0.7	68.1	1.0-1.1	56.9	0.7-1.3	25.3	0.4-0.7	51.4	0.5-1.1	20.4	1.0-1.5	18.4
0.7-1.0	34.8	1.1-1.5	30.7	1.3-1.7	23.5	0.7-1.5	24.7	1.1-2.0	17.9	1.5-2.5	18.1
1.0-1.7	43.4	1.5-1.7	10.6	1.7-2.3	37.7	1.5-2.5	20.6	2.0-2.4	23.4	2.5-3.15	23.0
1.7-1.8	118.1	1.7-2.4	21.8	2.3-3.0	30.2	2.5-2.8	24.9	2.4-2.6	22.1		
1.8-2.2	13.9	2.4-2.9	23.3	3.0-3.71	18.8	2.8-3.21	22.4	2.6-3.15	19.8		
2.2-2.3	67.5	2.9-3.1	39.2								
2.3-3.5	22.6	3.1-3.52	16.7								
3.5-4.02	18.2										
SAMPLE NUMBER CM-121		SAMPLE NUMBER CM-122		SAMPLE NUMBER CM-123		SAMPLE NUMBER CM-124		SAMPLE NUMBER CM-125		SAMPLE NUMBER CM-126	
$H_o = 3.12$ $H_f = 3.37$ $H_u = 0$ $W_o = 19.5$		$H_o = 3.12$ $H_f = 3.22$ $H_u = 0$ $W_o = 20.3$		$H_o = 3.11$ $H_f = 3.13$ $H_u = 0$ $W_o = 19.8$		$H_o = 3.12$ $H_f = 3.38$ $H_u = 0$ $W_o = 20.3$		$H_o = 3.11$ $H_f = 3.26$ $H_u = 0$ $W_o = 19.4$		$H_o = 3.12$ $H_f = 3.19$ $H_u = 0$ $W_o = 19.9$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.7	26.0	0.0-0.7	19.3	0.0-1.0	17.2	0.0-0.5	22.3	0.0-0.5	18.3	0.0-1.0	20.8
0.7-1.3	27.8	0.7-1.2	25.2	1.0-2.0	20.4	0.5-1.5	27.1	0.5-1.0	26.2	1.0-2.0	20.9
1.3-2.1	21.8	1.2-2.0	19.7	2.0-3.13	20.3	1.5-2.5	34.7	1.0-2.0	23.1	2.0-2.75	21.1
2.1-2.7	17.7	2.0-2.7	21.2			2.5-3.33	20.0	2.0-2.9	23.0	2.75-3.19	17.3
2.7-3.37	22.9	2.7-3.22	30.4					2.9-3.26	20.2		
SAMPLE NUMBER CM-127		SAMPLE NUMBER CM-128		SAMPLE NUMBER CM-129		SAMPLE NUMBER CM-130		SAMPLE NUMBER CM-131		SAMPLE NUMBER CM-132	
$H_o = 3.12$ $H_f = 4.15$ $H_u = 0$ $W_o = 20.0$		$H_o = 3.11$ $H_f = 3.52$ $H_u = 0$ $W_o = 17.9$		$H_o = 3.12$ $H_f = 3.55$ $H_u = 0$ $W_o = 20.7$		$H_o = 3.12$ $H_f = 3.52$ $H_u = 0$ $W_o = 19.3$		$H_o = 3.12$ $H_f = 3.47$ $H_u = 0$ $W_o = 20.6$		$H_o = 3.13$ $H_f = 3.42$ $H_u = 0$ $W_o = 19.8$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.4	41.6	0.0-0.5	20.8	0.0-0.4	11.6	0.0-1.5	32.9	0.0-0.4	25.1	0.0-0.5	16.1
0.4-1.0	75.8	0.5-1.1	33.6	0.4-1.5	28.5	1.5-2.6	22.2	0.4-1.5	28.1	0.5-1.5	30.0
1.0-1.8	29.2	1.1-1.8	25.3	1.5-2.5	28.8	2.6-3.1	22.6	1.5-2.5	27.2	1.5-2.5	26.5
1.8-2.2	75.3	1.8-2.5	23.0	2.5-3.0	34.0	3.1-3.52	18.8	2.5-2.9	28.9	2.5-3.3	26.1
2.2-2.9	25.7	2.5-3.0	29.5	3.0-3.55	22.4			2.9-3.47	25.2	3.3-3.42	17.6
2.9-3.6	27.2	3.0-3.52	19.8								
3.6-4.15	17.8										
H_o = Original Height in Inches. H_f = Final Height in Inches. H_u = Thickness of Unfrozen Portion in Inches. W_o = Original Water Content in Per Cent.											

TABLE D21

COLE ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

SAMPLE NUMBER CM-151		SAMPLE NUMBER CM-152		SAMPLE NUMBER CM-153		SAMPLE NUMBER CM-154		SAMPLE NUMBER CM-155		SAMPLE NUMBER CM-156	
$H_o = 3.07$	$H_f = 3.98$	$H_o = 3.05$	$H_f = 3.45$	$H_o = 3.07$	$H_f = 3.45$	$H_o = 3.09$	$H_f = 3.63$	$H_o = 3.09$	$H_f = 1.39$	$H_o = 3.09$	$H_f = 3.84$
$H_u = 0.13$	$H_u = 0$	$H_u = 0.06$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 25.9$	$W_o = 25.9$	$W_o = 27.4$	$W_o = 27.4$	$W_o = 27.8$	$W_o = 27.8$	$W_o = 25.3$	$W_o = 25.3$	$W_o = 25.0$	$W_o = 25.0$	$W_o = 25.6$	$W_o = 25.6$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	79.7	0.0-1.2	57.9	0.0-1.0	46.3	0.0-1.0	47.5	0.0-0.6	58.7	0.0-1.0	40.6
0.5-1.5	138.9	1.2-2.0	31.3	1.0-2.0	39.4	1.0-1.5	62.1	0.6-1.8	92.6	1.0-1.4	95.0
1.5-1.9	36.7	2.0-3.0	25.9	2.0-3.0	24.2	1.5-2.0	43.9	1.8-2.4	72.9	1.4-2.0	34.7
1.9-3.0	28.3	3.0-3.45	22.3	3.0-3.45	25.8	2.0-3.0	30.2	2.4-3.0	36.2	2.0-3.0	29.1
3.0-3.8	24.8					3.0-3.63	24.0	3.0-4.33	23.1	3.0-3.8	25.6
3.8-3.98	24.1										
SAMPLE NUMBER CM-157		SAMPLE NUMBER CM-158		SAMPLE NUMBER CM-159		SAMPLE NUMBER CM-160		SAMPLE NUMBER CM-161		SAMPLE NUMBER CM-162	
$H_o = 3.03$	$H_f = 4.23$	$H_o = 3.05$	$H_f = 3.87$	$H_o = 3.04$	$H_f = 3.99$	$H_o = 3.09$	$H_f = 4.73$	$H_o = 3.06$	$H_f = 3.83$	$H_o = 3.05$	$H_f = 3.73$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 26.7$	$W_o = 26.7$	$W_o = 26.9$	$W_o = 26.9$	$W_o = 29.1$	$W_o = 29.1$	$W_o = 26.7$	$W_o = 26.7$	$W_o = 27.4$	$W_o = 27.4$	$W_o = 27.9$	$W_o = 27.9$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	14.4	0.0-0.9	44.8	0.0-0.7	51.6	0.0-0.5	75.9	0.0-0.7	45.8	0.0-0.9	19.4
0.5-1.5	87.7	0.9-1.3	69.8	0.7-1.2	53.9	0.5-2.4	145.3	0.7-1.4	63.7	0.9-1.3	74.7
1.5-2.0	225.8	1.3-1.5	117.9	1.2-2.3	204.8	2.4-2.7	75.6	1.4-1.6	107.4	1.3-1.9	36.8
2.0-3.0	28.8	1.6-3.0	29.5	2.3-2.9	72.6	2.7-4.0	27.0	1.6-2.0	43.6	1.9-3.73	26.1
3.0-4.23	2.3	3.0-3.87	22.6	2.9-3.99	27.6	4.0-4.73	23.7	2.0-3.0	28.2		
								3.0-3.83	23.4		
SAMPLE NUMBER CM-163		SAMPLE NUMBER CM-164		SAMPLE NUMBER CM-165		SAMPLE NUMBER CM-166		SAMPLE NUMBER CM-167		SAMPLE NUMBER CM-168	
$H_o = 3.03$	$H_f = 4.78$	$H_o = 3.05$	$H_f = 3.76$	$H_o = 3.05$	$H_f = 3.49$	$H_o = 3.07$	$H_f = 3.83$	$H_o = 3.08$	$H_f = 3.95$	$H_o = 3.05$	$H_f = 3.18$
$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$	$H_u = 0$
$W_o = 30.1$	$W_o = 30.1$	$W_o = 28.1$	$W_o = 28.1$	$W_o = 27.0$	$W_o = 27.0$	$W_o = 26.7$	$W_o = 26.7$	$W_o = 25.2$	$W_o = 25.2$	$W_o = 24.8$	$W_o = 24.8$
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-1.8	75.4	0.0-0.5	26.2	0.0-0.9	140.3	0.0-0.5	50.0	0.0-1.0	37.4	0.0-1.0	21.7
1.8-2.9	144.0	0.5-0.7	73.8	0.9-1.7	35.0	0.5-1.7	56.6	1.0-2.1	64.8	1.0-2.0	25.7
2.9-4.78	32.5	0.7-1.7	73.6	1.7-3.49	27.0	1.7-2.0	74.3	2.1-3.95	24.0	2.0-3.18	20.0
		1.7-3.76	28.0			2.0-2.2	51.9				
						2.2-2.3	39.8				
						2.5-2.7	54.8				
						2.7-3.83	28.8				

H_o = Original Height in Inches.
 H_f = Final Height in Inches.
 H_u = Thickness of Unfrozen Portion in Inches.
 W_o = Original Water Content in Per Cent.

TABLE D22

COLD ROOM STUDIES OF FROST ACTION IN SOILS
FISCAL YEARS 1952 and 1953

WATER CONTENT DISTRIBUTION
AFTER FREEZING

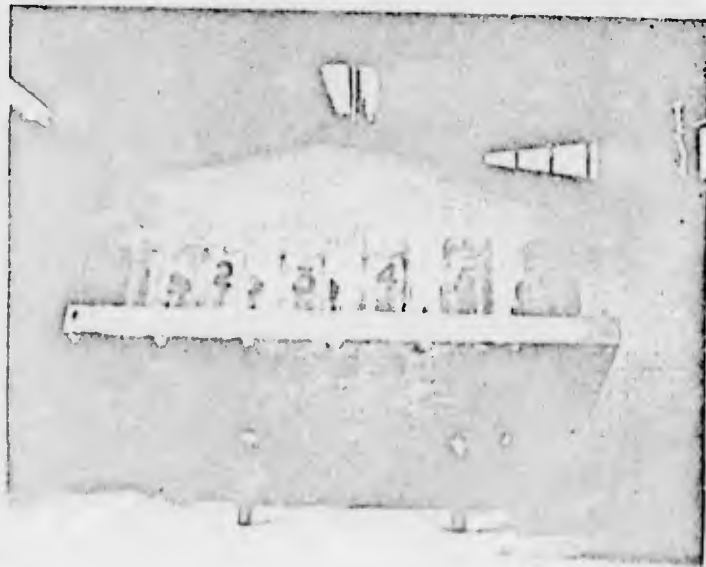
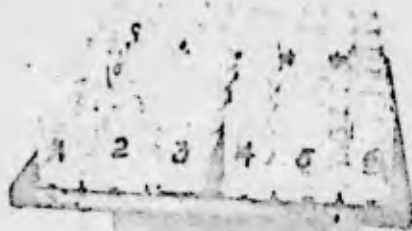
SAMPLE NUMBER CM-97		SAMPLE NUMBER CM-98		SAMPLE NUMBER CM-99		SAMPLE NUMBER CM-100		SAMPLE NUMBER CM-101		SAMPLE NUMBER CM-102	
$H_o = 3.11$ $H_f = 3.59$ $H_u = 0$ $W_o = 22.9$		$H_o = 3.11$ $H_f = 3.11$ $H_u = 0$ $W_o = 21.9$		$H_o = 3.11$ $H_f = 3.15$ $H_u = 0$ $W_o = 21.5$		$H_o = 3.11$ $H_f = 3.68$ $H_u = 0$ $W_o = 23.5$		$H_o = 3.11$ $H_f = 3.24$ $H_u = 0$ $W_o = 24.2$		$H_o = 3.11$ $H_f = 3.50$ $H_u = 0$ $W_o = 27.3$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.5	23.2	0.0-0.5	19.5	0.0-0.5	20.5	0.0-0.5	28.0	0.0-0.5	19.4	0.0-0.5	25.0
0.5-1.0	36.9	0.5-1.0	23.9	0.5-1.0	23.7	0.5-1.0	29.1	0.5-1.0	26.9	0.5-1.0	23.5
1.0-1.7	37.2	1.0-1.5	26.4	1.0-1.5	11.6	1.0-1.1	50.6	1.0-1.3	29.2	1.0-1.5	29.2
1.7-2.3	24.6	1.5-2.0	23.7	1.5-2.0	25.3	1.1-1.5	29.9	1.3-1.8	31.3	1.5-2.0	32.1
2.3-2.8	31.4	2.0-2.5	24.6	2.0-2.7	26.9	1.5-2.0	46.9	1.8-2.5	29.3	2.0-2.8	34.5
2.8-2.9	46.3	2.5-3.11	37.2	2.7-3.15	26.5	2.0-2.4	32.1	2.5-3.0	42.4	2.8-3.2	40.8
2.9-3.2	18.2					2.4-2.9	42.4	3.0-3.24	53.3	3.2-3.5	26.9
3.2-3.9	19.4					2.9-3.6	36.0				
						3.6-3.88	23.9				

SAMPLE NUMBER CM-103		SAMPLE NUMBER CM-104		SAMPLE NUMBER CM-105		SAMPLE NUMBER CM-106		SAMPLE NUMBER CM-107		SAMPLE NUMBER CM-108	
$H_o = 3.11$ $H_f = 3.96$ $H_u = 0$ $W_o = 22.3$		$H_o = 3.11$ $H_f = 4.60$ $H_u = 0$ $W_o = 26.1$		$H_o = 3.11$ $H_f = 4.53$ $H_u = 0$ $W_o = 36.7$		$H_o = 3.17$ $H_f = 4.32$ $H_u = 0$ $W_o = 30.6$		$H_o = 3.11$ $H_f = 3.87$ $H_u = 0$ $W_o = 32.1$		$H_o = 3.11$ $H_f = 4.01$ $H_u = 0$ $W_o = 31.6$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.7	32.7	0.0-0.5	31.0	0.0-0.5	57.6	0.0-0.5	34.6	0.0-0.5	32.1	0.0-0.5	33.1
0.7-1.3	51.5	0.5-1.4	49.0	0.5-1.0	64.5	0.5-1.0	72.2	0.5-1.0	57.1	0.5-1.0	51.7
1.3-1.5	32.6	1.4-2.2	66.3	1.0-1.5	60.4	1.0-1.5	61.2	1.0-1.5	50.4	1.0-1.6	49.5
1.5-1.7	71.9	2.2-2.6	54.4	1.5-2.0	33.3	1.5-2.0	70.0	1.5-2.2	55.9	1.6-2.0	59.5
1.7-2.6	26.4	2.6-2.7	71.0	2.0-2.7	83.8	2.0-2.5	70.3	2.2-3.0	41.7	2.0-2.5	48.7
2.6-2.9	55.1	2.7-2.9	115.3	2.7-3.0	16.8	2.5-3.0	82.1	3.0-3.5	50.3	2.5-3.0	47.5
2.9-3.2	27.0	2.9-3.6	42.1	3.0-3.3	49.0	3.0-3.5	36.7	3.5-3.87	24.7	3.0-3.5	47.9
3.2-3.5	21.8	3.6-4.3	46.4	3.3-3.7	51.1	3.5-4.0	54.4			3.5-4.01	25.0
3.5-3.98	21.2	4.3-4.6	26.2	3.7-4.53	30.4	4.0-4.32	26.2				

SAMPLE NUMBER CM-109		SAMPLE NUMBER CM-110		SAMPLE NUMBER CM-111		SAMPLE NUMBER CM-112		SAMPLE NUMBER CM-113		SAMPLE NUMBER CM-114	
$H_o = 3.11$ $H_f = 3.76$ $H_u = 0$ $W_o = 27.9$		$H_o = 3.14$ $H_f = 3.93$ $H_u = 0$ $W_o = 30.8$		$H_o = 3.11$ $H_f = 3.87$ $H_u = 0$ $W_o = 35.4$		$H_o = 3.11$ $H_f = 3.92$ $H_u = 0$ $W_o = 28.2$		$H_o = 3.11$ $H_f = 3.95$ $H_u = 0$ $W_o = 30.4$		$H_o = 3.11$ $H_f = 3.70$ $H_u = 0$ $W_o = 22.4$	
Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%	Depth	W.C.-%
0.0-0.7	35.6	0.0-0.5	48.8	0.0-0.5	45.9	0.0-0.5	40.9	0.0-0.5	46.2	0.0-0.5	28.4
0.7-2.0	48.5	0.5-1.0	59.5	0.5-1.0	53.6	0.5-1.0	36.3	0.5-1.2	59.0	0.5-1.0	42.3
2.0-2.4	40.1	1.0-1.5	48.9	1.0-1.5	57.9	1.0-1.5	44.4	1.2-1.5	50.6	1.0-1.5	72.6
2.4-2.7	35.2	1.5-2.0	54.8	1.5-2.0	66.1	1.5-1.9	50.2	1.5-2.2	67.0	1.5-2.0	20.9
2.7-3.5	34.8	2.0-2.5	53.6	2.0-2.5	47.4	1.9-2.5	46.5	2.2-2.5	59.1	2.0-2.5	33.5
3.5-3.76	23.4	2.5-3.0	40.6	2.5-3.0	44.8	2.5-3.2	51.3	2.5-2.6	103.4	2.5-3.0	33.9
		3.0-3.5	41.8	3.0-3.5	46.8	3.2-3.92	23.0	2.6-3.1	45.0	3.0-3.7	20.3
		3.5-3.98	27.2	3.5-3.87	29.4			3.1-3.7	44.1		
								3.7-3.98	26.0		

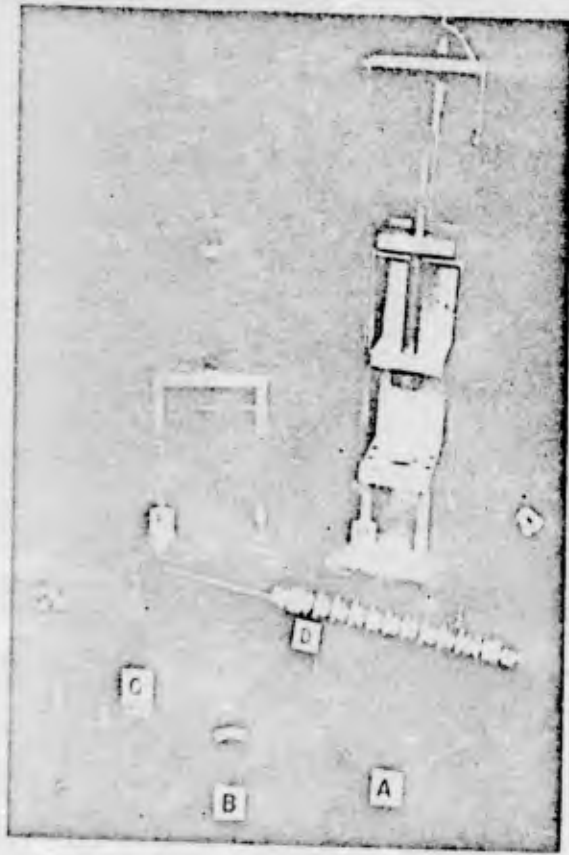
H_o = Original Height in Inches
 H_f = Final Height in Inches
 H_u = Thickness of Unfrozen Portion in Inches
 W_o = Original Water Content in Per Cent

TABLE 023



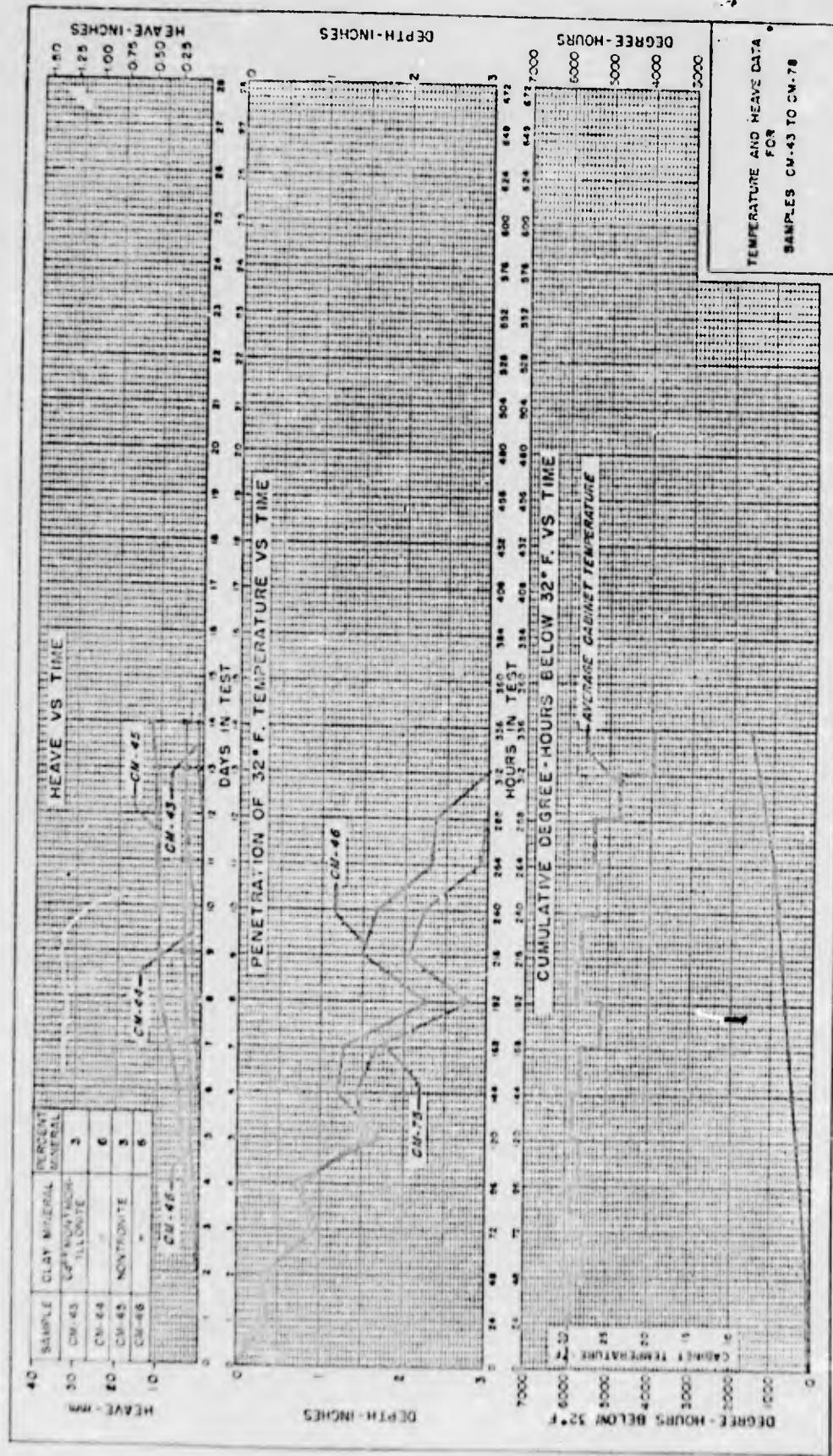
MINIATURE SAMPLE FREEZING TRAY.

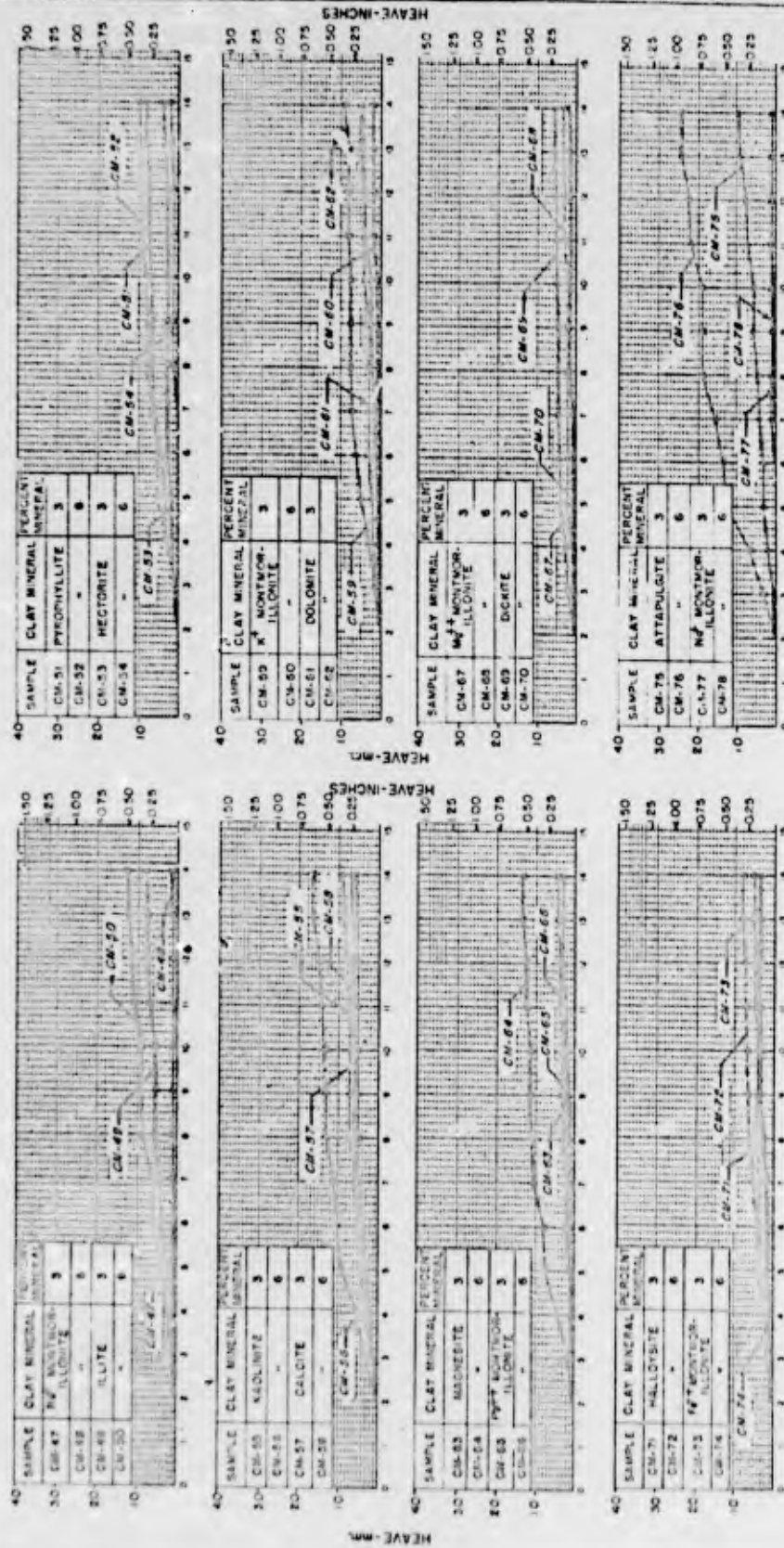
PLATE D I



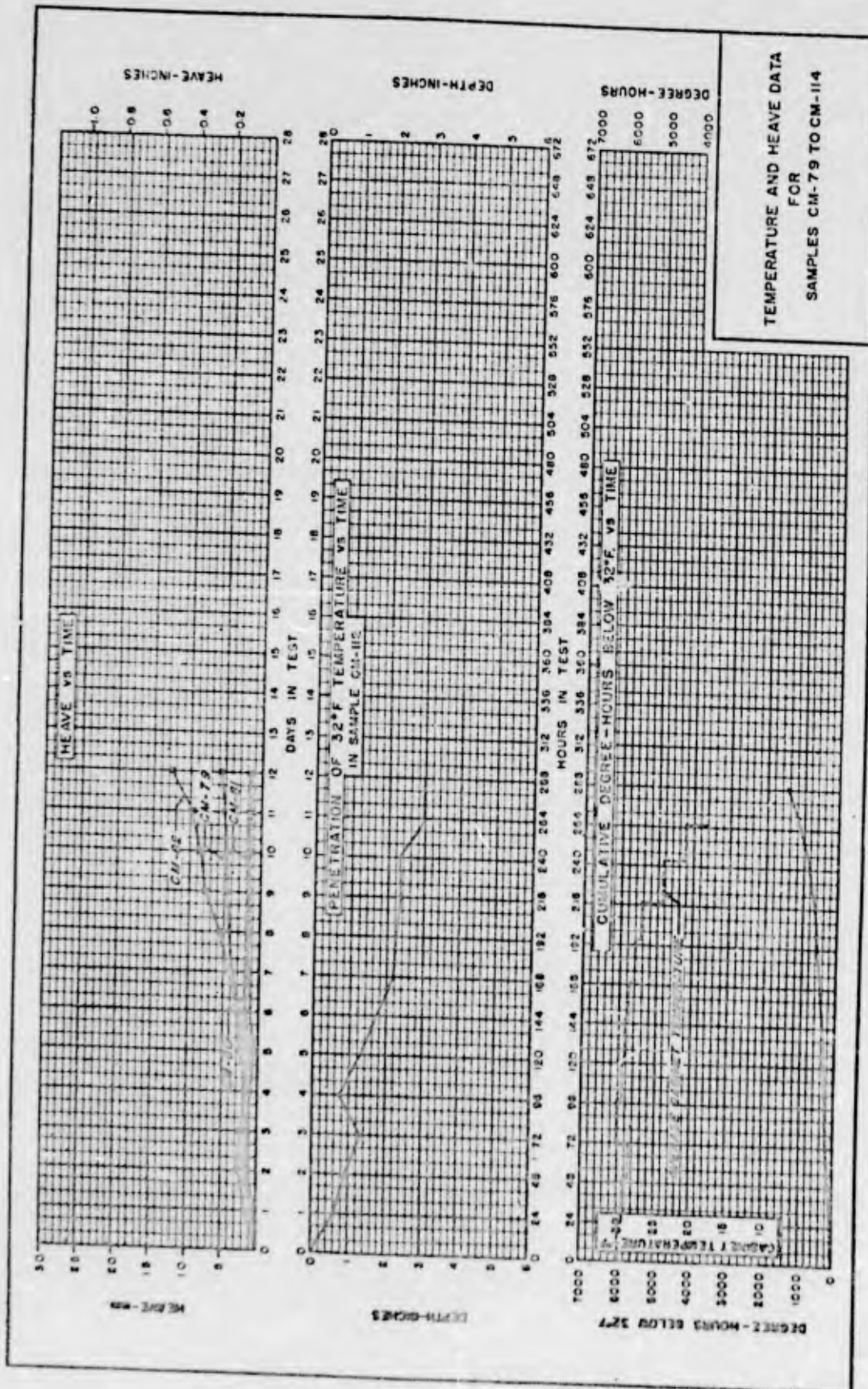
COMPONENTS OF HARVARD MINIATURE COMPACTION APPARATUS

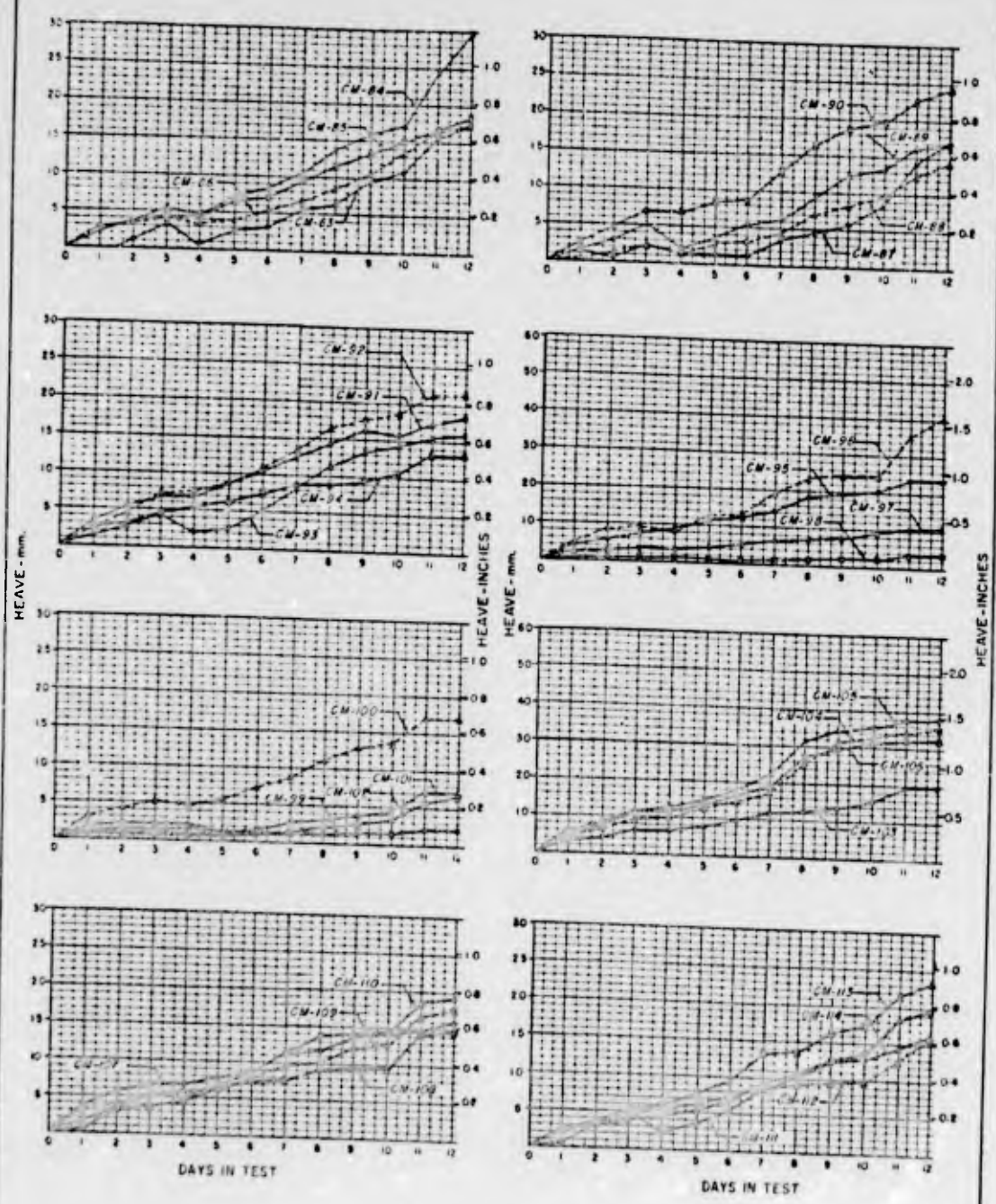
- A. MOLD
- B. EXTENSION COLLAR
- C. BASE
- D. TAMPER
- E. SAMPLE EJECTOR
- F. COLLAR REMOVER



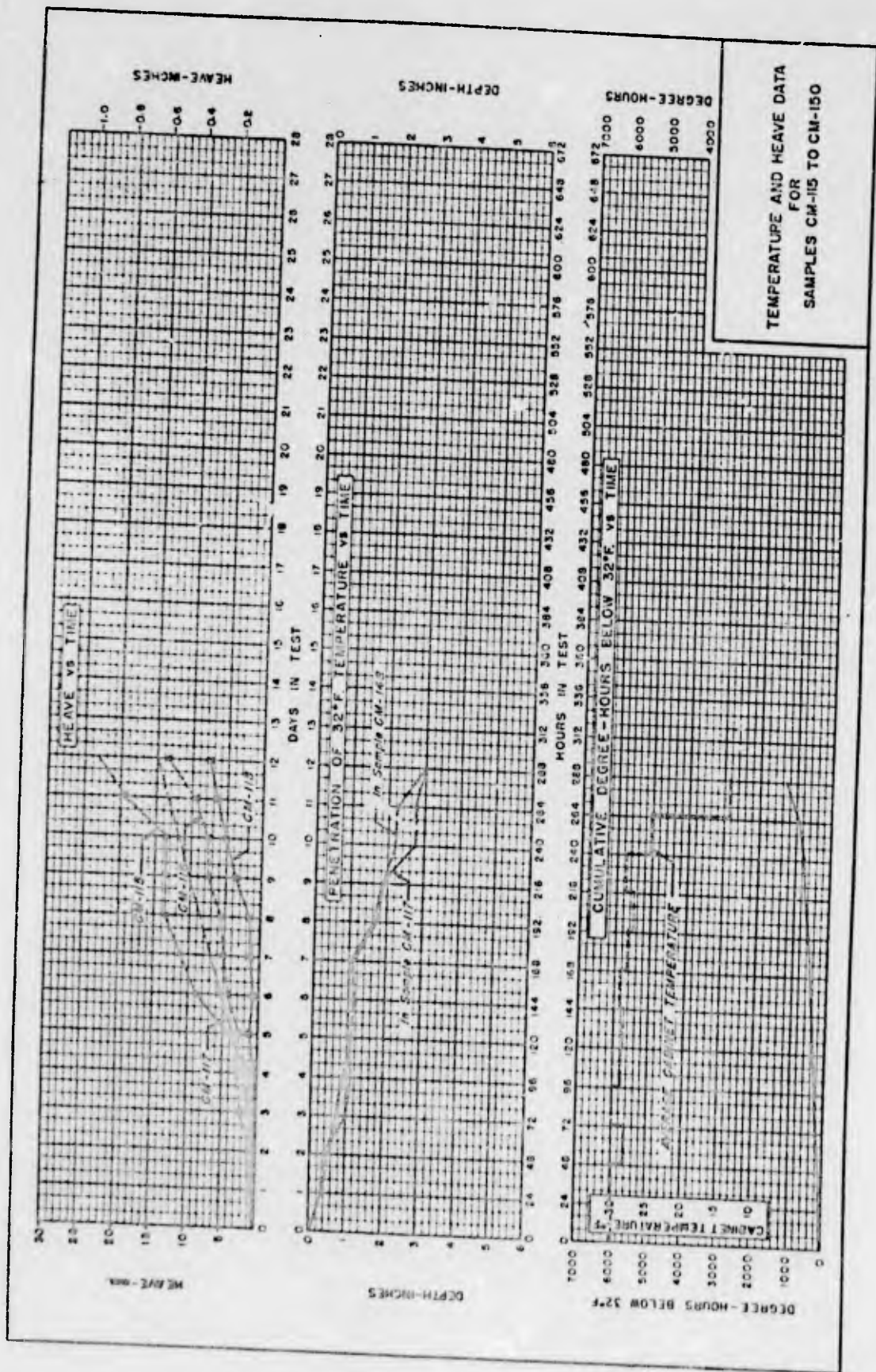


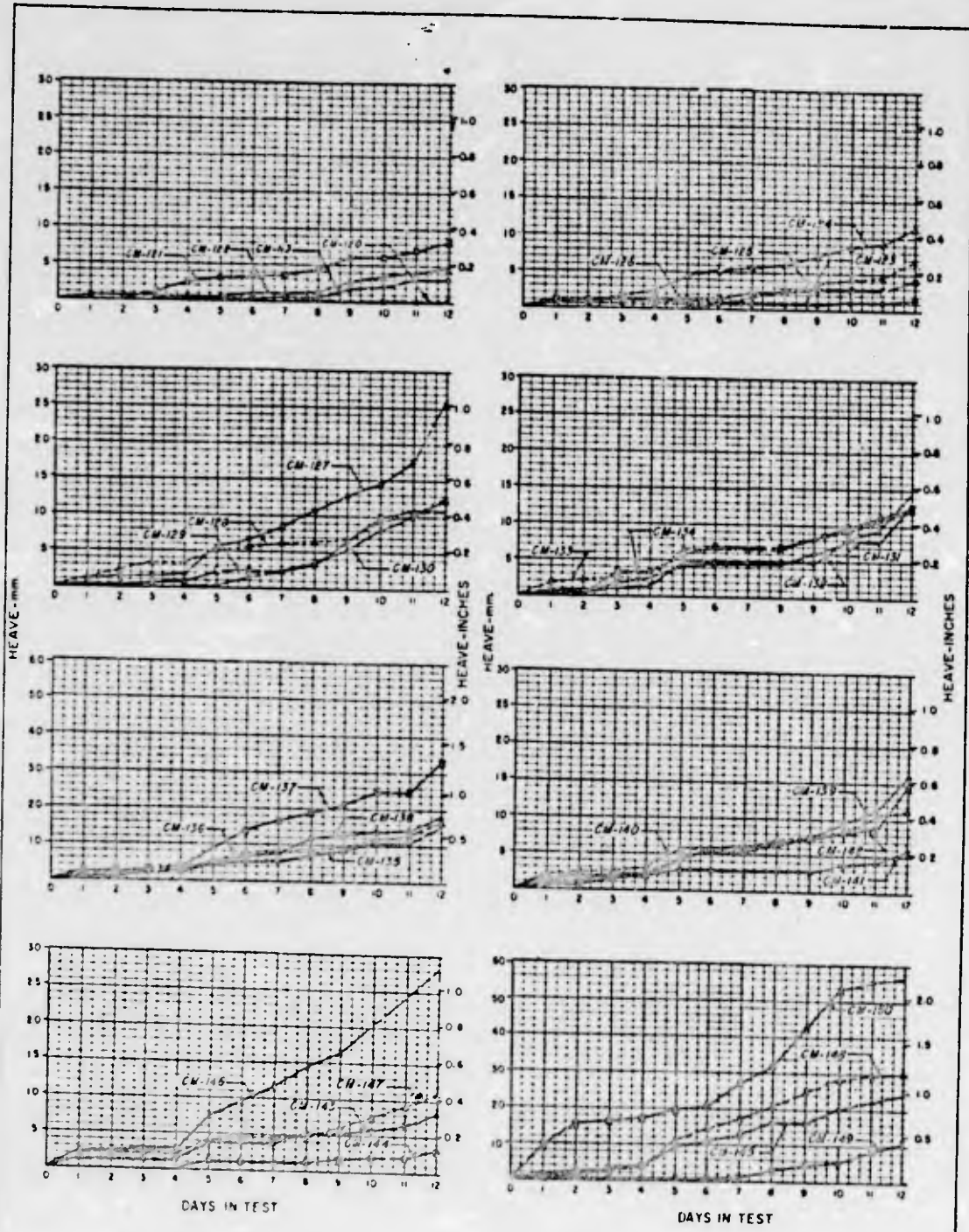
TEMPERATURE AND HEAVE DATA FOR SAMPLES CM-43 TO CM-78



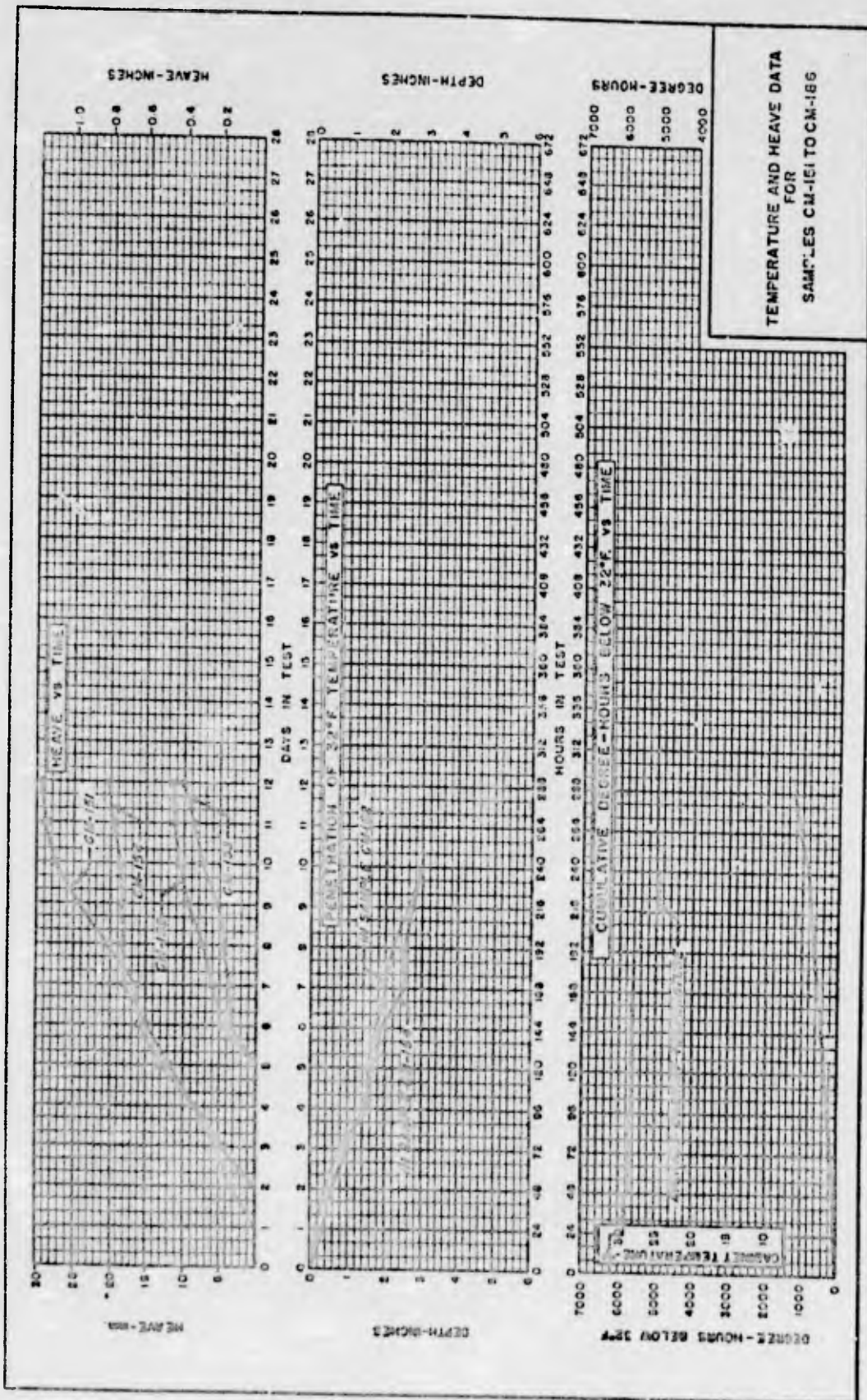


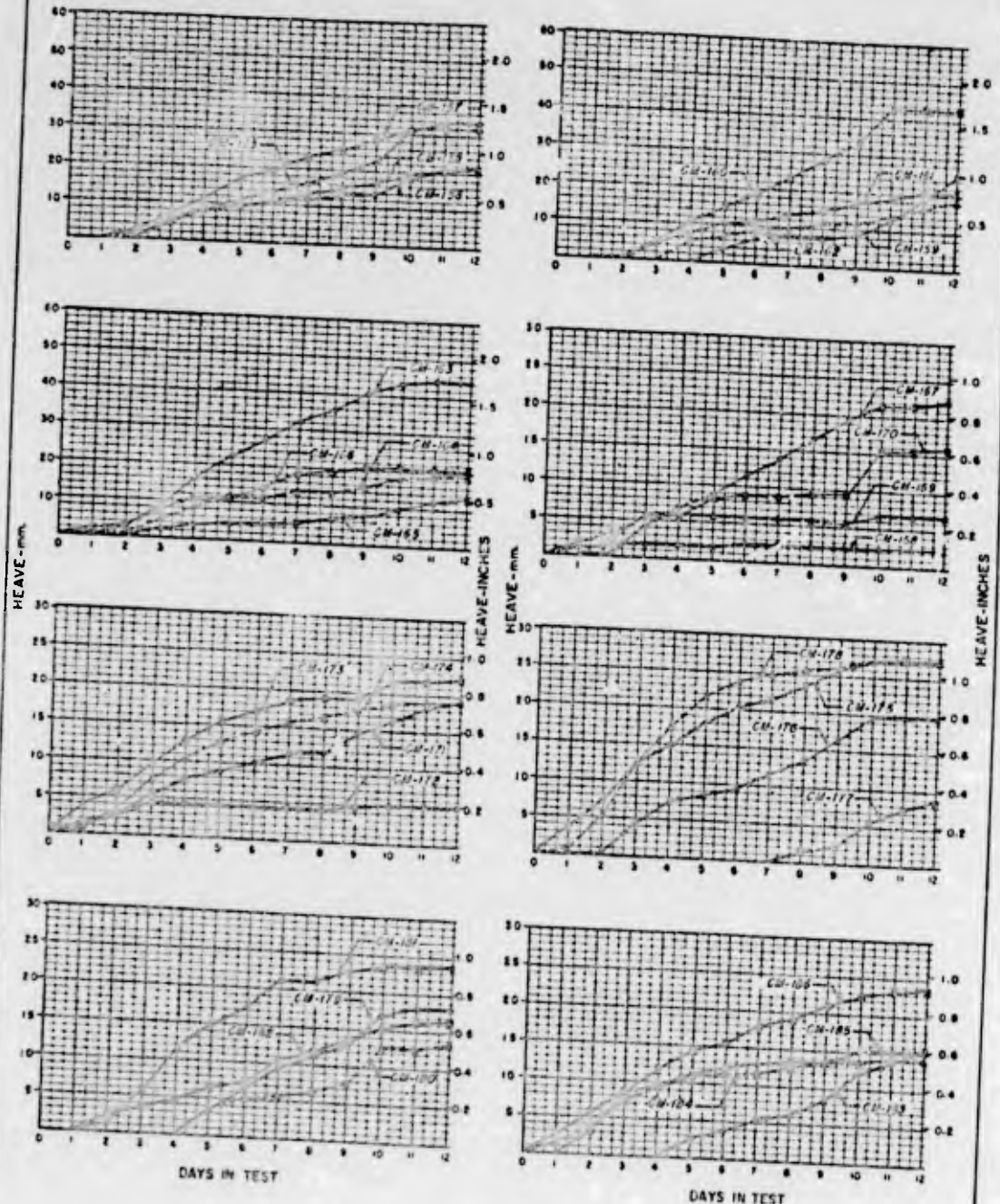
TEMPERATURE AND HEAVE DATA
 FOR
 SAMPLES CM-79 TO CM-114



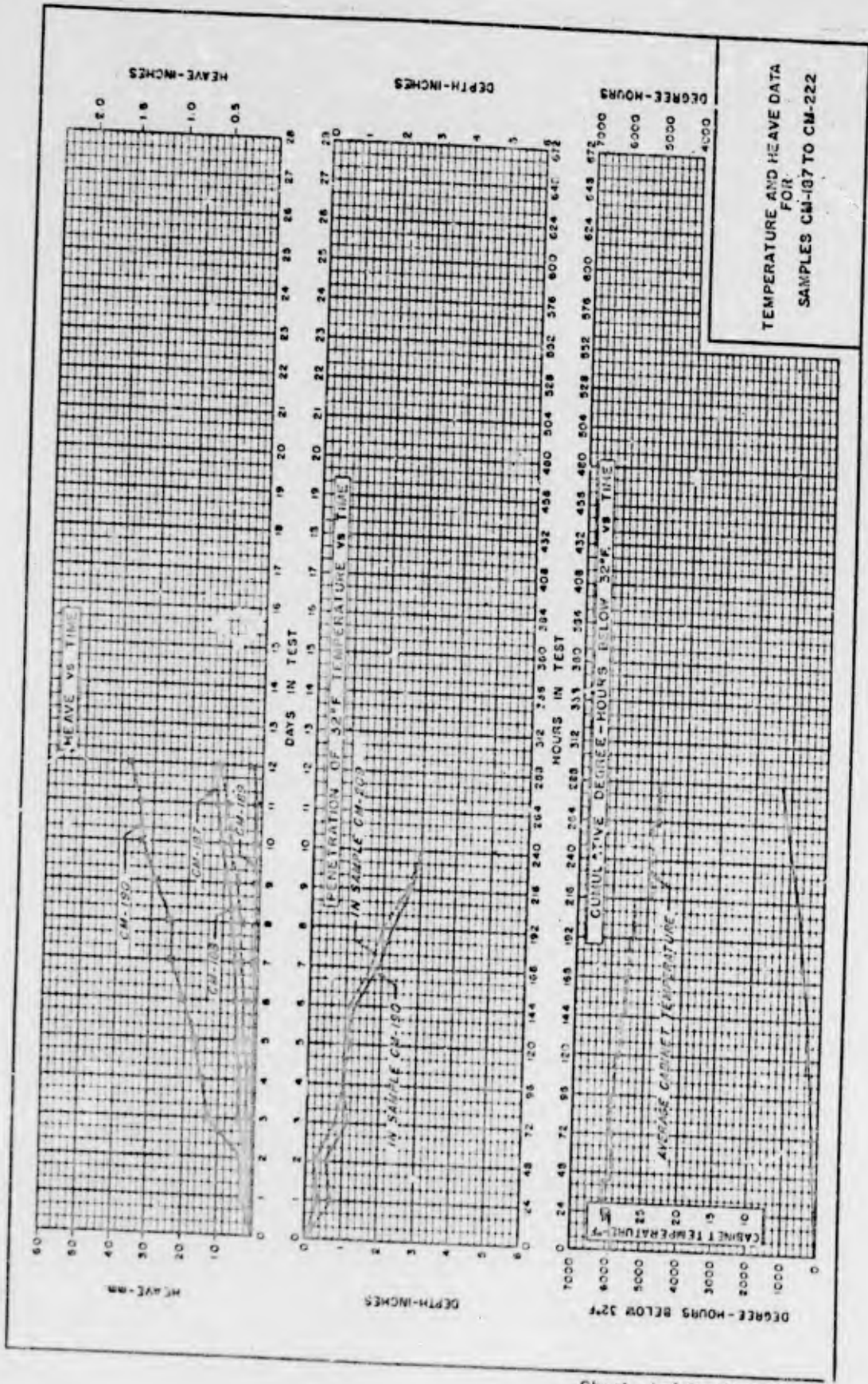


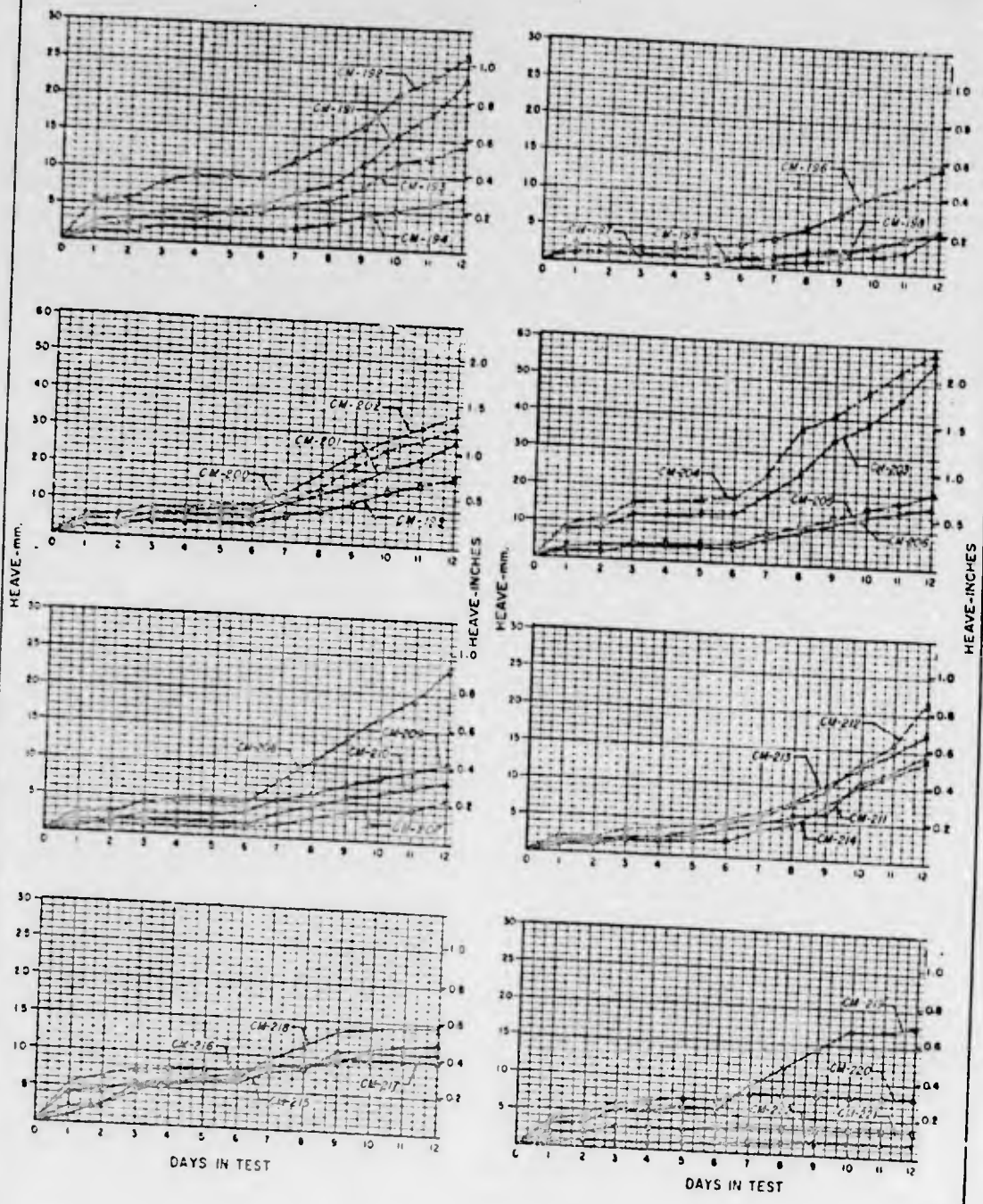
TEMPERATURE AND HEAVE DATA
 FOR
 SAMPLES CM-115 TO CM-150



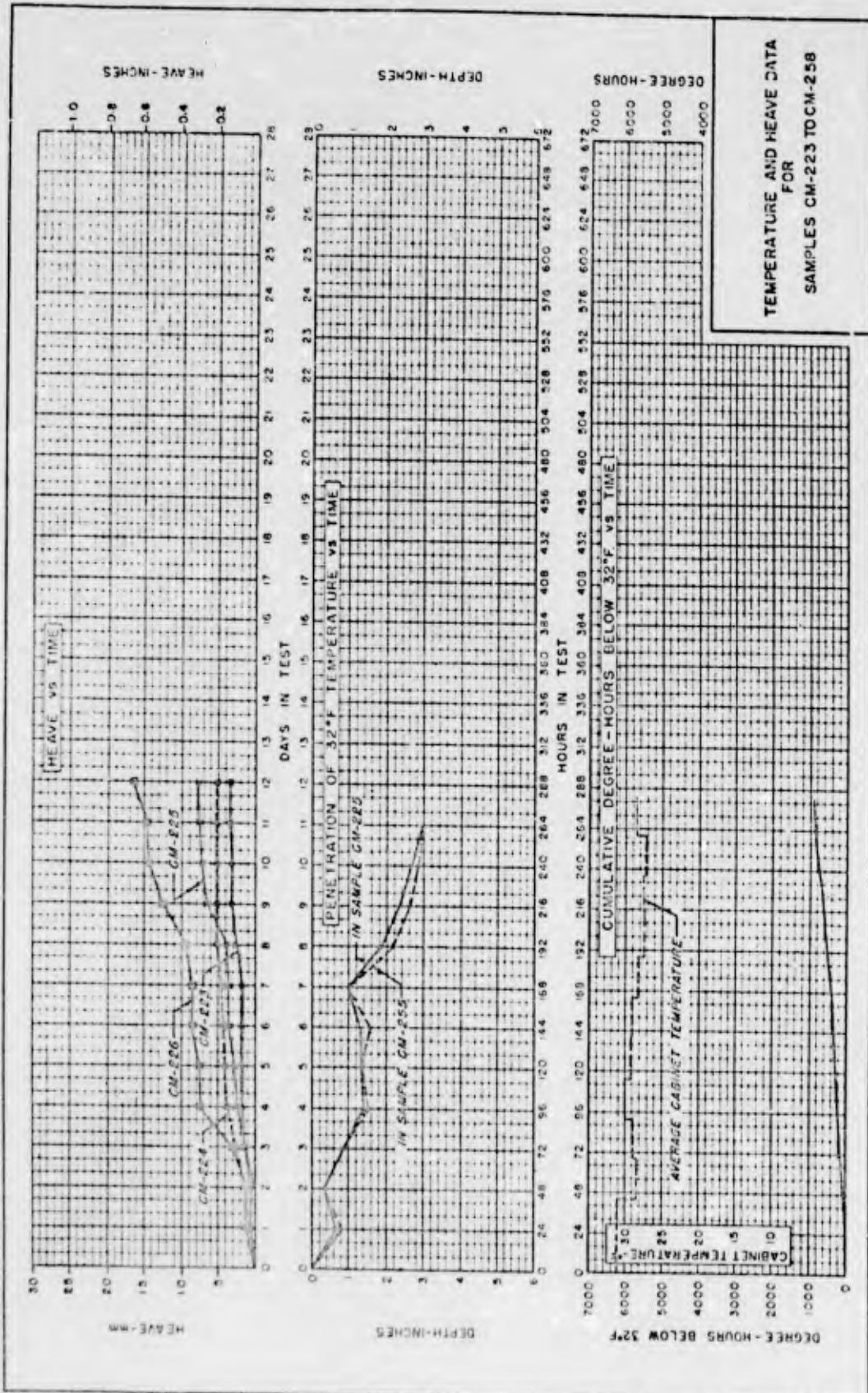


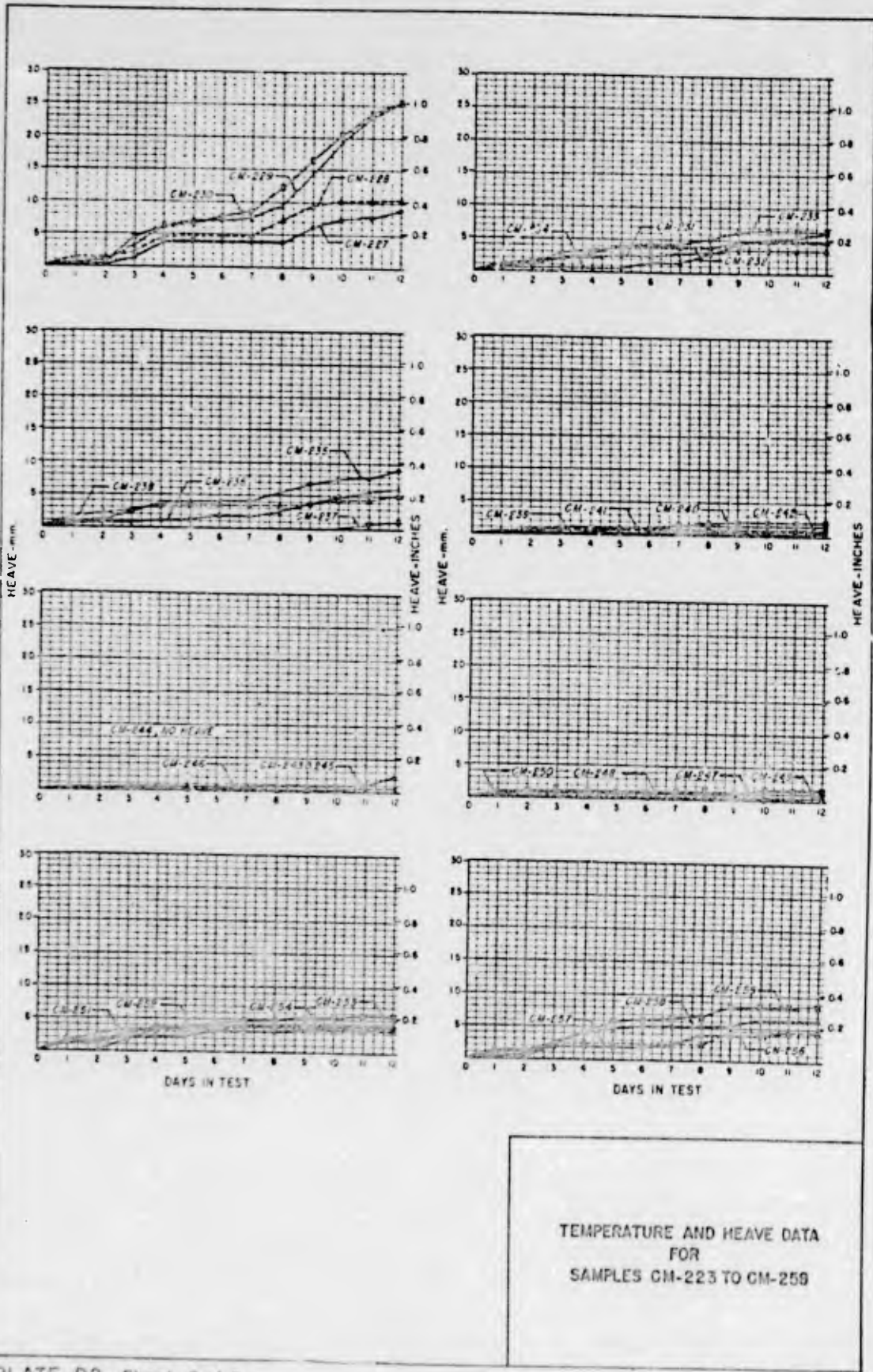
TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-151 TO CM-185



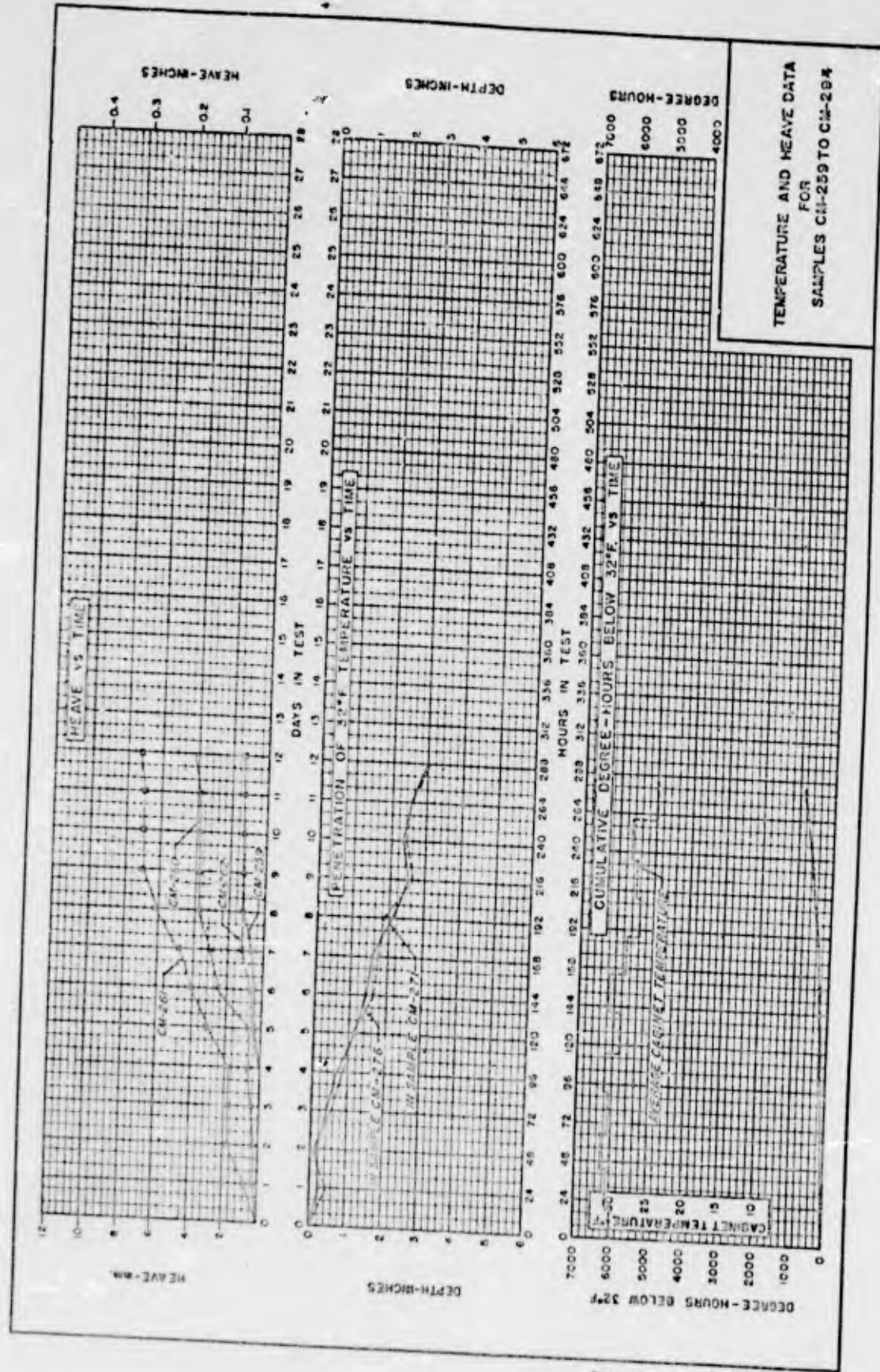


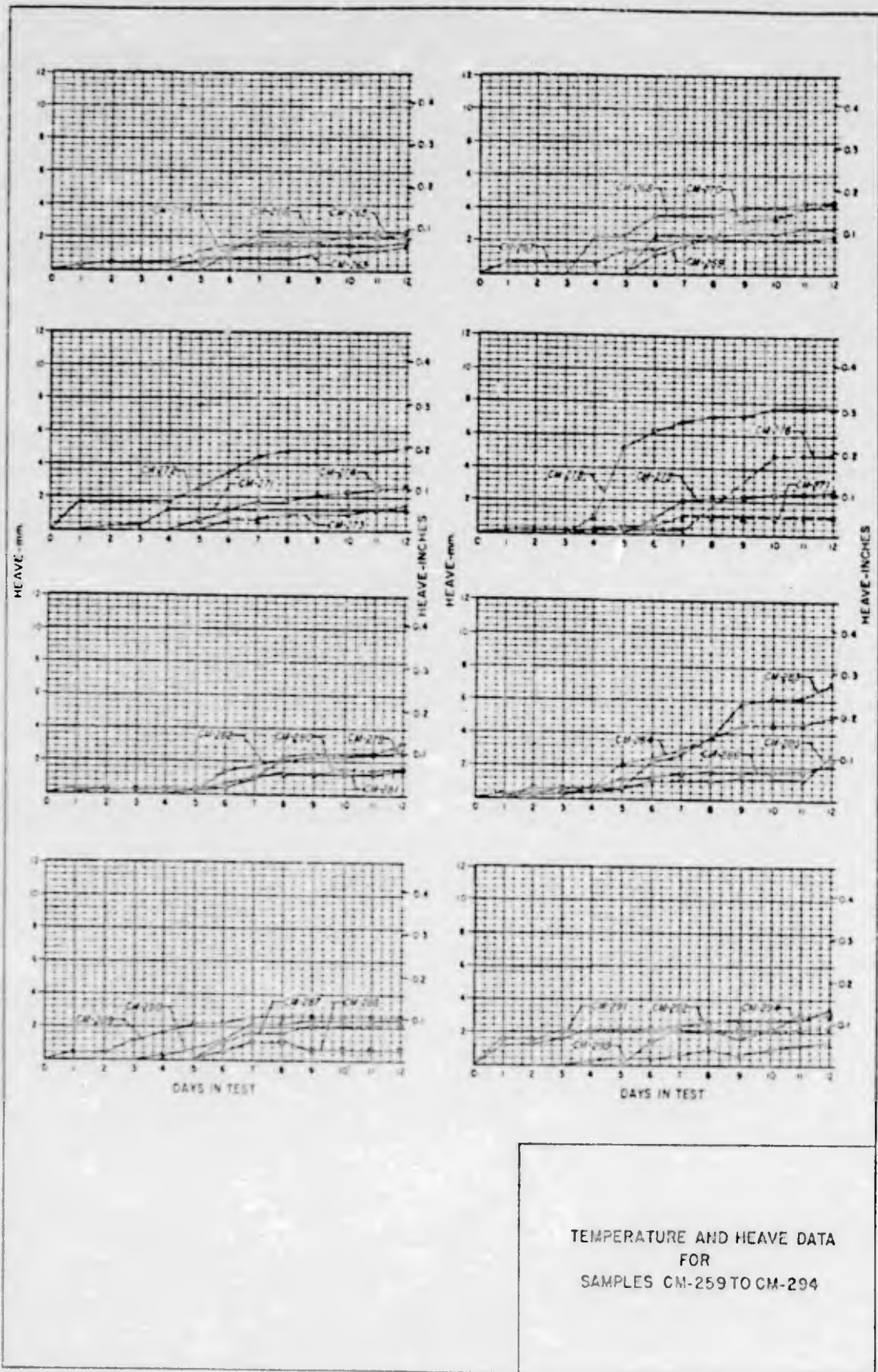
TEMPERATURE AND HEAVE DATA
 FOR
 SAMPLES CM-107 TO CM-222



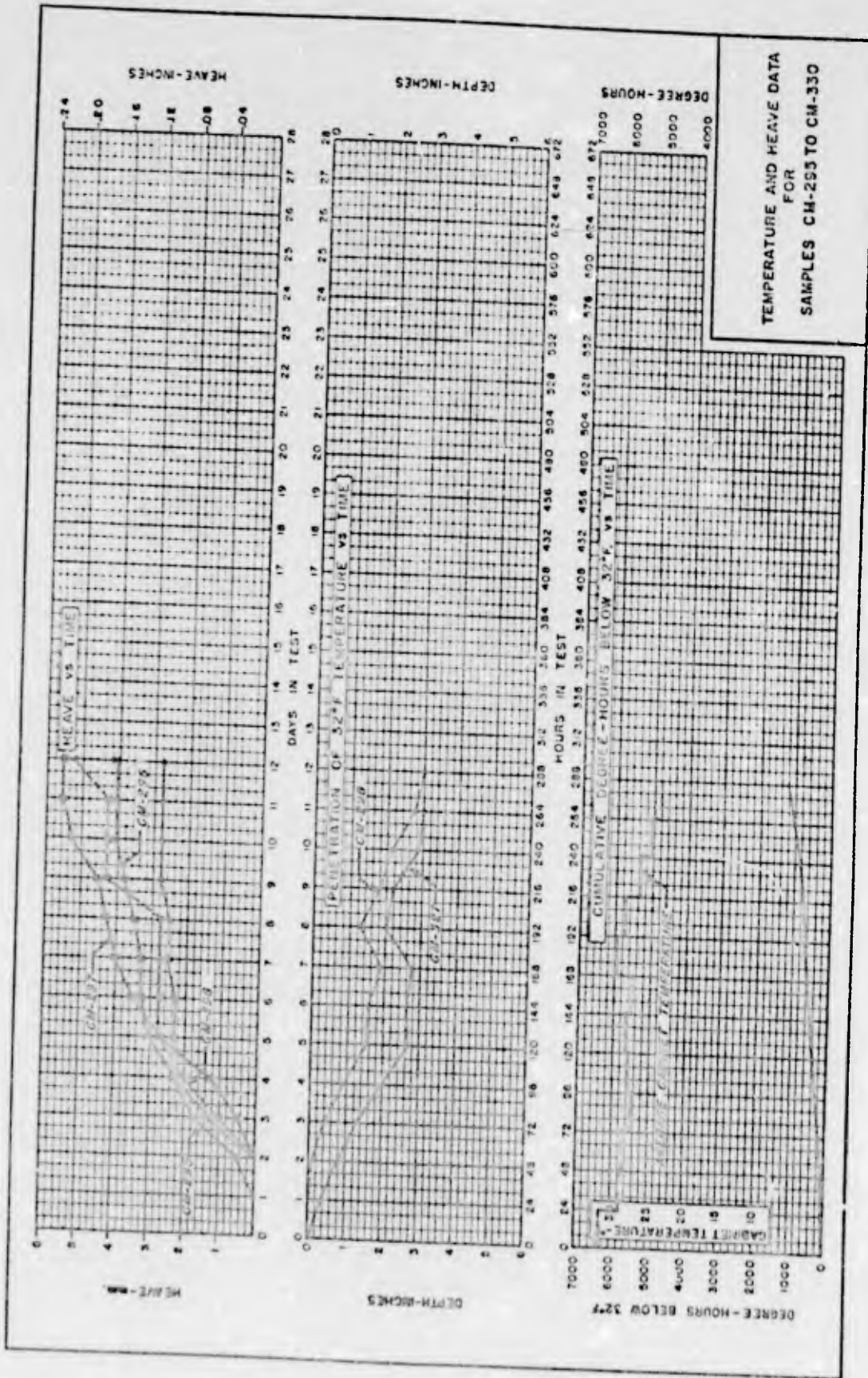


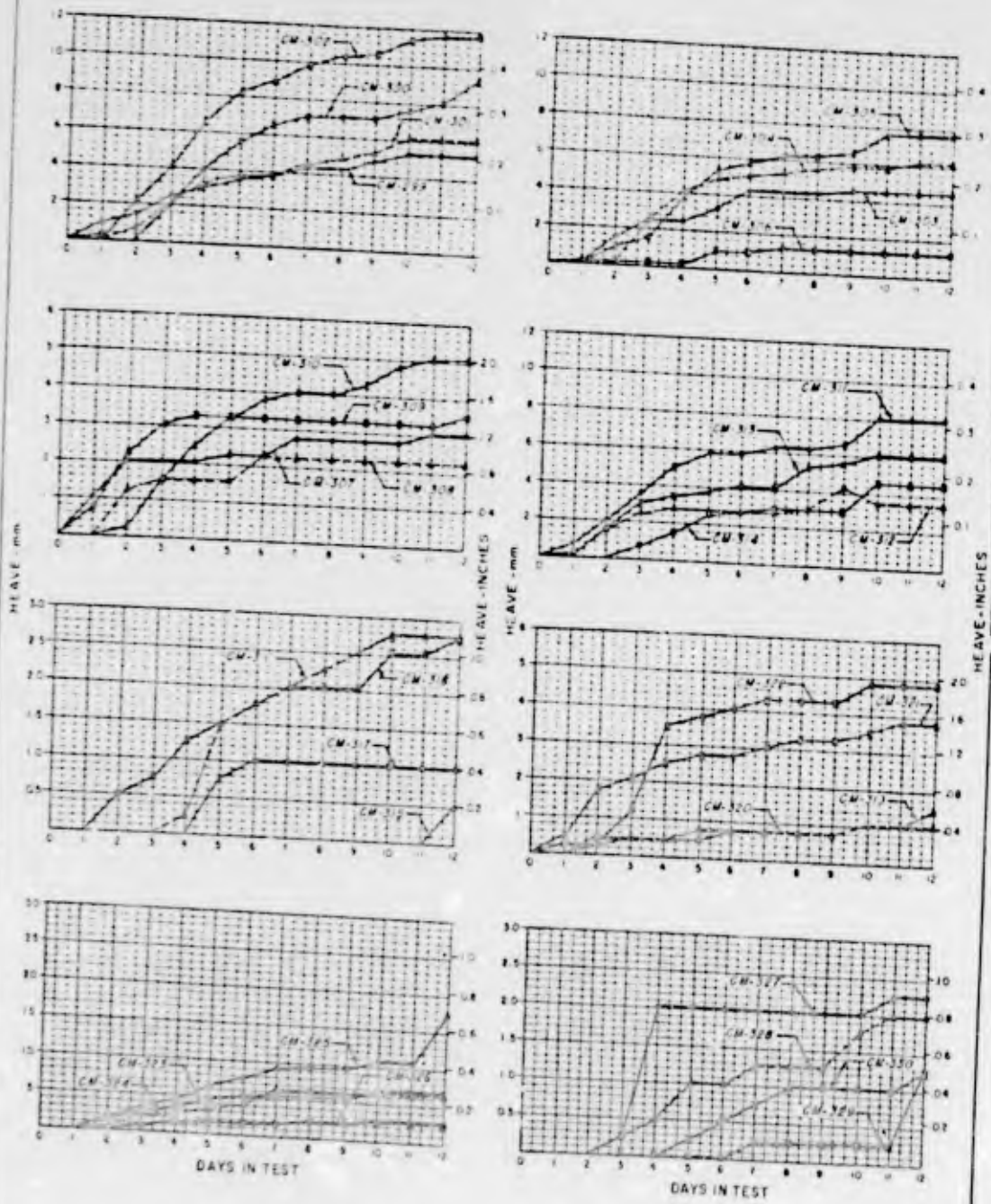
TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-223 TO CM-259



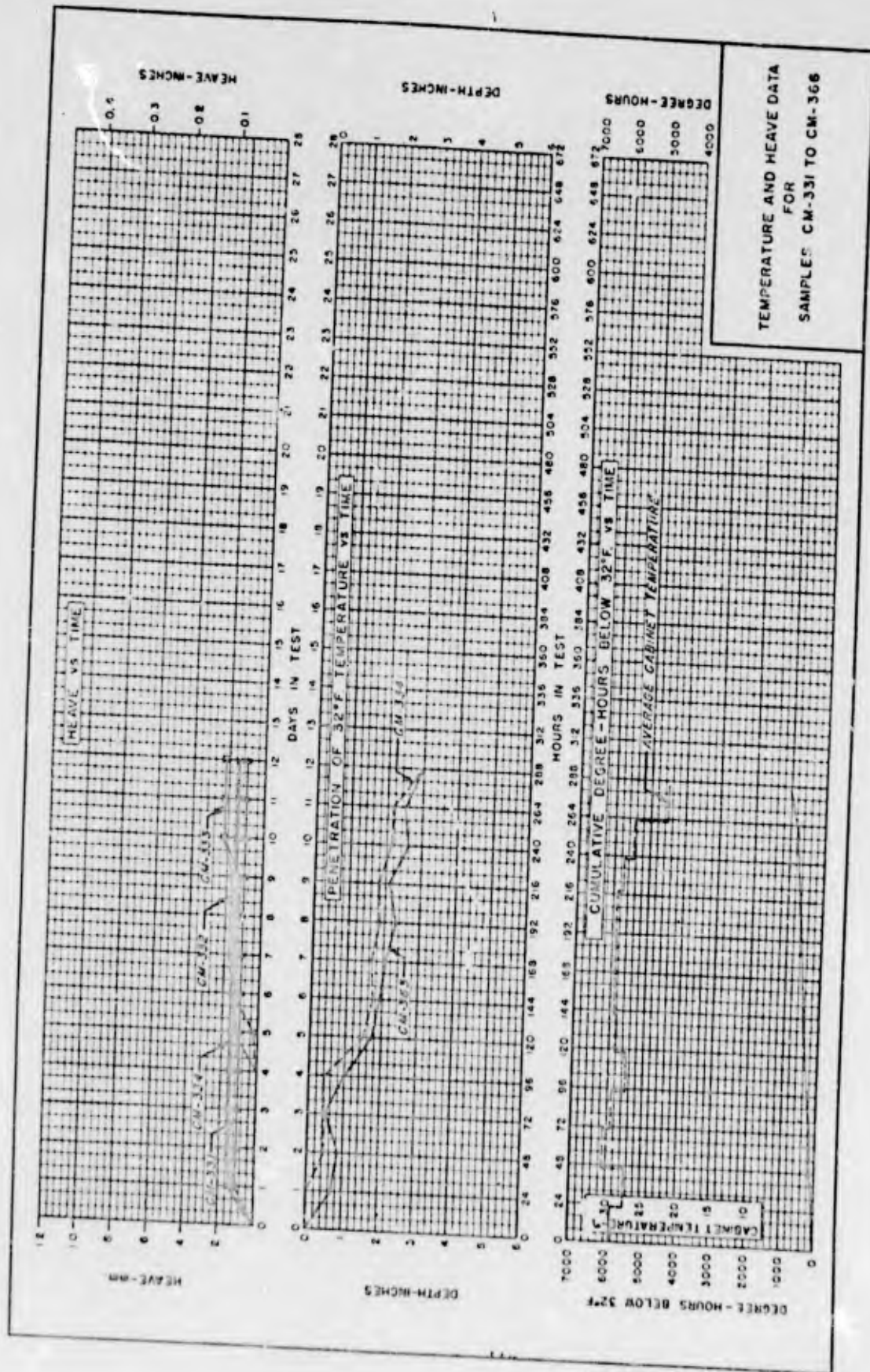


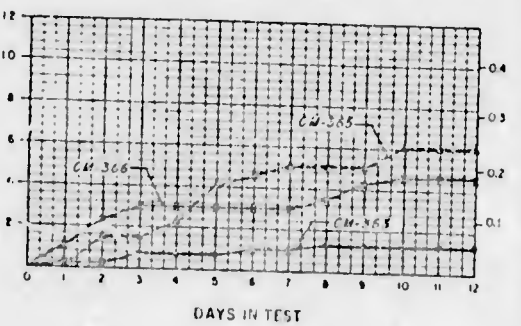
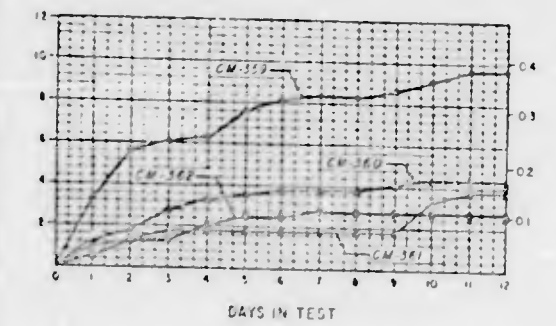
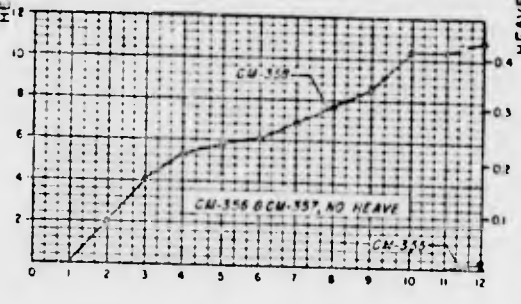
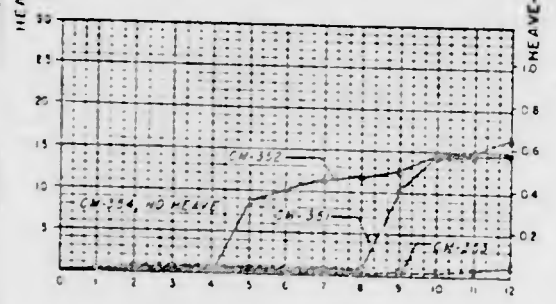
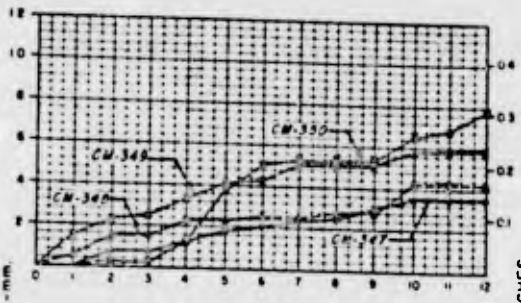
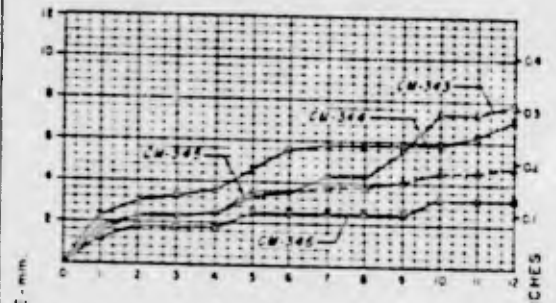
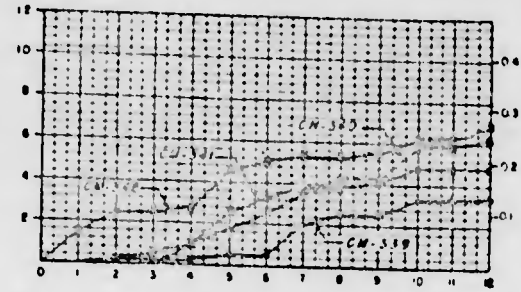
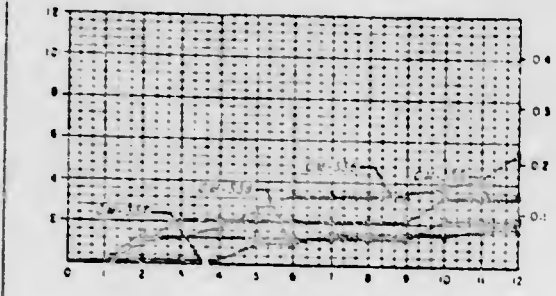
TEMPERATURE AND HEAVE DATA
 FOR
 SAMPLES CM-259 TO CM-294





TEMPERATURE AND HEAVE DATA
FOR
SAMPLES CM-295 TO CM-350





TEMPERATURE AND HEAVE DATA
 FOR
 SAMPLES CM-331 TO CM-366

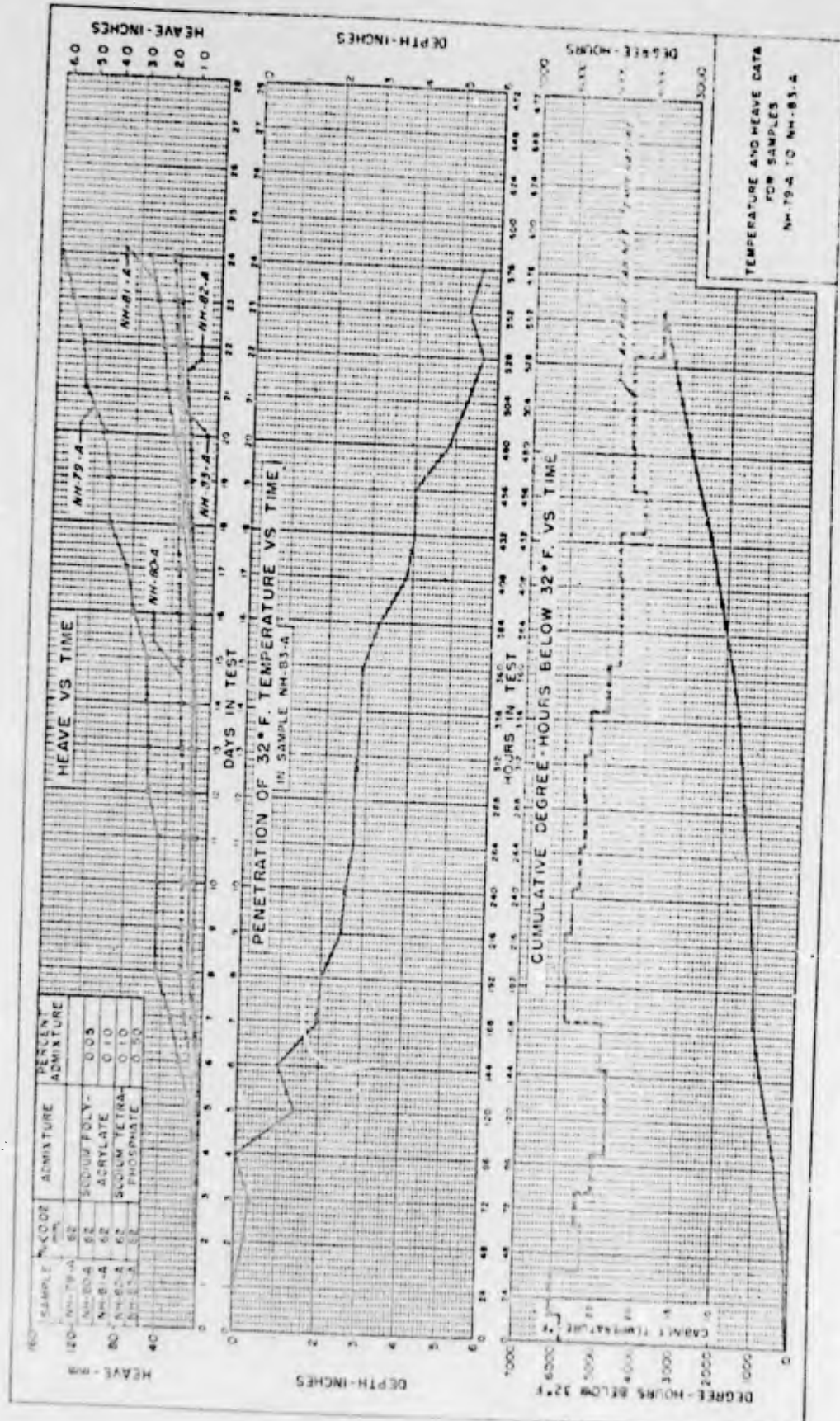
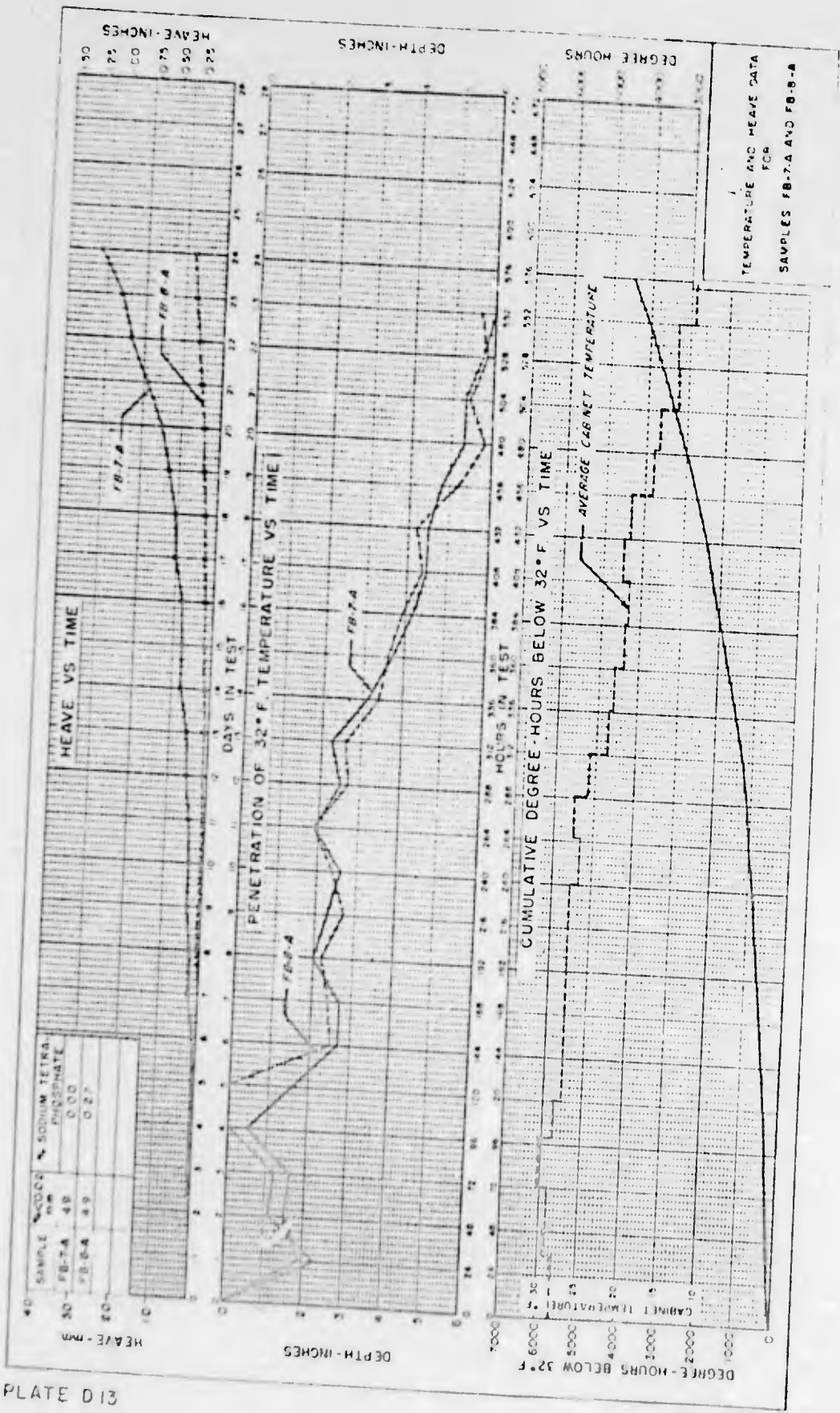


PLATE 012



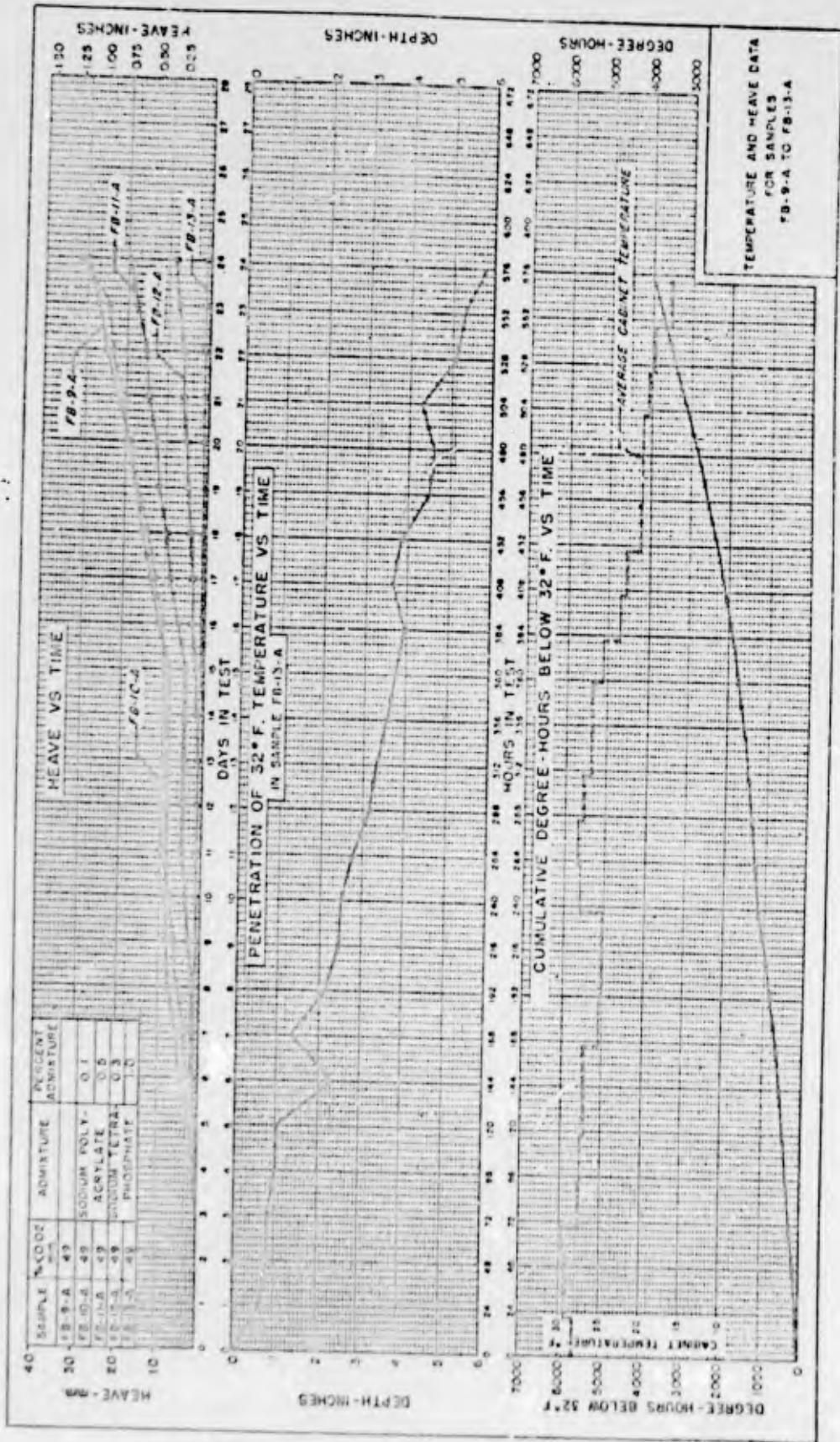
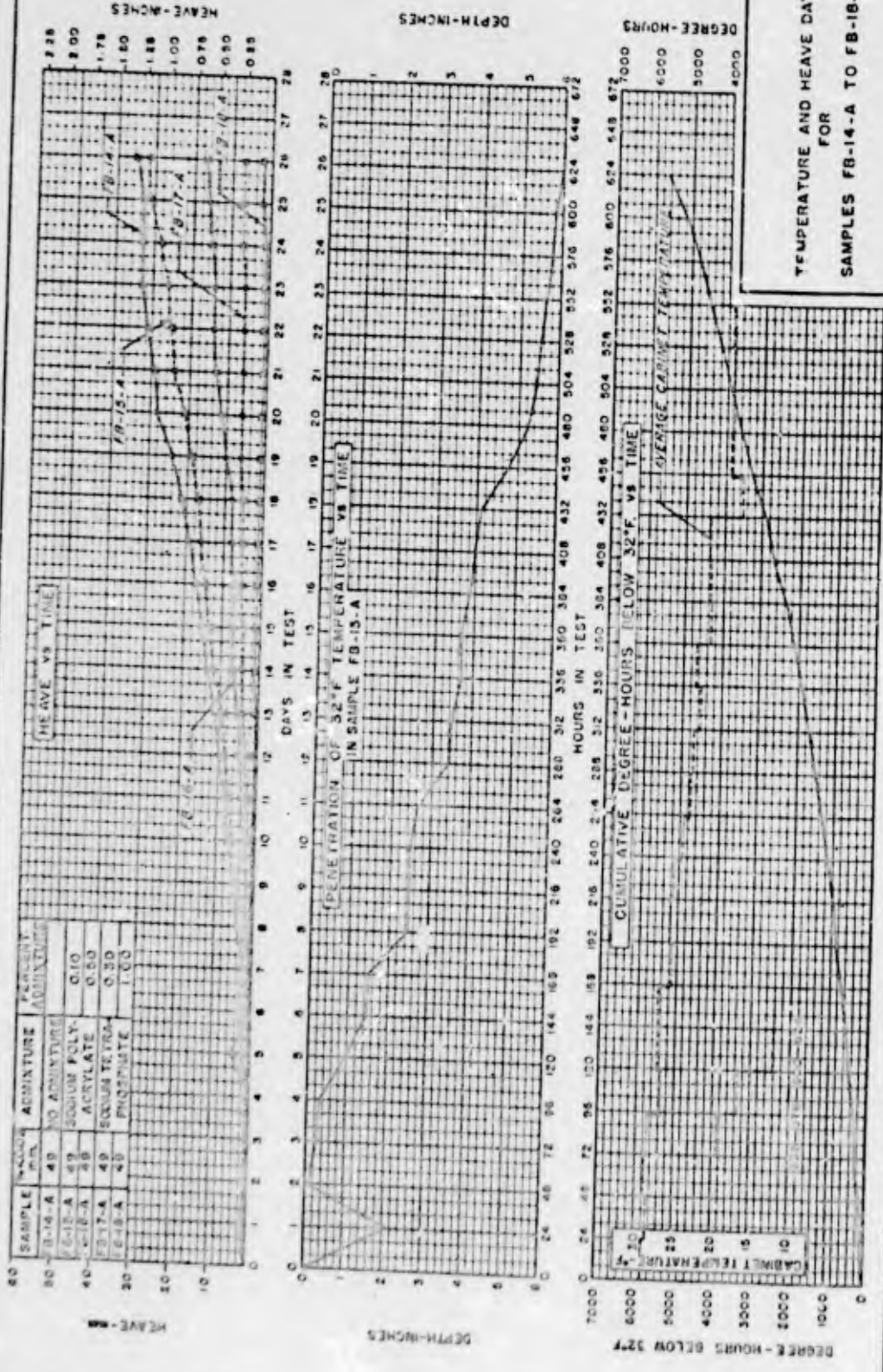


PLATE D14



TEMPERATURE AND HEAVE DATA FOR SAMPLES FB-14-A TO FB-18-A

END

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