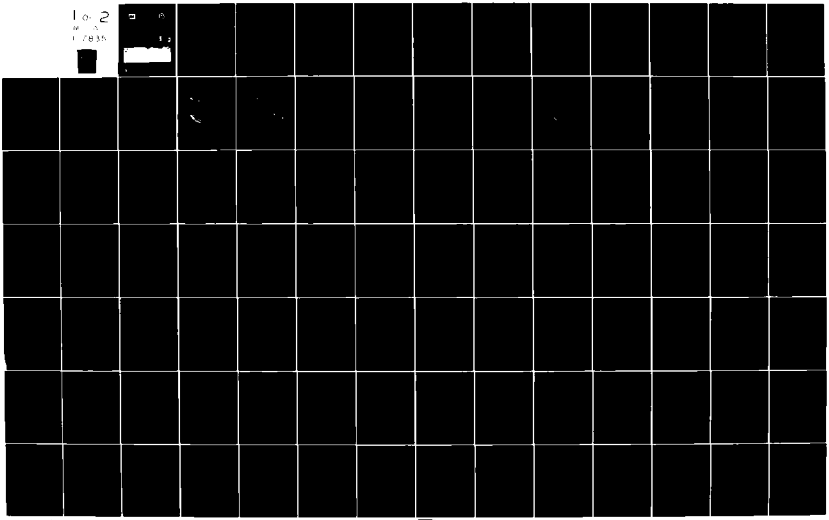
AD-A117 835 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/13
ANALYSIS OF FIELD COMPACTION DATA, DEGRAY DAM, CADDO RIVER, ARK--ETC(U)
MAR 82 W E STROHM, V H TORREY
UNCLASSIFIED WES/MP/GL-82-4 NL

1 of 2
AD A
117835



MISCELLANEOUS PAPER GL-82-4

ANALYSIS OF FIELD COMPACTION DATA, DEGRAY DAM, CADDO RIVER, ARKANSAS

by

William E. Strohm, Jr.
Victor H. Torrey III

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

March 1982

Final Report

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under CWIS 31173 and CWIS 31209

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper GL-82-4	2. GOVT ACCESSION NO. AD-A117 835	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ANALYSIS OF FIELD COMPACTION DATA, DeGRAY DAM, CADDO RIVER, ARKANSAS		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William E. Strohm, Jr. Victor H. Torrey III		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CWIS 31173 and CWIS 31209
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE March 1982 13. NUMBER OF PAGES 102
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Caddo Lake (Ark.)
DeGray Dam (Ark.)
Earth dams
Embankments
Soil stabilization

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a review of the materials, specifications, procedures, equipment, and testing pertinent to construction and compaction control of the earth-fill embankment of DeGray Dam, Caddo River, Arkansas, constructed by the U. S. Army Engineer District, Vicksburg. This report includes summation and analyses of the compaction control data submitted by the district to the U. S. Army Engineer Waterways Experiment Station.

(Continued)

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (Continued).

Statistical analyses are presented on the variation of fill water content from laboratory optimum water content and the variation of fill dry density from laboratory maximum dry density. These analyses are based on results of field density sampling in each major zone of the embankment. The overall compaction control achieved for each major embankment zone is indicated by frequency histograms, cumulative frequency distributions, and various statistical parameters for variation of both water content and density.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The study reported herein was authorized by letter from the Office, Chief of Engineers (DAEN-CWE-S), dated 7 December 1967, subject: Summaries of Field Compaction Control Data on Earth and Rockfill Dams. The study was accomplished under CWIS 31173, "Special Studies for Civil Works Soils Problems," and CWIS 31209, "Strength-Deformation Properties of Earth-Rock Mixtures."

This investigation was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) under the general direction of Messrs. James P. Sale and Richard G. Ahlvin, former Chiefs of the Geotechnical Laboratory (GL), Dr. William F. Marcuson III, Chief, GL, and Mr. Clifford L. McAnear, Chief, Soil Mechanics Division (SMD), GL. Principal engineers conducting the investigation and analyzing results were Messrs. William E. Strohm, Jr., Engineering Geology and Rock Mechanics Division, GL, and Victor H. Torrey III and Yu-Shih Jeng, SMD, GL. This report was prepared by Messrs. Strohm and Torrey.

Directors of WES during preparation and publication of this report were BG Ernest D. Peixotto, COL George H. Hilt, COL John L. Cannon, COL Nelson P. Conover, and COL Tilford C. Creel, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles	1.609344	kilometres
pounds (mass) per cubic foot	16.0185	kilograms per cubic metre
tons (2000 lb, mass)	907.1847	kilograms

ANALYSIS OF FIELD COMPACTION DATA, DeGRAY DAM, CADDO RIVER, ARKANSAS

PART I: INTRODUCTION

Background

1. This report is the third of a series of reports prepared on analyses of field compaction control data obtained on Corps of Engineers (CE) earth- and rock-fill dams. Data were collected and analyzed from a number of dams to examine results of field compaction and variations in field compaction data. As part of this effort, statistical analyses were made of the variation of water content and percent compaction of the fill material of several dams recently completed. The overall objectives of the study were to improve (a) design procedures, (b) specifications and control requirements, and (c) field construction control.

Purpose and Scope

2. The purposes of this study were to determine the feasibility of (a) establishing general ranges for the variations of in-place water contents and percent compaction for the fill materials used and (b) developing interrelations between compaction data and classification data (such as Atterberg limits) for the purpose of simplifying and improving correlation of field and laboratory compaction data.

3. Statistical analyses were made of the field compaction control data for DeGray Dam, an earth-fill dam designed and constructed by the U. S. Army Engineer District, Vicksburg. The embankment materials, the compaction control methods, the procedures used in the analyses of field data, and the results obtained are discussed in the remainder of the report.

PART II: CONSTRUCTION OF THE DAM AND DIKE

Description of the Site and Earth Structures

Plan and location

4. The general plan of DeGray Dam is shown in Figure 1. The damsite is located in the Athens Piedmont Plateau of the Quachita Mountain Region on the Caddo River in northern Clark County, Arkansas, approximately 8 miles* above its confluence with the Ouachita River. The project consists of the main earth-fill dam embankment with a maximum height of 243 ft and a length of approximately 3400 ft, an earth-fill dike embankment with a maximum height of 110 ft and a length of approximately 2-1/2 miles, a small earth-fill reregulating dam located downstream of the main dam, a power plant located riverward of the outlet works, an uncontrolled spillway, and associated outlet works (U. S. Army Engineer District, Vicksburg 1962, 1963, 1972). Construction was started in January 1964 and completed April 1971.

Geology

5. The main dam is in a rock-walled gorge about 500 ft wide at the bottom with valley walls rising within a short distance to 300 ft above the floodplain. The dam is founded on the Jackfork formation of Mississippian age, having alternating thin to moderately thick strata of sandstone and shale. The sandstone is fine- to coarse-grained, hard, occasionally conglomeritic, quartzitic, and moderately to lightly jointed. The shale is gray to black, hard, fissile, and moderately to lightly jointed. Faulting and fracturing of the foundation materials is common throughout the area.

Main dam

6. A typical dam section in the valley is shown in Figure 2. The dam embankment consists of a central impervious core, upstream and downstream shells of more pervious sandy and gravelly material, a vertical

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

sand drain and a horizontal sand and gravel drain. Shell material was to consist of any material from designated borrow areas except shale or shaley clays, and was to be placed so as to grade the more pervious material toward the outside of the section. The core was to be composed of material with about 50 percent finer than the No. 200 sieve (U. S. Army Engineer District, Vicksburg 1964). Because of the low percentage of sand in the natural deposits, the design of the various filters was such as to incorporate the maximum practicable quantity of gravel. The 10-ft-wide, vertical sand drain was located immediately downstream of the core and was connected to the 5-ft-thick horizontal sand and gravel drainage layers placed on the rock foundation. For 500 ft in the valley below el 220, the horizontal drain consisted on 1 ft of sand over 4 ft of gravel. Elsewhere the horizontal drain consisted of a single 5-ft sand and gravel layer except that no drain was provided above el 423. A 5-ft-thick horizontal sand and gravel blanket was placed on the rock foundation beneath that portion of the upstream shell constructed during the first construction season. The upstream slope was protected with 24 in. of riprap, and the downstream slope was protected with 12 in. of riprap. A rock toe was provided on the downstream slope.

Dike

7. A typical dike section is shown in Figure 3. The design of the dike section is similar to that of the main dam except that the slopes are somewhat steeper, the landside slope is protected by sod, and no filter layer was placed beneath the upstream shell. Construction of the dike was started before the dam.

Borrow sources

8. Impervious core and random shell materials were largely obtained from the borrow areas shown in Figure 1.

a. Borrow area A. Borrow area A, which lay immediately upstream from the spillway, was used in the construction of the dike. The material consisted of Pleistocene Terrace soils ranging from gravelly sandy clay (CH) to clayey gravel (GC). Since the terrace materials were somewhat heterogeneous, composite samples were selected to represent the various possible gradation ranges during the design and investigation stage. Generally, two groups of

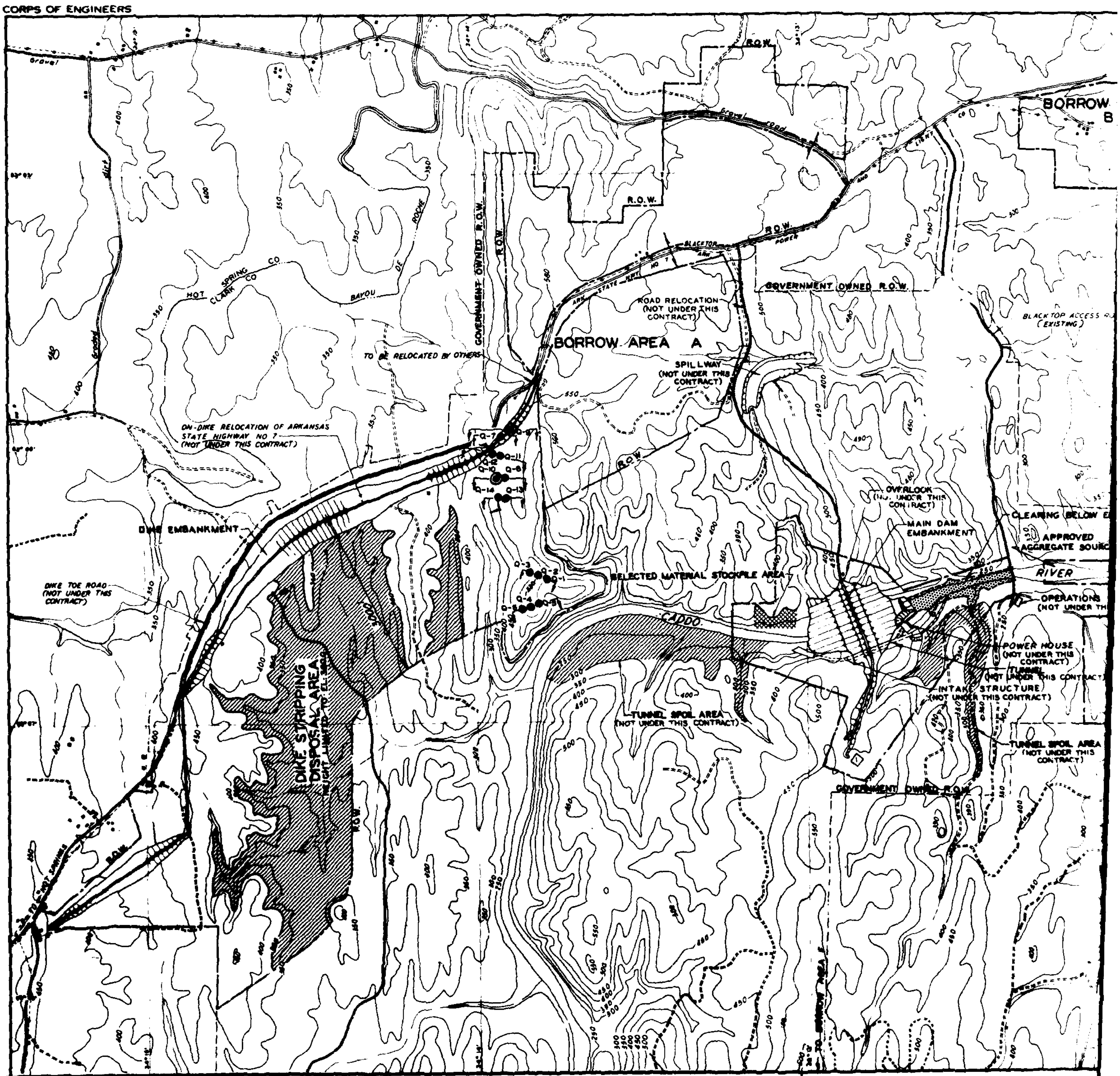


Figure 1. General plan

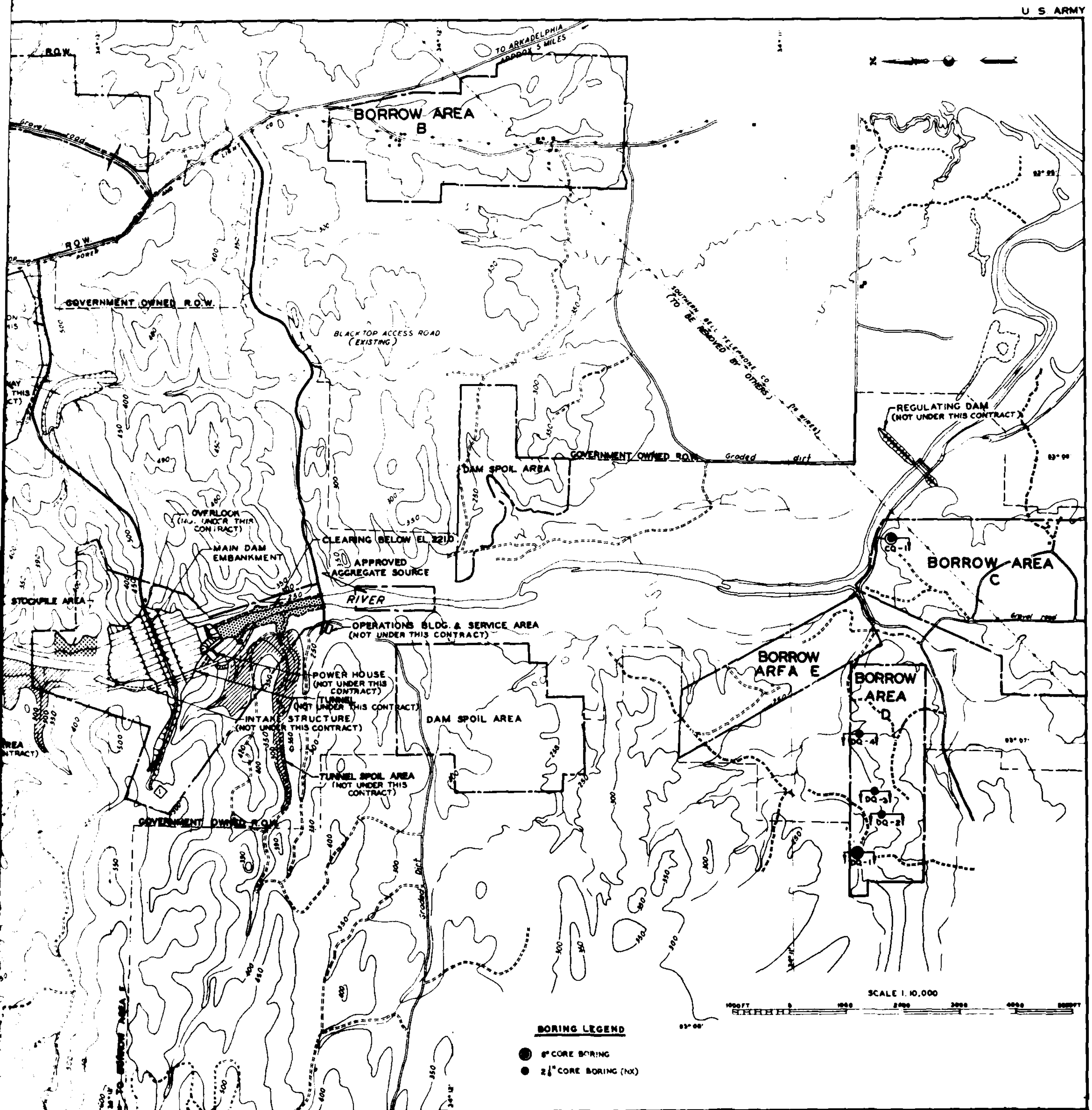


Figure 1. General plan

2

Notes:

1 Typical abutment sections differed from valley sections essentially as follows: (a) No sand and gravel filter on rock foundation beneath upstream shell and (b) downstream horizontal drain consisted of 5 ft of sand and gravel instead of 1 ft sand on 4 ft gravel.

2 Upstream sand and gravel filter drain installed only from approximately sta 4+00 to 9+00 as a filter and for drainage of rock foundation to facilitate construction of first season section.

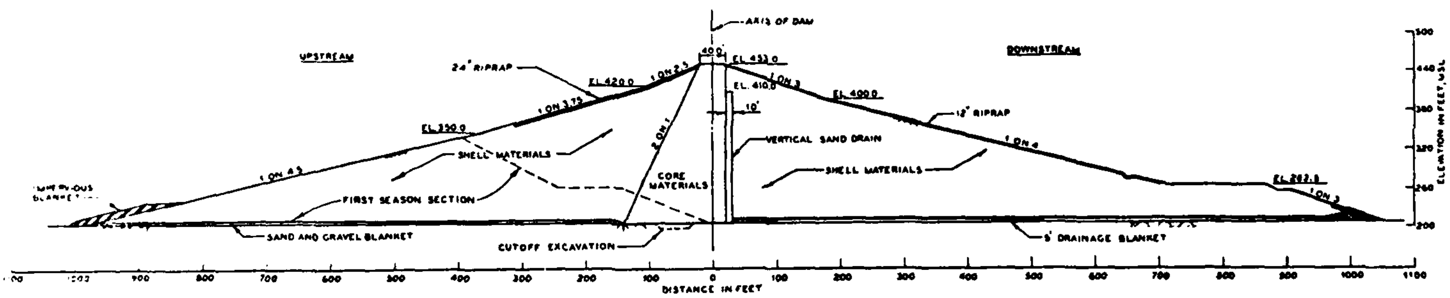


Figure 2. Valley section of dam (station 4+00 to 9+00)

Notes:

1 Dike section shown is typical for sta 15+50 to 73+00 and sta 118+10 to 141+00 except that (a) core width was greater between sta 18+30 and 69+70 and (b) no core zone was provided at ends of the two reaches when embankment heights were less than 41 to 48 ft.

2 Embankment sections for the remainder of the dike, primarily between sta 73+00 and 118+10 were less than 43 ft in height and were unzoned.

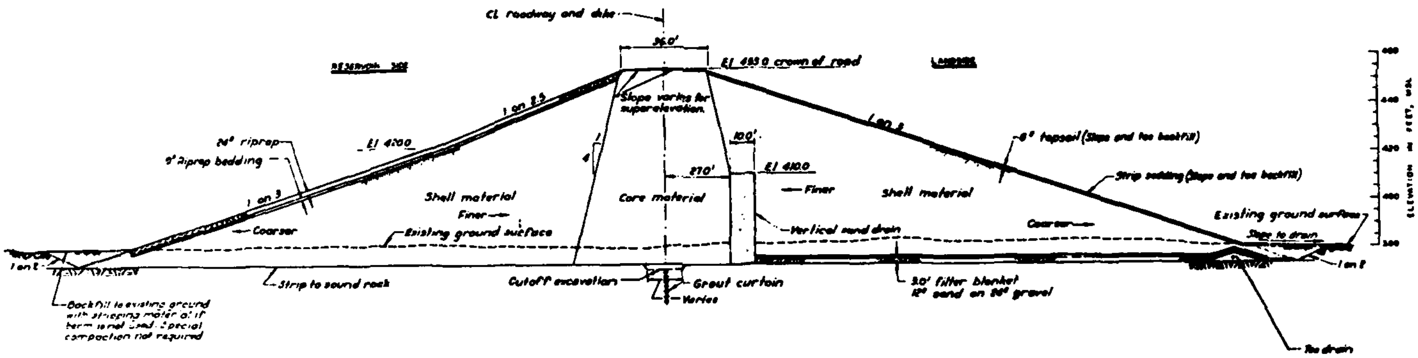


Figure 3. Typical dike section

material according to their gradation were evident. One was a fine-grained group having 50 to 70 percent of the material passing the No. 200 sieve. The other was a coarse-grained group having 10 to 30 percent of the material passing the No. 200 sieve. Natural water contents generally were on the wet side of optimum, and drying was required for use in the fill areas.

b. Borrow area B and its extension. Borrow area B and its extension B-ext were located about 2 miles southeast of the main damsite. Materials from this location consisted of clayey sandy gravel (GC), clayey sand (SC), sandy clay (CL), and occasional pockets of sandy silt (SM), clay (CH and CL), and silty sand (SP-SM). Maximum gravel size was about 3 in. Silty and sandy materials (SM and SP-SM) were more predominant in area B-ext, which was used with borrow area A in constructing the dike.

c. Borrow areas C, D, E, and F. Borrow areas C, D, and E were located about 2.5 miles downstream of the main dam. Borrow area F was located about 3 miles west of the main damsite. The materials in these four borrow areas were similar to those of borrow area B.

d. Pervious borrow. Since suitable borrow areas for filter and drainage materials could not be found in the immediate vicinity of the damsite, these materials were obtained from commercial sources.

Gradations of materials in borrow areas A through F are shown in Figures 4 and 5 with some Atterberg limits and specific gravity values. Specified gradations of pervious materials for vertical and horizontal drains are shown in Figure 6.

Field Data on Fill Materials

9. District field compaction control reports contained results of field density tests made in the main embankment and dike embankment. Fill materials were classified visually by field personnel at the time of the field density tests and were checked by gradation analyses and Atterberg limit tests performed at the field laboratory. This information was entered on the compaction control reports. Gradation analyses to determine the percentage of plus 1-in. material and percentages passing the No. 4 sieve and No. 200 sieve were performed on each field density sample. Atterberg limits tests were performed on as many samples

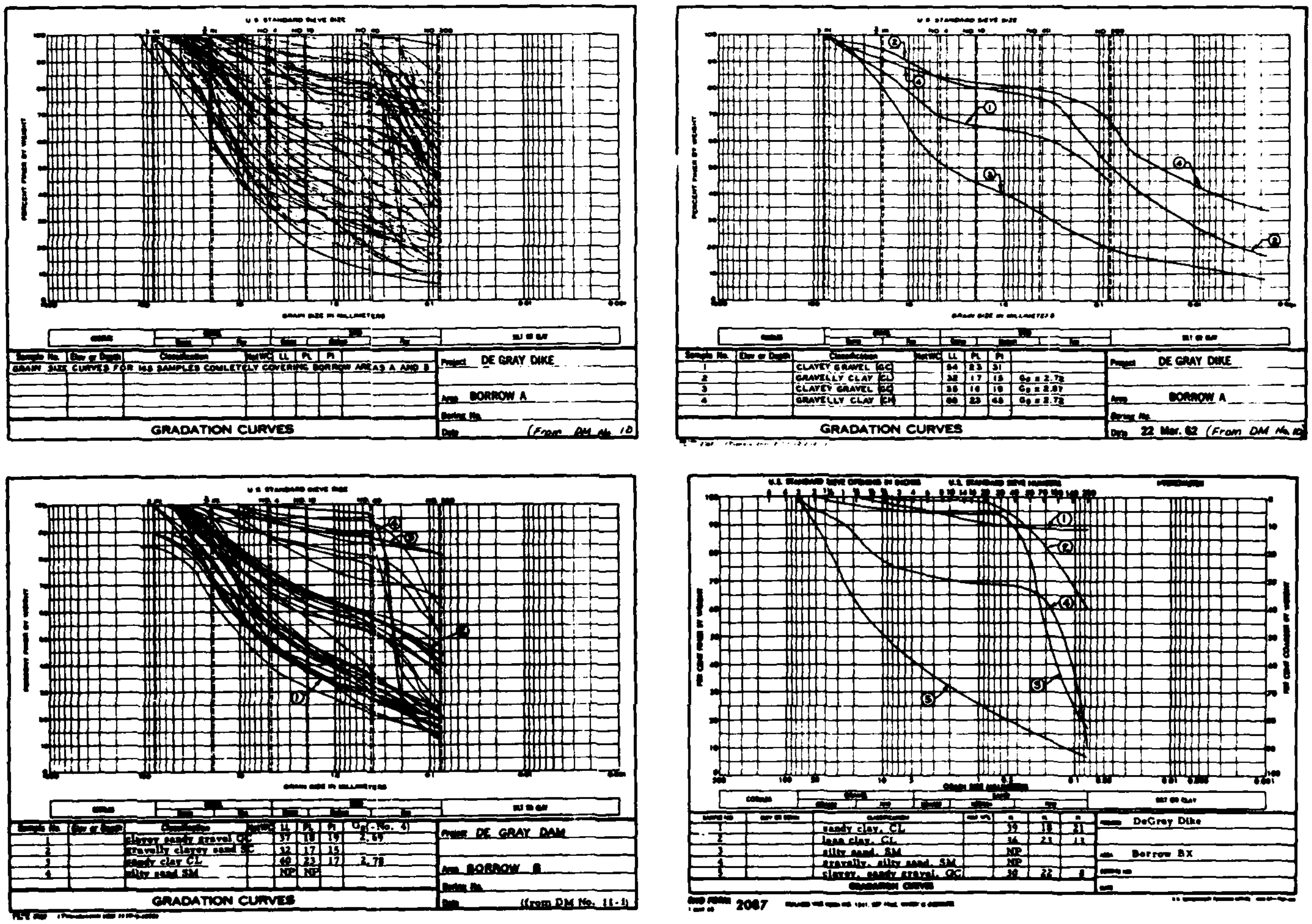


Figure 4. Gradation of materials in borrow areas A, B, and BX

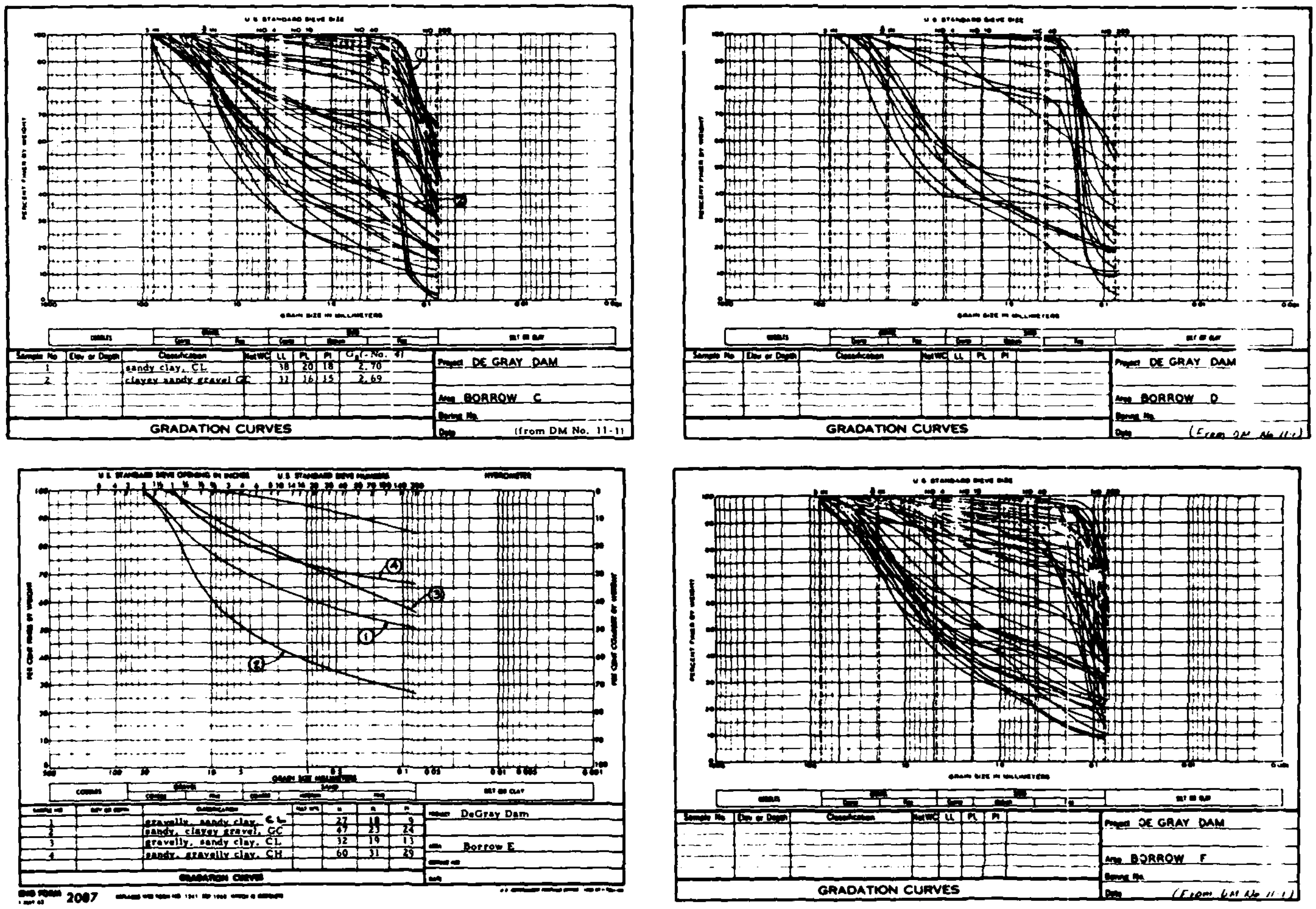


Figure 5. Gradation of materials in borrow areas C, D, E, and F

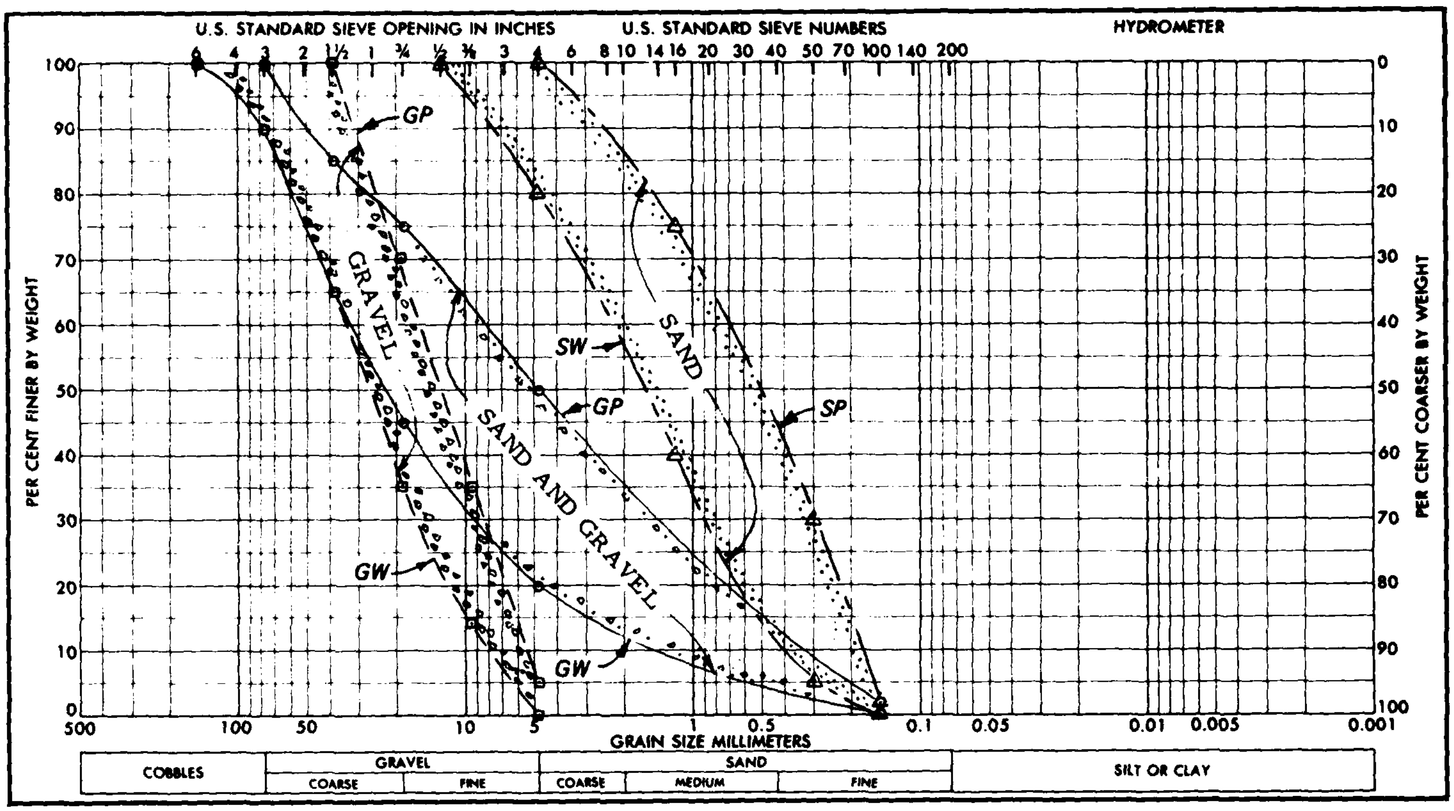


Figure 6. Specified gradation of pervious materials for vertical and horizontal drainage layers in the dam and dike

as possible, but were often estimated during times of heavy work load. Table 1 summarizes pertinent data on soil type, yardage, number of tests, compaction procedure, and compaction control reports. The materials used in each zone are described below:

a. Impervious fill. The impervious fill consisted essentially of gravelly sandy fat clay (CH) and sandy clay (CL) with minor quantities of clayey sand (SC) and clayey gravel (GC). Typical gradation curves of field density samples for the dam and dike, respectively, are shown in Figures 7 and 8.

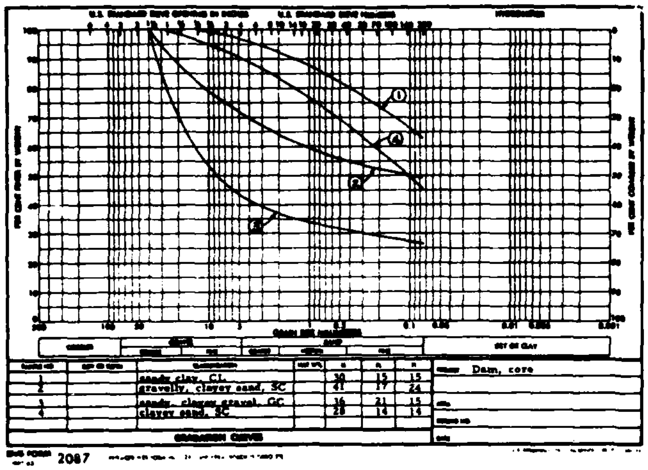
b. Shell fill. The shell fill material consisted primarily of clayey gravel (GC) and silty sand (SM). Typical gradation curves of field density samples for the dam and dike, respectively, are also shown in Figures 7 and 8. Typical gradations for the unzoned sections of the dike are also shown in Figure 8.

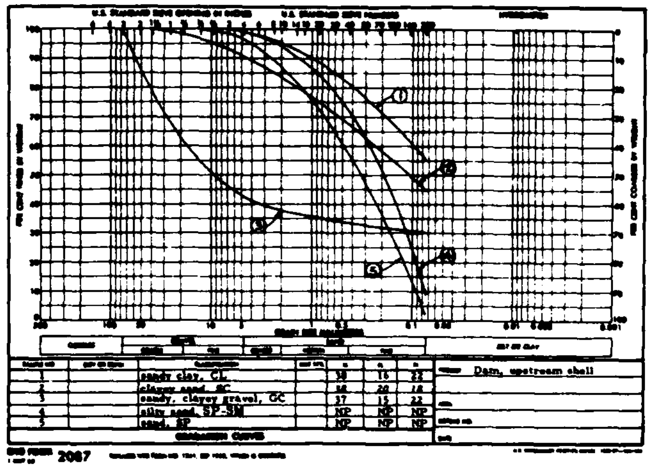
c. Pervious fill. The required pervious fill materials of the dam and dike were obtained from three commercial pits and consisted of gravel (GW), sand and gravel (GW), and sand (SW). The gravel and the sand were used for the horizontal drainage layers beneath the downstream section of the dam (below el 220) and dike, and the sand was used for the vertical drain in the dam and dike. The sand and gravel mixture was used in the downstream horizontal drain of the dam above el 220 and beneath the upstream shell section of the dam constructed during the first season. Typical as-placed gradations of the three types of pervious fill materials are shown in Figure 9.

Compaction Requirements and Procedures

Compaction requirements

10. Specifications for placement water content, desired compacted densities, and field compaction procedures are summarized in Table 1. The contract specifications contained requirements for placement water contents and compaction procedures, but did not stipulate minimum required densities. Construction of the dike was started first, and a test fill was made to develop the most suitable compaction procedures. Provision for additional rolling was included in the contract to ensure desired compaction of the embankment. The field compaction control criteria and procedures used in construction are outlined below:





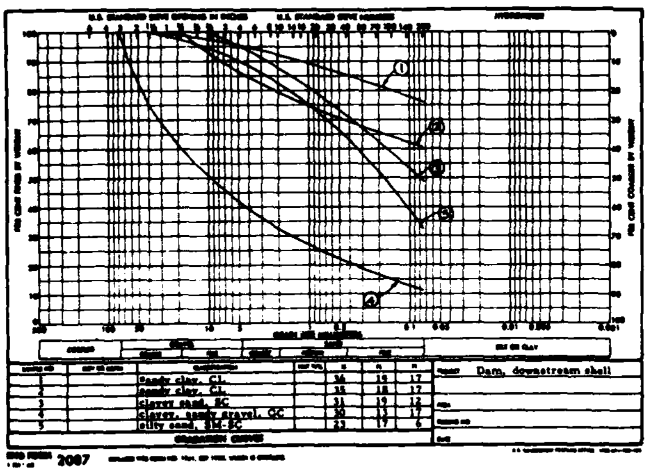


Figure 7. Typical gradations of materials used in main dam

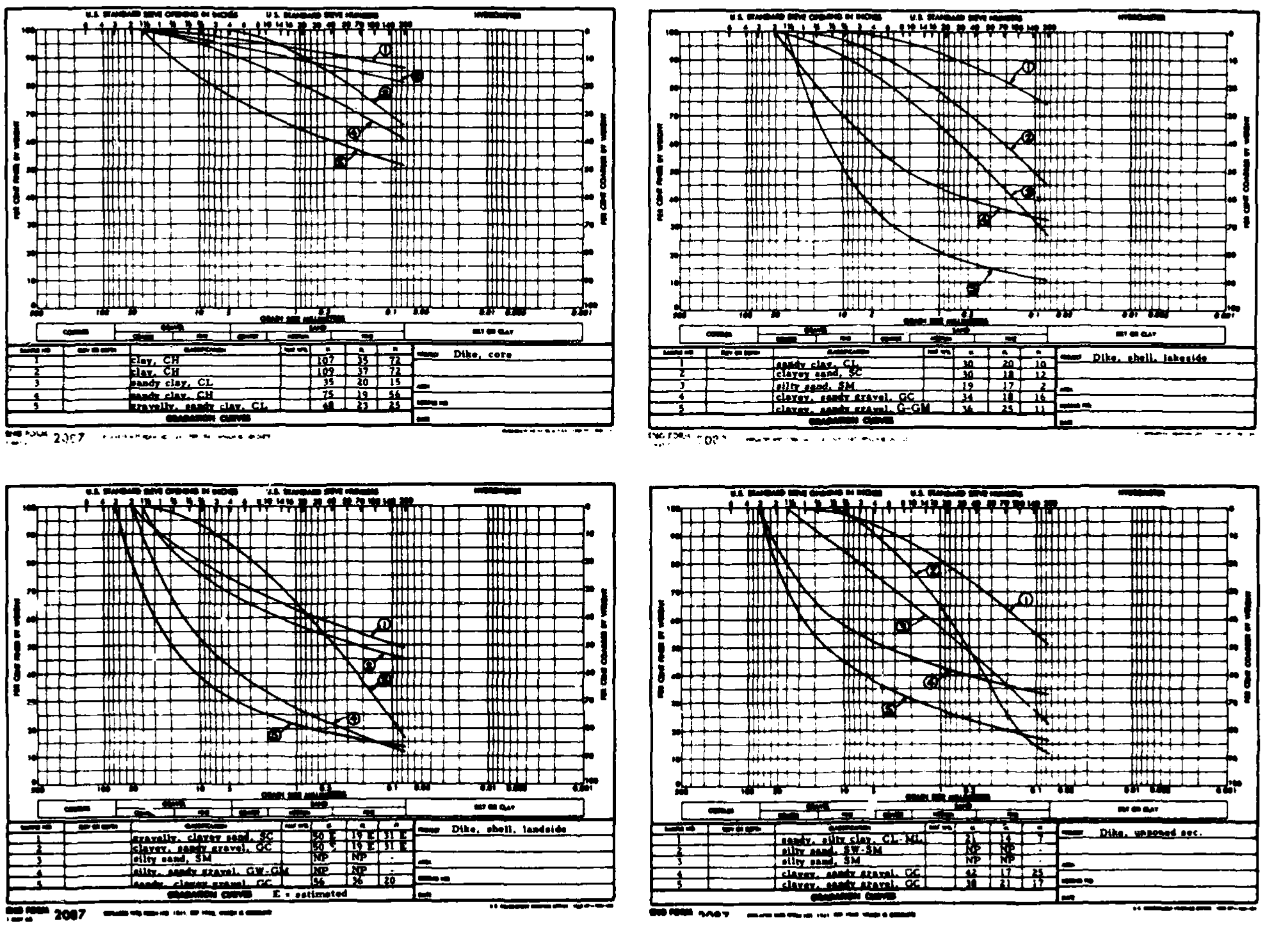
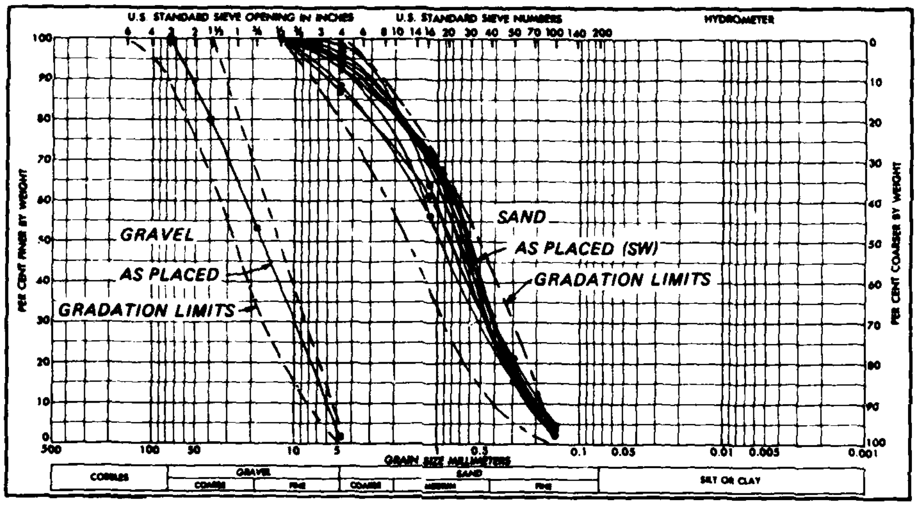


Figure 8. Typical gradations of materials used in dike



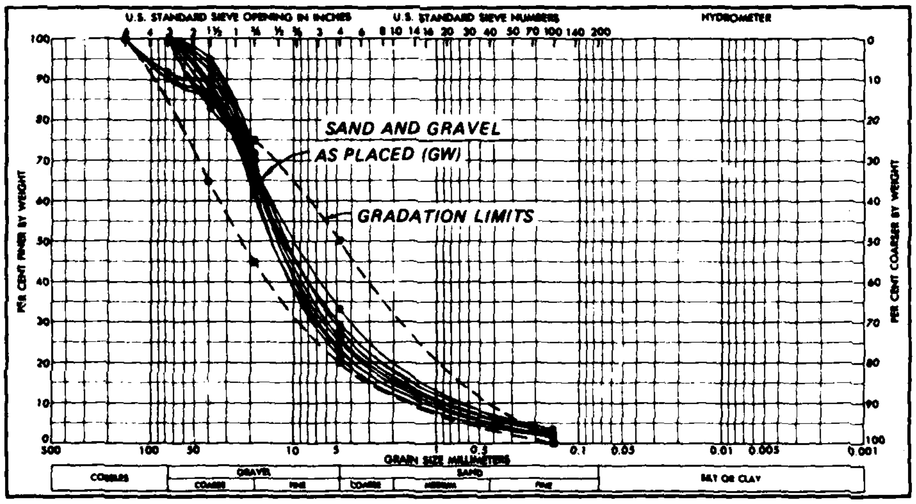


Figure 9. Typical gradation of pervious materials placed in vertical drain and horizontal drainage layers of main dam and dike

a. Core.

(1) The water contents during compaction of the dam fill were controlled within minus 2.0 to plus 1.0 percentage points of laboratory optimum water content (U. S. Army Engineer District, Vicksburg 1964). For the dike, the original specification was modified because of borrow area conditions encountered during construction. Initially, water content limits of minus 2.0 to plus 1.5 percentage points were specified, but were subsequently modified to minus 3.0 to plus 6.0.

(2) Desired minimum percentages of standard maximum dry density were established but not specified in the contract documents. The values were 100 percent for the dam and 98 percent for the dike.

b. Shell.

(1) Water contents during compaction were controlled within minus 2.0 to plus 1.0 percentage points of optimum water content for the dam and minus 2.0 to plus 1.5 for the dike.

(2) The desired minimum percentage of compaction was set at 100 percent of standard effort maximum dry density for the dam and 98 percent for the dike.

c. Pervious fill (vertical sand drain and horizontal sand or gravel drainage layers).

(1) Sand placed in the vertical drain and sand or gravel placed in the horizontal drainage layers were kept saturated during compaction to achieve the desired compaction.

(2) The desired compaction during initial construction of the dike was 70 percent relative density.* This was later changed to an average relative density of 85 percent to meet the requirements of ETL 1110-2-13, "Compaction of Cohesionless Fills and Filters." This requirement was used for the major portion of the vertical and horizontal drainage materials in the dike and all such materials in the dam.

Placement and compaction

11. Core and shell fill materials were placed in 8-in. loose lifts and compacted by a minimum of either six passes of a 4-wheel rubber-tired roller (usually loaded to 50 tons, but reduced to 32 tons

* Maximum dry density was determined using the vibratory table test procedure prescribed in the 1965 edition of EM 1110-2-1906.

in a few instances). Material was usually wetted or dried at the fill site, but a small amount of wetting or drying was accomplished in the borrow pits. Compaction of the vertical sand drain was by four passes of a "Tampo" Model VC-80, towed-type vibratory roller, with flooding ahead of the roller accomplished by spray bars attached to the compactor frame. A flexible hose connected the spray bars to a truck-mounted water tank. Compaction of the horizontal sand or gravel drainage layers was by eight passes of a crawler-type tractor equipped with water sprays as described for the vibratory compactor. The sand or gravel materials were placed in 6-in. loose lifts.

Field Sampling and Testing

Sampling of embankment fills

12. Two types of samples were obtained in the embankment:

a. Control samples (dam and dike). Disturbed control samples were taken for the purpose of controlling the placement and compaction of the embankment materials and at the same time to provide a permanent record for the project. A plan for locating control samples is shown in Figure 10. The following information was obtained on each sample of core or shell material (except as otherwise noted):

(1) Location of the sample in the fill (station, offset, elevation and depth below lift surface).

(2) In situ density.

(3) Water content.

(4) Gradation (maximum particle size, percents plus 1 in., minus No. 4, and minus No. 200 as a minimum).

(5) Five-point standard compaction test on material unlike those previously tested (made once a week as a minimum).

For field density tests of sand or gravel drainage layers, the following information was obtained:

(1) Location of the sample in the fill (station, offset, elevation, and depth below lift surface).

(2) In situ density.

(3) Gradation (maximum particle size and percents minus No. 4, minus No. 16, and minus No. 200 as a minimum).

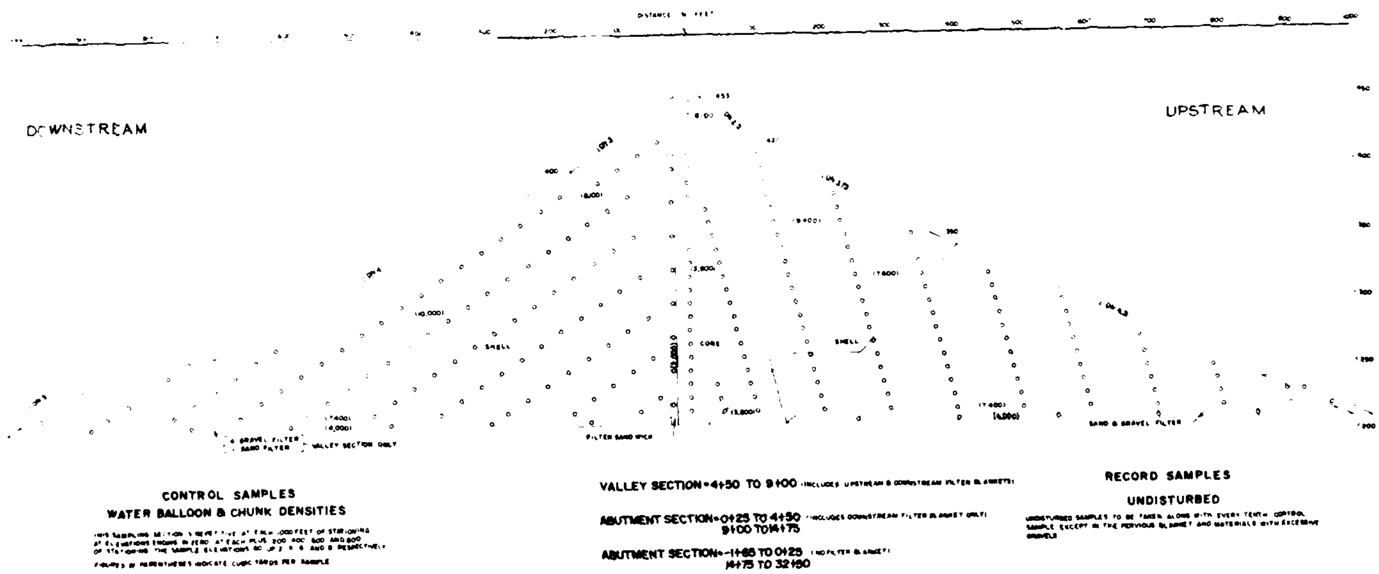


Figure 10. Sampling plan for compaction control

(4) Maximum-minimum density test on field density materials; a correlation with gradation was also established but was infrequently used.

b. Record samples (dam only). It was planned to obtain an undisturbed record sample (cube sample) with every tenth control sample except in drainage zone materials. However, it was found that intact cube samples could not be obtained in some of the more gravelly materials. Therefore, wherever gravel content precluded cube samples, disturbed bag samples were taken for the purpose of performing shear tests on recompacted specimens. A total of 45 undisturbed cube samples and 34 bag samples were taken in the main dam embankments; a total of 7 undisturbed cube samples and 24 disturbed bag samples were taken in the dike. Three water balloon density tests were made immediately adjacent to each undisturbed and disturbed record sample site; a density test was performed on each 6 in. of depth of compacted soil through which the record samples were taken (cube samples were about 13 in. in each dimension and bag samples were composed of the mixed soil taken through about 18 in. of compacted material). Q triaxial shear tests were performed either in the division laboratory at the U. S. Army Engineer Waterways Experiment Station (WES) or in the field laboratory on specimens trimmed from the undisturbed cube samples or on recompacted specimens of minus 1-in. material from the bag samples. The disturbed bag material was recompacted to appropriate fill density and water content to assure that design strengths were being attained in the embankment. Additionally, a standard effort compaction test was performed in the laboratory on minus 1-in. material from each bag sample to determine maximum dry density and optimum water content. The fill water content and density were then compared to the compaction test peak values to obtain percent compaction and percentage point variation in fill water content from optimum for the recompacted test specimens.

Field and laboratory testing procedures

13. Compaction control of core and shell materials was based on standard effort compaction tests using 4- or 6-in.-diam molds. The 6-in. mold was used for gravelly material with the plus 1-in. fraction removed. The 1965 edition of EM 1110-2-1906 permitted use of the 6-in.-diam mold for soils having up to 35 percent plus No. 4 material. Either 4- or 6-in.-diam molds were used for the fine-grained soils. Compaction

control of sand placed in the vertical drain and sand or gravel placed in the horizontal drainage layers was based on relative density using the test procedure with vibrated maximum density given in the 1965 edition of EM 1110-2-1906. A 6-in.-diam mold (0.1 cu ft) was used for vibrated density tests for the sand (maximum particle size of 1/2 in.) and an 11-in.-diam mold (0.5 cu ft) was used for the sand or gravel (maximum particle sizes of 3 to 6 in. plus 3-in. material removed before testing). In-place density, with a few exceptions, was determined using the water-balloon method. A nuclear moisture-density device was tried but was not found reliable for the gravelly soil. An oil displacement method using plastic sheeting to line a 3/4-cu yd hole and a buried steel frame method* were used for a few tests in the gravel and sand-gravel materials. Soil classification was determined by both laboratory tests or estimated by visual observation. Field water content samples were dried using either a hot plate or a gas burner. The water content determination by hot plate or gas burner methods was occasionally checked against the standard ovendrying method.

Field Control of Core and Shell Materials

Laboratory compaction curves

14. A series of 5-point standard effort compaction curves were developed initially for each of the known core or shell soil types in each borrow area. Additional laboratory compaction tests were performed during construction as follows:

a. On any field density test material that on the basis of gradation and plasticity characteristics appeared to be significantly different than soil types previously encountered.

b. Once a week as a minimum check procedure.

---

* A 3- by 3-ft by 6-in. steel frame was placed on the surface of the previously compacted lift and subsequently buried during placement and compaction of the next lift. After compaction of the lift was complete, the material above the buried frame was carefully excavated to a plane level with the top of the frame. The soil within the frame was then removed and saved to determine fill water content and density.

When materials contained gravel sizes 1 in. or greater, compaction tests were performed on the minus 1-in. fraction without replacement. An example of the information obtained for each laboratory compaction test is shown in Figure 11. Examples of compaction curves for minus 1-in. material (or finer) for each borrow area are given in Figures 12 and 13. These compaction curves, performed prior to construction and supplemented during construction, were the basis of compaction control in that their peak values, i.e., maximum dry density and optimum water content, were used to relate the fill density and fill water content to the specifications. The relation of the fill density and fill water content determined in a given field density test with the maximum density and optimum water content of a particular laboratory compaction curve was accomplished using the control procedures described in the following paragraph.

Control procedures

15. The technique employed to select the most appropriate laboratory compaction curve for comparison with the field density test results was based on visual classification, borrow area source, gradation, and Atterberg limits data of the field density test material. This field data set was compared to the data sets for the laboratory compaction curves (described in the previous paragraph and illustrated in Figure 11) for the borrow area from which the fill material came. The 5-point laboratory curve for the most similar borrow area material was then selected; the maximum dry density and optimum water content values of that laboratory curve were used to compute the percent compaction (fill dry density times 100 percent/maximum dry density) and the variation of fill water content from optimum water content. The suitability of the compacted lift could then be assessed by comparing the fill percent compaction to the desired percent compaction and the variation of fill water content from optimum water content to the specified maximum permissible range of variation of fill water content from the optimum stated in the contract documents. Much of the fill contained plus 1-in. material, and it was necessary to account for this in relating fill water contents and densities to optimum water contents and maximum

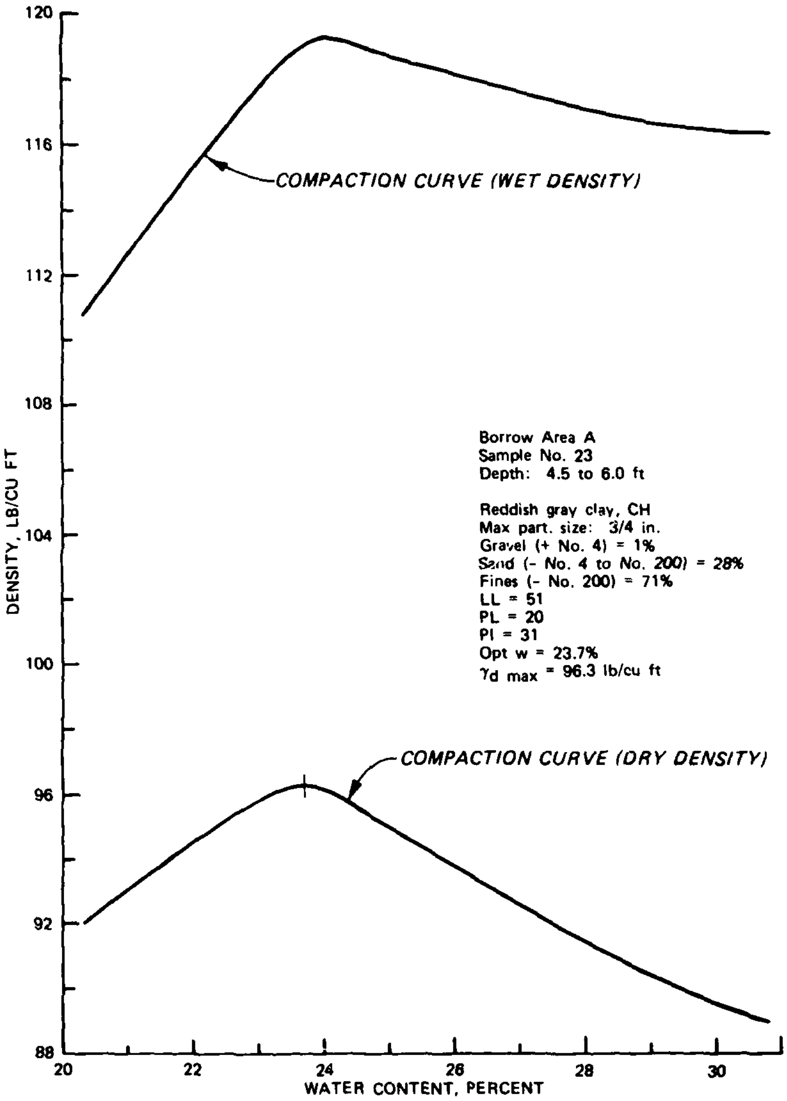


Figure 11. Example of information prepared for each standard effort laboratory compaction test

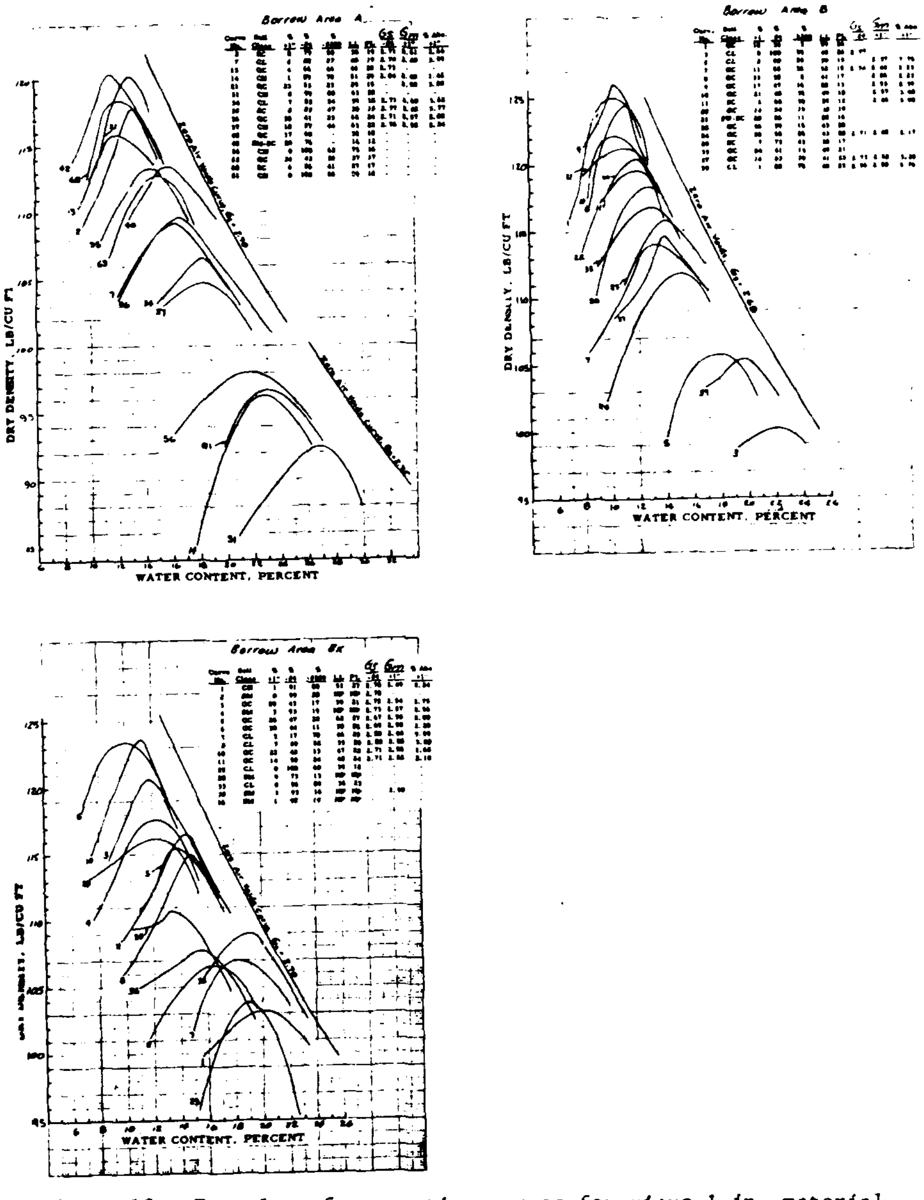


Figure 12. Examples of compaction curves for minus 1-in. material (or material having a maximum particle size less than 1 in.) from borrow areas A, B, and BX

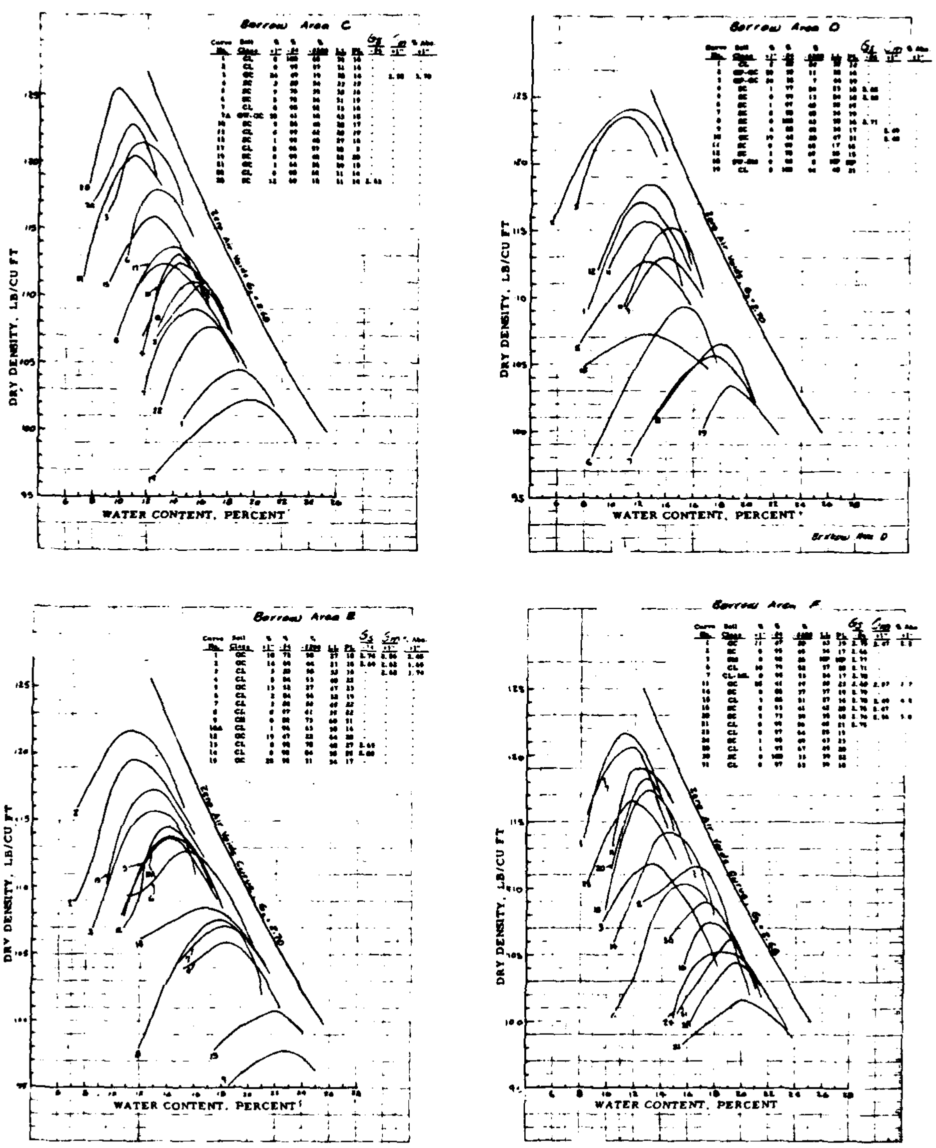


Figure 13. Examples of compaction curves for minus 1-in. material (or material having a maximum particle size less than 1 in.) from borrow areas C, D, E, and F

densities, as discussed in the following paragraph.

Soils with plus 1-in. material

16. Design shear strengths were based on tests performed on minus 1-in. material, and allowable water content limits in the specification and desired minimum percent compaction were therefore based on results of compaction tests on minus 1-in. material. The following equations were used to relate the in-place dry density and water content of fill containing plus 1-in. material to the laboratory compaction data on minus 1-in. material:

$$\gamma_f = \frac{f \gamma_t \gamma_w G_m}{\gamma_w G_m - c\gamma_t (1 + A)} \qquad (1)$$

$$w_f = \frac{w_t - cA}{f} \times 100 \qquad (2)$$

where

γ_f = dry density of minus 1-in. fraction, pcf

f = proportion of minus 1-in. fraction by weight expressed as decimal fraction

γ_t = dry density of total field density sample, pcf

γ_w = unit weight of water, 62.4 pcf

G_m = bulk specific gravity of plus 1-in. fraction, dimensionless

c = proportion of plus 1-in. fraction by weight expressed as decimal fraction

A = absorption of plus 1-in. fraction (saturated surface dry weight minus ovendry weight divided by ovendry weight), dimensionless

w_f = water content of minus 1-in. fraction, percent

w_t = water content of total field density sample, expressed as decimal fraction

Values of G_m and A were either determined in the laboratory or assumed. For convenience, conversion charts such as the one shown in Figure 14 were prepared for appropriate values of A and G_m. In

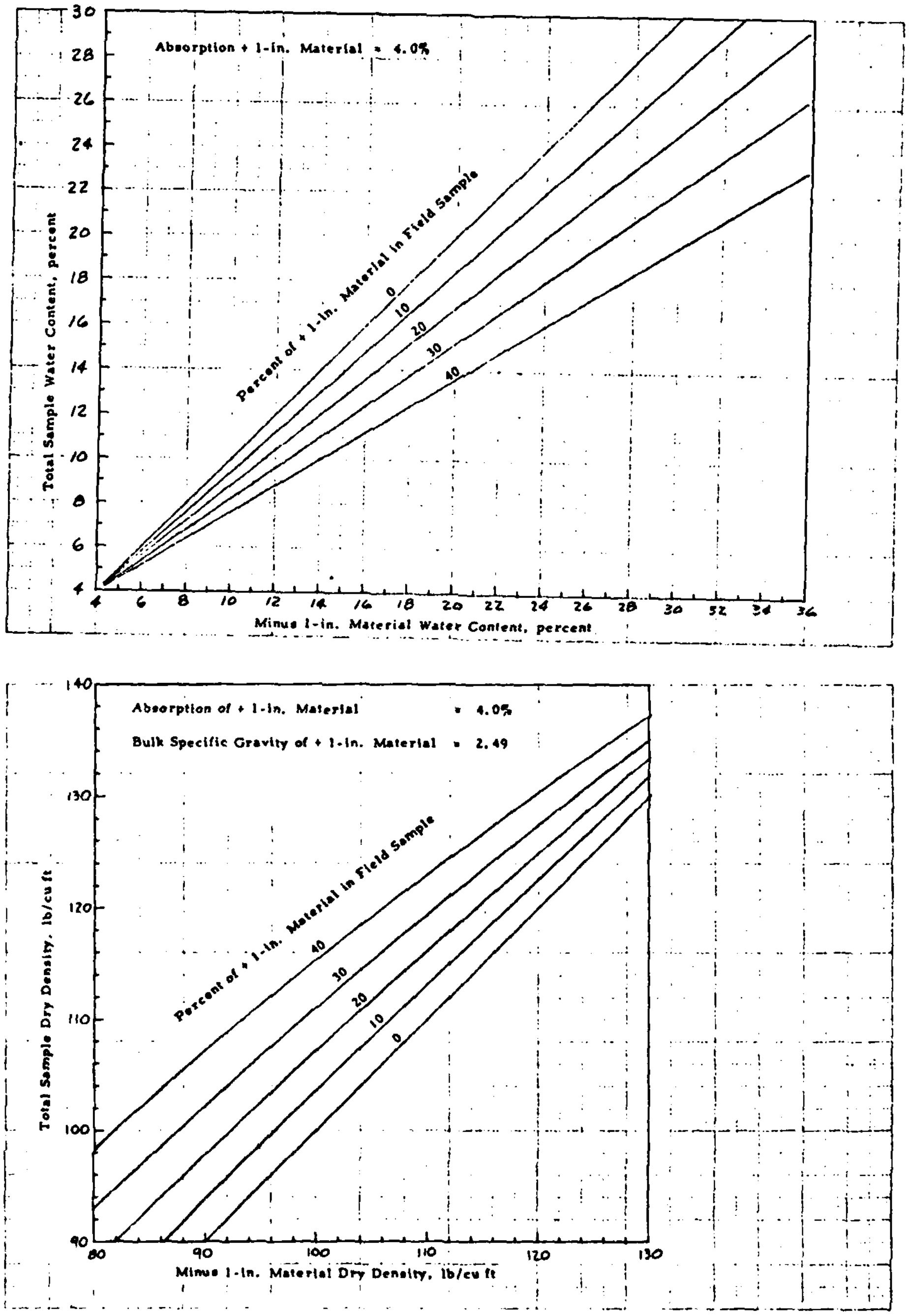


Figure 14. Example of conversion charts for water content and dry density of total sample and minus 1-in. material

early dike construction, the District properly adjusted the water contents and densities of field density samples containing plus 1-in. material to those for minus 1-in. material, using such charts. Thereafter, the District incorrectly adjusted the results of laboratory compaction tests on minus 1-in. material to values for soils containing the same proportions of plus 1-in. material as the field density samples under consideration. This is further discussed in PART III (paragraph 19) and in PART IV (paragraph 65).

Field Control of Pervious Drainage Materials

17. Results of in-place density tests in compacted drainage materials were compared to appropriate maximum and minimum density values to determine their relative density. Details on control for the different materials in drainage zones of the dam and dike are described below:

a. Sand and gravel used beneath upstream section of main dam. As shown in Figure 2, an upstream portion of the dam shell zone was constructed first to serve as a cofferdam. In-place density tests in the sand and gravel drainage layer beneath this section were taken by the water volume (balloon) method. Standard effort compaction tests, using 6-in.-diam mold and scalping plus 1-in. material with replacement, were performed on material from each field density test location. Comparison of results of maximum-minimum density tests on similar materials performed in the Division laboratory indicated that 104 percent of standard effort maximum dry density was equivalent to 85 percent relative density. Thus, if field densities equaled or exceeded 104 percent compaction, the soils were considered to have adequate relative densities. However, the correlation was based on one or at the most two relative density tests.

b. Sand placed in vertical and horizontal drains of the dike and dam. In the initial construction period of the dike, a minimum relative density of 70 percent was desired for the sand. Since the sand exhibited a relatively consistent gradation from sample to sample, a single set of maximum and minimum density values was used. Subsequently, as placement of fill progressed, the gradation of the material changed, and a second set of maximum-minimum density values were obtained from tests performed by the Division laboratory. With the issuance of

ETL 1110-2-13, "Compaction of Cohesionless Fills and Filters," in December 1968, the field office was required to change the relative density control value to 80 percent minimum with an average of 85 percent. Tests in the Division laboratory established that 85 percent relative density approximately corresponded to 98 percent of standard effort maximum dry density. This relation was based on one or at the most two relative density tests; however, this relation was used for approximately 34 field density tests (of a total of 167 tests of sands in the dike). Thereafter, a maximum-minimum density test apparatus (vibratory table device as described in the 1965 edition of EM 1110-2-1906) was procured for the field laboratory and the correlation of percent minus No. 16 with relative density shown in Figure 15 was developed in the project laboratory. However, for the remainder of construction, the gradation correlation was seldom used. A maximum-minimum density test was generally

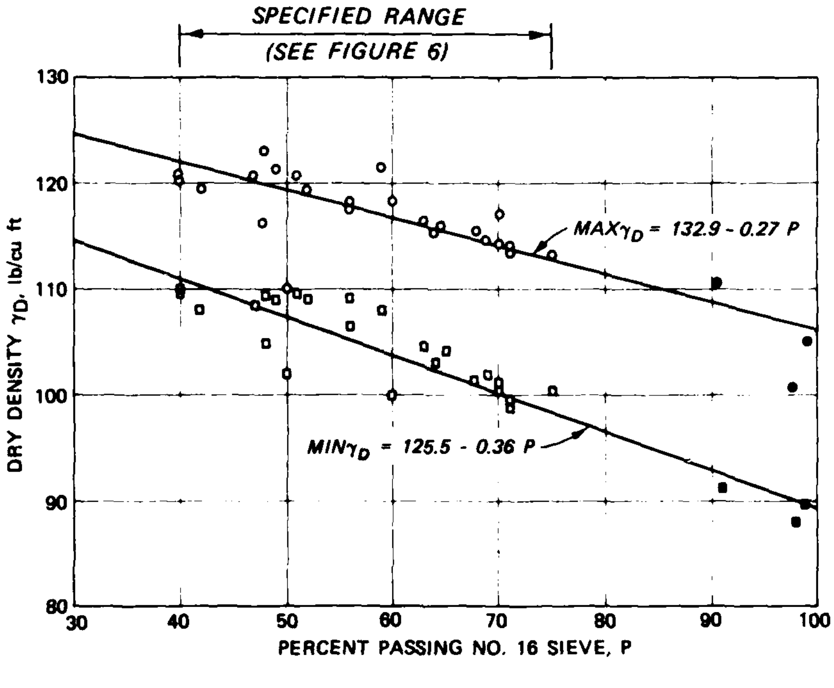


Figure 15. Maximum and minimum density of sands versus percent minus No. 16

performed on material from each field density test on sand in the dam and drainage zones of the dike unless several field density tests were made during the same day on material having essentially the same gradation.

c. Sand and gravel in horizontal drainage layer of dam. Results of field density tests were compared to results of maximum-minimum density tests performed generally on material from each field density test.

d. Gravel in horizontal drainage layer. During construction of the dike, results of eight field density tests were compared with results of maximum-minimum density tests on materials from the field density test locations. No testing was performed on the gravel placed in the horizontal drain of the dam since test results for the dike showed that 85 percent relative density was easily obtained with the field compaction procedure.

PART III: FIELD COMPACTION RESULTS AND ANALYSES

18. After the dam had been constructed, statistical analyses were performed by WES on compaction data furnished on the dam and dike. Initial test data on areas subsequently reworked or retested were excluded from the analyses. Analyses included frequency histograms and cumulative frequency distributions (percentage ogives) of the variation of fill water content from adjusted laboratory optimum and the variation of fill percent compaction (the ratio of in situ dry density to adjusted maximum dry density expressed in percent). The computation of other statistical parameters was accomplished by computer. The normal distribution curve best representing the observed data was determined by minimizing the value of chi-square computed from a set of ordinates of the normal curves and the corresponding ordinates of the observed histograms. Descriptions and discussion of these analyses are presented in the following paragraphs.

Correction of Field Control Data on Fill Containing Plus 1-in. Material

19. As stated in paragraph 16, District personnel generally used an incorrect procedure in comparing field densities and water contents of core and shell material containing plus 1-in. material to results of laboratory compaction tests on minus 1-in. material. In early construction of the dike, they correctly adjusted the field densities and water contents of samples containing plus 1-in. material to values for minus 1-in. fractions using charts such as Figure 14 and then compared these adjusted values to optimum water contents and maximum densities of compaction tests on minus 1-in. material. However, for the remainder of the dike construction and all of the dam construction, they adjusted optimum water contents and maximum densities from compaction tests on minus 1-in. material to values for materials containing the same proportions of plus 1-in. material as the field samples and then related the field values to these adjusted values.

20. The reasons why this latter procedure is incorrect are as follows:

a. The water content limits specified by the designer (and desired percent compaction) were based on results of shear strength tests on minus 1-in. materials, expressed in relation to optimum water contents and maximum densities from compaction tests on minus 1-in. material.

b. When field water contents and densities of samples containing plus 1-in. material are adjusted on the basis of the amounts of plus 1-in. material to values for the minus 1-in. fraction (using charts like Figure 14), they can truly be related to the optimum water content and maximum density of a compaction test on minus 1-in. material and to the limits established for construction.

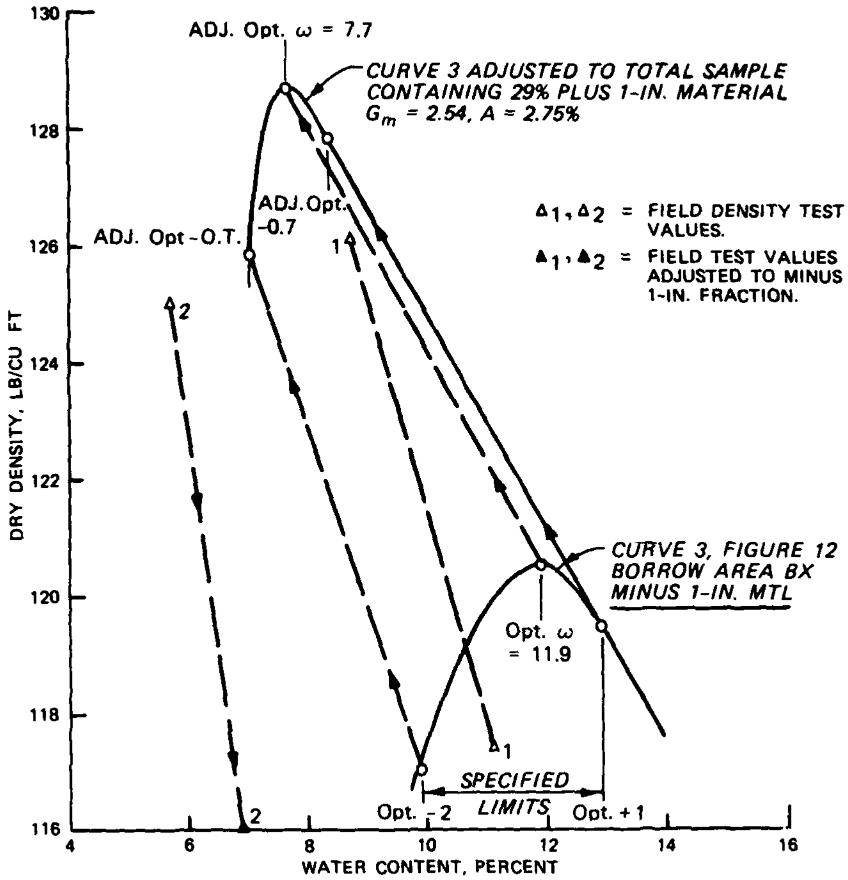
c. On the other hand, when the optimum water content and maximum density of a compaction test on minus 1-in. material is adjusted to values for a soil containing the same amount of plus 1-in. material as the field density sample, these adjusted values cannot be directly compared to the specified water content limits or to the desired minimum percent compaction.

21. Figure 16 demonstrates the incorrect procedure used by the District and the correct procedure for comparing densities and water contents of fill materials containing plus 1-in. sizes to results of compaction tests on minus 1-in. material.

22. Since about 80 percent of the field density samples from the shells of the dam and dike and 30 percent of the field density samples from the core fills contained plus 1-in. material, it was considered advisable by WES to recompute variation from optimum water content and percent compaction using the correct procedure. This was done by assuming an average value of G_m of 2.5 and an average A of 4.0 percent for all plus 1-in. material. (This was done not only to simplify recomputation, but also because in many cases the values used by the District were not determined by testing each field density sample.) Thus, all data presented in this report relative to percent compaction and variation from optimum water content of fill materials containing plus 1-in. material are corrected data.

23. The magnitude of errors associated with the incorrect procedure previously described are discussed in PART IV.

24. As a result of funding restrictions and higher priority work, review and revision of the initial draft of this report were deferred



	CORRECT PROCEDURE Adjusted Field Values Compared to Opt w and Max γ_d of Curve 3	INCORRECT PROCEDURE Field Values Compared to Adjusted Opt w and Max γ_d of Curve 3
% Compaction:		
Test 1 (Δ_1)	$\frac{117.4}{120.5}$ = 97.4	(Δ_1) $\frac{126.1}{128.7}$ = 98.0
Test 2 (Δ_2)	$\frac{116.0}{120.5}$ = 96.3	(Δ_2) $\frac{125.0}{128.7}$ = 97.1
Variation of w from opt		
Test 1 (Δ_1)	11.1 - 11.9 = -0.8	(Δ_1) 8.7 - 7.7 = +1.0
Test 2 (Δ_2)	6.9 - 11.9 = -5.0	(Δ_2) 5.7 - 7.7 = -2.0

Figure 16. Example of correct and incorrect procedures for comparing field data with laboratory compaction data

for several years. During the interim, EM 1110-2-1911, "Construction Control for Earth and Rock-Fill Dams," was written. In the course of preparing that manual, it was discovered that Equation 1 of this report requires the use of bulk specific gravity, G_m , calculated on the basis of the saturated surface-dry weight of the oversized particles. This value for G_m is obtained as given for the second method in ASTM Standards, Part 14, Designation C-127-77, "Specific Gravity and Absorption of Coarse Aggregate." However, the field laboratory at DeGray used the method prescribed in EM 1110-2-1906, "Laboratory Soils Testing," which is based on the oven-dry weight of the oversized fraction. This method is the same as the first method given in the above referenced ASTM Standard. If G_m is based on the dry weight, the absorption, A , does not appear in the density correction equation. The version of Equation 1 which should have been used is as follows:

$$\gamma_f = \frac{f \gamma_t \gamma_w G_m}{\gamma_w G_m - C \gamma_t} \tag{3}$$

25. Because the original compaction data set was no longer in a form allowing expedient usage and because funds were limited, it was not possible to determine the effects of the erroneous practice. It is noted that the approximate maximum occurrence of plus 1-in. sizes for DeGray materials was 35 percent. For a soil containing 35 percent oversized (+1-in.) particles, the erroneous equation would yield a dry density for the minus 1-in. fraction of from 1.5 to 2.0 pcf too high depending on the value of G_m . This could translate to error in the computed percent compaction of as much as two percentage points too high. It is observed that a portion of the soils placed in the dam and dike contained no oversized particles at all, while those which did averaged about 15 percent. On the basis of these facts, it is not unreasonable to believe that use of the erroneous equation had a negligible effect with respect to identifying fill density samples which failed to meet the desired percent compaction.

Dam Embankment, Core

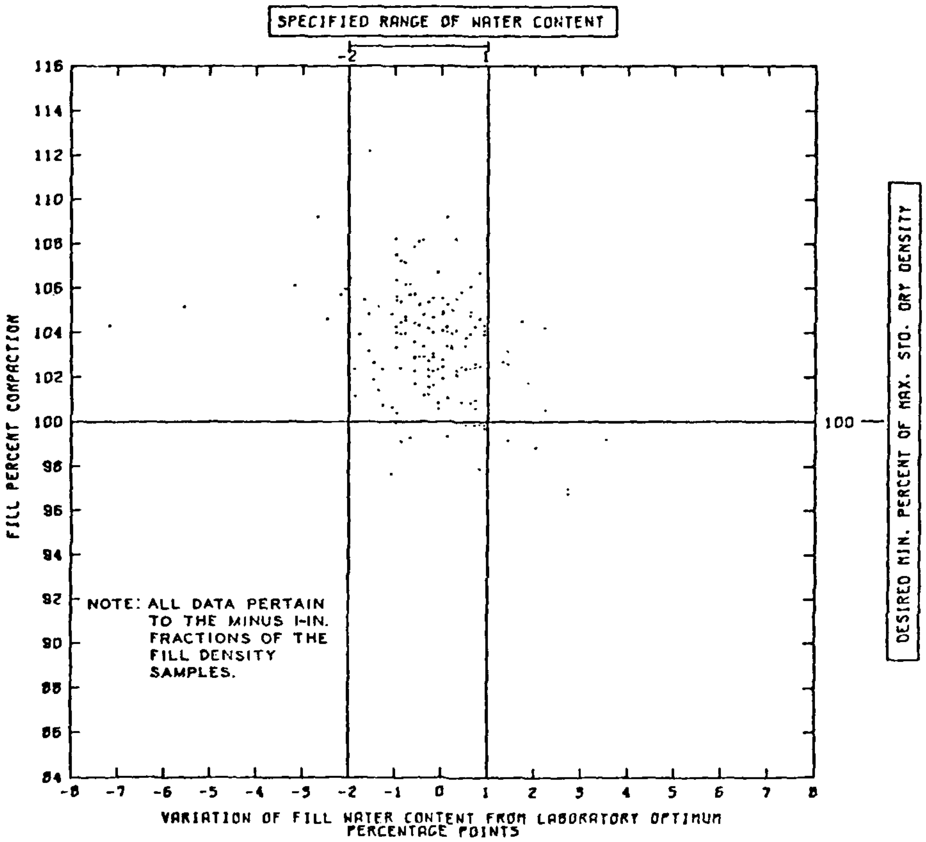
26. Data for the core material of the dam were obtained from field density sampling between sta 0+00 and 14+00 and from el 212 to 450. A plot of fill percent compaction versus variation of fill water content from laboratory optimum is shown in Figure 17. Of the 154 tests, 29 tests (19 percent) did not meet the established density or water content criteria. Thirteen samples (8 percent) had adequate densities but had water content requirements outside specified limits: 11 samples (7 percent) met the water content requirements but had densities lower than the desired minimum, and 5 (3 percent) met neither water content nor density standards. Examination of the field data indicated that the tests not meeting the contract specifications for water content were dispersed randomly throughout the fill. A plot of actual fill dry density versus fill water content for the 154 samples is shown in Plate 1. A few of the data points on Plate 1 appear questionable since they plot on the right of the average zero air void curve for the impervious soils. The mean field water content was 15.4 percent, and the mean field dry density was 114.5 pcf.

Water content

27. The physical and statistical data on core fill water content are summarized in Table 2. The frequency histogram and the percentage ogive for variation of fill water content from optimum water content for the field density test data are shown in Plate 2. The normal theoretical distribution curve best fitting the observed fill water content data is also shown superimposed on the histogram of Plate 2. For a normal array, 68.3 percent of all values (i.e., 68.3 percent of the area under the normal curve) are within plus or minus one standard deviation (σ) from the mean. Of the 154 test values, 81.2 percent fell within plus or minus one standard deviation. Thus, the observed distribution tends to be more concentrated toward the mean than the normal distribution. Mean water content was 0.3 percentage point dry of optimum water content.

Percent compaction

28. Although a value of minimum percent compaction was not



TESTS 154

TESTS OUTSIDE DESIRED LIMITS

W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
13	11	5	29

Figure 17. Variation of test results with respect to desired limits, core of dam

required by the contract specifications, the compaction procedures were expected to achieve densities of at least 100 percent of standard maximum dry density. Of the total of 154 samples, 10.4 percent failed to meet the desired percent compaction. The physical and statistical results for field density are summarized in Table 3. The frequency histogram and percentage ogive of fill percent compaction are shown in Plate 3. Mean percent compaction was 103.

Dam Embankment, Upstream Shell

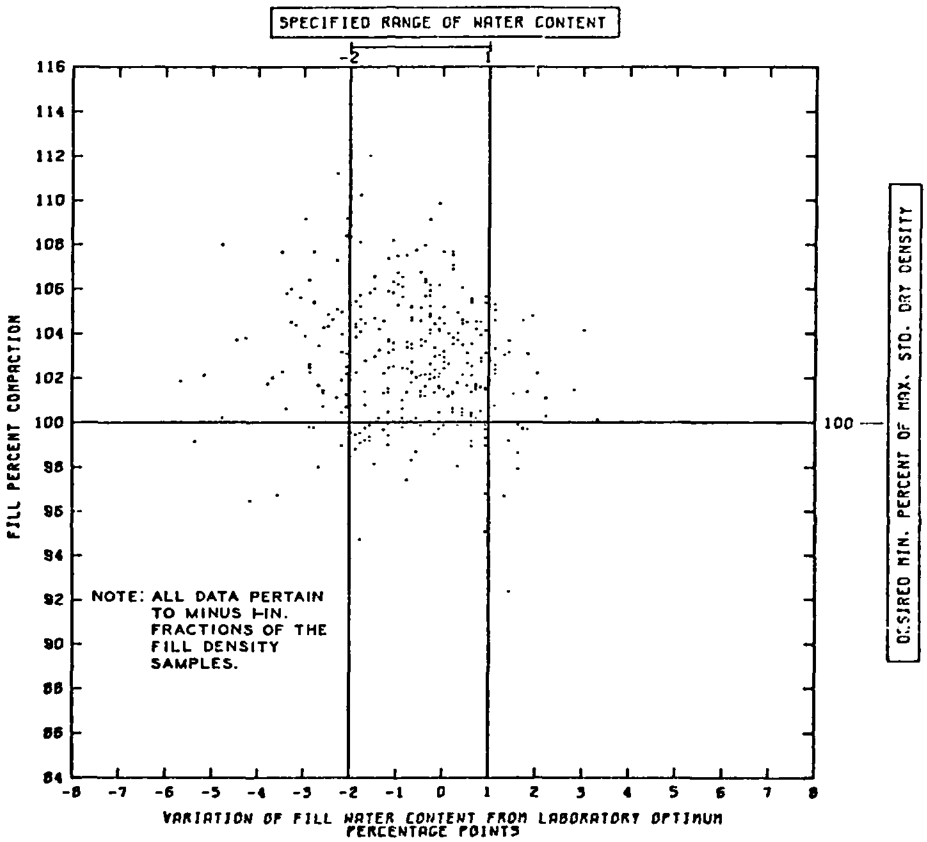
29. Data for the upstream shell were from field density sampling between sta 0+00 and 12+00 and from el 219 to 446. A plot of fill percent compaction versus variation of fill water content from optimum is shown in Figure 18. Of the total of 321 tests, 127 (40 percent) had densities or water contents outside the desired limits as follows: 73 samples (23 percent) had adequate densities but water contents were outside specified limits; 38 samples (12 percent) had acceptable water contents but were below desired minimum percent compaction; and 16 samples (5 percent) failed to meet both the water content and density criteria. Those samples failing to meet water content or density requirements were dispersed randomly within the impervious fill. A plot of actual fill dry density versus fill water content for the 321 samples is shown in Plate 4. The mean water content was 13.0 percent and the mean dry density was 119.0 pcf.

Water content

30. The physical and statistical water content data for the upstream shell are summarized in Table 2. The frequency histogram and the percentage ogive for variation of fill water content from optimum are shown in Plate 5. The observed data fitted very closely the theoretical normal distributions. Mean field water content was 0.7 percentage point dry of optimum water content.

Percent compaction

31. The physical and statistical data for percent compaction of the upstream shell are summarized in Table 3. The frequency histogram



TESTS 321

TESTS OUTSIDE DESIRED LIMITS

W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
73	38	16	127

Figure 18. Variation of test results with respect to desired limits, upstream shell of dam

and percentage ogive for the variation of percent compaction are shown in Plate 6. With 69.2 percent of the total data within plus or minus one standard deviation from the mean, the observed array is very close to a normal distribution case. Mean percent compaction was 103.

Dam Embankment, Downstream Shell

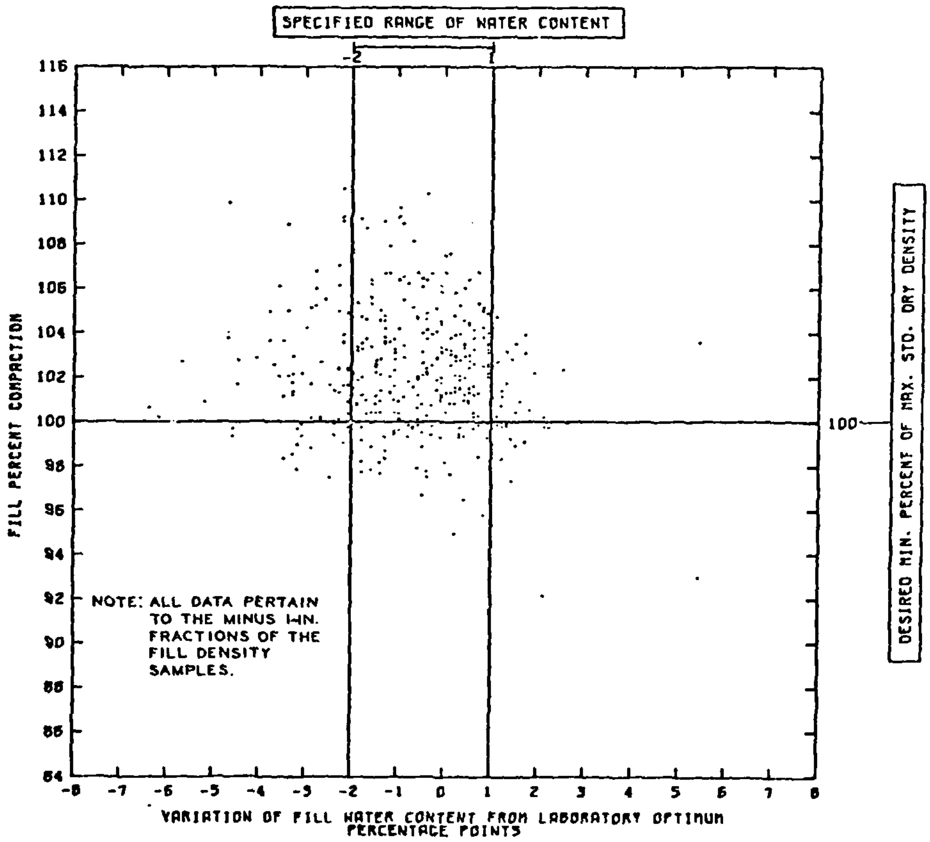
32. Data for the downstream shell of the dam embankment were obtained from field density sampling between sta 0+00 and sta 15+75 and from el 214 to 449, i.e., from foundation level to the top of the dam. A plot of fill percent compaction versus variation of fill water content from optimum is shown in Figure 19. Of the 378 total tests, 161 (42 percent) had densities or water contents outside the desired limits as follows: 84 samples (22 percent) had adequate densities but water contents were outside specified limits; 46 samples (12 percent) had acceptable water contents but were below the desired minimum percent compaction; and 31 samples (8 percent) failed to meet both the water content and density criteria. Examination of the field data indicated that the tests not meeting the contract specification for water content were dispersed randomly throughout the fill. A plot of actual fill dry density versus fill water content for the minus 1-in. fraction for the 378 samples is shown in Plate 7. The mean water content was 13.1 percent and the mean dry density was 117.0 pcf.

Water content

33. The physical and statistical data for fill water content for the downstream shell of the dam are summarized in Table 2. The frequency histogram and the percentage ogive for variation of fill water content from optimum are shown in Plate 8. The observed data are slightly more concentrated toward the mean than a normal distribution since 72.5 percent of the values fall within plus or minus one standard deviation from the mean. Mean field water content was 0.8 percentage point dry of optimum water content.

Percent compaction

34. The physical and statistical data for percent compaction of



TESTS 378

TESTS OUTSIDE DESIRED LIMITS

W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
84	46	31	161

Figure 19. Variation of test results with respect to desired limits, downstream shell of dam

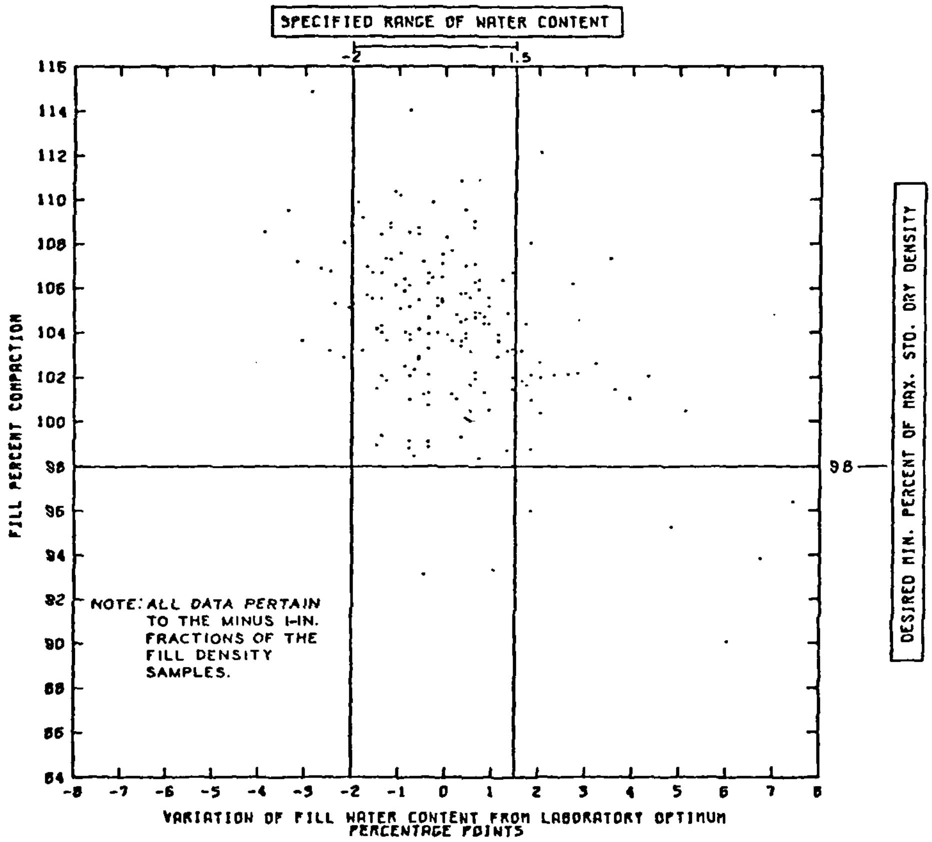
the upstream shell of the dam are summarized in Table 3. The frequency histogram and percentage ogive for the variation of percent compaction are shown in Plate 9. With 72.7 percent of the total data within plus or minus one standard deviation from the mean, the observed array is slightly more concentrated toward the mean than a normal distribution case. Mean percent compaction was 102.

Dike Core (First Specification)

35. Data for the core material placed under the first water content specification (optimum minus 2 percent to optimum plus 1.5 percent) were obtained from field density sampling between sta 18+00 and 68+00 and from el 343 to 446 of the dike. A plot of fill percent compaction versus variation of fill water content from optimum is shown in Figure 20. Of the 175 tests, 41 tests (23 percent) did not meet the established compaction or water content criteria. Thirty-four samples (19 percent) had adequate densities but had water contents outside specified limits; 2 samples (1 percent) met the water content standard but had inadequate densities, and 5 samples (3 percent) met neither water content nor density standards. Examination of the field data indicated that the tests not meeting the contract specifications for water content were dispersed randomly throughout the fill. A plot of actual fill dry density versus fill water content for the 175 samples is shown in Plate 10. Some data points in Plate 10 appear questionable since they fall well to the right of the average zero air void curve representing the impervious soils. The mean field water content was 24.4 percent and the mean field dry density was 99.4 pcf.

Water content

36. The physical and statistical data for fill water content for the core fill (first specification) are summarized in Table 2. The frequency histogram and the percentage ogive for variation of fill water content from optimum are shown in Plate 11. The observed data agree very closely with the theoretical normal distribution. Mean fill water content was 0.1 percentage point dry of optimum water content.



TESTS 175

TESTS OUTSIDE DESIRED LIMITS

W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
34	2	5	41

Figure 20. Variation of test results with respect to desired limits, core of the dike (first specification)

Percent compaction

37. The physical and statistical data for percent compaction of the core fill (first specification) are summarized in Table 3. The frequency histogram and percentage ogive for the variation of percent compaction are shown in Plate 12. With 73.7 percent of the total data within plus or minus one standard deviation from the mean, the observed array is relatively close to a normal distribution case. Mean percent compaction was 104.

Dike Core (Second Specification)

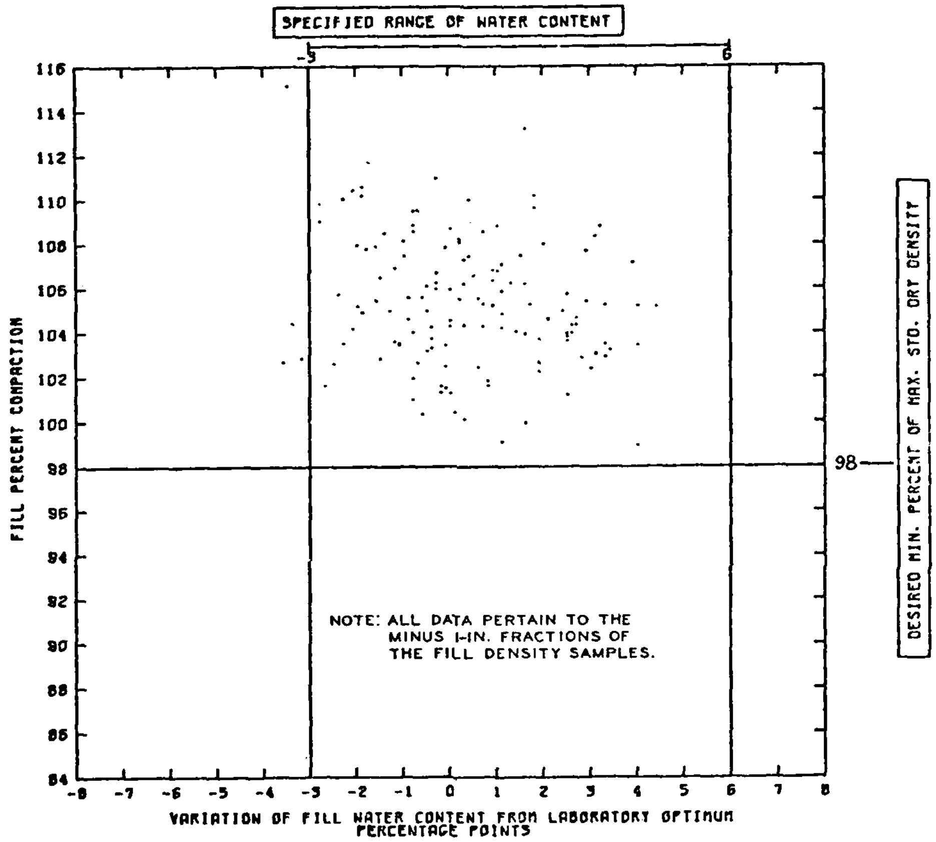
38. Data for the dike core placed under the second specification were from field density sampling from sta 30+00 to 68+00 and 120+00 to 140+00 and from el 377 to 448. A plot of fill percent compaction versus variation of fill water content from optimum is shown in Figure 21. Of the total of 138 tests, none had densities outside the desired limits. The 4 samples (3 percent) failing to meet water content requirements were dispersed randomly within the impervious fill. A plot of actual fill dry density versus fill water content for the 138 samples is shown in Plate 13. Plate 13 indicates a significant number of samples falling well to the right of the zero air voids curve. The mean water content of all samples was 27.3 percent and the mean dry density was 96.9 pcf.

Water content

39. The physical and statistical data for fill water content for the dike core (second specification) are summarized in Table 2. The frequency histogram and the percentage ogive for variation of fill water content from laboratory optimum are shown in Plate 14. The observed data fit very closely the theoretical normal distribution. Mean field water content was 0.4 percentage point wet of optimum water content.

Percent compaction

40. The physical and statistical data for percent compaction of the dike core fill are summarized in Table 3. The frequency histogram and percentage ogive for the variation of percent compaction are shown in Plate 15. With 71.7 percent of the total data within plus or minus



TESTS 138

TESTS OUTSIDE DESIRED LIMITS

W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
4	0	0	4

Figure 21. Variation of test results with respect to desired limits, core of the dike (second specification)

one standard deviation from the mean, the observed array is relatively close to a normal distribution case. Mean percent compaction was 105.

Dike Shell, Landside

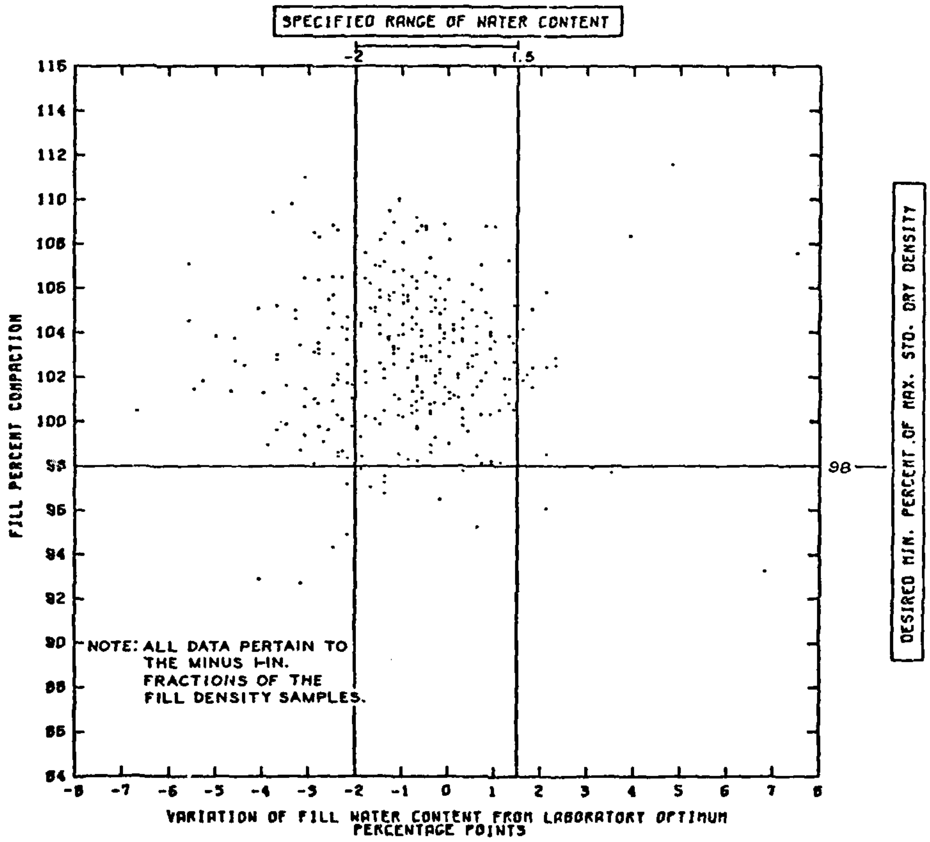
41. Data for the dike landside shell were from field density sampling from sta 18+00 to 70+00 and 120+00 to 138+00 and from el 346 to 442. A plot of fill percent compaction versus variation of fill water content from optimum is shown in Figure 22. Of the total of 314 tests, 105 (33 percent) had densities or water contents outside the desired limits as follows: 86 samples (27 percent) had adequate densities but water contents were outside specified limits; 9 samples (3 percent) had acceptable water contents but were below desired minimum percent compaction; and 10 samples (3 percent) failed to meet both the water content and density criteria. Those samples failing to meet water content or density requirements were dispersed randomly within the impervious fill. A plot of actual fill dry density versus fill water content for the 314 samples is shown in Plate 16. Excluding the areas reworked only, mean water content was 12.9 percent and the mean dry density was 118.2 pcf.

Water content

42. The physical and statistical data for fill water content for the landside shell are summarized in Table 2. The frequency histograms and the percentage ogive for variation of fill water content from optimum are shown in Plate 17. The observed data agree very closely with the theoretical normal distribution. Mean field water content was 0.9 percentage point dry of optimum water content.

Percent compaction

43. The physical and statistical data for percent compaction of the landside shell are summarized in Table 3. The frequency histogram and percentage ogive for the variation of percent compaction are shown in Plate 18. With 69.4 percent of the total data within plus or minus one standard deviation from the mean, the observed array is slightly more centered than a normal distribution case. Mean percent compaction was 103.



TESTS 314

TESTS OUTSIDE DESIRED LIMITS

W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
86	9	10	105

Figure 22. Variation of test results with respect to desired limits, landside shell of the dike

Dike Shell, Lakeside

44. Data for the dike lakeside shell were from field density sampling between sta 18+00 to 72+00 and 120+00 to 140+00 and from el 337 to 440. A plot of fill percent compaction versus variation of fill water content from optimum is shown in Figure 23. Of the total of 312 tests, 105 (34 percent) had densities or water contents outside the desired limits as follows: 82 samples (26 percent) had adequate densities but water contents outside specified limits; 9 samples (3 percent) had acceptable water contents but were below desired minimum percent compaction; and 14 samples (5 percent) failed to meet both the water content and density criteria. Those samples failing to meet water content or density requirements were dispersed randomly within the impervious fill. A plot of actual fill dry density versus fill water content for the 312 samples is shown in Plate 19. The mean water content was 13.0 percent and the mean dry density was 117.8 pcf.

Water content

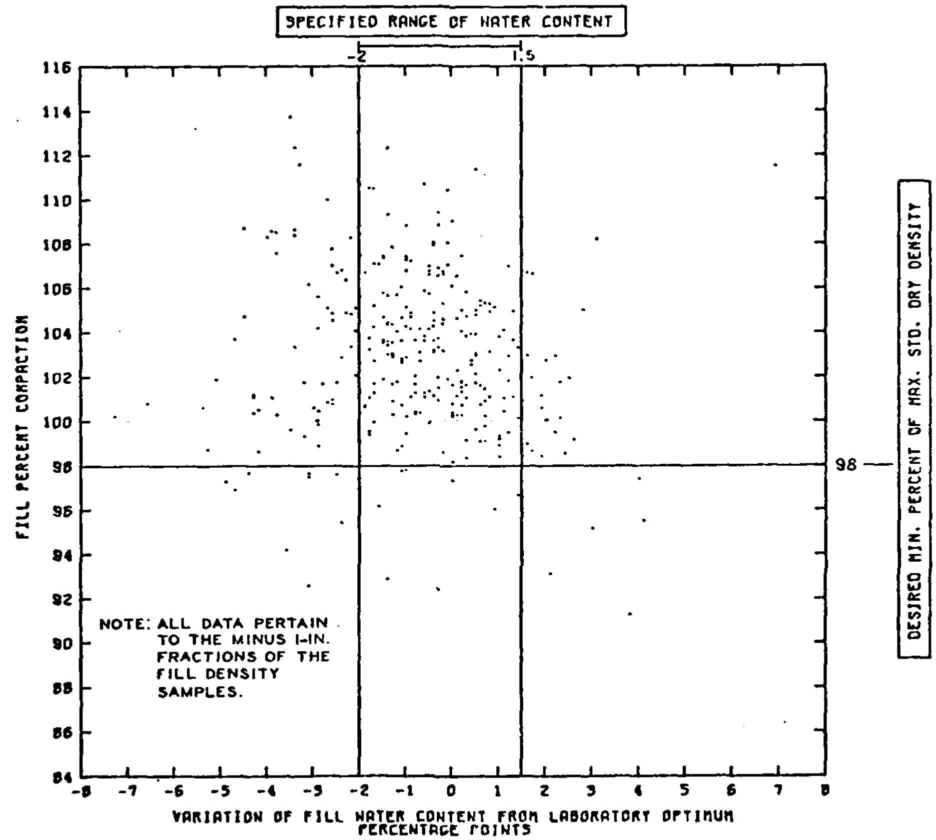
45. The physical and statistical data for fill water content for the lakeside shell are summarized in Table 2. The frequency histogram and the percentage ogive for variation of fill water content from optimum are shown in Plate 20. The observed data is very close to the theoretical normal distribution. Mean field water content was 0.8 percentage point dry of optimum water content.

Percent compaction

46. The physical and statistical data for percent compaction of the lakeside shell are summarized in Table 3. The frequency histogram and percentage ogive for the variation of percent compaction are shown in Plate 21. With 68.9 percent of the total data within plus or minus one standard deviation from the mean, the observed array approaches a normal distribution case. Mean percent compaction was 103.

Dike, Unzoned

47. Data for the unzoned dike sections were from field density



TESTS 312

TESTS OUTSIDE DESIRED LIMITS			
W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
82	9	14	105

Figure 23. Variation of test results with respect to desired limits, lakeside shell of the dike

sampling between sta 70+00 to 96+00, 104+00 to 118+00, and 140+00 to 146+00 and from el 343 to 440. A plot of fill percent compaction versus variation of fill water content from optimum is shown in Figure 24. Of the total of 89 tests, 31 (35 percent) had densities or water contents outside the desired limits as follows: 23 samples (26 percent) had adequate densities but water contents outside specified limits; 6 samples (7 percent) had acceptable water contents but were below desired minimum percent compaction; and only 2 samples (2 percent) failed to meet both the water content and density criteria. Those samples failing to meet water content or density requirements were dispersed randomly within the impervious fill. A plot of actual fill dry density versus fill water content for the 89 samples is shown in Plate 22. The mean water content was 13.8 percent and the mean dry density was 115.5 pcf.

Water content

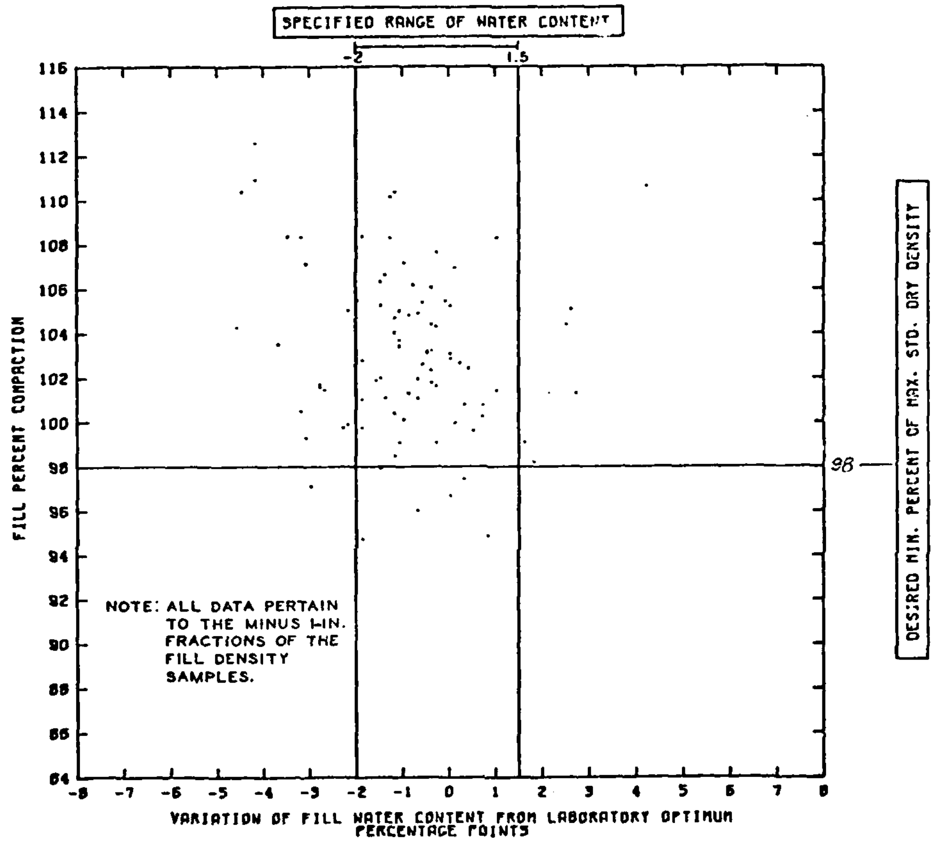
48. The physical and statistical data for fill water content of the unzoned fill are summarized in Table 2. The frequency histogram and the percentage ogive for variation of fill water content from optimum are shown in Plate 23. The observed data agree very closely with the theoretical normal distribution. Mean field water content was 0.9 percentage point dry of optimum water content.

Percent compaction

49. The physical and statistical data for percent compaction for the dike unzoned reach are summarized in Table 3. The frequency histogram and percentage ogive for the variation of percent compaction are shown in Plate 24. With 66.3 percent of the total data within plus or minus one standard deviation from the mean, the observed array is slightly more dispersed than a normal distribution case. Mean percent compaction was 103.

Dam, Upstream Drainage Layer

50. A total of 20 field density tests were made in the sand and gravel drainage layer beneath the upstream shell of the first-season section from sta 5+00 to 9+00 and from 150 to 970 ft upstream of the main



TESTS 89

TESTS OUTSIDE DESIRED LIMITS

W.C. ONLY	DEN. ONLY	W.C. AND DEN.	TOTAL
23	6	2	31

Figure 24. Variation of test results with respect to desired limits, unzoned reaches of the dike

dam center line between el 210 and 214. The results are summarized in Table 4, and individual test results are shown in Figure 25. With three exceptions, in-place densities were greater than those corresponding to 104 percent standard effort compaction, which was assumed to be equivalent to 85 percent relative density.

Dam, Downstream Drainage Zones

Vertical sand drain and horizontal sand drainage layer

51. A total of 49 field density tests were made in the vertical sand drain, and 17 in the horizontal sand drainage layer (excluding original tests for areas reworked or retested). The results are

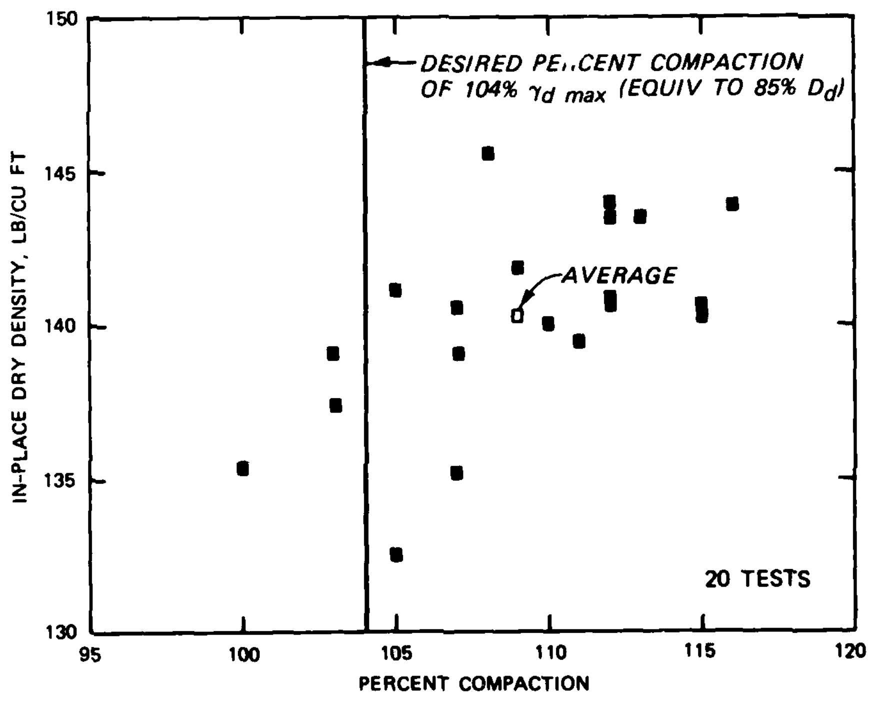


Figure 25. Results of field density tests, upstream horizontal sand and gravel drainage layer, dam

summarized in Table 4, and individual test results are plotted in Figure 26a. All areas tested (or retested after reworking) exceeded the requirements of 80 percent minimum relative density, and the average in-place relative density exceeded the desired value of 85 percent. Two tests in the vertical sand drain indicated a relative density of 79 percent. These two locations were retested after the next lift had been compacted and relative densities were found to have increased to 97 and 100 percent. The three unrealistically high values of relative density for the horizontal sand drainage layer shown in Figure 26a were determined on the basis of individual maximum-minimum density tests on material from each field density test; no reason can be advanced for these values.

Horizontal sand and gravel drainage layer

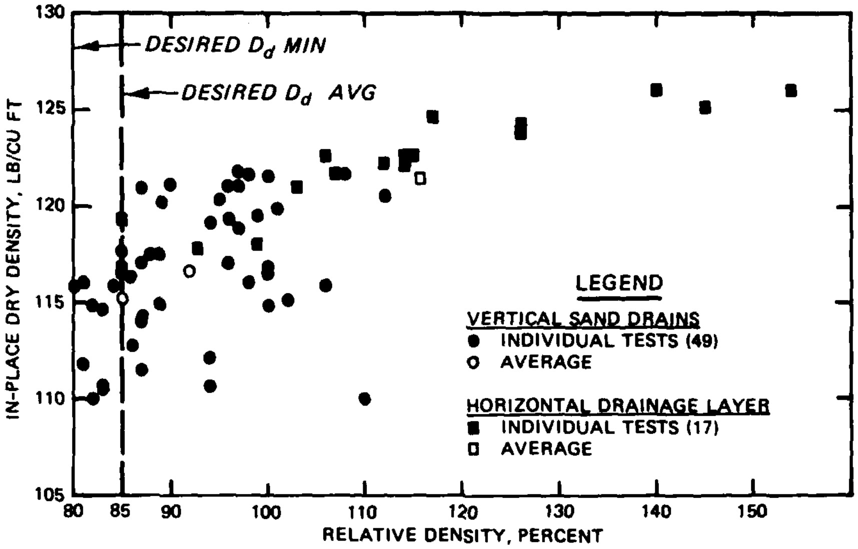
52. A total of 43 field density tests (excluding original tests for areas reworked or retested) were performed on the sand and gravel placed in the horizontal drainage layer. The results are summarized in Table 4, and individual test results are shown in Figure 26b. All areas tested (or retested after reworking) met the requirements of 80 percent minimum relative density, and the average in-place relative density exceeded the desired value of 85 percent.

Dike Drainage Zones

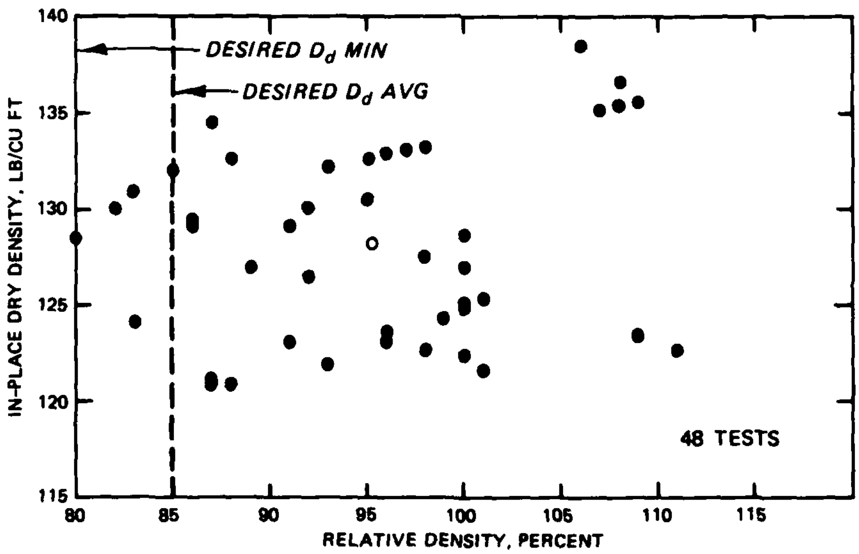
Vertical sand drain and horizontal sand drainage layer

53. A total of 61 field density tests were made in the vertical sand drain, and 106 were made in the horizontal sand drainage layer (excluding original tests for areas reworked or retested). The results are summarized in Table 5, and individual test results are shown in plots a, b, and c of Figure 27. Explanation of the different control procedures used in these zones was given previously in paragraph 17.

- a. 70 percent relative density requirement. A desired minimum relative density of 70 percent was used initially on material placed from sta 17+00 to 44+00 between el 357 and 423. The plot of test results, shown in Figure 27a,



a. Vertical sand drain and horizontal sand drainage layer



b. Downstream horizontal sand and gravel drainage layer

Figure 26. Results of field density tests, vertical sand drain and downstream horizontal drainage layer, dam

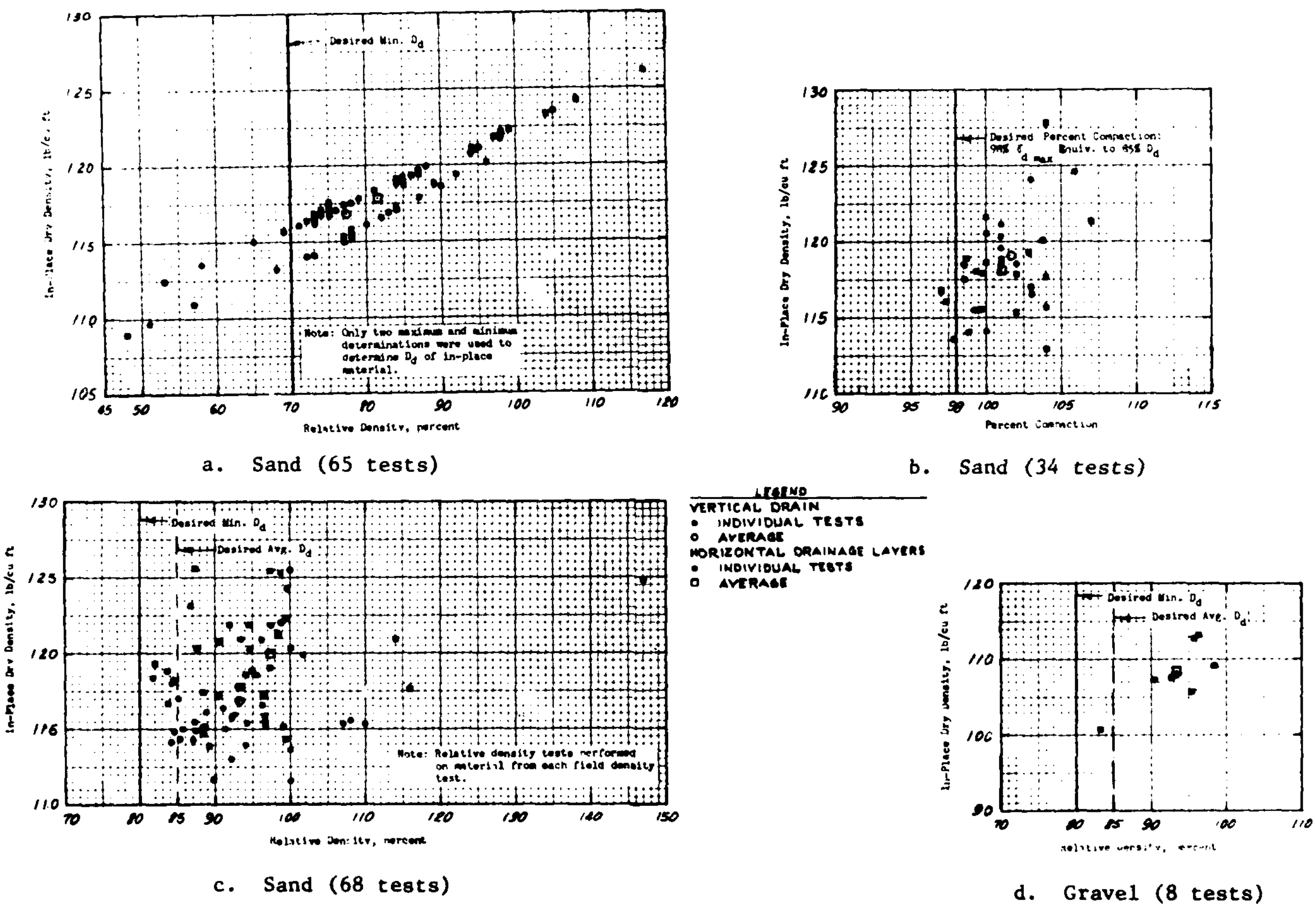


Figure 27. Results of field density tests, vertical sand drain and horizontal drainage layers, dike

indicates four tests each in the vertical drain and horizontal layer as having less than 70 percent relative density. However as indicated in paragraph 47, retesting of low relative density locations in similar materials at the dam indicated significant increases in relative density after placement of additional fill. Therefore, it is probable that a significant increase in relative density also occurred at these eight locations, since they were at relatively low elevations in the dike. The lines of data points in Figure 27a indicate that only two sets of maximum-minimum density values were used. The average values of D_d for a total of 65 tests, shown in Figure 27a, were 77.5 and 81.5 percent for the vertical drain and horizontal drainage layer, respectively.

b. 85 percent minimum relative density. A requirement for a minimum of 98 percent standard effort compaction (which was considered equivalent to D_d = 85 percent) was used for sand placed from sta 36+00 to 50+00 between el 355 and 368. The plot shown in Figure 27b indicates that all but three test values exceeded this minimum. The average percent compaction for the 34 tests was 102 and 101 for the vertical sand drain and horizontal sand drainage layer, respectively.

c. 80 percent minimum, 85 percent average relative density. A total of 68 tests were performed under the requirement for 80 percent minimum and 85 percent average relative density used for the remainder of the dike pervious fill. The plot shown in Figure 27c indicates all test values exceeded the minimum with average relative densities of 93 and 97 percent for sands in the vertical drain and horizontal drainage layer, respectively.

Horizontal gravel drainage layer

54. A total of eight tests were performed in the horizontal gravel drainage layer. As shown in Figure 27d, the in-place relative density generally exceeded 85 percent, the average being 93 percent.

Summary of Compaction Results

Water content

55. The statistical results of fill water content variation from optimum for the dam and dike listed in Table 2 are shown graphically in Figure 28.

56. Dam. The best water content control was achieved in the core

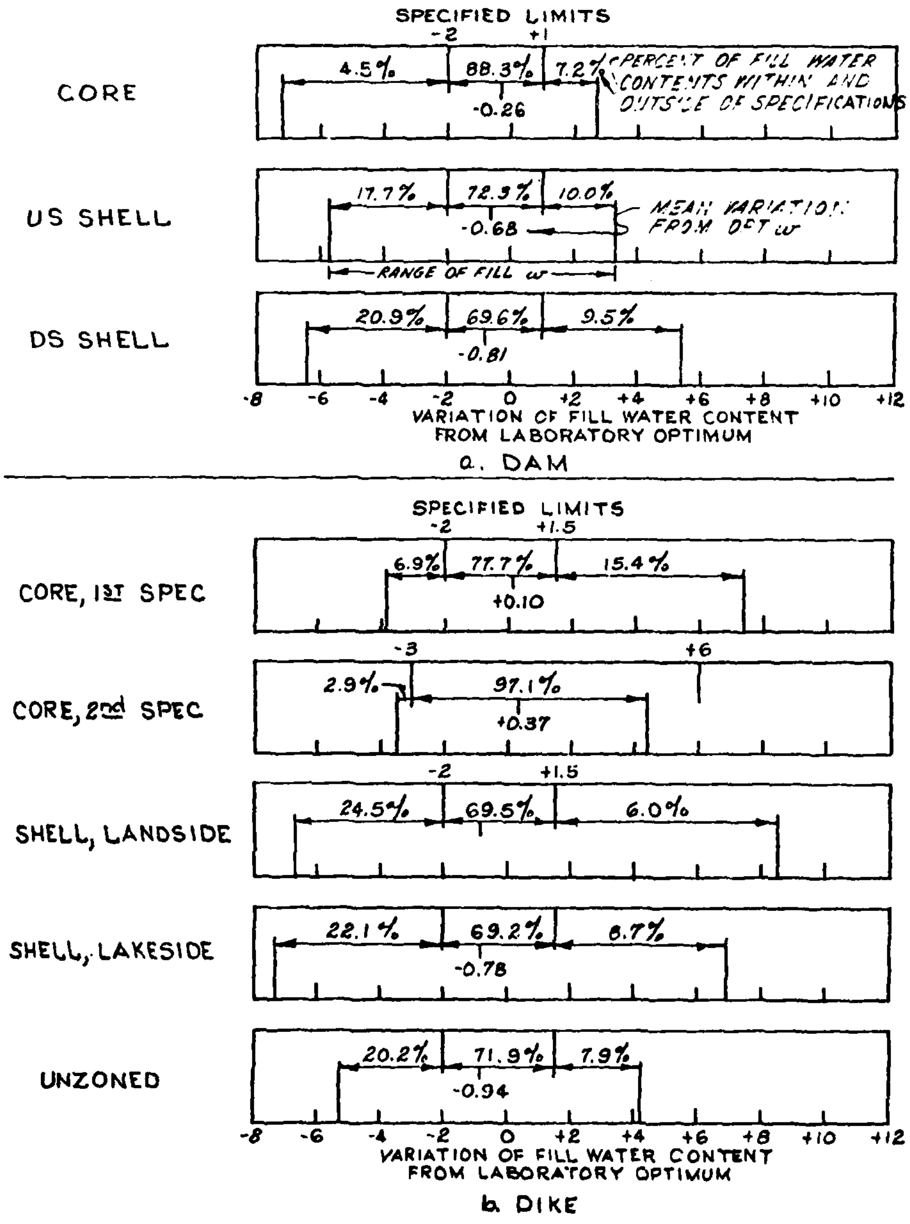


Figure 28. Comparison of variation in fill water content from optimum with specified limits, dam and dike

fill where less than 12 percent of the determinations were outside specified limits. For the shell fills, about 30 percent of the determinations were outside specified limits, with about 20 percent being on the dry side. Mean variations of water contents from optimum were minus 0.3 percentage point for the core material and minus 0.7 to minus 0.8 for the shells.

57. Dike. Under the first water content specification for the core fill, about 22 percent of the determinations were outside specified limits, with 15 percent being on the wet side. When the water content limits were widened in the second specification, particularly on the wet side of optimum, only 3 percent of the determinations fell outside specifications, all being on the dry side. Water content variations of the landside and lakeside shells and of the unzoned sections of the dike were very similar with respect to specified limits, 20 to 24 percent of the determinations being outside on the dry side and 6 to 9 percent being outside on the wet side. The wide range of water contents of the dike shells shown in Figure 28 was caused by only a very few determinations (see histograms on Plates 17 and 20).

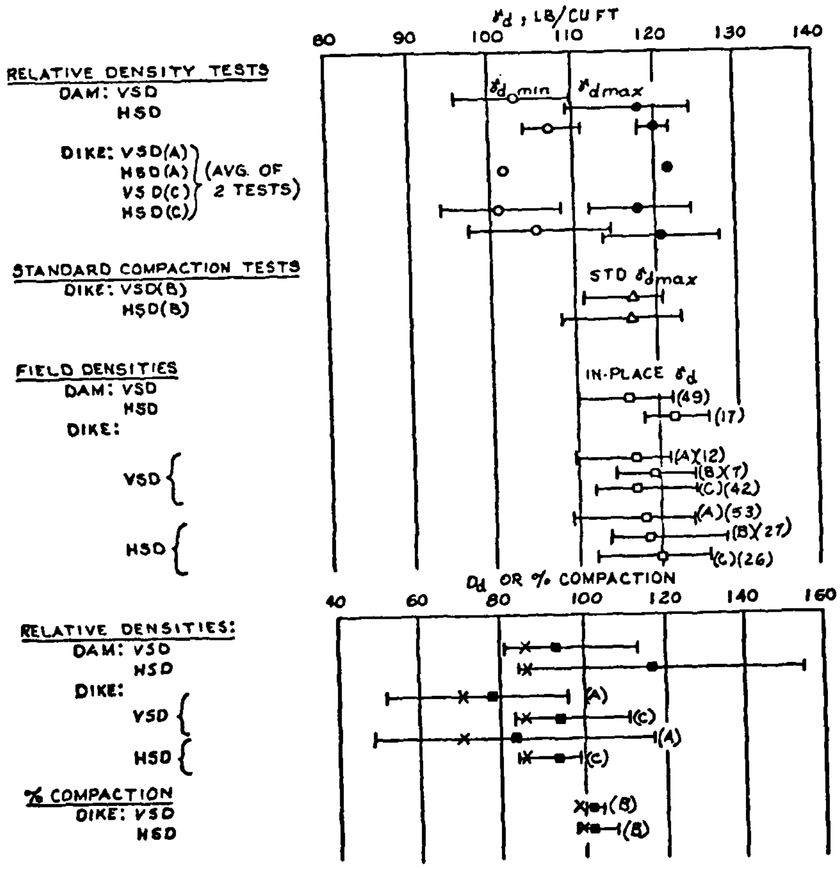
Dry density

58. Dam. Data listed in Table 3 show that 10 percent of the field density determinations on core material and 17 to 20 percent of those on shell material were below the desired minimum of 100 percent compaction. Mean percent compaction values ranged from 102.3 to 103.4, and standard deviations between 2.61 and 2.87.

59. Dike. Only a few of the density determinations made on fill in the various zones of the zoned dike section were below the desired minimum percent compaction of 98; none in the core (second specification) and 4 to 7.4 percent in the core (first specification) and shells. However, 9 percent of the determinations in the unzoned dike section were below 98 percent compaction. Average percent compaction for all zones ranged narrowly from 102.9 to 105.4 and standard deviations σ only from 3.05 to 3.81.

Pervious drains

60. Figure 29 summarizes density data for the sand drainage zones

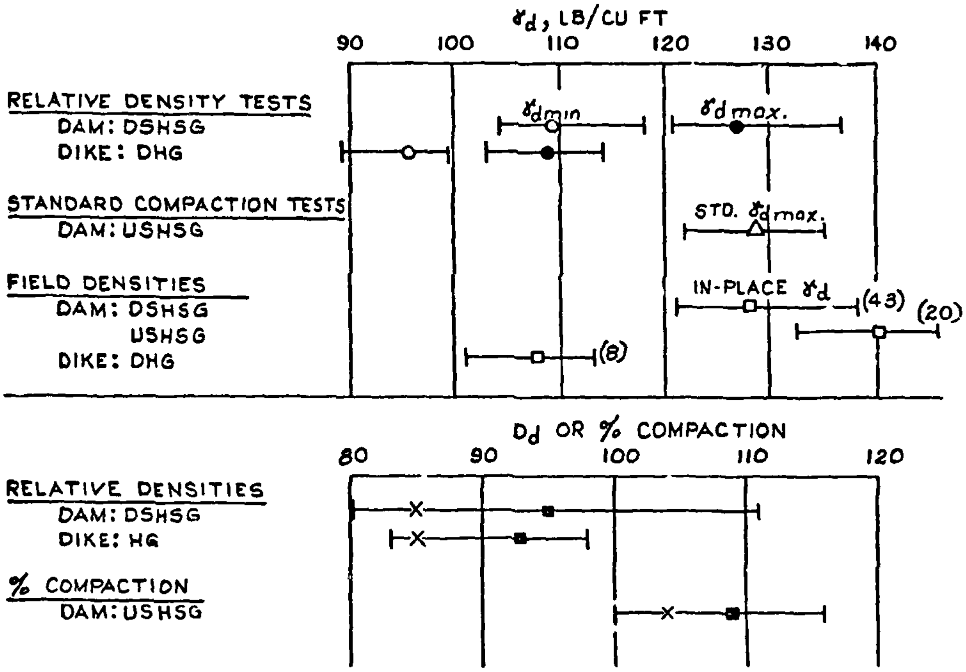


NOTES: 1. VSD, HSD = VERTICAL AND HORIZONTAL SAND DRAINS RESPECTIVELY.
2. (A), (B), (C) REFER TO GROUPS LISTED ON TABLE 5.
3. SYMBOLS ○ ● △ □ ■ INDICATE AVERAGE VALUES.
4. ├───┤ INDICATES RANGE OF TEST VALUES.
5. X INDICATES DESIRED AVERAGE VALUES.
6. (49) INDICATES NUMBER OF FIELD DENSITY TESTS

Figure 29. Density data on sand drains, dam and dike

in the dam and dike. The figure shows that while average as-placed dry densities ranged narrowly from 116.6 to 121.6 pcf, average relative densities ranged from 77 to 116 percent, reflecting not only the sensitivity of D_d to fairly small change in γ_d, but also the method of relating in-place γ_d to D_d. Desired average relative densities of 70 percent in the early construction of the dike and of 85 percent for the dam and the remainder of the dike sand zones are shown to have been exceeded in all cases.

61. Figure 30 summarizes the density data for the gravel or sand



NOTES: 1. DSHSG AND USHSG ARE DOWNSTREAM AND UPSTREAM SAND AND GRAVEL HORIZONTAL DRAINS. DHG IS DOWNSTREAM HORIZONTAL GRAVEL DRAIN.
2. SYMBOLS ○, ●, △, □, ■ INDICATE AVERAGE VALUES.
3. ├──┤ INDICATES RANGE OF TEST VALUES.
4. X INDICATES DESIRED AVERAGE VALUES.
5. (43) INDICATES NUMBER OF FIELD DENSITY TESTS.

Figure 30. Density data on sand and gravel and gravel drains, dam and dike

and gravel drainage zones in the dam and dike. There was a wide variation in average field densities of the three zones (from 108.1 to 140.2 pcf) which might possibly be caused by differences in gradation. Average relative densities were well in excess of the desired value of 85 percent.

PART IV: EVALUATION OF COMPACTION CONTROL PROCEDURES

Core and Shell Materials

Laboratory compaction test

62. The use of a 6-in. compaction mold has generally been restricted to materials passing the 3/4-in. screen. The 1970 edition of EM 1110-2-1906 requires the use of a 12-in. mold when the amount of plus 3/4-in. material exceeds 10 percent. Thus the use of a 6-in. mold in compaction tests of minus 1-in. DeGray Dam material (without replacement) might appear questionable. However, results of a comparative compaction test investigation (Donaghe and Townsend 1973) indicate that the DeGray compaction procedure produced satisfactory results.

63. In Donaghe and Townsend (1973), material from borrow area F was tested in compaction molds ranging from 6 to 18 in. in diameter. The soil had 9 percent plus 2-in. sizes, 22 percent plus 1-in. sizes, and 27 percent plus 3/4-in. sizes. G_m of plus No. 4 material was 2.5 and A is assumed to have been 2.5 percent. A compaction test was made on the total material in an 18-in. mold using a mechanical compactor, and on minus 1-in. (with no replacement) and on minus 3/4-in. (with replacement) using the standard CE compactor. Results of the 18-in. mold test were adjusted using Equations 1 and 2 of paragraph 16 to minus 1-in. and minus 3/4-in. to give the following comparisons with actual tests:

	Optimum w percent	Max γ_d pcf
Total sample (3-in. maximum size in 18-in. mold)	8.7	127.9
1-in. max size		
Test in 6-in. mold (no replacement)	11.6	121.8
Computed from total sample results	10.5	122.4
3/4-in. max size		
Test in 6-in. mold (with replacement)	10.8	122.3
Computed from total sample results	11.0	120.8

While there appears to be better agreement of water contents with the test on minus 3/4-in. material, other tests with the mechanical compactor on minus 3/4-in. material indicated lower optimum water contents than obtained using the hand compactor. The agreement of water contents for 1-in. material would probably be closer if the method of compaction had been the same for both the minus 3-in. and minus 1-in. materials. Maximum densities of adjusted and actual tests for minus 1-in. material are in good agreement.

Selection of appropriate laboratory compaction test results

64. The preparation of a separate set of compaction curves for each borrow area and the selection of appropriate compaction curves on the basis of soil type, gradation, liquid limit (LL), plastic limit (PL), and classification appears to have been an appropriate procedure for the wide variety of material types and high gravel content of borrow material. The construction control reports indicated that during initial construction, the liquid limit and plastic limit were measured for each field density test and subsequently were frequently estimated; the gradation of each field density sample was measured (percentage of plus 1-in., minus No. 4 sieve, and minus No. 200 sieve material). A large number of additional laboratory compaction tests were performed as construction progressed.

65. The use of Equations 1 and 2 of paragraph 16 requires values of G_m or A. These equations are used to adjust densities and water contents of fills containing plus 1-in. material so that they can be related to optimum water contents and maximum densities of compaction tests on minus 1-in. material. It could not be determined from the field reports which values of G_m and A were based on actual determinations and which were simply estimated. For samples listed in Figures 13 and 14 having 10 percent or more of plus 1-in. material, values of G_m ranged from 2.44 to 2.62 with an average of about 2.55; values of A ranged from 1.7 to 5.2 percent with an average of about 4.0 percent.

66. Figures 31 and 32 demonstrate the differences in variation of water contents from optimum and the differences in variation of percent

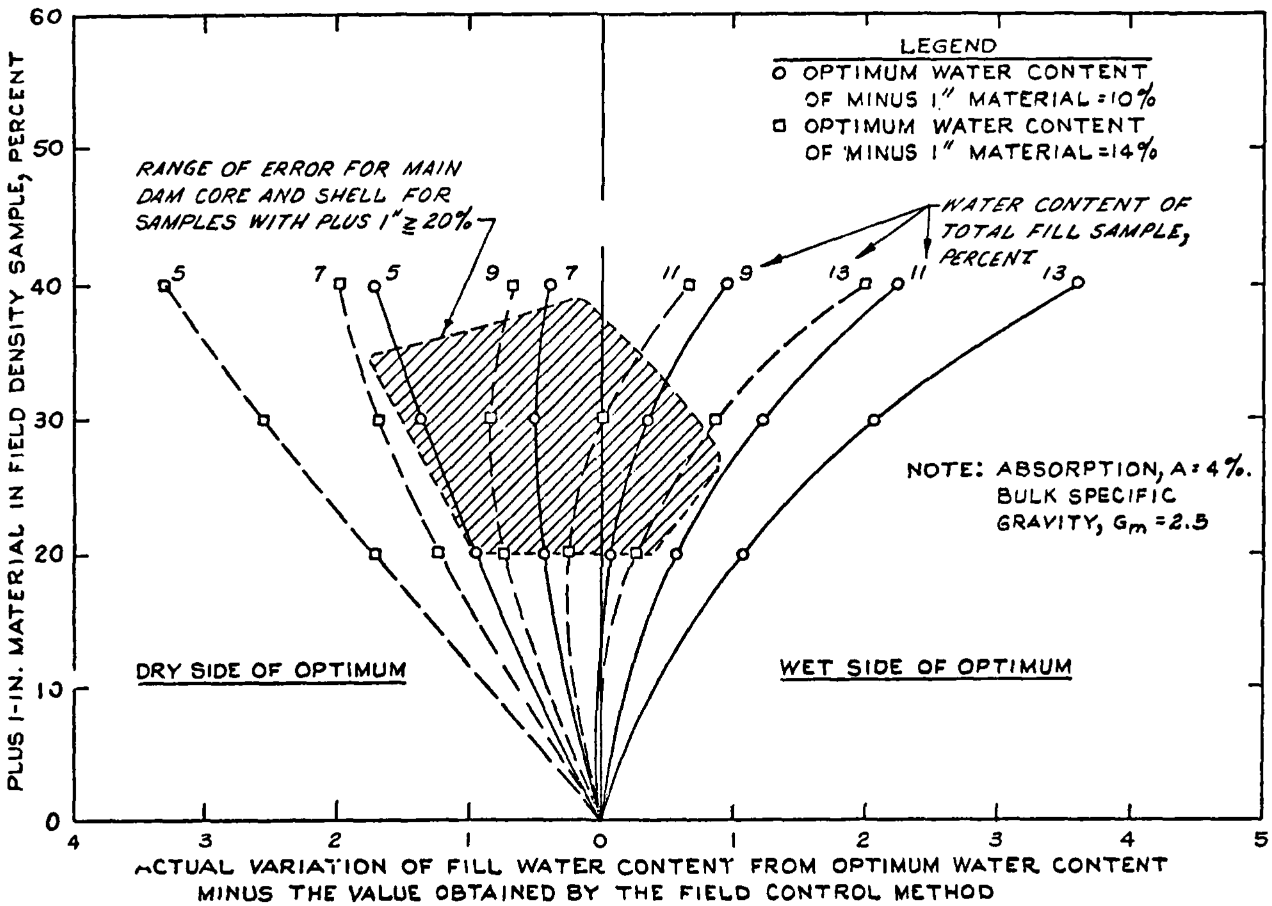


Figure 31. Differences in variation of water content from optimum for correct and incorrect procedures of comparing field water contents to optimum

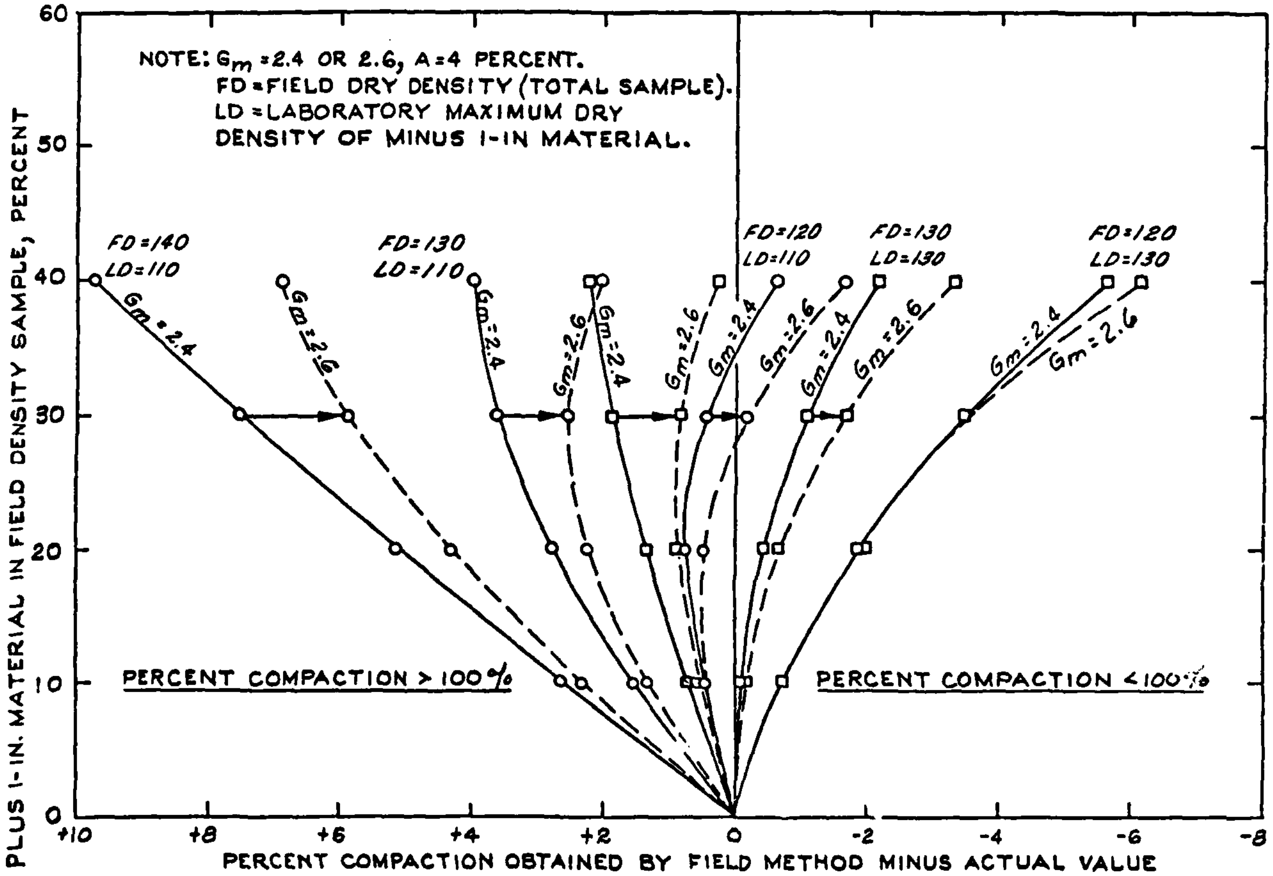


Figure 32. Differences in variation of percent compaction from maximum density for the correct and incorrect procedures of comparing field densities to maximum density

compaction when using the correct and incorrect procedures for comparing field water content and density values with compaction test results (as discussed in paragraph 19). Table 6 compares results of reported data on percent compaction and variation of water contents from optimum with values adjusted by WES. The table shows that more field samples failed to meet water content specifications and desired minimum percent compaction than were indicated by the reported District data. However, the compaction achieved in constructing the dam and dike is considered satisfactory since 8 of every 10 samples taken in the core and shells met water content specifications and 9 of every 10 exceeded the minimum desired percent compaction. More importantly, required strength characteristics of in-place fill were verified throughout construction by means of a thorough record sampling and testing program.

Drainage Zone Materials

67. Compaction control of sand, sand and gravel, and gravel materials by performance of maximum and minimum density tests on material from each field density sample location appears to have been the best procedure. However, the use of one relative density test for several field density tests on practically identical material being placed during one work shift appears to have been adequate.

68. Results of standard effort compaction tests with 98 or 104 percent maximum dry density related to 85 percent relative density does not appear to have been a very satisfactory procedure since the correlation was based on one or at the most two relative density tests. Changes in gradation and particle shape affect the maximum and minimum density test results, and the validity of this procedure is questionable.

69. For the sand materials, the correlation of maximum and minimum density with the percent minus No. 16 sieve (see Figure 15) was fairly well defined. However, several tests on material with the same percentage of minus No. 16 sieve material indicated erratic dry density variations, which could lead to significant errors. This correlation was infrequently used and would not be too satisfactory unless maximum

variations along a fitted line for maximum density and for minimum density were less than about plus or minus 2 pcf.

PART V: *SUMMARY AND CONCLUSIONS*

Water Content and Compaction Results, Core and Shell Materials

Summary

70. The water content and compaction results for the core and shell zones of DeGray Dam and Dike are summarized below.

71. Fill water content.

- a. Fills in the core and shell zones were generally placed at average water contents slightly dry of optimum. The extreme variations from optimum generally fell within 5 percentage points above optimum to 7 percentage points below optimum for the dam and within 8 percentage points above optimum to 7 percentage points below optimum for the dike.
- b. The percent of samples within specified water content limits for the dam and dike was not related to material type. The variation within specified limits for the core zones ranged from 78 to 97 percent and for the shell and unzoned dike zones from 69 to 72 percent.
- c. The test locations where the water content specifications were not met occurred in a random fashion in the core and shell zones of the dam and dike. Variations in the percentage of test results outside the specification limits ranged from 5 to 25 percent dry of optimum and from 0 to 15 percent wet of optimum.

72. Dry density.

- a. The average value of fill percent compaction for the dam generally exceeded the desired value (100 percent) by 3 percentage points and for the dike generally exceeded the desired value (98 percent) by 6 percentage points.
- b. The test locations where the desired density was not achieved occurred in a random fashion within all zones. Extreme minimum values of percent compaction ranged from 92 to 97 percent in the dam and 90 to 99 percent in the dike except for a value of 82 percent in the unzoned section of the dike.

73. Variation in fill water content.

- a. The frequency distributions for the variation of fill water content from laboratory optimum water content for the dam and dike approach a normal frequency distribution, with a significantly higher concentration toward the mean than the normal for the core of the dam and only slightly more concentrated toward the mean for all other zones except the dike core (second specification), which was less dispersed than the normal case.

b. For the dam, better control was indicated for the core. For the dike, somewhat better control was indicated for the core (second specification) and landside shell.

74. Variation in fill dry density.

a. The frequency distributions for the variation of percent compaction for the dam and dike approach a normal frequency distribution, with a slightly higher concentration toward the mean than the normal except for the unzoned material in the dike, which was slightly less concentrated toward the mean.

b. For the dam, slightly better control was indicated for the downstream shell. For the dike, somewhat better control was indicated for the core (second specification).

Conclusions

75. The selection of an appropriate laboratory compaction curve on the basis of gradation, LL, PL, and classification of the fill samples appears to have been adequate for the variety of fill materials. Total sample water content and density corrected for the amount of plus 1-in. material in the fill sample to obtain an estimate of water content and density of the minus 1-in. fraction were of sufficient accuracy for control purposes. The correct procedure of relating field test values on fills containing plus 1-in. material to laboratory compaction tests on minus 1-in. material is emphasized in this report primarily for future guidance in compaction control of such materials.

Compaction Results, Drainage Materials

Summary

76. The relative density of the sand, sand and gravel, and gravel placed in the drainage zones of the dam and dike generally exceeded the desired relative densities. The few unsatisfactory relative densities in the dike drainage zones were scattered in location, and several fill

density tests several layers below the fill surface indicated a significant increase in relative density.

Conclusions

77. The best procedure for determining in-place relative density was the performance of a relative density test on material from each field density test location. The correlation of maximum density and minimum density for the sand with the percent minus No. 16 sieve was infrequently used and did not appear to be sufficiently accurate for use in controlling compaction. Results obtained using correlations of standard effort percent compaction with relative density appear questionable since a sufficient number of relative density tests were not performed.

REFERENCES

Donaghe, R. T. and Townsend, F. C. 1973. "Compaction Characteristics of Earth-Rock Mixtures, Report 1, Vicksburg Silty Clay and DeGray Dam Clay Sandy Gravel," Miscellaneous Paper S-73-25, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

U. S. Army Engineer District, Vicksburg. 1962. "DeGray Reservoir, Caddo River, Arkansas," Design Memorandum No. 10, "Dike," Vicksburg, Miss.

__________. 1963. "DeGray Reservoir, Caddo River, Arkansas," Design Memorandum No. 11-1, "Dam," Vicksburg, Miss.

__________. 1964. "DeGray Reservoir, Caddo River, Arkansas," Supplement A to Design Memorandum No. 11-1, "Dam," Vicksburg, Miss.

__________. 1972. "Earth Dam Criteria Report 53, DeGray Dam and Lake, Caddo River, Arkansas," Vicksburg, Miss.

Table 1

Fill Materials and Compaction Control

Type of Fill	Soil Classification	Maximum Particle Size in.	Plus No. 4 Material %	Fill Volume, 1000 cu yd	No. of Field Density Tests*	Cu Yd of fill per Density Test	Specified Placement Water Content** %	Desired Minimum Density† or D_d††	Field Compaction Procedure	Procedures for Correlating Field Densities and Water Contents With Results of Laboratory Tests
Main Dam										
(a) Core	CH, CL GC, SC	3	0 to 50	1229	178	6,900	-2.0 to +1.0	100% $\gamma_{d\,max}$	4 passes of 50-ton rubber-tired roller or 6 passes of 6-ton tamping roller on 8-in. loose lift	1. Control by standard compaction (core and shell): a. In-place density was compared to laboratory standard compaction results on minus 1-in. materials corrected for the percentage of plus 1-in. materials in the field density material.
(b) Shell	CL, GC SC, SM	3	0 to 60	5242	891	5,900	-2.0 to +1.0	100% $\gamma_{d\,max}$	Same as above	b. The appropriate laboratory maximum dry density and optimum water content were selected by visual classification of fill material supplemented by gradation and Atterberg limits tests and reference to a family of compaction curves determined on minus 1-in. material for each borrow area.
(c) Pervious Fill: (1) vertical sand drain	SW	0.5	1 to 17	63	57	1,100	Saturated	85% avg D_d with min D_d of 80%	4 passes of "Tampo" Model VC-80 towed-type vibratory compactor on 6-in. lift	
(2) sand and gravel drainage layers	SW, GW, GP	6	3 to 90	199	63	3,100	Saturated	85% avg D_d with min D_d of 80%	8 passes of D-8 crawler tractor on 6-in. lift	c. The water content of the minus 1-in. material was determined by direct measurement, while the total sample water content was calculated by using the percent of plus 1-in. material and its absorption.
Dike										
(a) Core	CH, CL GC, SC	3	0 to 50	3400	336	10,100	-2.0 to +1.5 -3.0 to +6.0	98% $\gamma_{d\,max}$	Same as Main Dam	
(b) Shell	CL, GC SC, SM	3	0 to 60	8050	738	10,900	-2.0 to +1.5	98% $\gamma_{d\,max}$	Same as Main Dam	2. Control by relative density (pervious fill): Maximum (vibrated) and minimum densities were generally determined on material from each field density test, and infrequently estimated for sand based on correlation with percent < No. 16 sieve.‡‡
(c) Pervious (vertical and horizontal drains)	SW, GW, GP	Sand 0.5 Gravel 6		288	218	1,300	Saturated	85% avg D_d with min D_d of 80‡	Same as Main Dam	
(d) Unzoned	CL-ML, SW-SM SM GC	3	0 to 60		89		-2.0 to +1.5	98% $\gamma_{d\,max}$	Same as Main Dam, Core and Shell	

* All tests (including original tests for areas reworked and/or retested)

** In respect to standard optimum water content

† In percent of standard maximum dry density, $\gamma_{d\,max}$

†† D_d = relative density

‡ During initial construction of the dike, the desired minimum relative density was 70%

‡‡ During early construction of the dike, a correlation of standard effort maximum density with relative density was used for control

Table 2

Fill Water Content Data
Core, Shells, and Unzoned Sections

Embankment Zone	No. Tests	Adjusted Fill Water Content % Range	Adjusted Fill Water Content % Mean	Optimum Water Content % Range	Optimum Water Content % Mean	Variation of Adjusted Fill Water Content from Laboratory Optimum Percentage Points Range	Mean	Std Dev, σ	Specified Limits With Respect to Optimum in Percentage Points	Percent of Test Values with Respect to Specified Limits Below	Within	Above
Dam, Core	154	9.8 to 24.7	15.4	11.1 to 22.5	15.7	-7.2 to +2.7	-0.26	1.24	-2.0 to +1.0	4.5	88.3	7.2
Dam, Upstream Shell	321	6.0 to 22.6	13.0	9.7 to 22.0	13.7	-5.7 to +3.3	-0.68	1.51	-2.0 to +1.0	17.7	72.3	10.0
Dam, Downstream Shell	378	6.7 to 22.8	13.1	8.8 to 22.0	13.9	-6.4 to +5.4	-0.81	1.63	-2.0 to +1.0	20.9	69.6	9.5
Dike, Core, 1st Water Content Specification	175	8.5 to 36.4	24.4	13.2 to 36.8	24.3	-3.9 to +7.4	+0.10	1.69	-2.0 to +1.5	6.9	77.7	15.4
Dike, Core, 2nd Water Content Specification	138	3.7 to 39.2	27.3	13.9 to 38.6	26.9	-3.5 to +4.4	+0.37	1.86	-3.0 to +6.0	2.9	97.1	0.0
Dike, Landside Shell	314	6.3 to 25.7	12.9	7.0 to 25.9	13.8	-6.7 to +8.5	-0.90	1.83	-2.0 to +1.5	24.5	69.5	6.0
Dike, Lakeside Shell	312	5.7 to 32.3	13.1	8.5 to 32.1	13.9	-7.3 to +6.9	-0.78	1.94	-2.0 to +1.5	22.1	69.2	8.7
Dike, Unzoned	89	7.3 to 35.1	13.8	9.5 to 36.1	14.5	-5.3 to +4.2	-0.94	1.67	-2.0 to +1.5	20.2	71.9	7.9

Table 3

Fill Density Data

Core, Shells, and Unzoned Sections

Embankment Zone	No. Tests	Fill Dry Density pcf		Standard Maximum Dry Density pcf		Fill Percent Compaction			Desired Minimum Percent Compaction	Percent Test Values Below Desired Percent Compaction
		Range	Mean	Range	Mean	Range	Mean	Std Dev, σ		
Dam, Core	154	101.6 to 125.7	114.5	97.5 to 121.6	110.8	96.7 to 112.2	103.8	2.61	100.0	10.4
Dam, Upstream Shell	321	97.4 to 136.6	119.0	99.3 to 133.6	120.3	92.3 to 112.0	102.8	2.87	100.0	16.8
Dam, Downstream Shell	378	101.4 to 134.8	117.0	99.0 to 134.0	115.6	92.1 to 110.5	102.3	2.82	100.0	20.4
Dike, Core, 1st specification	175	82.3 to 124.5	99.4	79.7 to 118.5	95.2	90.0 to 114.8	104.0	3.76	98.0	4.0
Dike, Core, 2nd specification	138	81.2 to 120.2	96.9	76.8 to 118.3	91.4	98.9 to 117.5	105.4	3.05	98.0	0
Dike, Landside Shell	314	93.5 to 138.2	118.2	92.0 to 128.5	115.2	92.6 to 111.6	103.0	3.29	98.0	6.0
Dike, Lakeside Shell	312	86.5 to 139.1	117.8	85.0 to 135.7	114.5	91.2 to 112.3	102.9	3.70	98.0	7.4
Dike, Unzoned	89	87.0 to 134.0	115.5	91.9 to 126.3	107.5	82.0 to 118.1	103.1	3.81	98.0	9.0

Table 4

Summary of Field Density Results, Drainage Materials, Dam

Drainage Layer	No. Field Density Tests*	Range of Max. Particle Size in.	Passing No. 4 Sieve, %		γ_d min lb/cu ft		γ_d max** lb/cu ft		In-Place γ_d lb/cu ft		In-Place Rel. Den. %		In-Place Compaction %	
			Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg
In-Place Density Compared to Standard $\gamma_{d\ max}$ (104% Compaction = Desired Avg D_d = 85%)														
Upstream Horizontal Sand and Gravel (GP, GW)	20	3 to 6	20 to 33	25	--	--	122.1 to 135.1	128.7	132.5 to 145.6	140.2	--	--	100 to 116	109
Relative Density of In-Place Material Determined (Desired Avg D_d = 85%)														
Downstream Vertical Sand (SW)	49	3/8 to 1/2	83 to 99	90	95.6 to 109.9	103.1	109.1 to 124.6	118.1	110.0 to 121.8	116.6	80 to 112	92	--	--
Downstream Horizontal Sand (SW)	17	1/2	89 to 97	93	103.9 to 110.8	107.3	117.7 to 121.8	120.0	117.8 to 126.1	121.5	85 to 154	116	--	--
Downstream Horizontal Sand and Gravel (GW)	43	2 to 6	10 to 36	19	104.2 to 117.8	109.5	120.8 to 137.3	127.2	120.9 to 138.5	128.2	80 to 111	95	--	--

* Excluding results of original tests for areas reworked and/or retested.

** From standard effort compaction test or vibrated relative density test as indicated.

Table 5

Summary of Field Density Results, Drainage Materials, Dike

Drain	No. Field Density Tests*	Maximum Particle Size in.	Passing No. 4 Sieve % Range	Passing No. 4 Sieve % Avg	$\gamma_{d\ min}$ lb/cu ft Range	$\gamma_{d\ min}$ lb/cu ft Avg	$\gamma_{d\ max}$ lb/cu ft Range	$\gamma_{d\ max}$ lb/cu ft Avg	In-Place γ_d lb/cu ft Range	In-Place γ_d lb/cu ft Avg	In-Place Relative Density % Range	In-Place Relative Density % Avg	In-Place Compaction % Range	In-Place Compaction % Avg
Group A: Desired Minimum Relative Density = 70%														
Vertical Sand (SW)	12	1/2	91 to 94	94	100.0 and 103.1	101.6	121.2 and 122.4	121.8	109.6 to 121.2	116.9	51 to 95	77	--	--
Horizontal Sand (SW)	53	1/2	91 to 95	94	100.0 and 103.1	101.6	121.2 and 122.4	121.8	109.0 to 126.2	117.8	48 to 117	82	--	--
Group B: Desired Average Relative Density = 85%														
Vertical Sand (SW)	7	1/2	85 to 95	89	--	--	110.9 to 120.5	117.2	114.2 to 124.1	119.1	--	--	100 to 104	102
Horizontal Sand (SW)	27	3/8 to 3/4	85 to 95	91	--	--	108.1 to 122.6	116.9	113.6 to 127.8	118.2	--	--	97 to 107	101
Group C: Desired Average Relative Density = 85% and Minimum Relative Density = 80%														
Vertical Sand (SW)	42	3/8 to 1/2	81 to 98	92	93.5 to 108.2	100.8	111.6 to 124.3	117.7	111.6 to 124.2	116.8	82 to 110	93	--	--
Horizontal Sand (SW)	26	1/2 to 3/4	76 to 9[illegible]	88	97.2 to 114.0	105.5	113.6 to 127.6	120.3	111.7 to 125.7	120.0	82 to 147	97	--	--
Horizontal Gravel (GW)	8	2 to 3	0.5 to 53	8	89.4 to 99.5	95.7	103.3 to 113.8	109.1	100.7 to 113.2	108.1	83 to 98	93	--	--

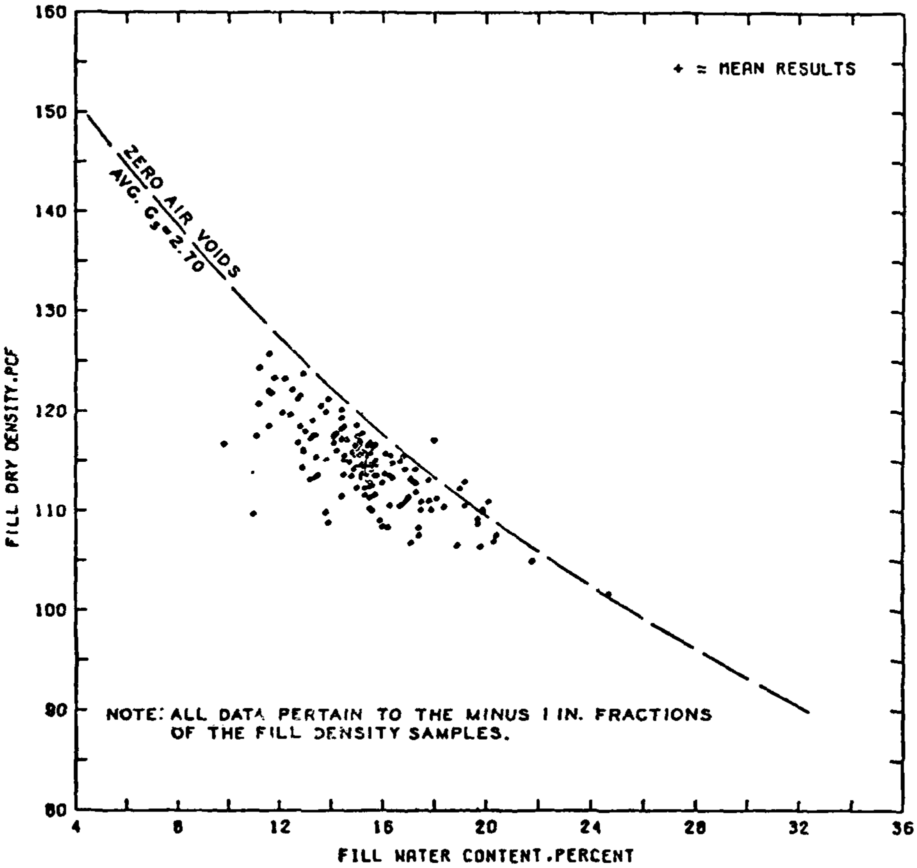
* Excludes original tests for areas reworked or retested.

Table 6

Comparison of Compaction Control Results, Corrected and Uncorrected Data

Embankment Zone	Field Data*	No. Tests	Variation of Fill Water Content from Laboratory Optimum Percentage Points: Mean	Std Dev, σ	Percent of Test Values with Respect to Specified Limits: Below	Within	Above	Fill Percent Compaction: Mean	Std Dev, σ	Percent of Test Values Below Desired Percent Compaction
Dam, Core	U	154	-0.33	1.22	5.8	87.8	6.4	103.4	2.57	1.2
	C		-0.26	1.24	4.5	88.3	7.2	103.4	2.61	10.4
Dam, Upstream Shell	U	321	-0.59	1.26	11.1	83.3	5.6	102.7	2.51	2.2
	C		-0.68	1.51	17.7	72.3	10.0	102.8	2.87	16.8
Dam, Downstream Shell	U	378	-0.76	1.52	17.5	73.4	7.1	102.2	2.47	3.0
	C		-0.81	1.63	20.9	69.6	9.5	102.3	2.82	20.4
Dike, Core, 1st specification	U	175	-0.09	1.68	8.6	79.4	12.0	104.3	3.47	2.3
	C		+0.10	1.69	6.9	77.7	15.4	104.0	3.76	4.0
Dike, Core, 2nd specification	U	138	+0.32	1.83	2.9	97.1	0.0	105.4	3.03	0.0
	C		+0.37	1.86	2.9	97.1	0.0	105.4	3.05	0.0
Dike, Landside Shell	U	314	-0.69	1.56	14.8	80.8	4.4	102.9	2.93	3.5
	C		-0.90	1.83	24.5	69.4	6.1	103.0	3.29	6.0
Dike, Lakeside Shell	U	312	-0.60	1.71	16.1	76.0	7.9	102.7	3.40	5.4
	C		-0.78	1.94	22.1	69.2	8.7	102.9	3.70	7.4
Dike, Unzoned	U	89	-0.79	1.57	15.4	76.9	7.7	103.3	4.03	8.8
	C		-0.94	1.67	20.2	71.9	7.9	103.1	3.81	9.0

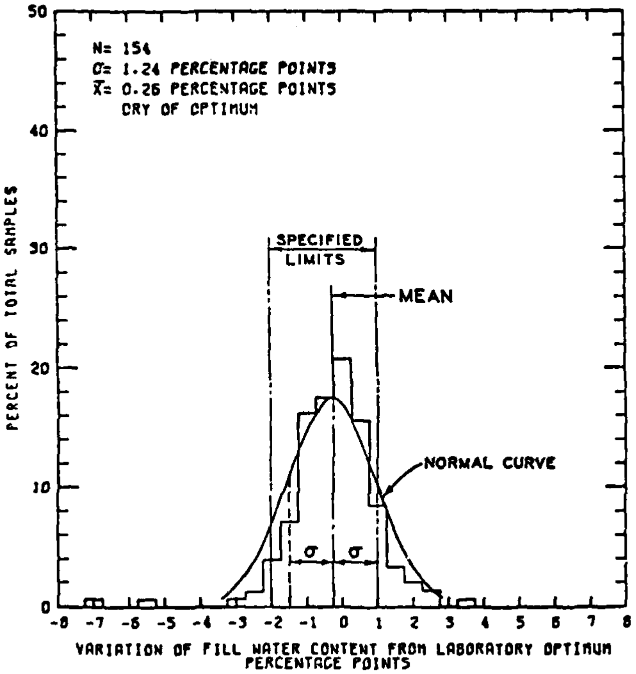
* U - uncorrected; C - corrected



NUMBER OF TESTS = 154
MEAN FILL DENSITY = 114.5 PCF
MEAN FILL WATER CONTENT = 15.4 PERCENT

FIELD DRY DENSITY VERSUS FILL WATER CONTENT, CORE OF THE DAM

PLATE 1



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

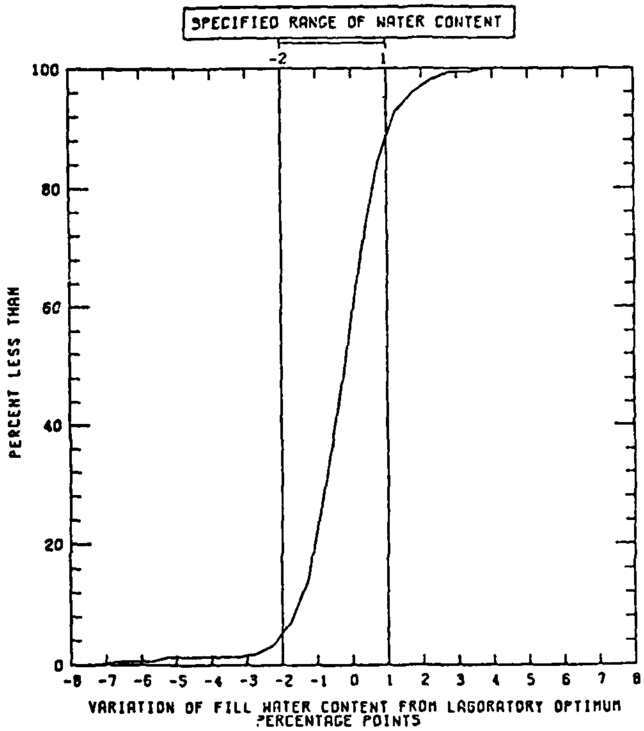
BELOW	WITHIN	ABOVE
9.74	81.17	9.09

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

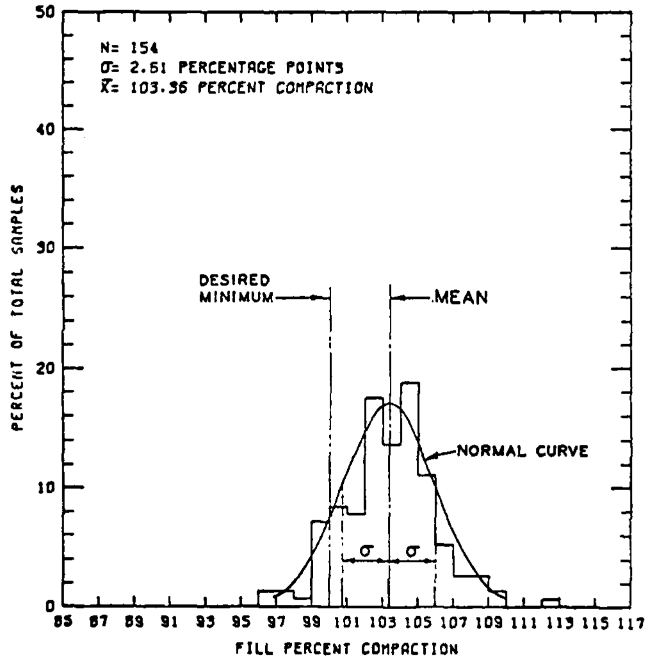
$\bar{X}$ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
4.55	88.31	7.14

VARIATION OF FILL WATER CONTENT, CORE OF THE DAM



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

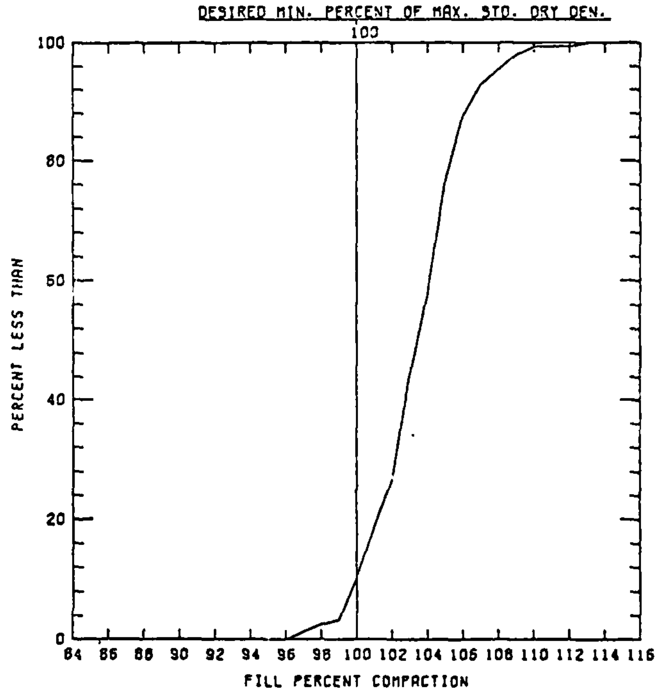
BELOW	WITHIN	ABOVE
16.23	72.08	11.69

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

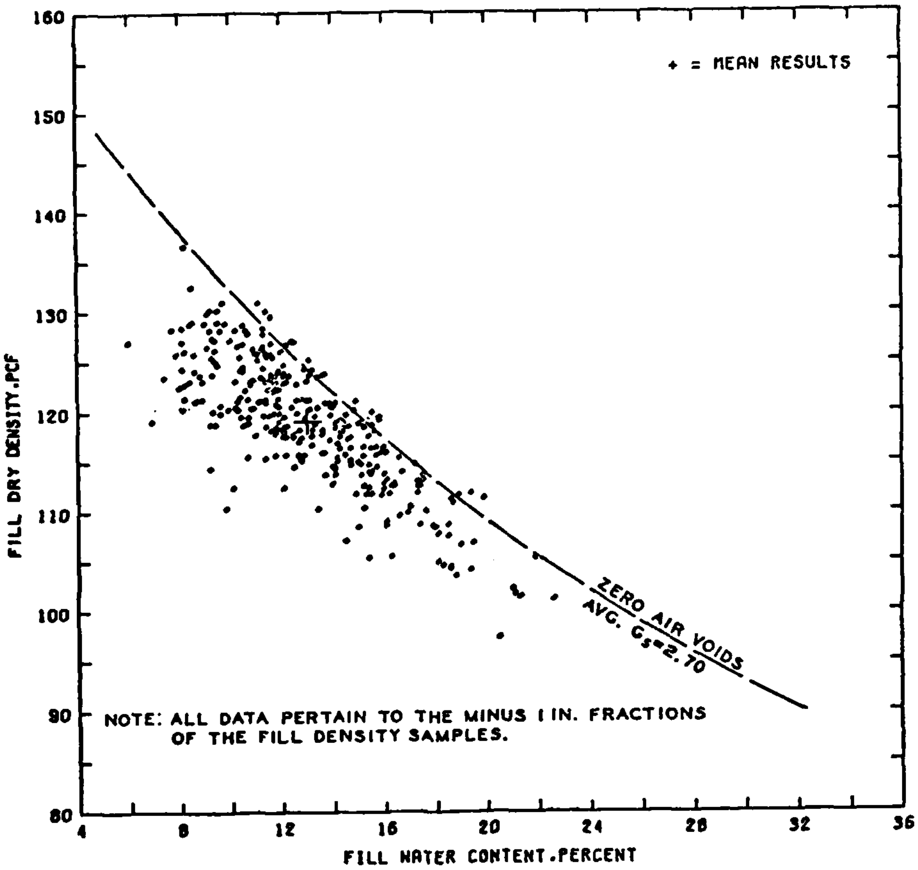
$\bar{X}$ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION

BELOW	ABOVE
10.39	89.61

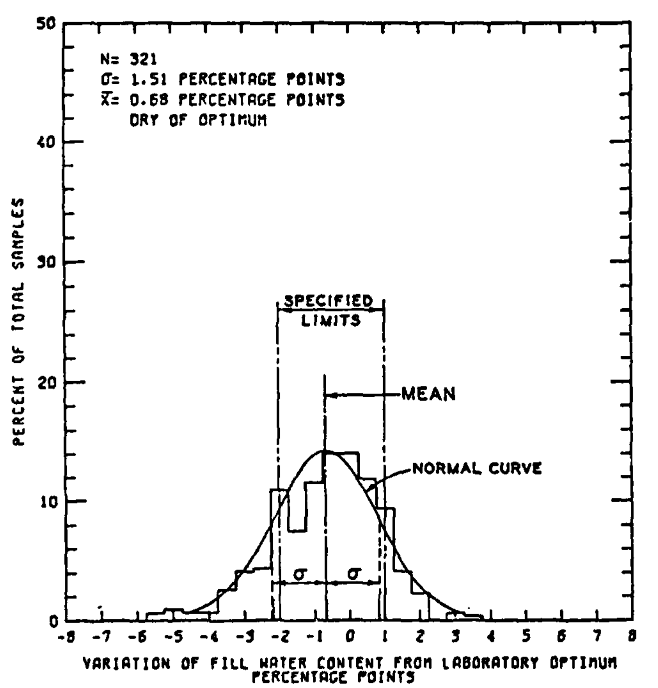
VARIATION OF PERCENT COMPACTION, CORE OF THE DAM



NUMBER OF TESTS = 321
MEAN FILL DENSITY = 119.0 PCF
MEAN FILL WATER CONTENT = 13.0 PERCENT

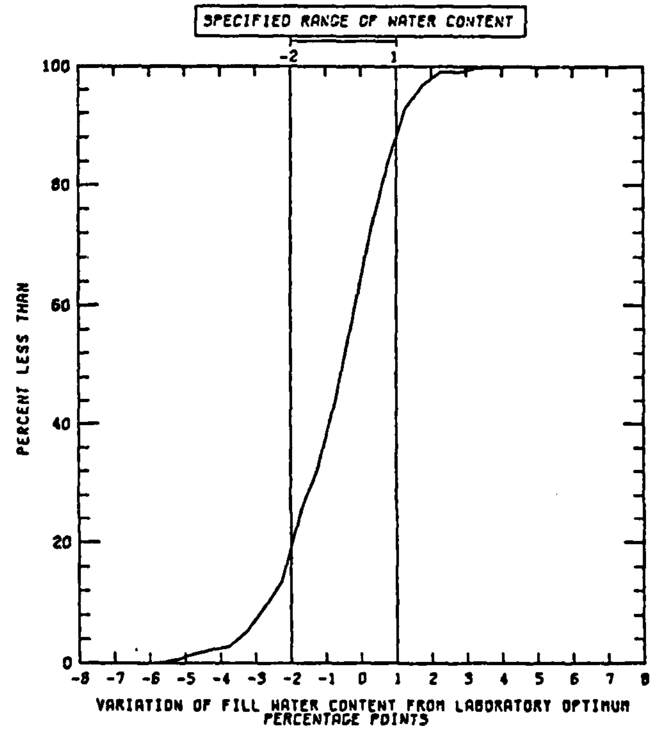
FIELD DRY DENSITY VERSUS FILL WATER CONTENT, UPSTREAM SHELL OF THE DAM

PLATE 4



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

BELOW	WITHIN	ABOVE
15.58	70.09	14.33



PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
17.76	72.27	9.97

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

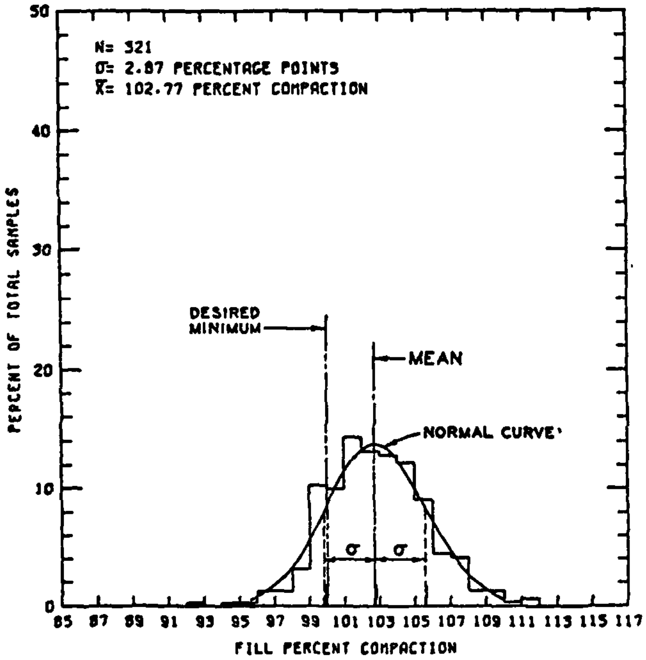
σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

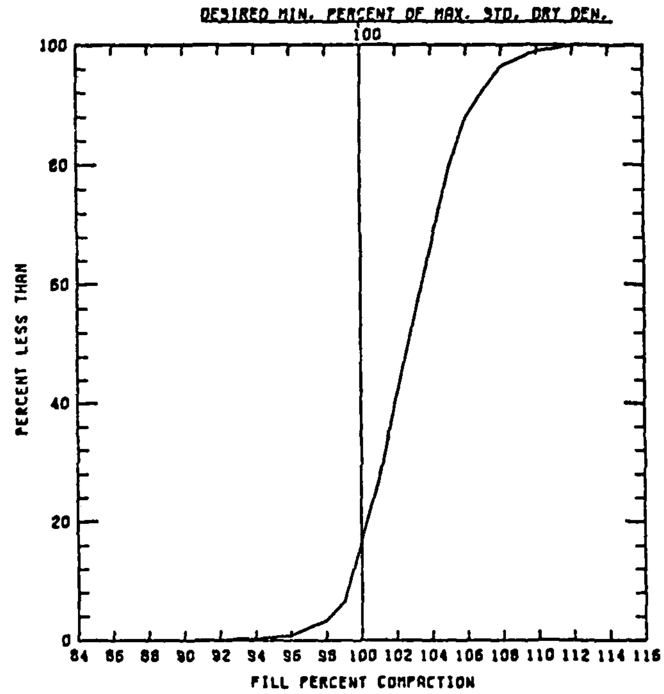
X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points

VARIATION OF FILL WATER CONTENT, UPSTREAM SHELL OF THE DAM

PLATE 5

PLATE 6





PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

BELOW	WITHIN	ABOVE
16.20	69.16	14.64

PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION

BELOW	ABOVE
16.82	83.18

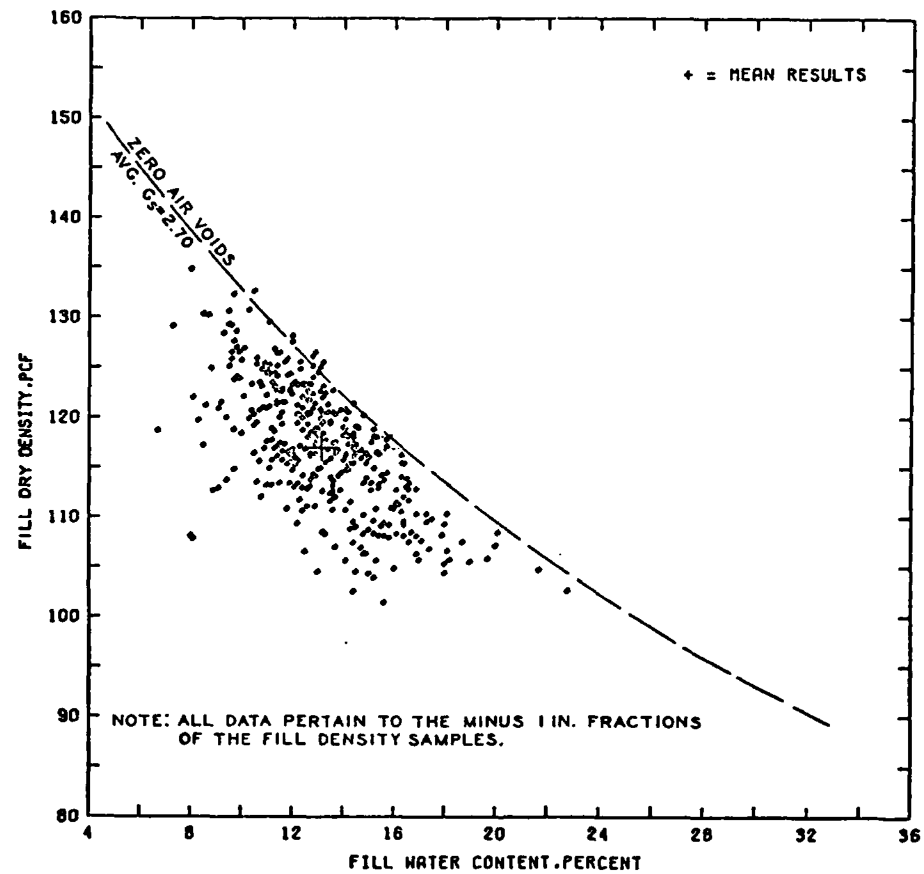
NOTE: All data pertain to the minus 1-in. fractions of the fill density samples.

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points

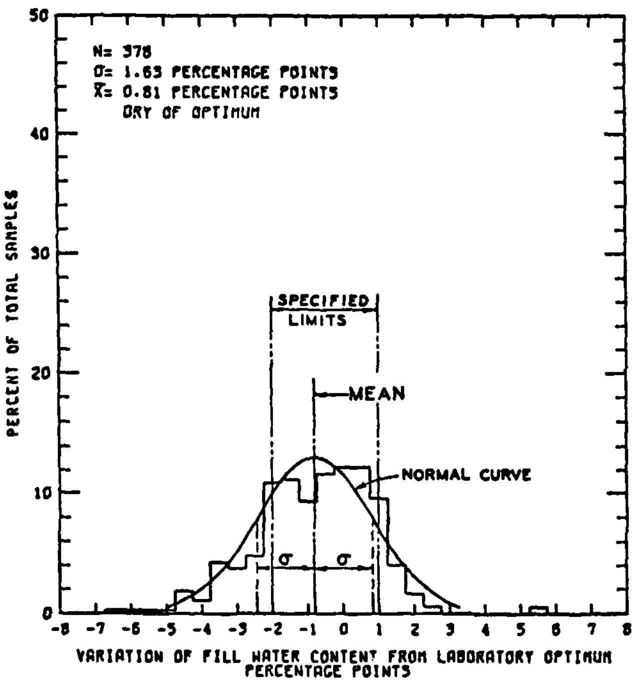
VARIATION OF PERCENT COMPACTION, UPSTREAM SHELL OF THE DAM



NUMBER OF TESTS = 378
MEAN FILL DENSITY = 117.0 PCF
MEAN FILL WATER CONTENT = 13.1 PERCENT

FIELD DRY DENSITY VERSUS FILL WATER CONTENT, DOWNSTREAM SHELL OF THE DAM

PLATE 7



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

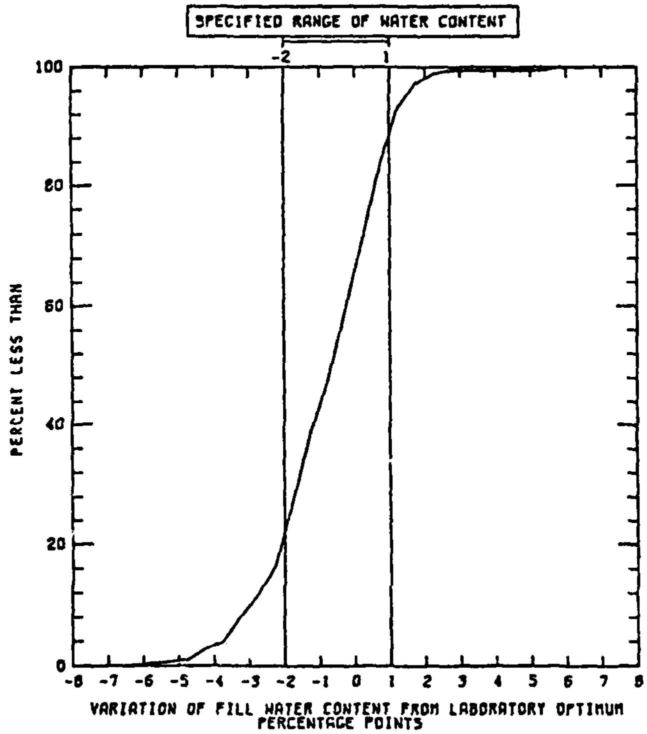
BELOW	WITHIN	ABOVE
13.23	72.49	14.28

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

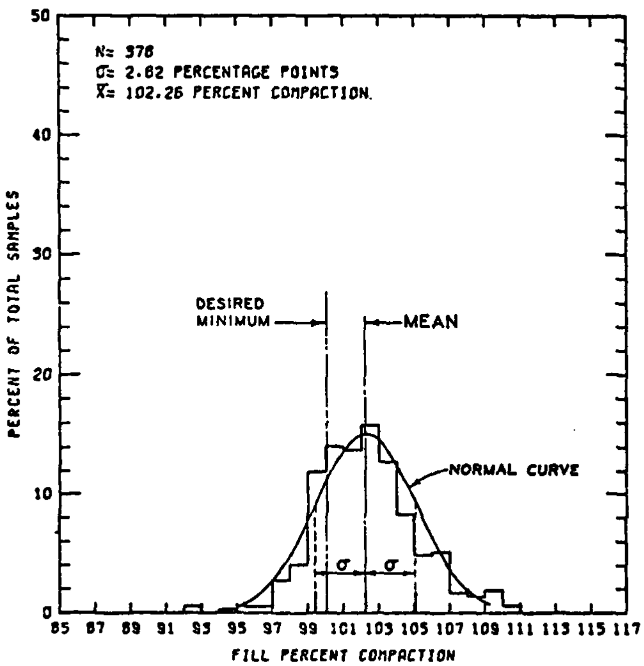
$\bar{X}$ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
20.90	69.58	9.52

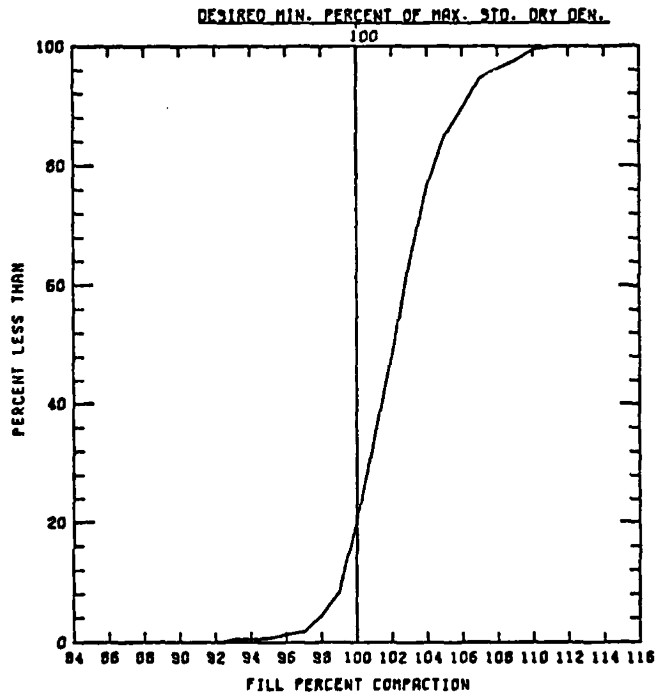
VARIATION OF FILL WATER CONTENT, DOWNSTREAM SHELL OF THE DAM



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

BELOW	WITHIN	ABOVE
12.70	72.75	14.55

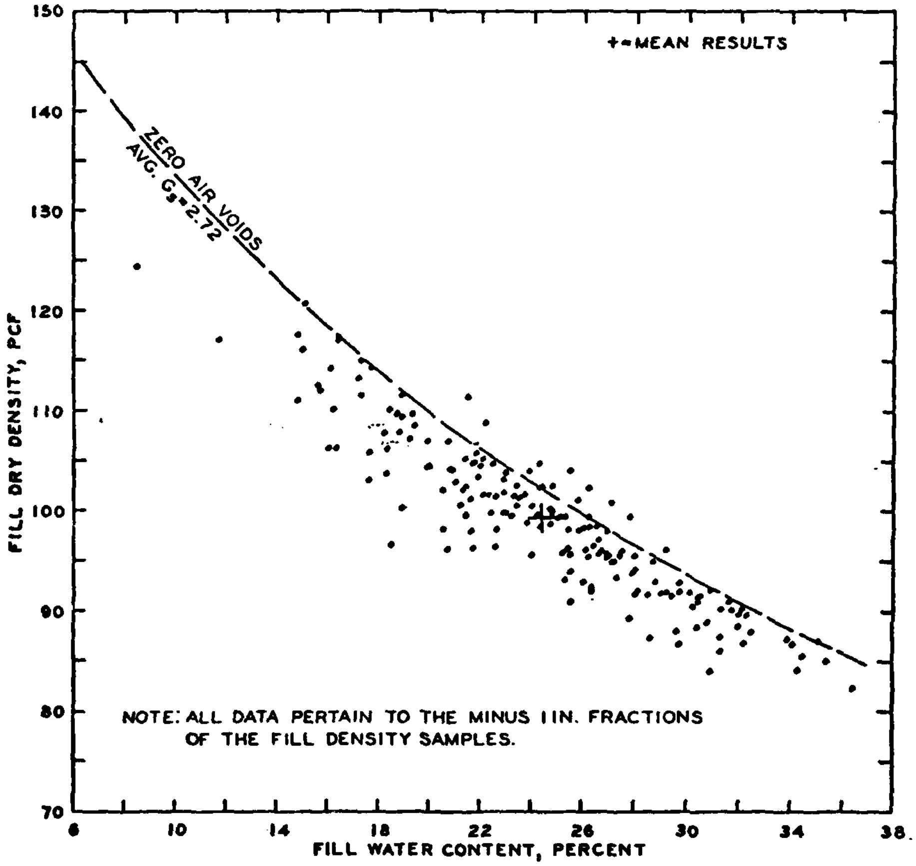
NOTE: All data pertain to the minus 1-in. fractions of the fill density samples
N = Number of tests
σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum
X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION

BELOW	ABOVE
20.37	79.63

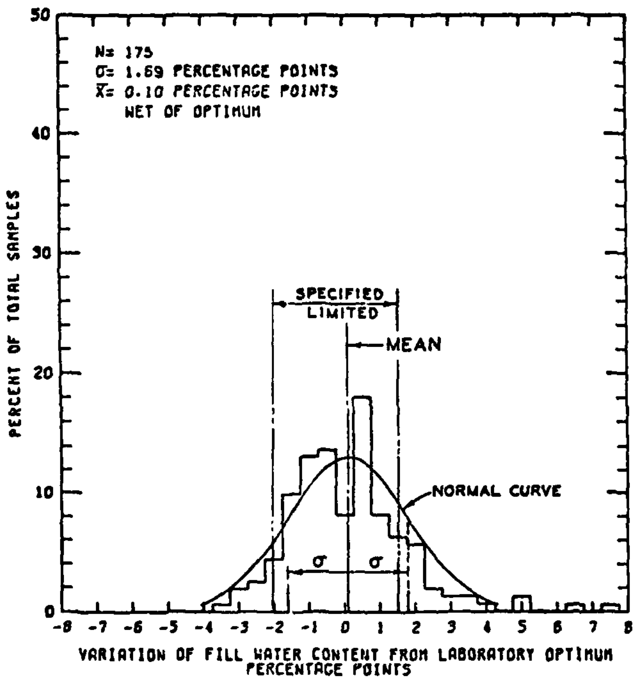
VARIATION OF PERCENT COMPACTION, DOWNSTREAM SHELL OF THE DAM



NUMBER OF TESTS = 175
MEAN FILL DENSITY = 99.4 PCF
MEAN FILL WATER CONTENT = 24.4 PERCENT

FIELD DRY DENSITY
VERSUS FILL WATER
CONTENT, CORE
OF THE DIKE
(FIRST SPECIFICATION)

PLATE 10



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

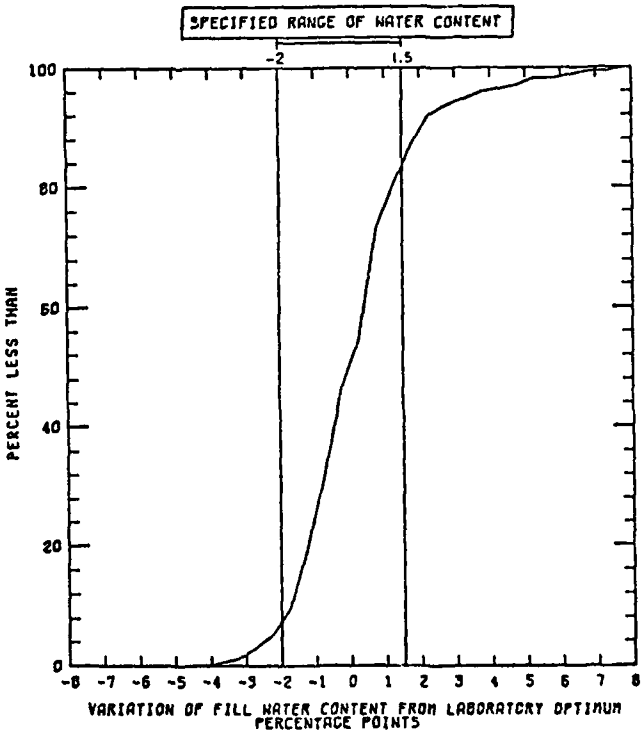
BELOW	WITHIN	ABOVE
12.00	74.86	13.14

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points



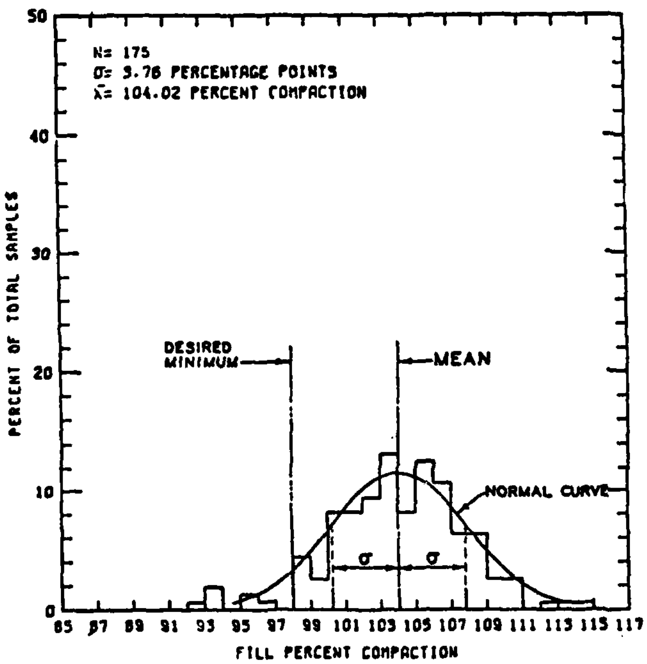
PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
6.86	77.71	15.43

VARIATION OF FILL WATER CONTENT, CORE OF THE DIKE (FIRST SPECIFICATION)

PLATE 11

PLATE 12



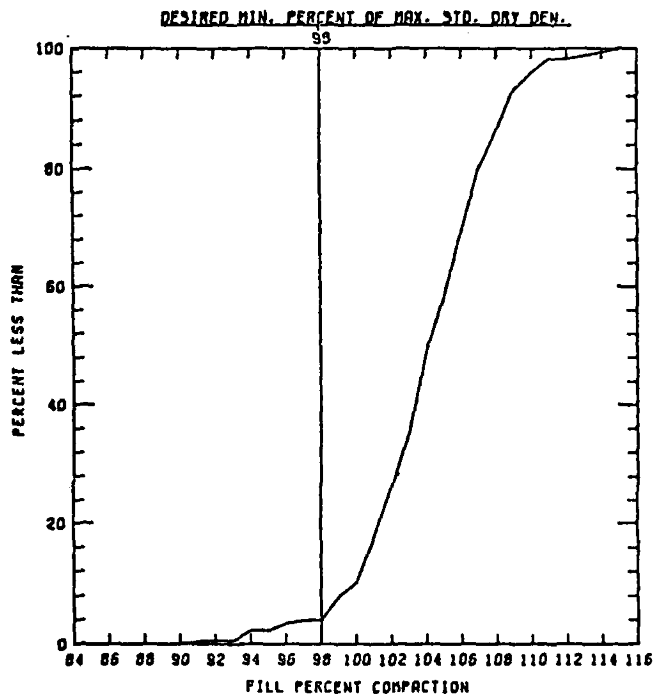
PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE S.D. DEV. (σ)		
BELOW	WITHIN	ABOVE
12.00	73.71	14.29

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

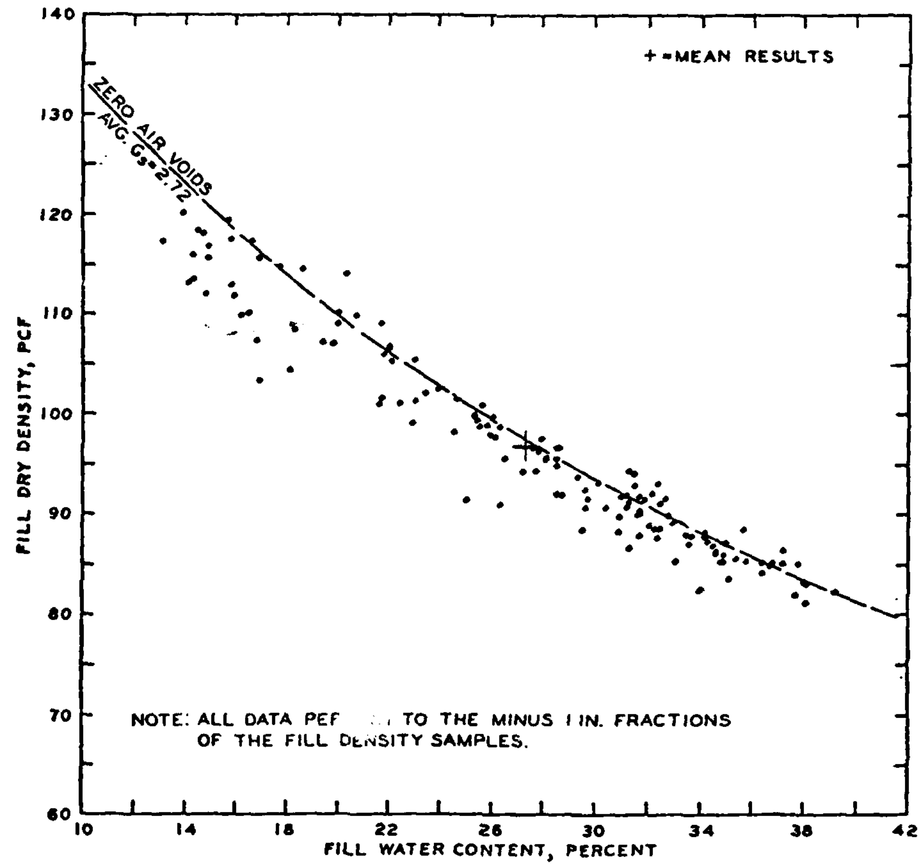
σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION	
BELOW	ABOVE
4.00	96.00

VARIATION OF PERCENT COMPACTION, CORE OF THE DIKE (FIRST SPECIFICATION)

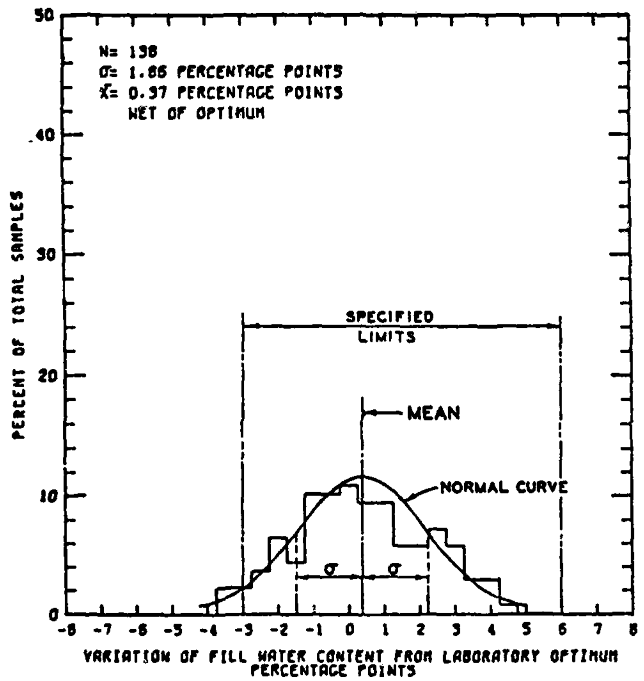


NUMBER OF TESTS = 138
MEAN FILL DENSITY = 96.9 PCF
MEAN FILL WATER CONTENT = 27.3 PERCENT

FIELD DRY DENSITY VERSUS FILL WATER CONTENT, CORE OF THE DIKE (SECOND SPECIFICATION)

PLATE 13

PLATE 14



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

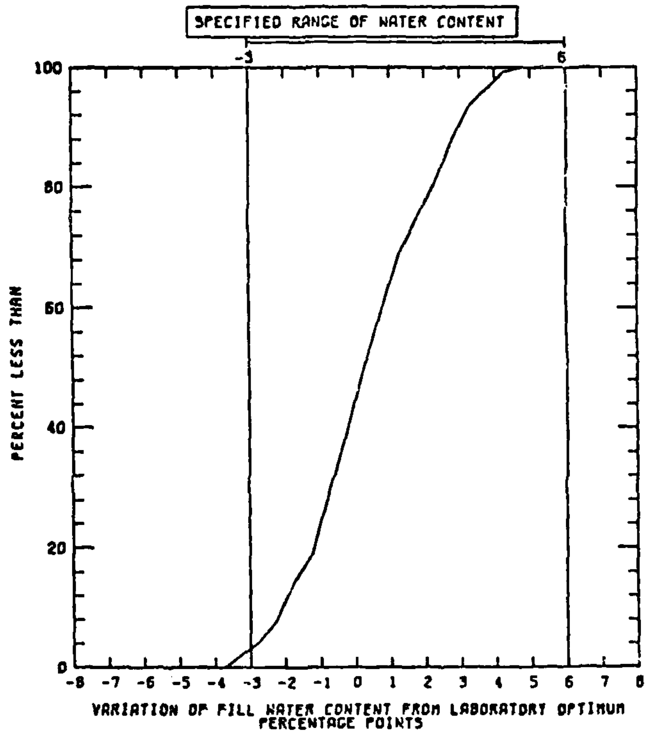
BELOW	WITHIN	ABOVE
17.39	63.04	19.57

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

$\bar{X}$ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS

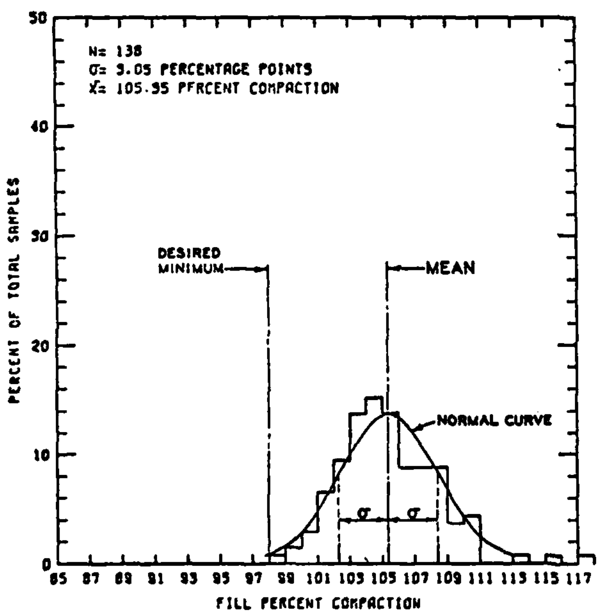
BELOW	WITHIN	ABOVE
2.90	97.10	0.00

VARIATION OF FILL WATER CONTENT, CORE FILL OF THE DIKE (SECOND SPECIFICATION)

AD-A117 835 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/13
ANALYSIS OF FIELD COMPACTION DATA, DEGRAY DAM, CADDO RIVER, ARK--ETC(U)
MAR 82 W E STROHM, V H TORREY
UNCLASSIFIED WES/MP/GL-82-4 NL

2 of 2

END
DATE FILMED
8 82
DTIC

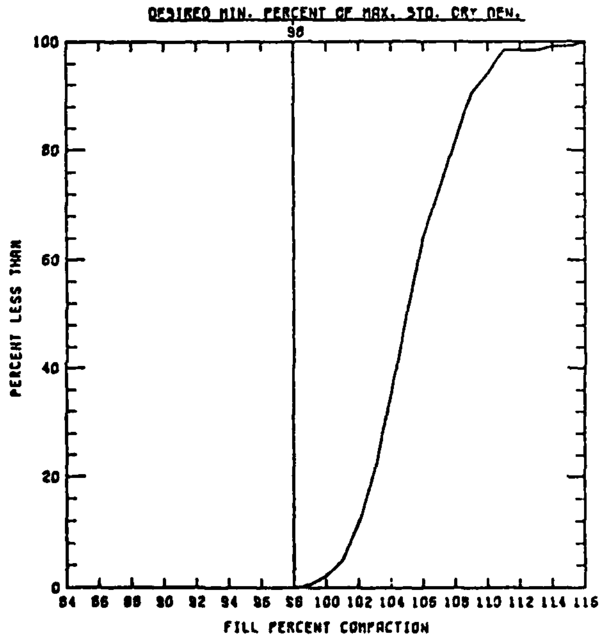


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

BELOW	WITHIN	ABOVE
12.32	71.74	15.94

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

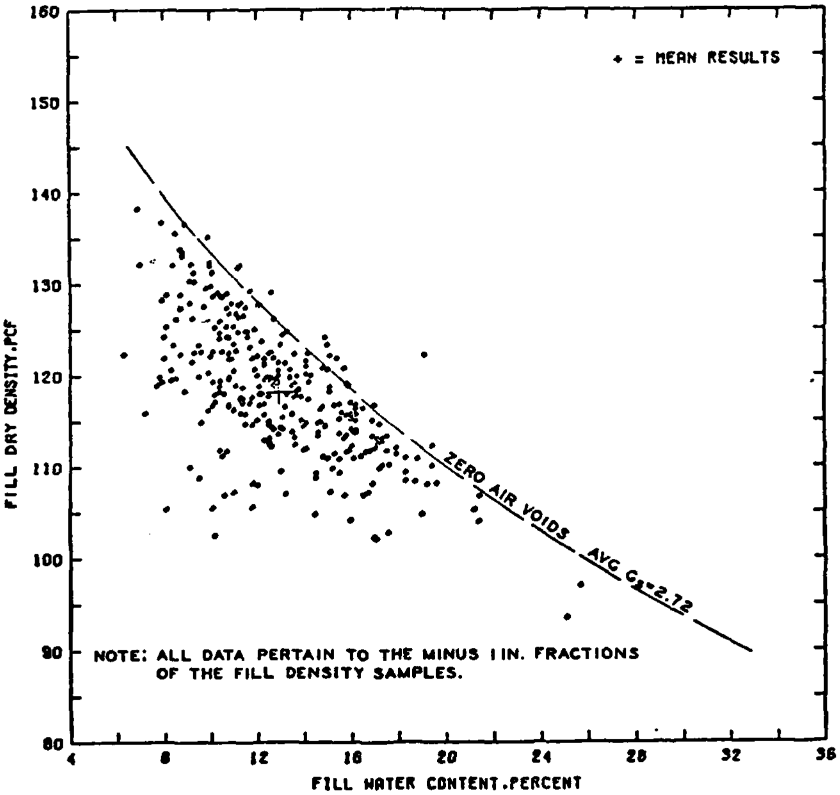
- N = Number of tests
- σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum
- X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION

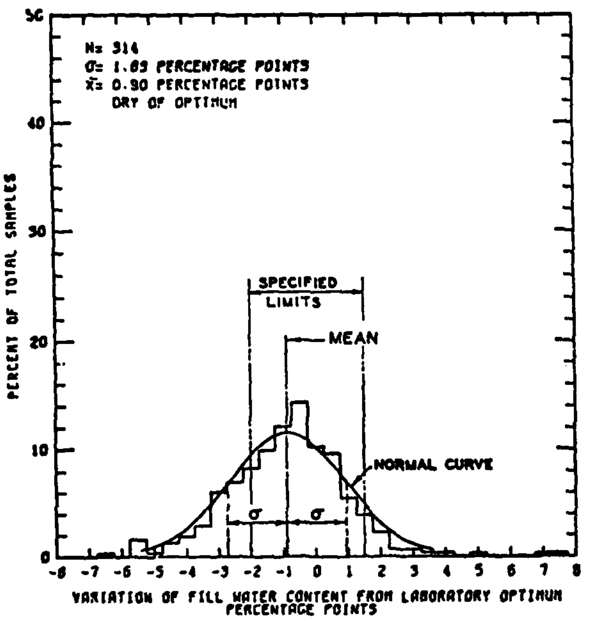
BELOW	ABOVE
0.00	100.00

VARIATION OF PERCENT COMPACTION, CORE FILL OF THE DIKE (SECOND SPECIFICATION)



NUMBER OF TESTS = 314
MEAN FILL DENSITY = 118.2 PCF
MEAN FILL WATER CONTENT = 12.9 PERCENT

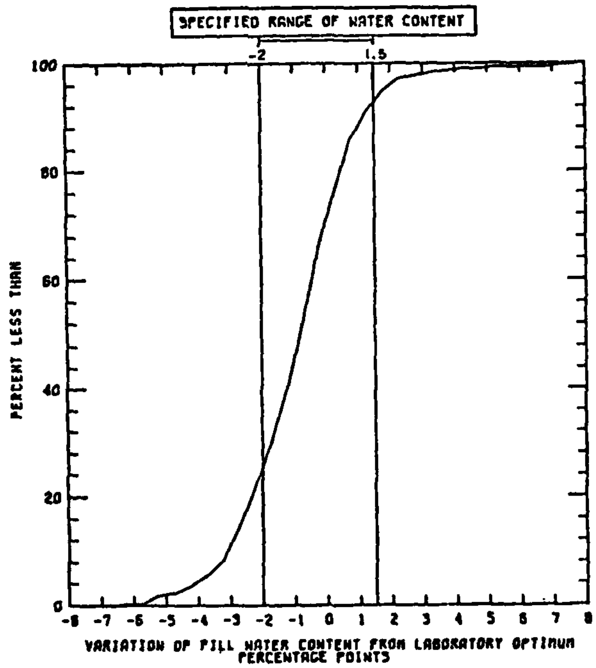
FIELD DRY DENSITY VERSUS FILL WATER CONTENT, LANDSIDE SHELL OF THE DIKE



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

BELOW	WITHIN	ABOVE
14.33	74.52	11.15

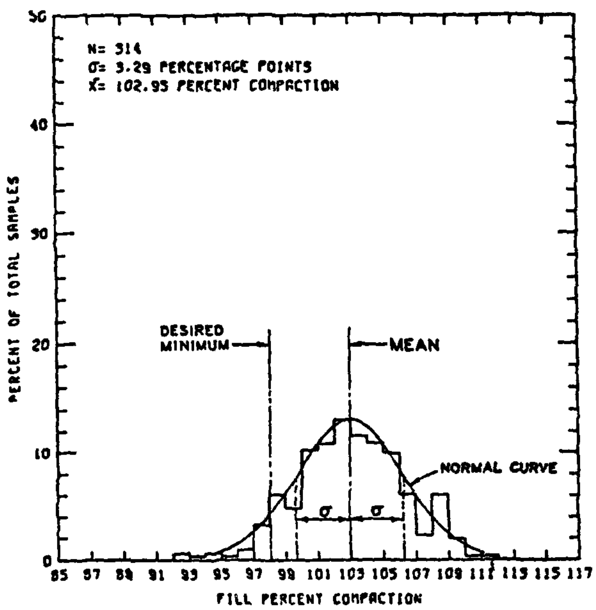
NOTE: All data pertain to the minus 1-in. fractions of the fill density samples.
- N = Number of tests
- σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum
- $\bar{X}$ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
24.52	69.43	6.05

VARIATION OF FILL WATER CONTENT, LANDSIDE SHELL OF THE DIKE



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

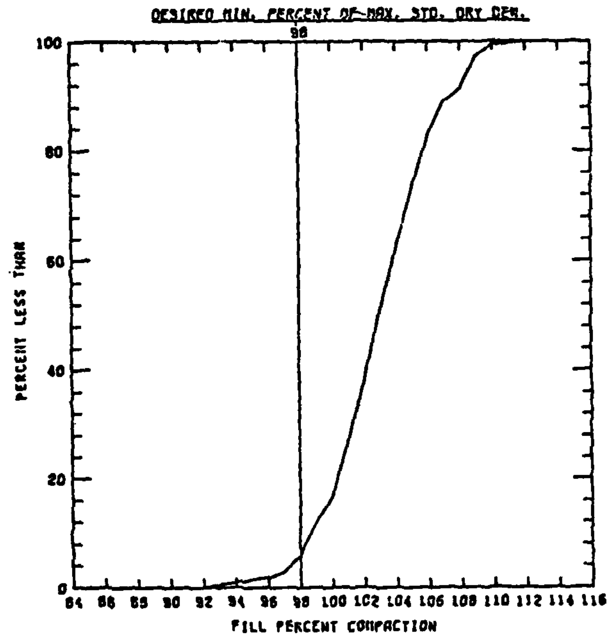
BELOW	WITHIN	ABOVE
14.65	69.43	15.92

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

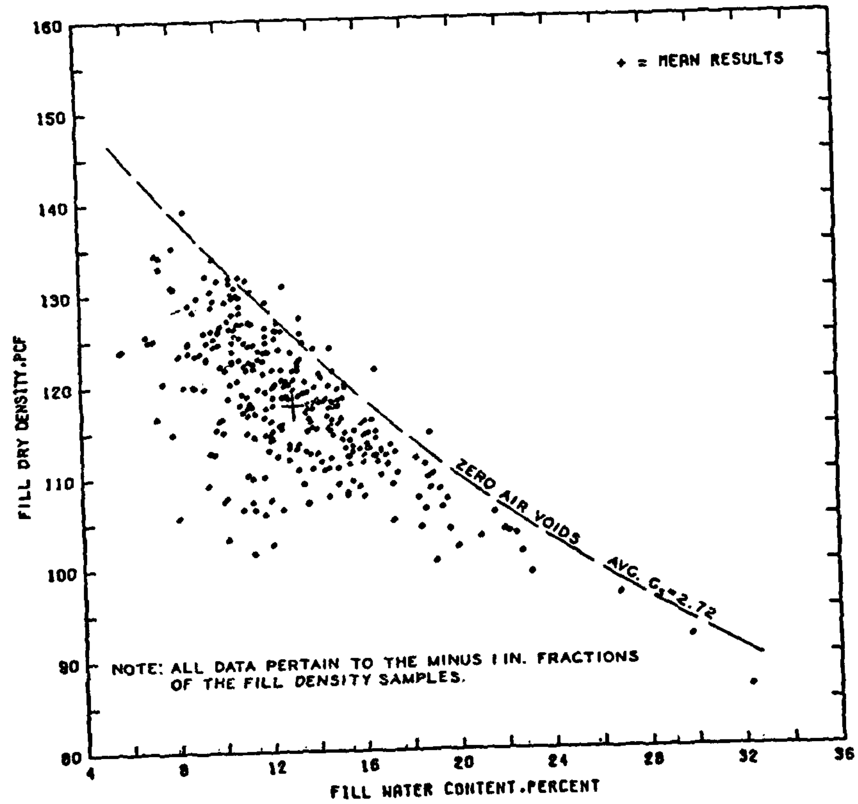
$\bar{X}$ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION

BELOW	ABOVE
6.05	93.95

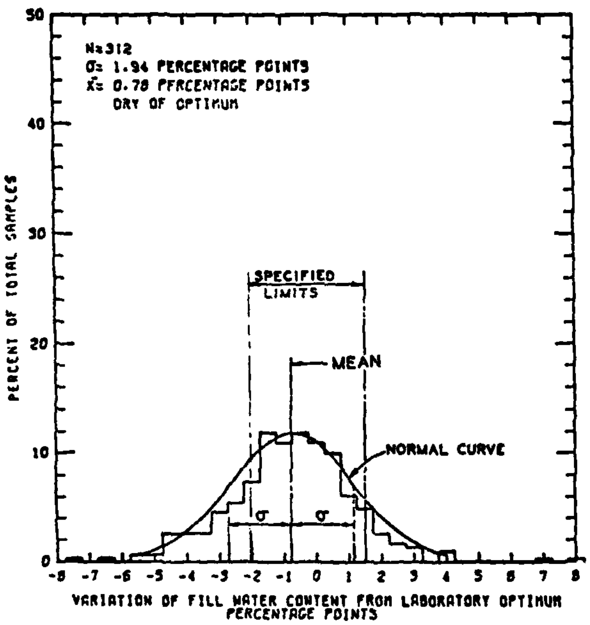
VARIATION OF PERCENT COMPACTION, LANDSIDE SHELL OF THE DIKE



NUMBER OF TESTS = 312
MEAN FILL DENSITY = 117.8 PCF
MEAN FILL WATER CONTENT = 13.0 PERCENT

FIELD DRY DENSITY VERSUS FILL WATER CONTENT, LAKESIDE SHELL OF THE DIKE

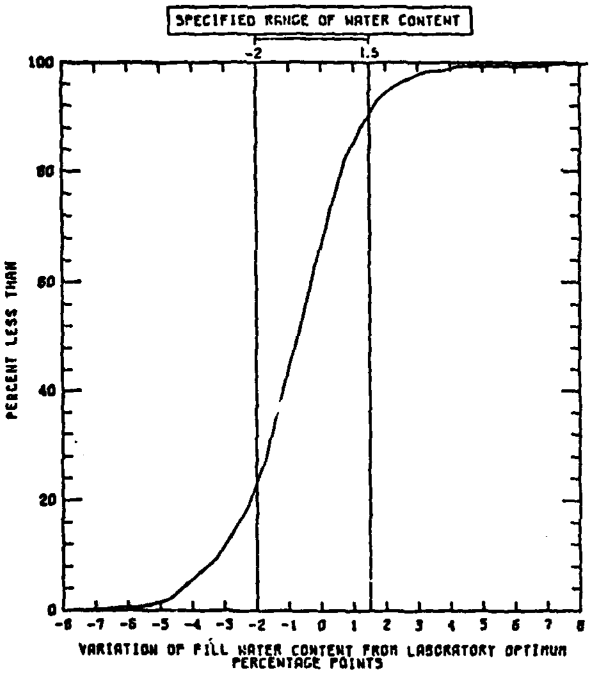
PLATE 19



PERCENT OF TOTAL SAMPLES WITH
RESPECT TO ONE STD. DEV. (σ)

BELOW	WITHIN	ABOVE
14.10	73.40	12.50

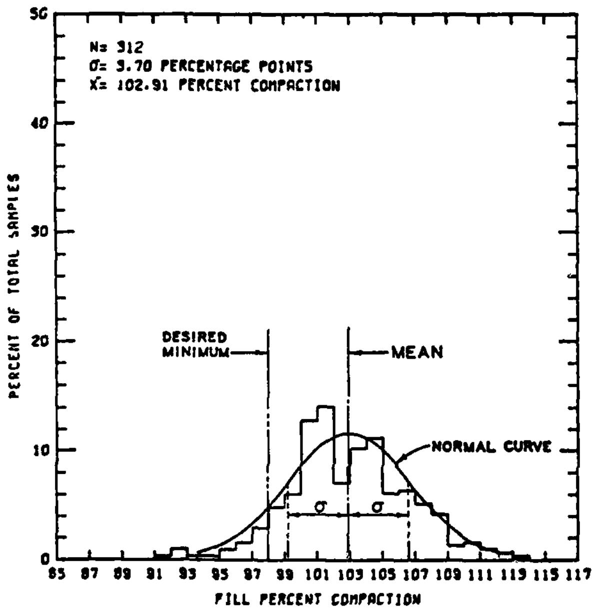
NOTE: All data pertain to the minus 1-in. fractions of the fill density samples
N = Number of tests
σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum
X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH
RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
22.12	69.23	8.65

VARIATION OF FILL WATER CONTENT, LAKESIDE SHELL OF THE DIKE



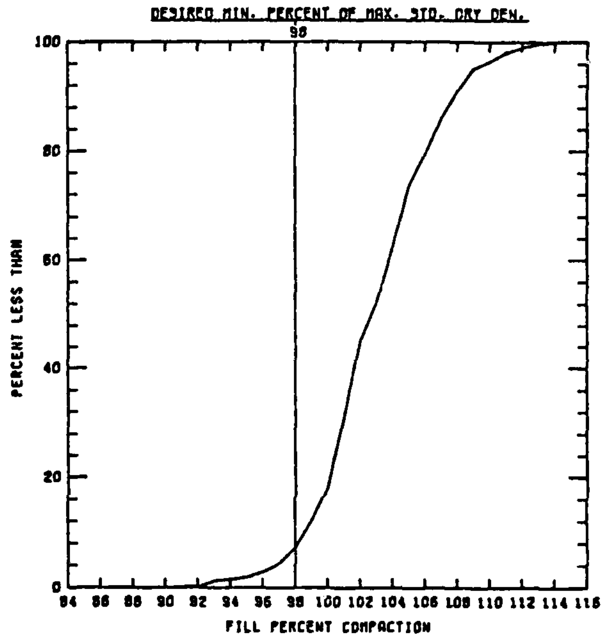
PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
13.78	68.91	17.31

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

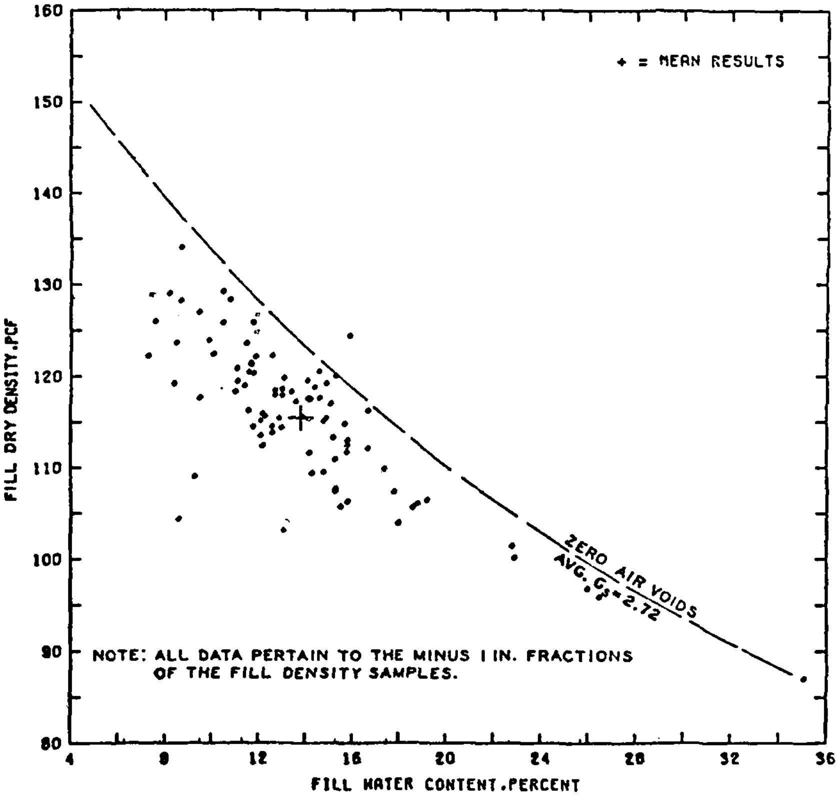
$\bar{X}$ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION	
BELOW	ABOVE
7.37	92.63

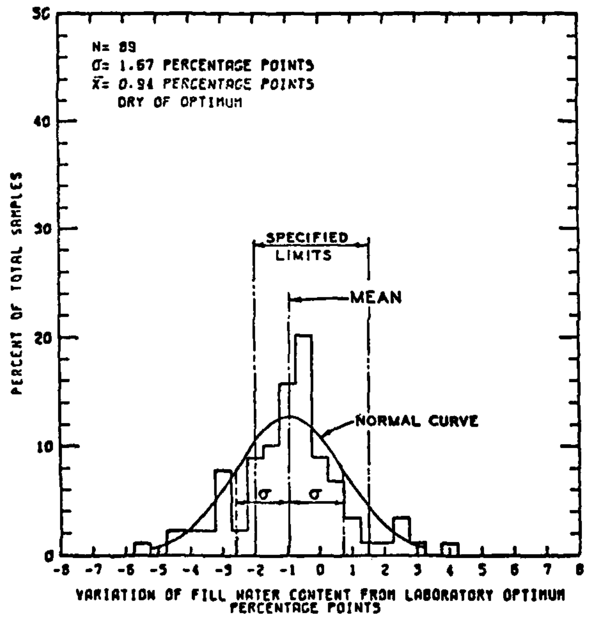
VARIATION OF PERCENT COMPACTION, LAKESIDE SHELL OF THE DIKE

PLATE 21



NUMBER OF TESTS = 89
MEAN FILL DENSITY = 115.5 PCF
MEAN FILL WATER CONTENT = 13.8 PERCENT

FIELD DRY DENSITY
VERSUS FILL WATER
CONTENT, UNZONED
SECTIONS OF THE DIKE



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

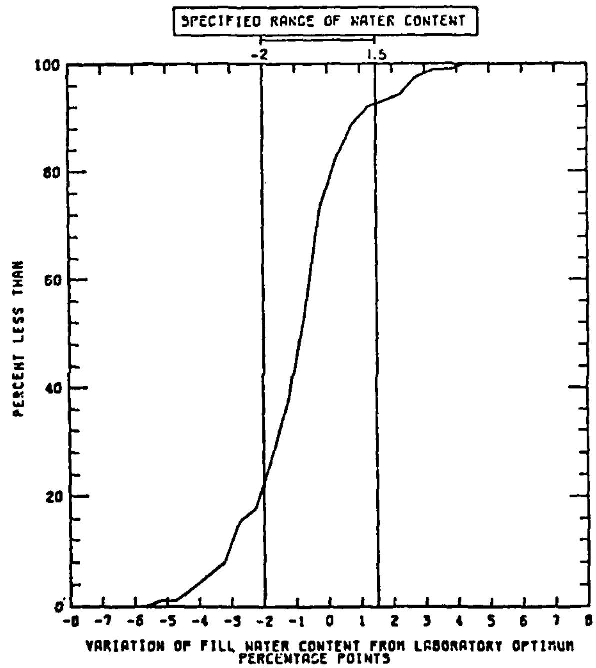
BELOW	WITHIN	ABOVE
16.85	71.91	11.24

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points

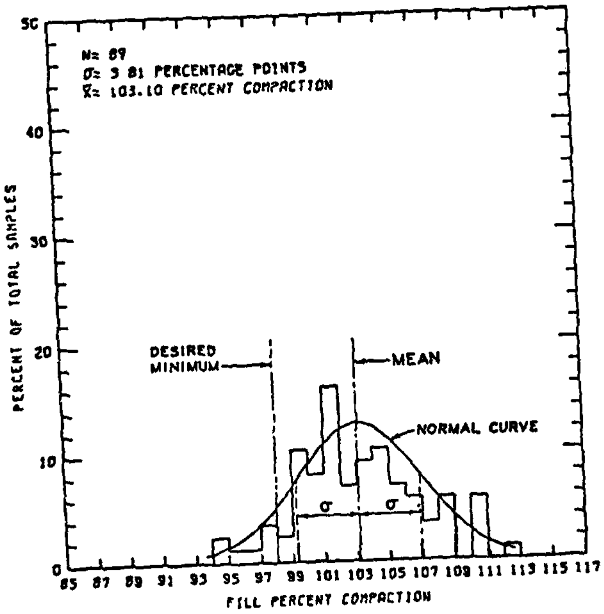


PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
20.22	71.91	7.87

VARIATION OF FILL WATER CONTENT, UNZONED FILL OF THE DIKE

PLATE 24



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)

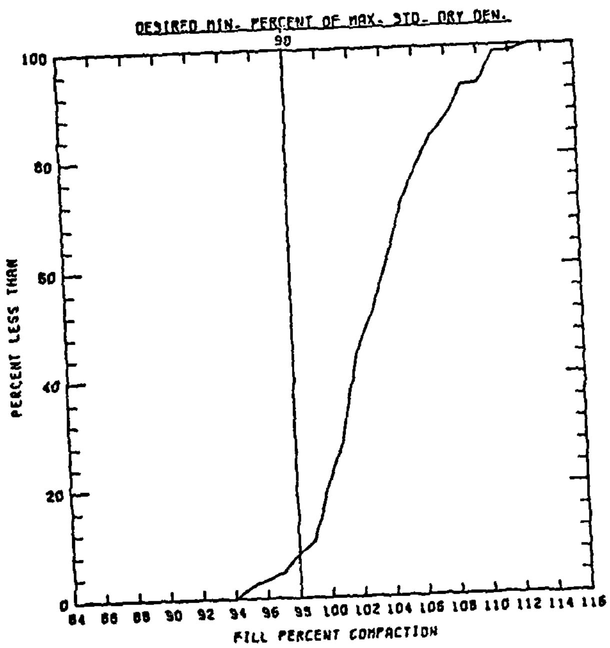
BELOW	WITHIN	ABOVE
15.73	66.29	17.98

NOTE: All data pertain to the minus 1-in. fractions of the fill density samples

N = Number of tests

σ = One standard deviation expressed in percentage points relative to the mean variation of fill water content from laboratory optimum

X̄ = Mean variation of fill water content from laboratory optimum expressed in percentage points



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION

BELOW	ABOVE
8.99	91.01

VARIATION OF PERCENT COMPACTION, UNZONED FILL OF THE DIKE

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Strohm, William E.
Analysis of field compaction data, DeGray Dam, Caddo River, Arkansas / by William E. Strohm, Jr., Victor H. Torrey III (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1982.
71, [6] p., 24 p. of plates : ill. ; 27 cm. -- (Miscellaneous paper ; GL-82-4)
Cover title.
"March 1982."
Final report.
"Prepared for Office, Chief of Engineers, U.S. Army under CWIS 31173 and CWIS 31209."
Bibliography: p. 72.

1. Caddo Lake (Ark.) 2. DeGray Dam (Ark.) 3. Earth dams. 4. Embankments. 5. Soil stabilization. I. Torrey, Victor H. II. United States. Army. Corps of Engineers.

Strohm, William E.
Analysis of field compaction data, DeGray Dam : ... 1982.
(Card 2)

Office of the Chief of Engineers. III. U.S. Army Engineer Waterways Experiment Station. Geotechnical Laboratory. IV. Title V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; GL-82-4.
TA7.W34m no.GL-82-4

END
DATE
FILMED
8-82
DTIC