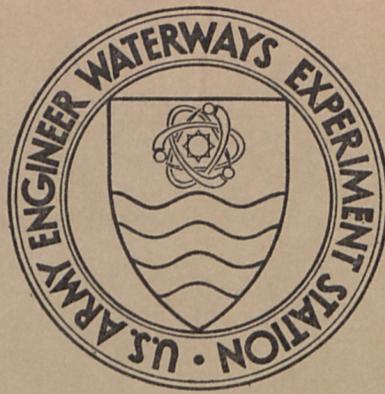


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ANALYSIS OF FIELD COMPACTION DATA

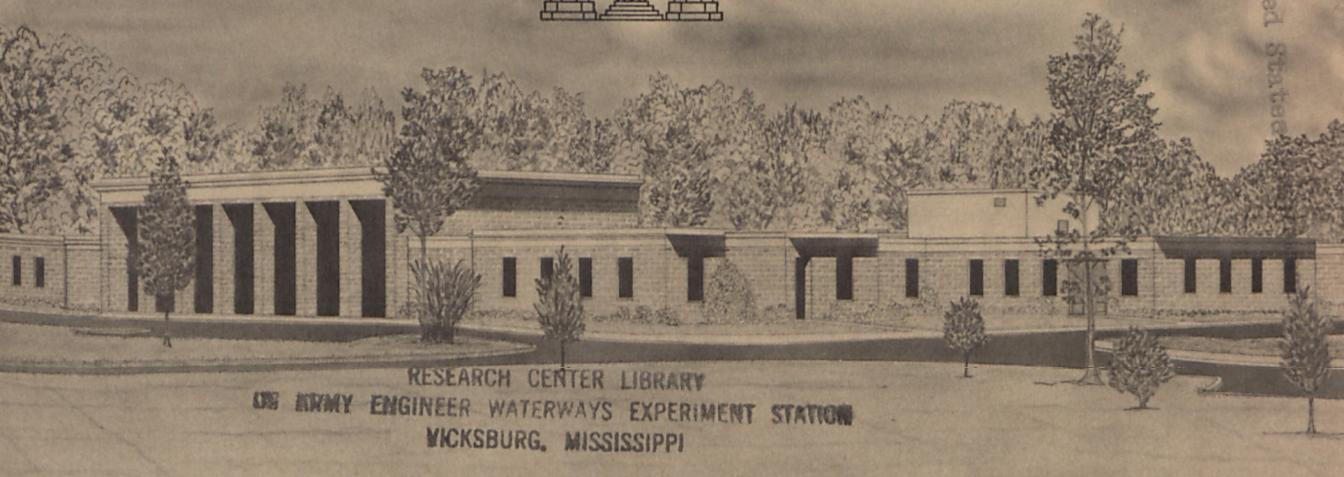
Report 2

LITTLEVILLE DAM, WESTFIELD RIVER, MASSACHUSETTS

by

V. H. Torrey III

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FOREWORD

The study reported herein was authorized by letter from the Office, Chief of Engineers (ENGCW), dated 7 December 1967, subject: Summaries of Field Compaction Control Data on Earth and Rockfill Dams. The study was accomplished under ES 537, "Special Studies Group for Civil Works Soils Problems." This is the second in a series of interim reports on the analysis of field compaction control data from completed dams. A final report will incorporate the significant results of the interim reports.

This investigation was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) under the general direction of Messrs. W. J. Turnbull, J. P. Sale, A. A. Maxwell, and J. R. Compton. Principal engineers conducting the investigation and analyzing results were Messrs. W. E. Strohm, Jr., and V. H. Torrey, III. This report was prepared by Mr. Torrey.

Directors of the WES during preparation and publication of this report were COL John R. Oswalt, Jr., CE, COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimeters
feet	0.3048	meters
miles	1.609344	kilometers
square inches	6.4516	square centimeters
cubic yards	0.764555	cubic meters
pounds	0.4535924	kilograms
tons (2000 lb)	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter

SUMMARY

This report is a review of the materials, specifications, procedures, equipment, and testing pertinent to construction and compaction control of the earth-fill embankment of Littleville Dam, Westfield River, Mass., constructed by the U. S. Army Engineer Division, New England. This report includes summation and analyses of the compaction control data submitted by the division to the U. S. Army Engineer Waterways Experiment Station.

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, 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.

ANALYSIS OF FIELD COMPACTION DATA

Report 2

LITTLEVILLE DAM, WESTFIELD RIVER, MASSACHUSETTS

PART I: INTRODUCTION

Background

1. This report is the second (see reference 1 for Report 1) of a series of interim reports being prepared on statistical analyses of field compaction control data obtained from Corps of Engineers' (CE) earth- and rock-fill dams. Data on several representative dams are being analyzed to determine variations in field compaction results. The study is being accomplished under Engineering Study (ES) 537, Special Studies Group for Civil Works Soils Problems. As part of this effort, statistical analyses are being made of the variation of fill water content and fill percent compaction of several dams recently completed. In addition, correlations are being established between optimum water content, maximum dry density, and Atterberg limits. A final report will be prepared to summarize analyses of data and conclusions presented in the reports of individual projects.

Purpose and Scope

2. The overall objectives of the study are to improve (a) design procedures, (b) specifications and control requirements, and (c) field construction control. Statistical analyses have been made of the field compaction control data for Littleville Dam, constructed by the New England Division (NED). The embankment materials, the compaction control methods, the procedures used in analyses of field data, and the results obtained are discussed in the following paragraphs.

PART II: CONSTRUCTION OF THE DAM

Description of the Site and Structure

Plan and location

3. The general plan of Littleville Dam is shown in fig. 1. The structure is located on the Middle Branch of the Westfield River within the counties of Hampden and Hampshire in western Massachusetts, at the westerly side of the Connecticut River basin. The damsite is about 1 mile* north of the confluence of the Middle Branch and Westfield River and about 2.7 miles north of the town of Huntington, Mass. The project consists of an earth-fill embankment with a maximum height of 164 ft above the stream-bed, a water supply outlet works along the left riverbank, an uncontrolled service spillway and an associated controlled outlet works in the left abutment, and an earth-fill dike with a maximum height of 46 ft located in the left abutment saddle approximately 500 ft beyond the spillway. Construction of the Littleville Dam project was initiated in April 1963 and completed in November 1964.

Geology^{2,3}

4. The Westfield River flows in a deep, preglacial valley in the New England upland section of western Massachusetts. It is a maturely dissected region of moderate relief which has been modified by glaciation. The bedrock hills and ridges are generally blanketed by a thin cover of glacial till consisting of unsorted materials deposited directly from the glacier and ranging in gradation from clay to boulders. The bottom of most of the main valley has been deeply filled by deposits of till and outwash. The outwash deposits, which consist of variable, roughly stratified sands, silt, and gravel, form narrow floodplains along the valley bottoms and terraces on the valley walls. Bedrock outcrops commonly through the thin till cover on the upper slopes and tops the

* A table of factors for converting British units of measurement to metric units is presented on page vii.

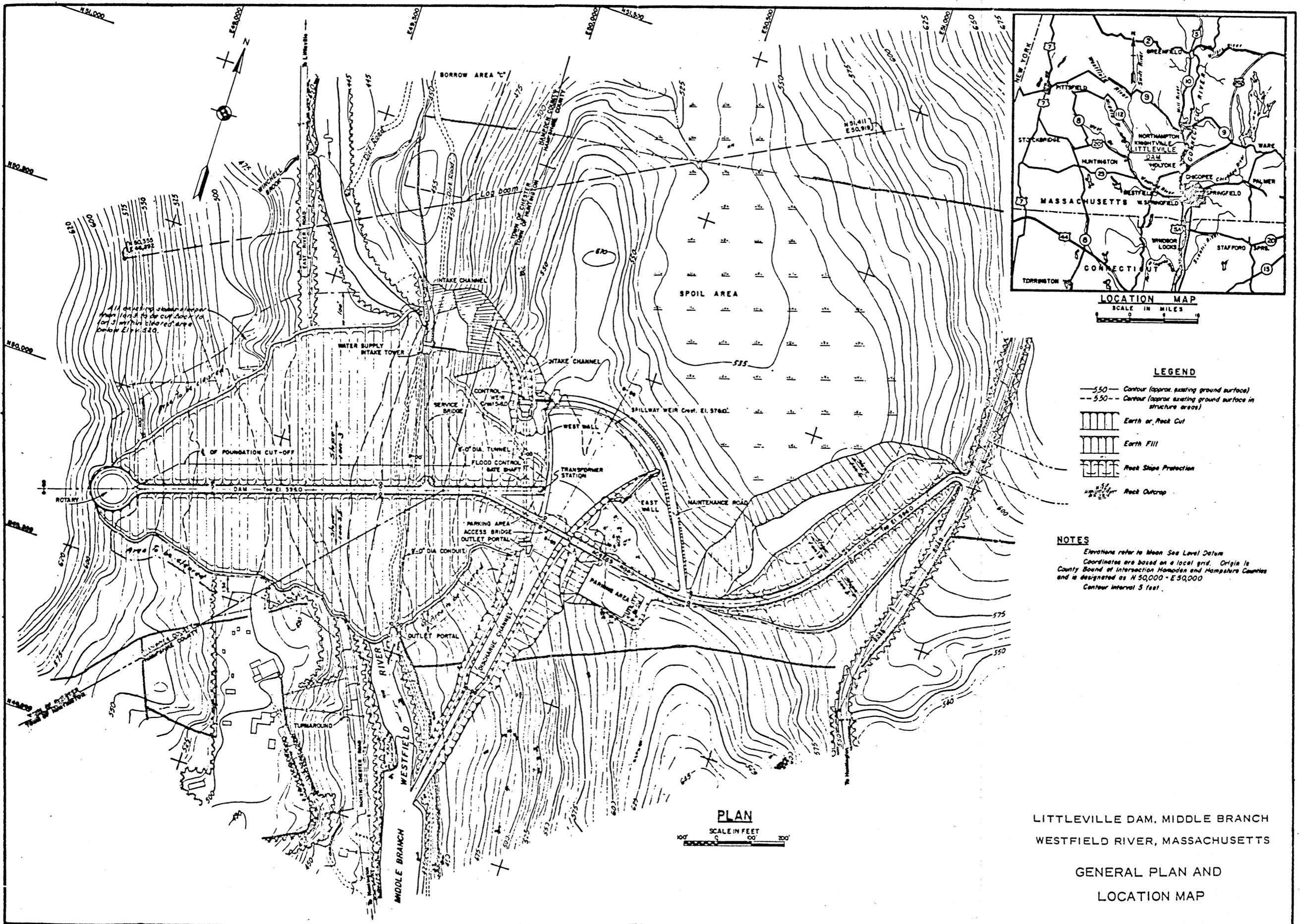


Fig. 1. General plan

hills. In the valleys, the bedrock is exposed only where the rivers have cut through the till and outwash to expose rock spurs on the sides of the valleys. The bedrock of the region consists of a series of folded Paleozoic crystalline rocks, mostly schist, of several formations.

Construction

Embankment

5. A typical embankment section of Littleville Dam is shown in fig. 2. The embankment is an earth-fill structure, approximately 1360 ft long and with a maximum height above streambed of 164 ft. It is essentially a homogeneous impervious fill section (incorporating an upstream cofferdam), except for a small random zone within the central portion, an inclined internal drain with a three-layer horizontal drainage blanket in the downstream portion of the impervious fill, and a small downstream rock-fill toe. Gravel bedding was placed beneath the riprap slope protection.

Dike

6. A typical section of the dike for Littleville Dam is shown in fig. 3. The dike is an earth-fill structure, approximately 935 ft long, with a maximum height of 46 ft. The section consists of an upstream impervious blanket, and a downstream random fill zone serving as a pervious zone. A foundation trench backfilled with pervious material was constructed beneath the downstream zone. A gravel bedding was provided beneath the rock slope protection.

Borrow sources

7. The borrow sources and pertinent specifications for the major embankment materials for the dam and dike were as follows:

- a. Impervious fill. Impervious fill material was placed in two areas of the dam and dike: the central impervious zones of the dam and dike and the impervious backfill areas of the dam (placed adjacent to bedrock surfaces and around concrete structures). In the subsurface investigations for this

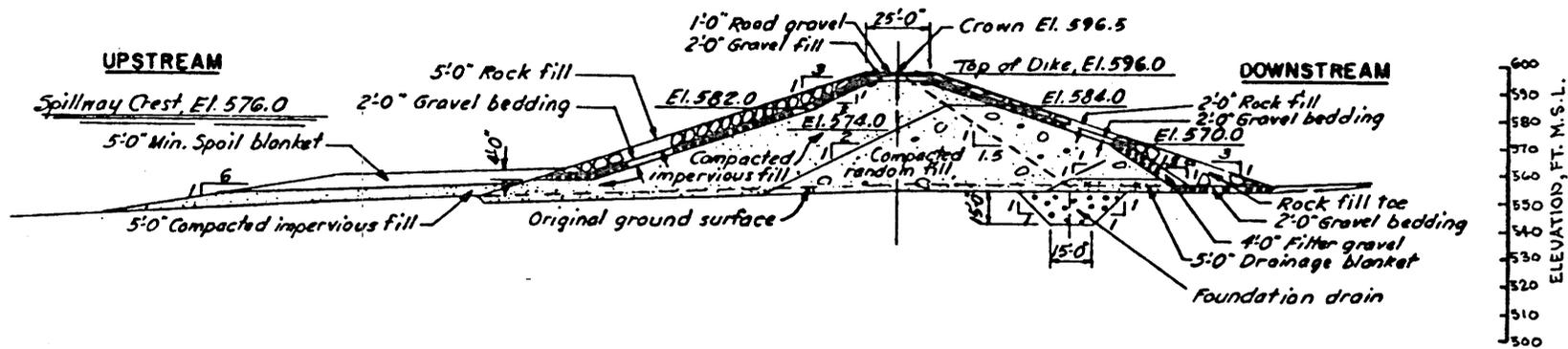


Fig. 3. Typical dike section

project, a large deposit of glacial till was located on the top and east slope of the ridge forming the left abutment for the dike. This location, designated borrow area "B" as shown in fig. 4, was the specified source of all impervious fill material. The overburden in area B consisted of glacial till of relatively uniform character, except for occasional surficial layers, 4 to 9 ft thick, of slightly coarser material. The soils in this area consisted principally of gravelly silty sand (SM and SM-SC) and gravelly sandy silt (ML and ML-CL) with occasional gravel phases (GM). Gravel contents varied, but were generally less than 25 percent; silt contents ranged from 40 to 60 percent of the fraction passing the No. 4 sieve, except in the surficial zones where they were as low as 30 percent. Soils in the southern half of area B had generally higher silt contents than in the northern half and included several slightly plastic soils having liquid limits of from 19 to 24 and plasticity indexes from 1 to 7. Natural densities throughout the deposit were relatively high, ranging from moderately compact to very compact except in the zone of frost action. Natural water contents of the minus No. 4 fractions of samples from the borings in the area were 1 to 3 percentage points above optimum water content. The deposit contained numerous cobbles and occasional boulders. Specifications for the impervious fill zones required the removal of all stones that exceeded two-thirds the loose-lift thickness (8 in.) used during placement on the fill. All stones exceeding a 3-in. diam were removed from the impervious backfill material.

- b. Random fill. Random fill was taken from required excavations, including the foundation cutoff trench for the dam, the foundation drain trenches for the dam and the dike, the excavation to bedrock on the left abutment of the dam for the water supply conduit, and the excavation of the spillway channel. Since the bulk of these excavated materials became available at the same time that the embankments were being constructed, economical considerations required that as much of the excavated materials as practicable be used in the permanent work. Because a relatively wide range of soil types would be obtained from these excavations, provisions were made to include random fill zones in the embankment sections of the dam and dike to utilize those soils. The random fill included (1) material having enough plasticity to exhibit well defined water content versus compacted unit weight relationships and (2) more granular material for which the Providence vibratory density test was applicable. For the first type of material,

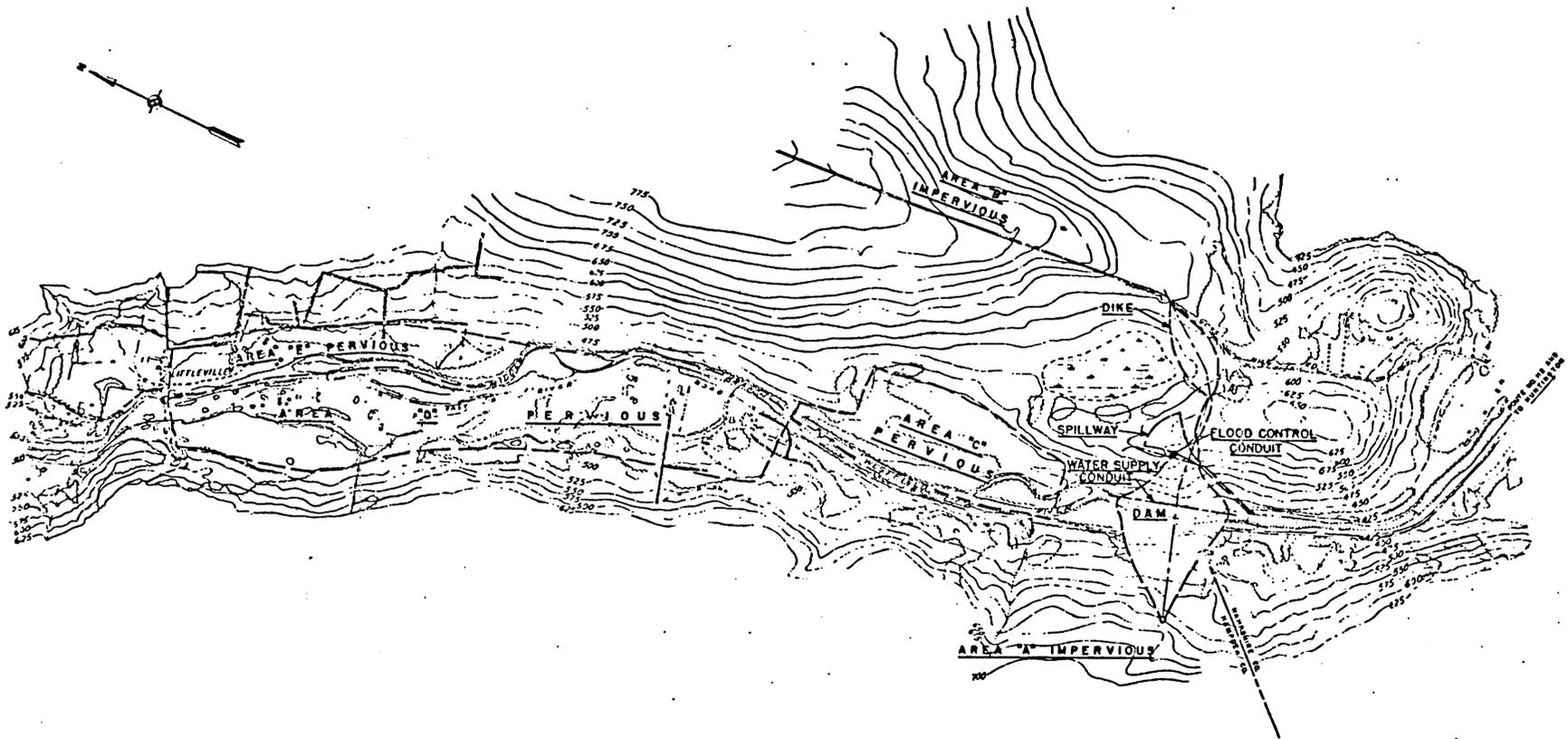


Fig. 4. Location of the borrow areas, Littleville Dam

field compaction was compared with standard effort compaction test results; for the second type, field compaction was compared with the Providence vibratory density test results. For the purposes of this report, these materials have been subdivided into Type I random fill for material with a well defined water content-compacted density relationship whose field compaction was therefore compared with standard compaction test results, and Type II random fill for material without a well defined relationship whose field compaction was compared with results of Providence vibratory density tests. These subdivisions for the random material do not represent zonations of the embankment as these materials were placed indiscriminately in the random zones. It was specified that materials from the first-stage cutoff trench excavation in the valley bottom for the dam be placed in the random fill zone of the dike, in order to avoid stockpiling of the excavated material. They consisted principally of silty sandy gravel (GP-GM and GM). The materials from the second stage of the cutoff trench excavation (abutment areas) and the other excavations were much more variable. They included gravelly silty sand (SM); gravelly sandy silt (ML); and outwash materials composed of silty sandy gravel (GP-GM and GM), gravelly silty sand (SP-SM and SM), sandy gravel (GP), and sandy silt (ML). These soils from the second stage cutoff trench excavation and the other excavations were placed in the random fill zone of the dam. All stones exceeding two-thirds the loose-lift thickness in diameter were removed from the Type I random and Type II random materials before compaction.

c. Embankment drainage materials. The borrow sources and specifications for these materials are described below:

(1) Sources. Extensive reconnaissance was made to locate sources of embankment drainage materials for use in the internal inclined drain of the dam embankment, in the foundation drains, and in the drainage blankets. Processed sand fill for the horizontal drainage blanket of the dam was obtained from a commercial source near the damsite. Materials other than processed sand fill were available in borrow areas C, D, and E. These areas were located on low terraces along the river from 1/4 to 1-1/2 miles upstream of the damsite, as shown in fig. 4. The materials within these areas are described below:

(a) Borrow area C. The silt and topsoil blanket in

area C was from 1 to 4 ft thick. Depths to bedrock or glacial till ranged from 12 to 25 ft in general. The materials in this area, beneath the blanket and above the till or bedrock, consisted of roughly stratified, loose to compact, brown sandy gravel (GP), silty sandy gravel (GP-GM), gravelly silty sand (SP-SM), and scattered lenses of sandy silt (ML), with occasional phases of silty sands and gravels in the SM and GM categories. These materials contained numerous cobbles, of which a significant number were highly weathered. In general, gravel contents ranged from 30 to 70 percent and silt contents ranged from 5 to 20 percent of the minus No. 4 fraction. For the bulk of these soils, however, the silt contents were less than 15 percent of the minus No. 4 fraction.

- (b) Borrow area D. The sands and gravels in this area were similar to those in area C. Their distribution, however, was more erratic, and in a considerable portion of the area, the silt and topsoil blanket directly overlay glacial till. For this reason, the development of this area as a Government designated borrow area for gravel bedding and embankment drainage materials was not economically feasible. This area was, however, available as a limited source of contractor furnished material.
- (c) Borrow area E. The silt and topsoil blanket in area E was from 1 to 6 ft thick. Depths to bedrock or glacial till ranged from 4 to 12 ft. The sands and gravels in this area were similar to those in area C except that their gravel contents were generally higher and their silt contents tended to be lower.

(2) Specifications.⁴ The contract specifications governing the nature of the embankment drainage materials were as follows:

- (a) Pervious fill. Materials to be placed in the internal inclined drain of the dam (pervious fill zone) were to consist of bank-run sand and bank-run gravelly sand from borrow areas C and E and from which all over-size stones (see subparagraph (f) below) were to be removed.
- (b) Sand fill. Sand fill material placed in the horizontal drainage blankets and foundation drains of the dam and dike was to meet the requirements for processed sand as specified in subparagraph (c) below or was to

consist of reasonably well-graded bank-run sand or gravelly sand furnished by the contractor from approved sources and from which all oversize stones (see subparagraph (f) below) were to be removed. Bank-run material was to conform to the following requirements:

- (1) Of the fraction passing the 3-in. sieve, between 50 and 95 percent by dry weight of the particles were to pass the No. 10 sieve.
 - (2) Of the fraction passing the No. 4 sieve, between 10 and 50 percent by dry weight of the particles were to pass the No. 40 sieve, not more than 10 percent by dry weight of the particles were to pass the No. 200 sieve, and not more than 3 percent by dry weight of the particles were to have a diameter of less than 0.02 mm.
- (c) Processed sand fill. Processed sand fill placed in the horizontal drainage blanket of the dam was to meet the gradation specifications for fine concrete aggregate as given below:

<u>Sieve Designation</u> <u>U. S. Standard Square Mesh</u>	<u>Percentage</u> <u>by Weight Passing</u>
No. 4	95-100
No. 8	80-90
No. 16	55-75
No. 30	30-60
No. 50	12-30
No. 100	3-10

- (d) Gravel fill. Gravel fill material placed in the drainage blankets of the dam and dike was to consist of reasonably well-graded bank-run sandy gravel or gravelly sand from which all oversize stones (see subparagraph (f) below) were to be removed. Gravel fill material was to conform to the following gradation requirements:
- (1) Of the fraction passing the 3-in. sieve, at least 25 percent and no more than 50 percent by dry weight of the particles were to pass the No. 4 sieve.
 - (2) Of the fraction passing the No. 4 sieve, not more than 10 percent by dry weight of the particles

were to pass the No. 200 sieve or more than 3 percent by dry weight of the particles were to have a diameter of less than 0.02 mm.

- (e) Backfills. Pervious backfill, gravel backfill, and sand backfill materials to be placed in confined spaces and around structures as they occurred in the respective zones of drainage material were to be obtained from the same sources and were to meet all requirements for materials as specified for the corresponding fill.
- (f) Oversize stones. Stones having maximum dimensions greater than two-thirds the thickness of the layer in which any of the foregoing embankment drainage materials were to be placed were to be removed, either at the source or from the fill during spreading.

Field data

8. Field compaction control reports contain results of field density tests made on six soil types in the main embankment and dike sections. These soils were classified visually by field personnel at the time of the field density tests. Subsequent to field classifications, grain-size analyses were performed by the field laboratory on material from selected field density samples. These gradational data and the borrow source descriptions indicate that in actuality, twelve soil types were probably represented in the dam and dike embankments. Table 1 summarizes pertinent data on soil types, yardage, number of tests, compaction procedures, and compaction control procedures for those fill materials included in the compaction control reports. Pervious, gravel, and sand backfill materials are not listed in table 1 since there were no field data available from these areas. The description and source of the fill materials actually used in each zone are given below:

- a. Impervious fill and backfill. Field reports based on visual classification indicate all field density test samples to be gravelly silty sand and silty sand (SM). Laboratory tests made later on record samples indicate that some of these samples were slightly plastic and in the SM-SC class. Typical gradation curves of field density samples are shown in fig. 5.

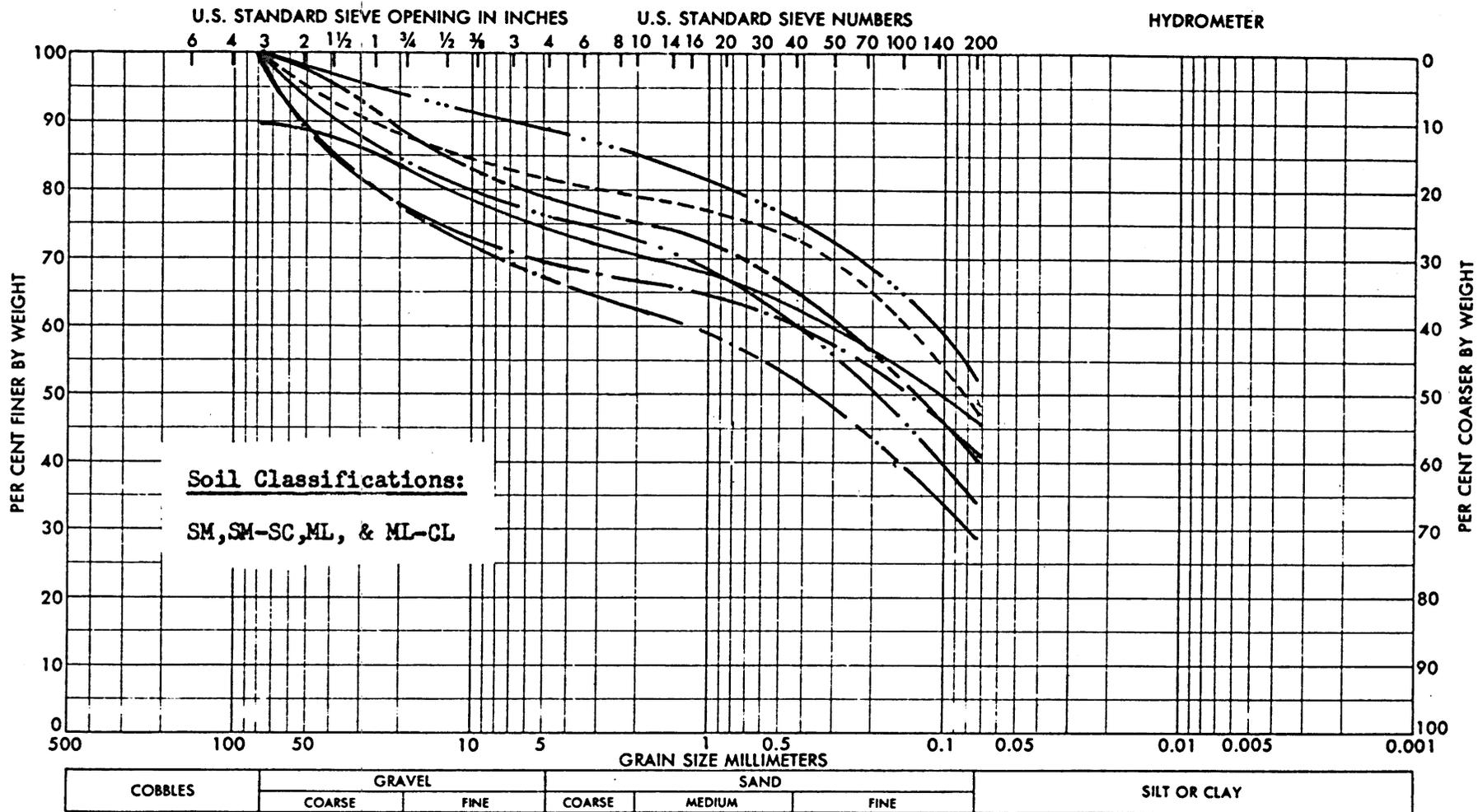


Fig. 5. Gradation curves of impervious fill

One of these curves represents a gravelly sandy silt (ML or ML-CL), a soil type known to occur in the borrow source (see subparagraph 7a). Impervious backfill material was obtained from the same borrow source (Area B) and consisted of the same soil types as the impervious fill material. Typical gradation curves extracted from the field data for impervious backfill material are shown in fig. 6. No distinction was made in the field between materials used in the backfill and those used in the fill.

- b. Random fill. In table 1, random fill materials of the dam and dike have been subdivided into Type I and Type II random fills on the basis of compaction characteristics (see subparagraph 7b). The assignment of a field density test by WES to one of these classes for analytical purposes was made in accordance with the type of field control test reported by NED. Further description of these materials is given below.
- (1) Dam embankment. Random fill material for the dam was taken from the required excavations and from borrow area B as specified. Field compaction control reports classified this fill visually as silty sand (SM). However, the typical gradation curves for the in situ material shown in fig. 7 show gravelly silty sand (SP-SM) as well. While sandy silt (ML), silty sandy gravel (GP-GM and GM), and sandy gravel (GP) were stated to be in the applicable areas of required excavations (see paragraph 7b), none were reported in the field reports.
 - (2) Dike embankment. Random fill for the dike zone came primarily from the first-stage cutoff trench excavation as specified. This material was predominantly gravelly silty sand (SM and SP-SM) as indicated by the typical gradation curves in fig. 8. The description of the applicable areas of required excavations (see paragraph 7b) indicates inclusion of silty sandy gravel (GP-GM and GM), sandy gravel (GP), and gravelly sand (SP) as well. An additional quantity of material was required to complete the dike random zone, since the first-stage cutoff trench excavation failed to yield an adequate volume. The minor amount of supplementary material required was supplied by the contractor from borrow area D (previous borrow) and consisted of sand (SP), gravelly sand (SP), and sandy gravel (GP). No gradation data are available for this additional material.

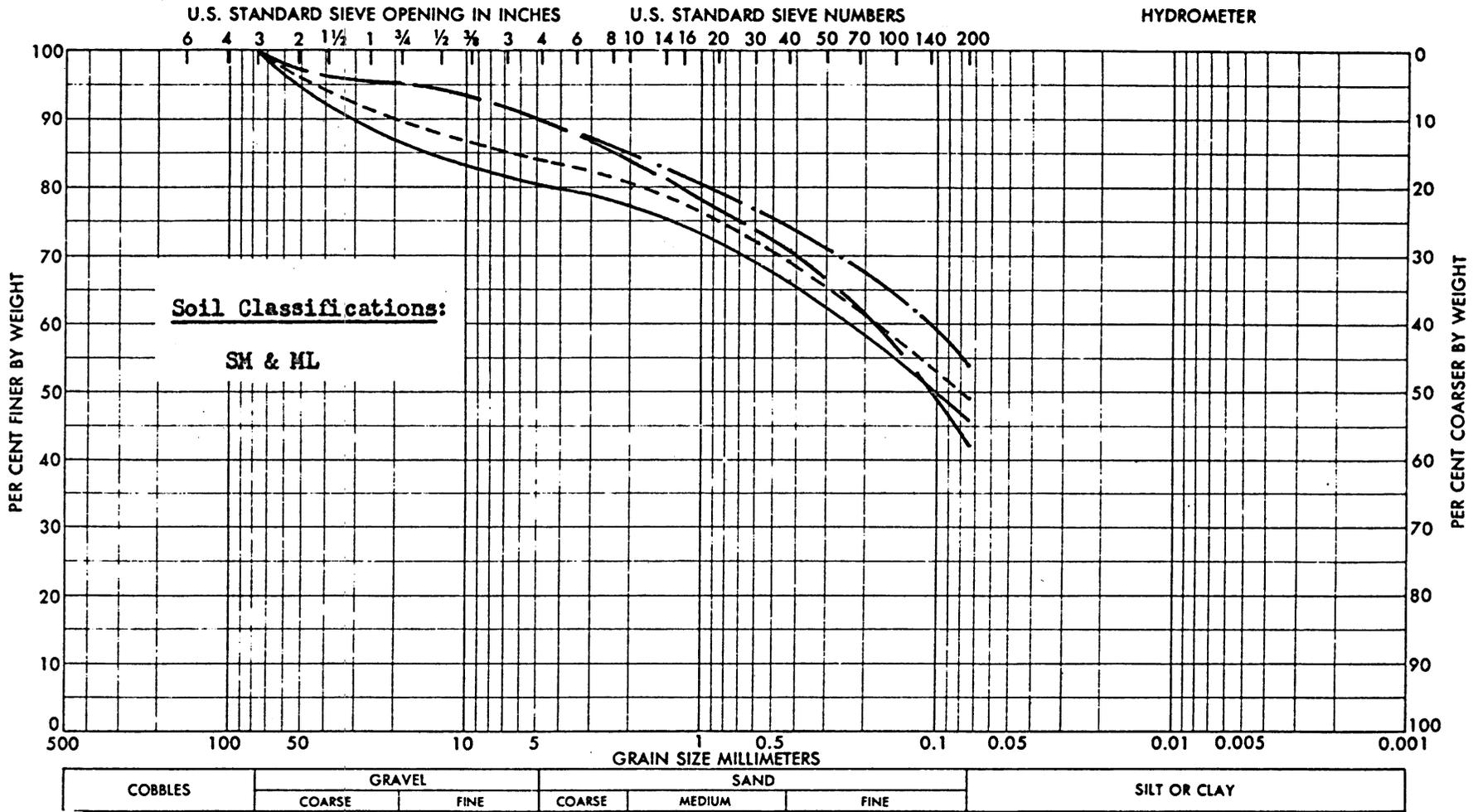


Fig. 6. Gradation curves of impervious backfill

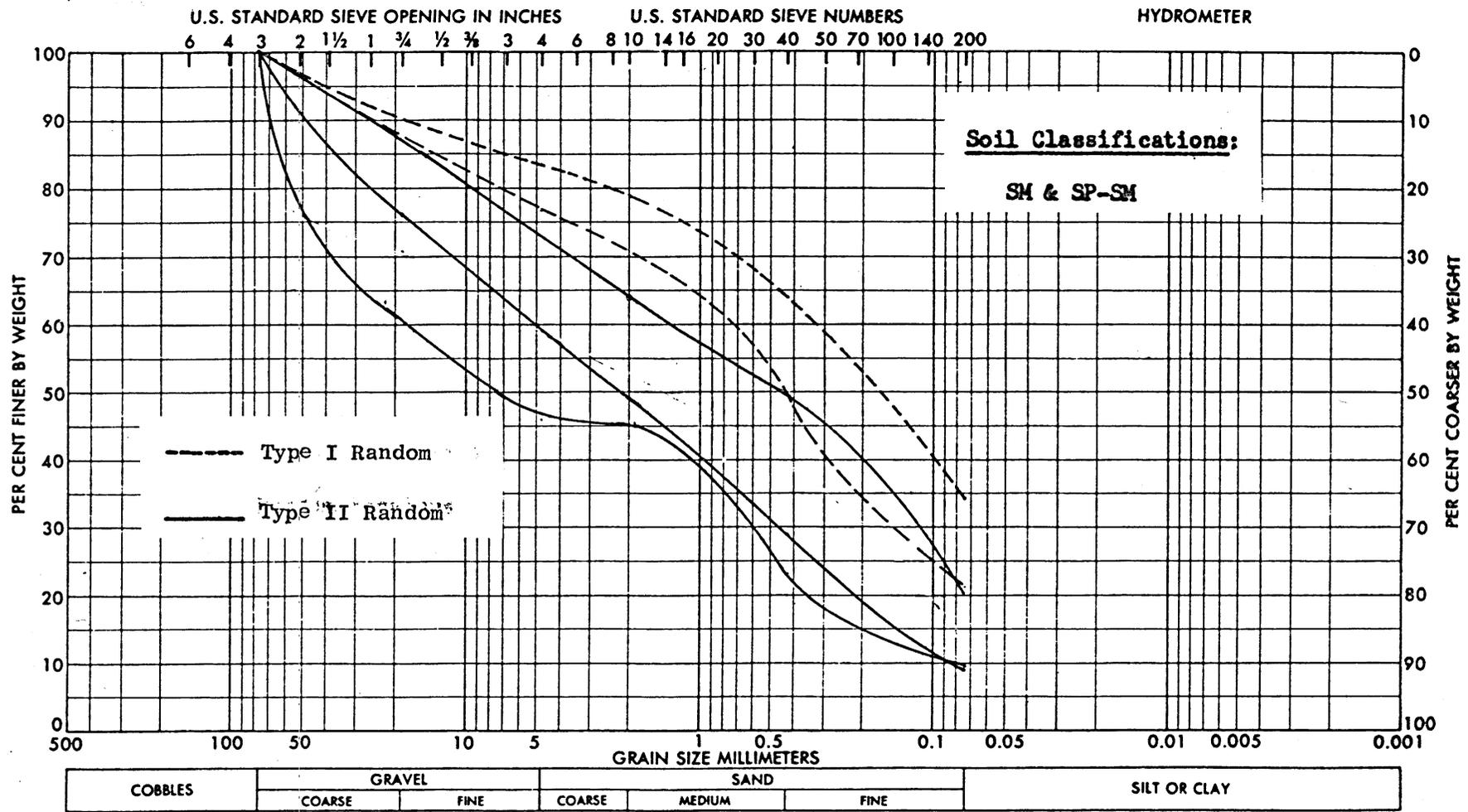


Fig. 7. Gradation curves of random fill in the dam.

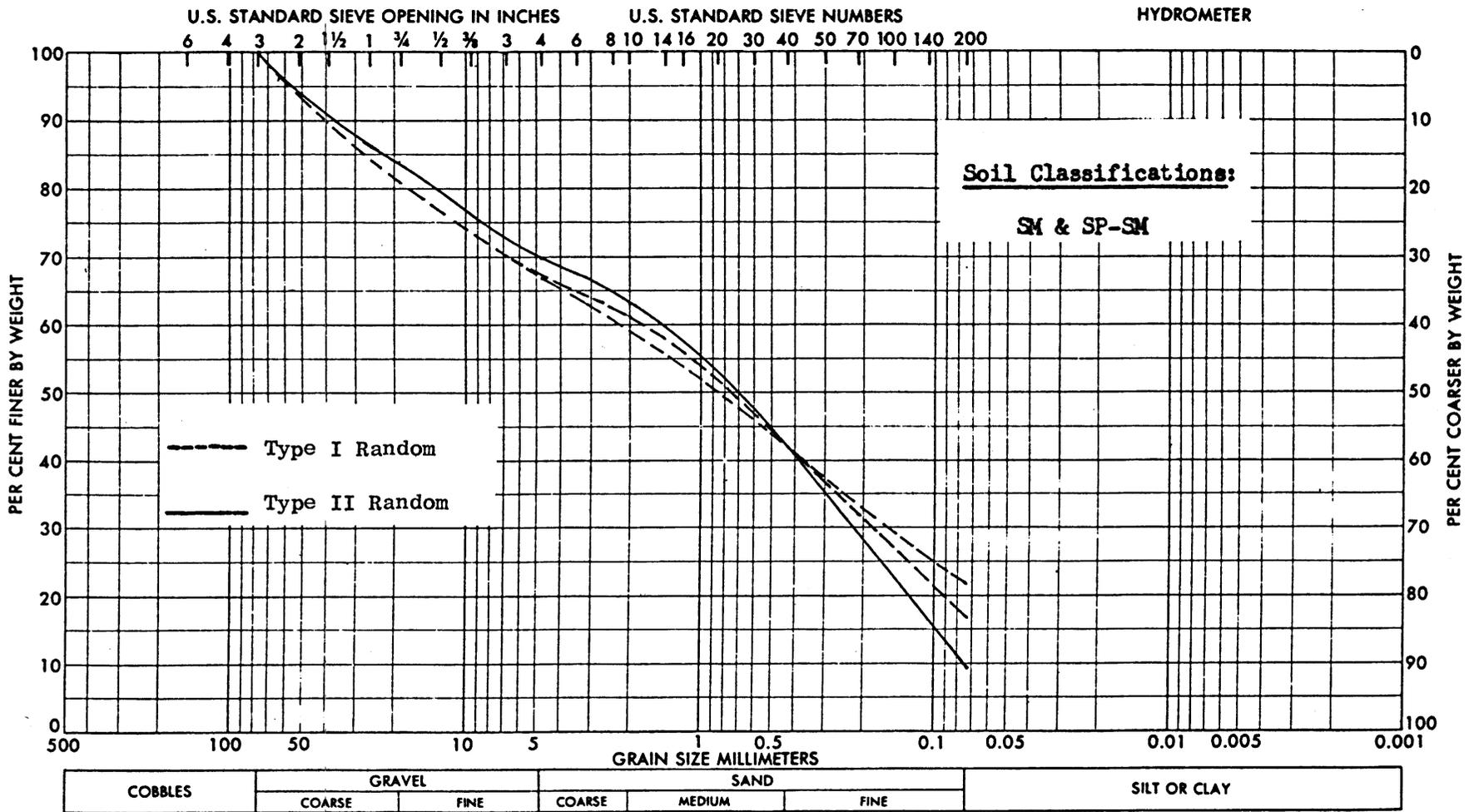


Fig. 8. Gradation curves of random fill in the dike

- c. Pervious fill. The pervious material for use in the inclined drain of the dam embankment was taken from borrow areas C and E (see paragraph 7c). The typical gradation curves in fig. 9 show that the fill included gravelly sand (SP), gravelly silty sand (SP-SM), and sandy gravel (GW and GP).
- d. Gravel fill. Gravel fill materials for use in portions of the foundation drains and drainage blankets were taken from below the water table in borrow area C and from selected areas within an upstream terrace deposit on the right bank of the river. This material consisted of sandy gravel (GP) and bank-run gravelly sand (SP). The typical gradation curves in fig. 10 show that this material met the specifications (see paragraph 7c(2)(b)).
- e. Sand fill. Sand fill material for use in drainage blankets and foundation drains was taken from borrow area C and from selected areas of an upstream terrace deposit on the right bank of the river. The typical gradation curves in fig. 11 classify the material as gravelly sand (SP) and gravelly silty sand (SP-SM), meeting the specifications (see paragraph 7c(2)(c)).
- f. Processed sand fill. The processed sand fill placed in the horizontal drainage blanket of the dam was obtained by the contractor from a commercial source. The typical gradation curves in fig. 12 show this material to classify as sand (SP) meeting the specifications (see paragraph 7c(2)(c)).

Compaction control

9. Compaction requirements and control. Compaction specifications, field compaction procedures, and methods of correlating field density with laboratory density for those materials reported are summarized in table 1. The contract specifications contained required placement water contents and compaction procedures, but did not establish minimum densities. Therefore, the minimum densities stated herein apply to design expectations. The field compaction control criteria and procedures used in constructing Littleville Dam are outlined below:

a. Impervious and Type I random fill

- (1) Control water content of the minus No. 4 fraction of the impervious fill and Type I random fill within ± 2 percentage points of optimum water content. Control the

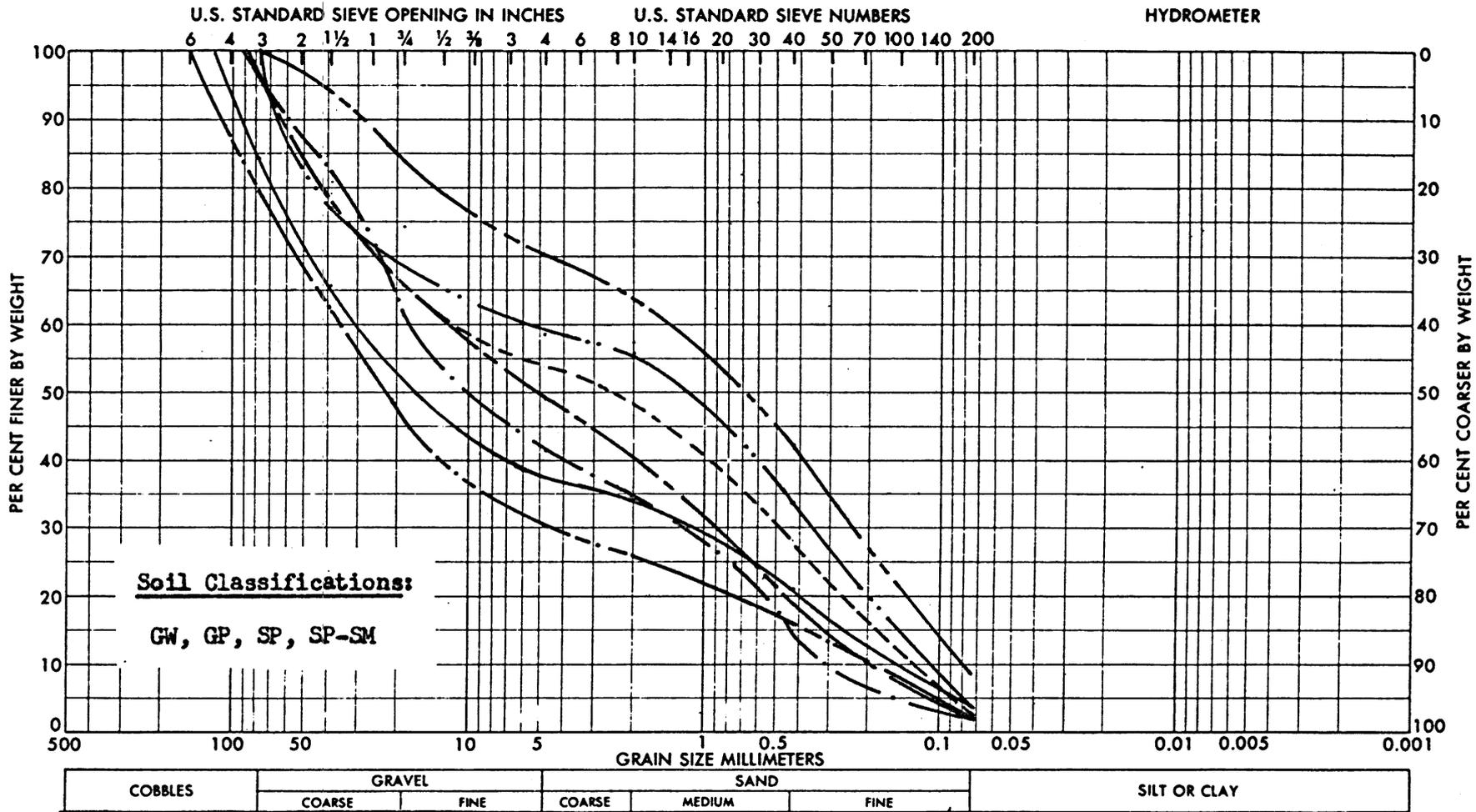


Fig. 9. Gradation curves of pervious fill

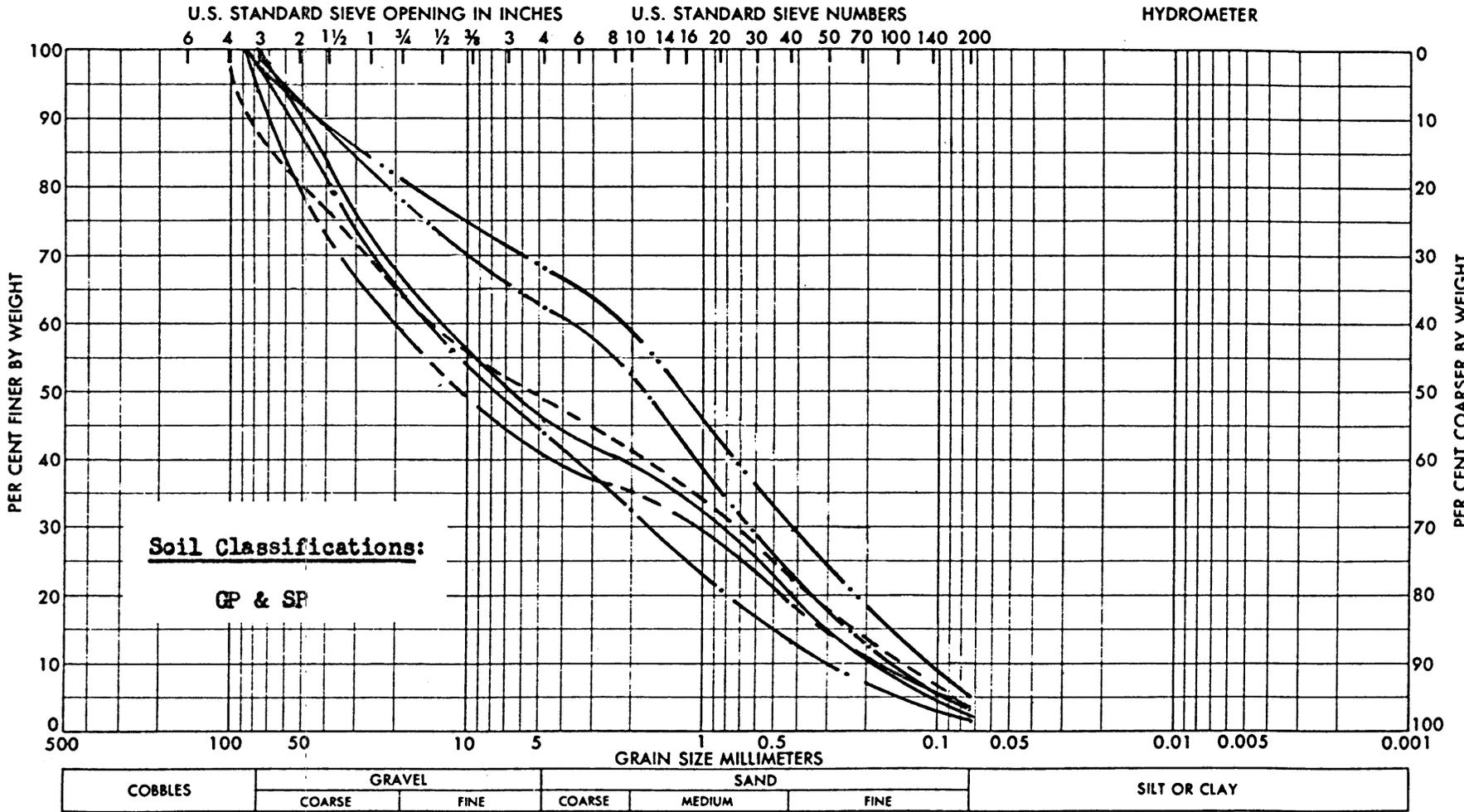


Fig. 10. Gradation curves of gravel fill

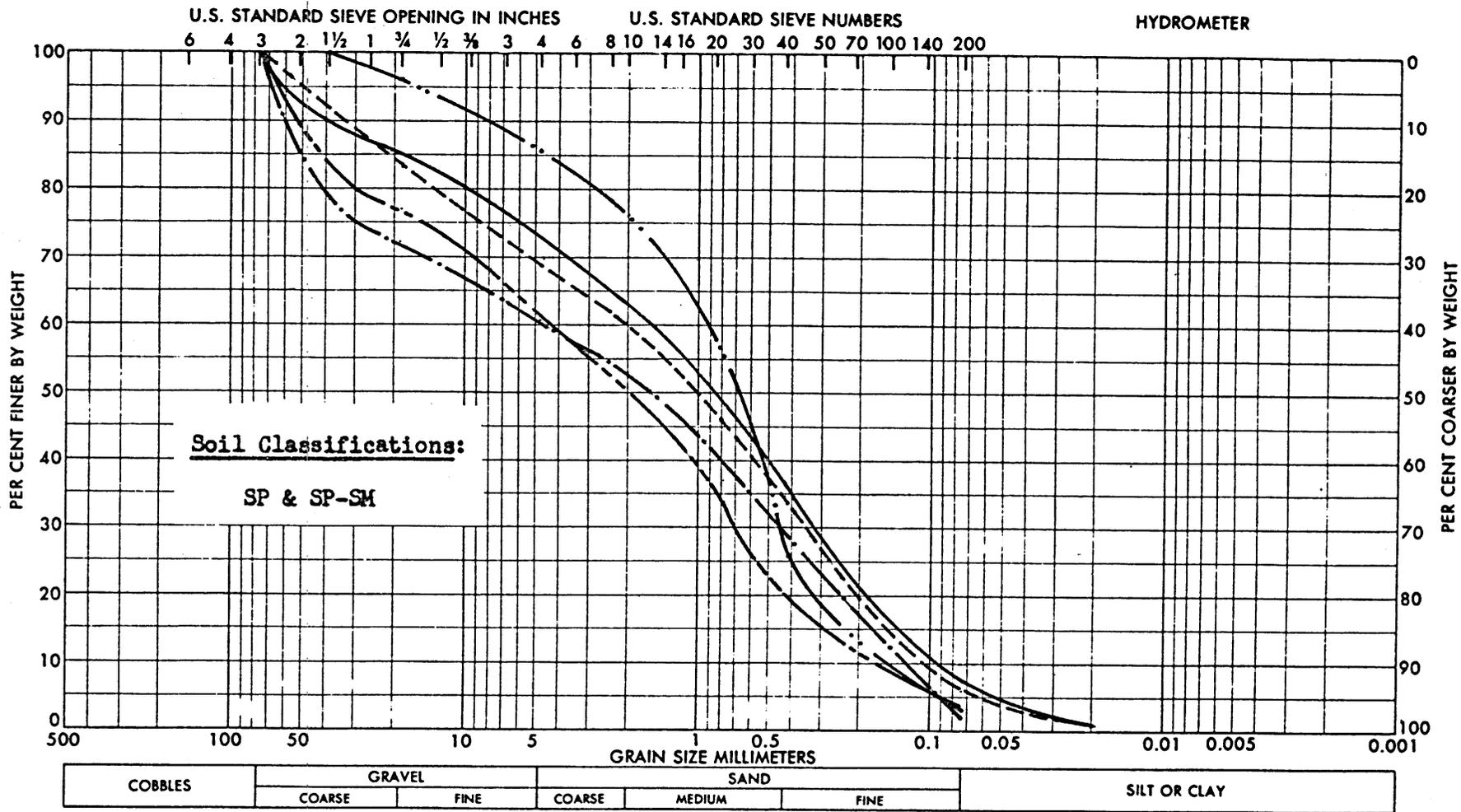


Fig. 11. Gradation curves for sand fill material placed in the horizontal drainage blanket

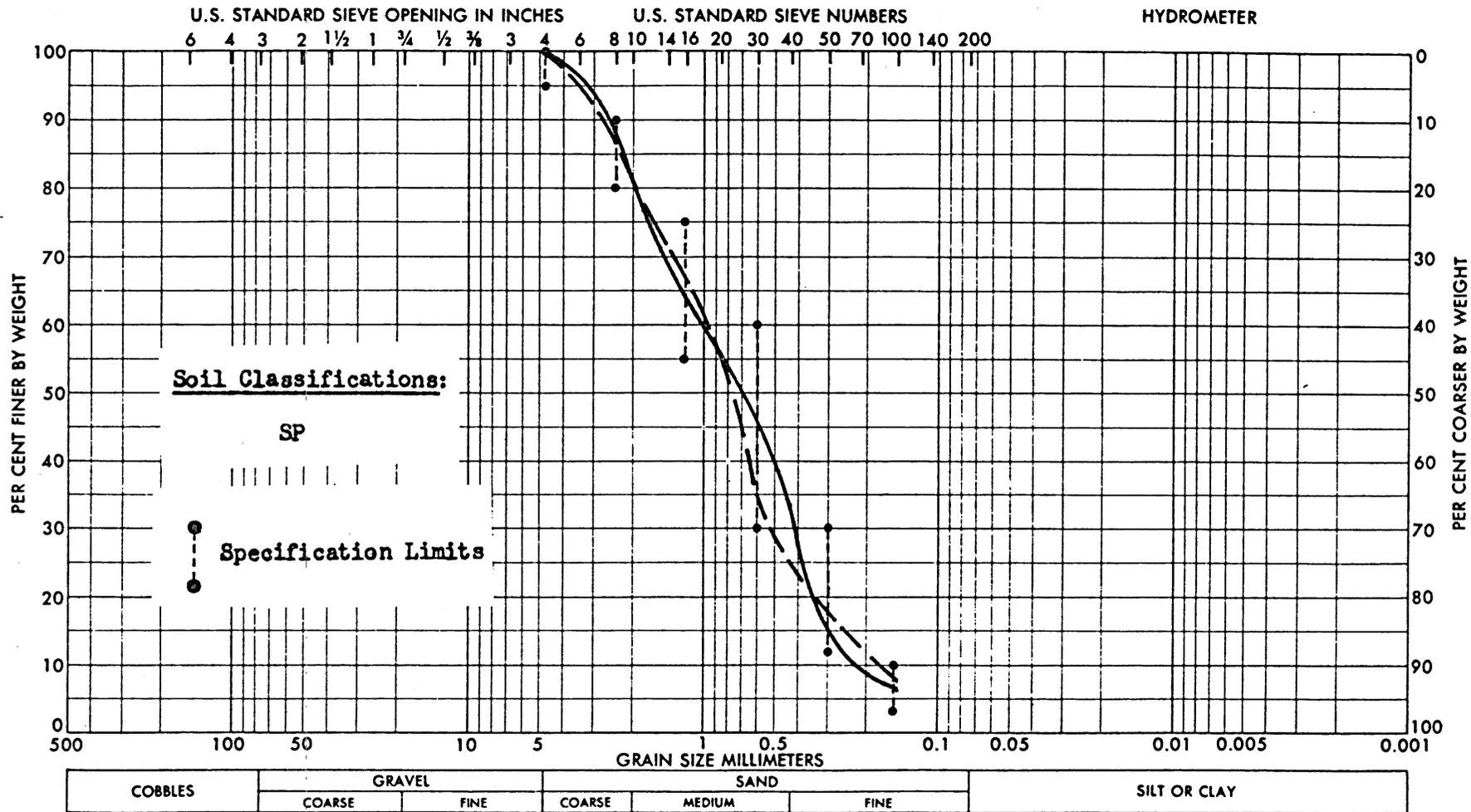


Fig. 12. Gradation curves for processed sand fill material, placed in the horizontal drainage blanket

water content of the minus No. 4 fraction of the impervious backfill within 0 to + 3 percentage points of optimum water content.

- (2) Control compaction of the impervious fill, impervious backfill, and Type I random fill to produce a minimum of 95 percent of laboratory maximum dry density (standard effort) for the minus No. 4 fraction.
- (3) Perform a 1-point standard effort compaction test (see paragraph 11a) on the minus No. 4 fraction of the material from each field density test taken in the impervious fill, impervious backfill, and Type I random fill, and apply the results to a set of compaction curves based on tests of the minus No. 4 fraction of the borrow materials. In addition, perform not less than one 5-point standard compaction test each week during placement of fill to augment the family of curves.

b. Pervious, sand, gravel, and Type II random fill

- (1) Control compaction to produce a minimum of 95 percent of Providence vibrated density for the pervious fill, sand fill, gravel fill, and Type II random fill.
- (2) Perform a Providence vibrated density test on the material from each field density sample taken in the pervious fill, sand fill, gravel fill, and Type II random fill.
- (3) Control water content of pervious fill, gravel fill, and sand fill so as to prevent excessive rutting and dust and to permit satisfactory operation of hauling and compacting equipment.

10. Placement and compaction. The placement and compaction operations employed in the construction of Littleville Dam are described below and summarized in table 1.

- a. Impervious fill and backfill. The impervious fill was spread in 8-in. loose lifts and compacted by six passes of a towed tamping roller (sheepsfoot) weighing approximately 12 tons when fully loaded with water, having dual drums with four feet per row, each foot with a 7-sq in. end area, exerting a foot pressure of about 432 psi, and operating at a speed of 2 to 3 mph. The impervious backfill was placed in 2-in. loose layers and compacted by a 32-lb pneumatic hand tamper with a foot diameter of 5-3/4 in.

- b. Random fill. Type I random fill, which constituted the major portion of the random fill zone of the dam, was spread in 8-in. loose layers and compacted by six passes of a 12-ton sheepsfoot roller exerting a foot pressure of 432 psi and operating at a speed of 2 to 3 mph. The Type II random fill was placed in 12-in. loose layers and compacted by four passes of a 50-ton pneumatic roller with tire pressures between 80 and 100 psi, 25-ton wheel loads, and operating at a speed of 3 to 4 mph.
- c. Pervious fill. At first the pervious fill was spread in 12-in. loose layers and compacted by four passes of a 50-ton pneumatic roller operating at a speed of 3 to 4 mph; later the pervious fill was compacted in 6-in. loose layers by six coverages of the tread of a crawler tractor exerting a contact pressure of about 9.5 psi and operating at a speed of about 10 mph. Pervious backfill was placed in 4-in. loose layers and compacted by a 235-lb surface vibrator having a 12-in. by 18-in. tamping pad, exerting an impact load of 2900 lb, and covering 50 to 60 linear fpm.
- d. Sand fill and processed sand fill. The sand fill and processed sand fill were spread in 6-in. loose layers and compacted either by a crawler tractor exerting a contact pressure of about 9 psi and operating at a speed of about 10 mph, or by a 50-ton pneumatic roller operating at a speed of 3 to 4 mph.
- e. Gravel fill. The gravel fill was spread in 6-in. loose layers and compacted by six passes of a 50-ton pneumatic roller operating at a speed of 3 to 4 mph.

11. Field and laboratory tests. Field density was determined on all materials using the water balloon method (Washington Dens-O-Meter).

a. Impervious and Type I random fill

- (1) Laboratory tests were performed on the minus No. 4 fractions of the field density samples from the impervious fill, impervious backfill, and Type I random fill materials. Using the water content, determined by oven drying, of the minus No. 4 fractions, and the percent of plus No. 4 material, the water content of the total sample was determined by the nomograph in fig. 13. Assuming that all voids in the total sample were associated only with the minus No. 4 fraction, the dry density of the minus No. 4 fraction of the field density sample was computed. The density of the minus No. 4 fraction was compared to a

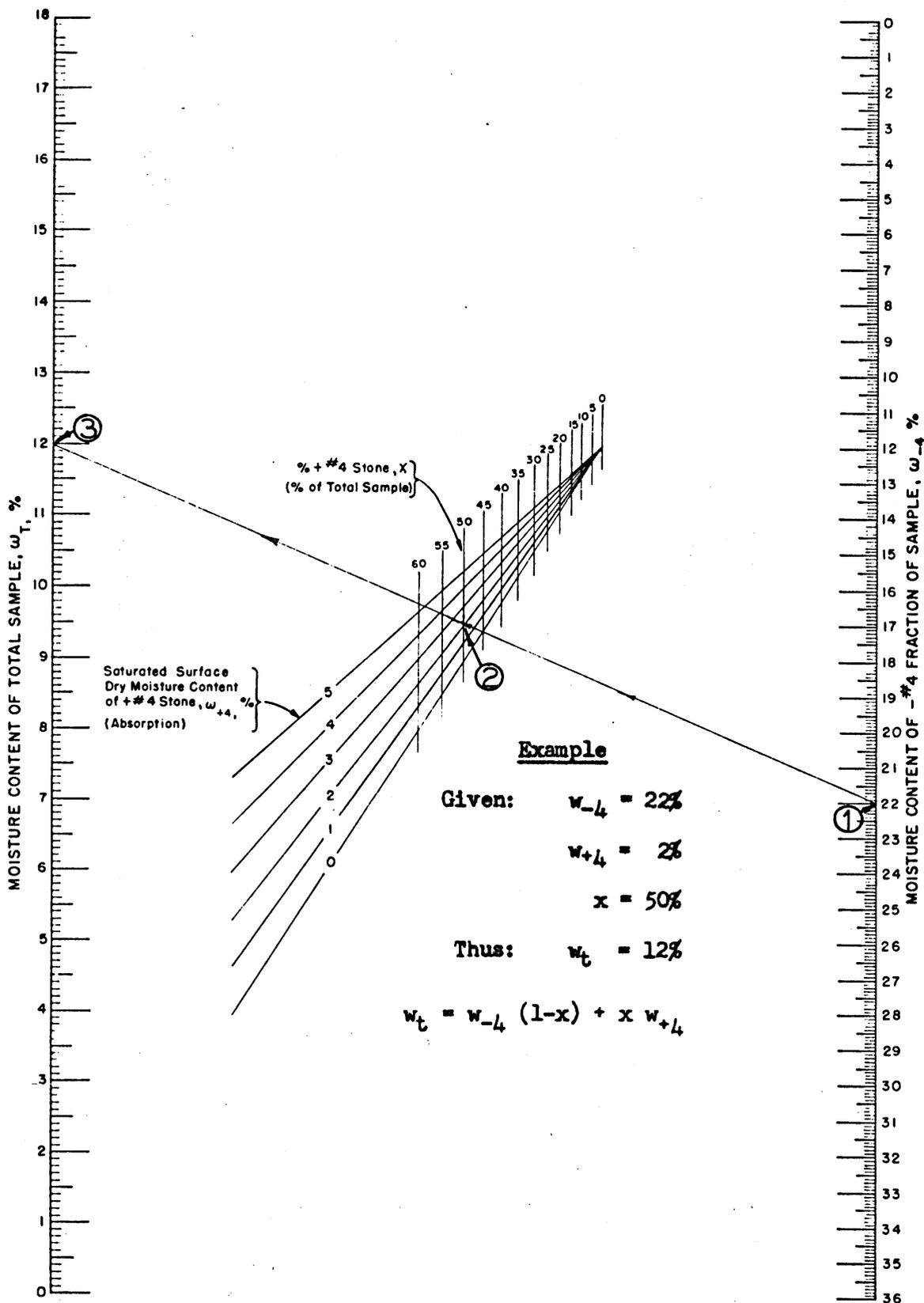


Fig. 13. Nomograph for determining water content of the total sample

family of laboratory compaction curves (see fig. 14) for minus No. 4 fractions of the impervious borrow materials.

(2) A "one-point" standard effort compaction test was performed on the minus No. 4 fraction dried to below optimum water content. The "one-point" datum was projected to the line of optimums of the family of compaction control curves as shown in fig. 15, and the optimum water content and maximum dry unit weight were determined for the field sample. This method has inherent inaccuracies when there is no unique line of optimums. As shown in fig. 14, there is a wide scatter in the family of compaction curves due to heterogeneity of materials.

b. Pervious materials. The water content of the pervious materials (including Type II random fill) was obtained by oven drying the total sample. The dry density of the field sample was compared to the results of a Providence vibrated density test performed on minus 2-1/2-in. material from the field density sample. Material larger than 2-1/2 in. was replaced by an equal weight of material passing the 3-1/2 in. sieve and retained on the 1-in. sieve.

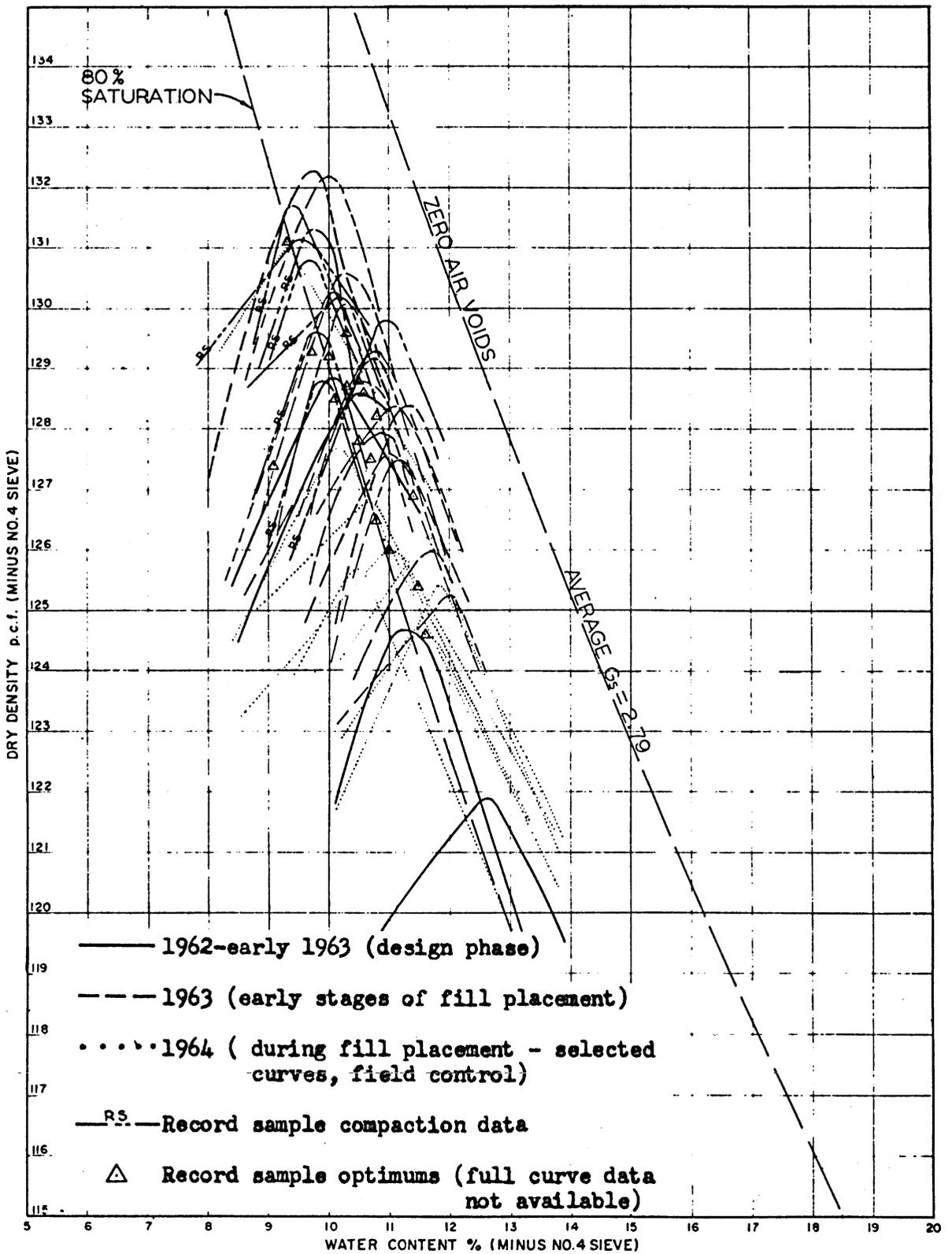
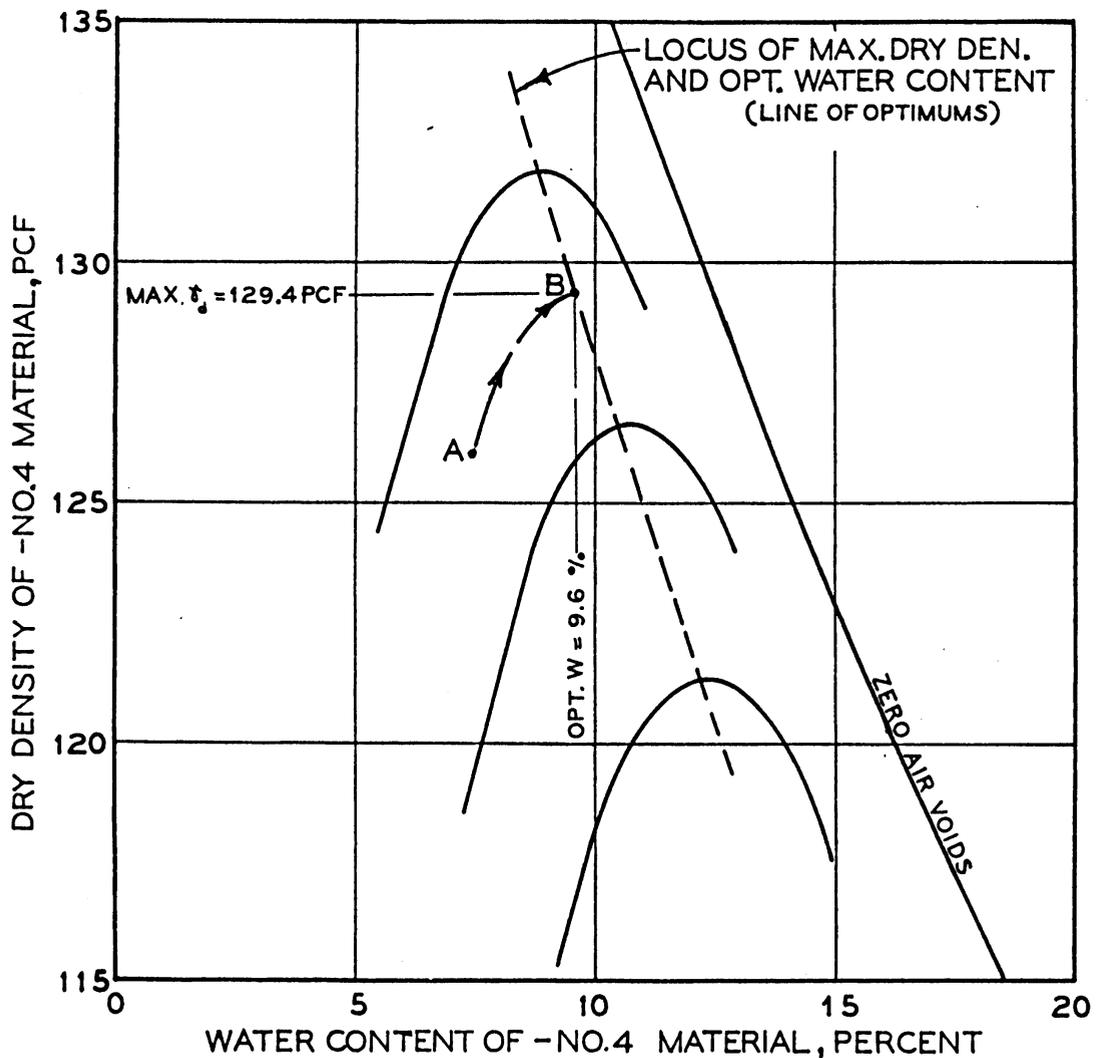


Fig. 14. Typical compaction curves for minus No. 4 fraction of impervious and impervious backfill materials



PROCEDURE:

1. Point A established as the result of a one-point standard effort compaction test on the -No. 4 fraction. This point required to fall on the dry side of optimum water content.
2. Point B represents the projection of point A to the locus of the maximum dry densities and optimum water contents of the family of compaction control curves. The projection is made approximately parallel to the dry of optimum portion of the adjacent compaction curves. Point B is then taken as the values of maximum dry density and optimum water content of the -No. 4 fraction of the field density sample.

Fig. 15. Illustration of compaction control procedure

PART III: FIELD COMPACTION RESULTS AND ANALYSIS

12. Statistical analyses* performed by the WES after construction on the data from the impervious fill and Type I random fill zones included frequency histograms and cumulative frequency distributions (percentage ogives) of the variation of fill water content from laboratory optimum and the variation of fill percent compaction (100 times in situ dry density/maximum dry density). The computation of other statistical parameters for the impervious and Type I random fill 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. The frequency curves and the pertinent statistical parameters for the pervious material were computed and plotted manually. Description and discussion of these analyses are presented in the following paragraphs.

Impervious Fill, Dam Embankment (Cofferdam Portion)

13. In order to secure the construction site against flooding, an upstream cofferdam was constructed, which later comprised a portion of the embankment as shown in fig. 2. The cofferdam was constructed of the same materials and under the same specifications and procedures as the remainder of the impervious zone of the embankment. However since the water contents of the cofferdam fill appeared to be significantly higher than the remainder of the impervious fill, the field control data on the cofferdam are treated separately herein.

14. Data for the cofferdam were obtained from field density sampling between sta 3+30 and 12+25 and from el 392 to 505** of the dam. A plot of fill

* Statistical terms and procedures used in this report are briefly defined in Appendix A. Reference 5 is cited as a source of complete definitions and thorough explanations of the statistical procedures employed in this report.

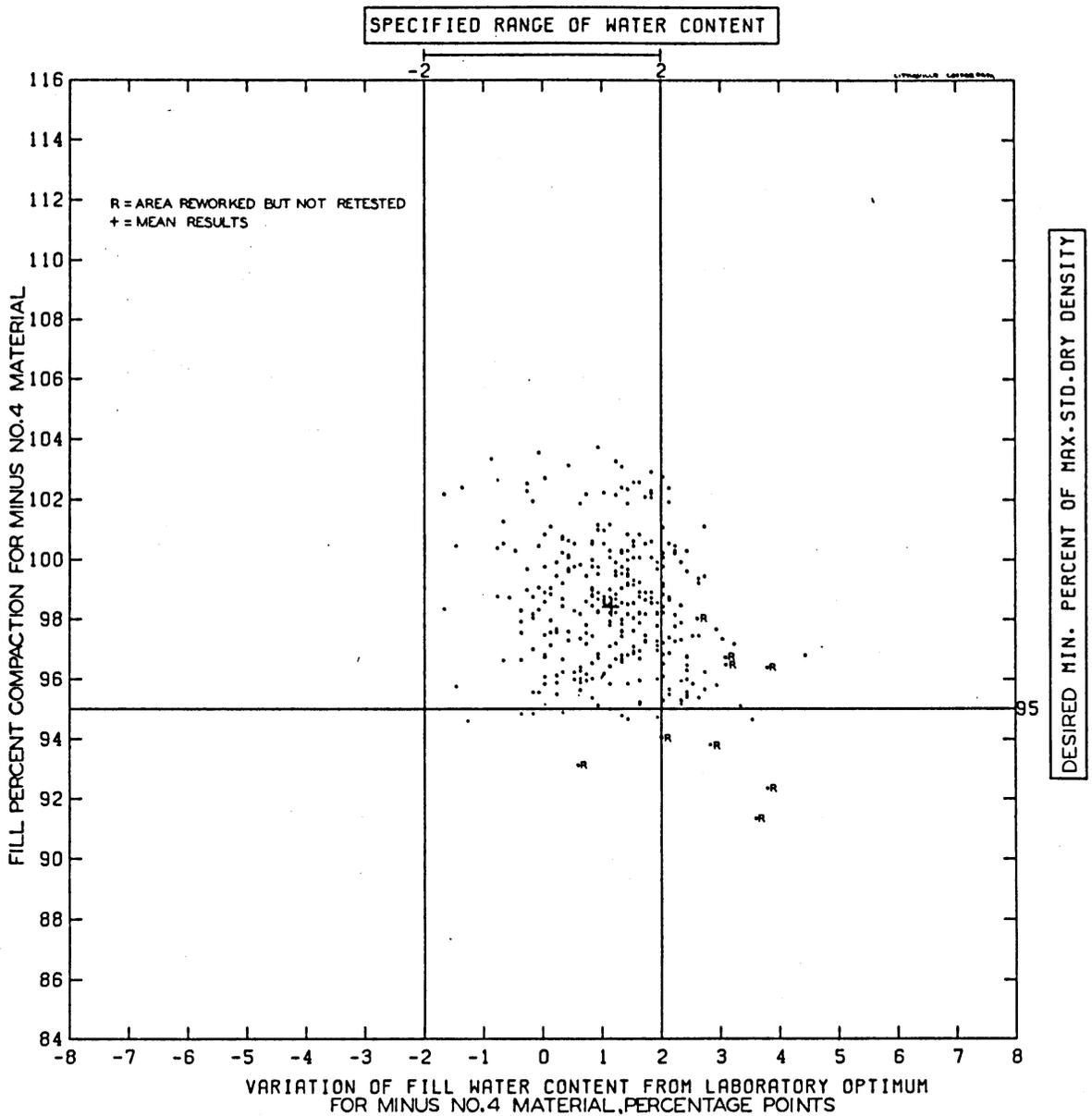
** All elevations (el) are in feet referred to mean sea level.

percent compaction versus variation of fill water content from laboratory optimum is shown in fig. 16. Of the total of 324 tests, 59 tests (18 percent) did not meet the established compaction and/or water content criteria. Forty-nine samples (15 percent) had adequate densities but had water contents outside specified limits; 8 samples (2 percent) met the water content requirements but had densities lower than the desired minimum; and 2 (1 percent) met neither water content nor density standards. Thirteen of the 59 areas in which test results did not meet desired criteria were reworked; of these, only 4 were retested and these were found to have satisfactory densities and water contents. Examination of the field data indicated that the tests not meeting the contract specifications for water content were dispersed randomly throughout the cofferdam.

15. Statistical analyses of compaction control of the cofferdam portion of the dam utilized 315 samples representing the as-built embankment. In the case of the four areas that were reworked and retested, the original test data were replaced by the retest results. The data for those nine areas that were reworked but not retested were excluded, since they no longer represented final states of compaction. A plot of actual fill dry density versus fill water content for the minus No. 4 fraction for the 315 samples is shown in plate 1. A small number of the data on plate 1 appear questionable, since they fall well above the average zero-air void curve representing the impervious soils. Excluding the reworked areas, the mean field water content was 11.7 percent, and the mean field dry density was 126.1 pcf.

Water content

16. The physical and statistical data for fill water content for the cofferdam portion of the impervious zone of the dam are summarized in table 2. The frequency histogram and the percentage ogive for variation of fill water content from laboratory 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



NO. TESTS 324*

<u>TESTS OUTSIDE DESIRED LIMITS</u>			
<u>W.C. ONLY</u>	<u>DEN. ONLY</u>	<u>W.C. AND DEN.</u>	<u>TOTAL</u>
49	8	2	59

*Includes 9 areas reworked but not retested

Fig. 16. Variation of test values with respect to desired limits, cofferdam portion of dam impervious fill

superimposed on the histogram of plate 2. For a normal array, 68.3 percent of the total number of values (i.e., 68.3 percent of the area under the normal curve) is contained within plus or minus one standard deviation σ from the mean. Of the 315 test values, 70.2 percent fell within plus or minus one standard deviation. Thus the observed distribution tends to be slightly more concentrated toward the mean than the normal distribution. Pearson's first coefficient of skewness* is minus 0.4, verifying the asymmetrical displacement to the right evident in plate 2. Since the values of the standard deviation (0.97) and the mean variation from optimum (1.1 percentage points wet) are of the same order of magnitude, the value of the coefficient of variation fails to be useful.

Percent compaction

17. Although a value of minimum percent compaction was not required by the contract specifications, the compaction procedures were expected to achieve densities of at least 95 percent of laboratory standard maximum dry density. Of the total of 315 samples, only 2.8 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 (based on minus No. 4 material) for the cofferdam are shown in plate 3. The standard deviation of plus or minus 2.17 percentage points from the mean includes 68.6 percent of the samples. Since Pearson's first coefficient of skewness is very nearly zero, the normal distribution curve is an appropriate representation of the fill percent compaction histogram. The coefficient of variation $c_v = \sigma/m$ was 2.2 percent.

Impervious Fill, Dam Embankment (Excluding the Cofferdam)

18. Data for the impervious zone of the dam outside the limits of the cofferdam were obtained from field density sampling between sta 1+60 and

* Defined in Appendix A.

14+85 and from el 445 to 593 (i.e., from foundation level to the top of the dam). A plot of fill percent compaction versus variation of fill water content from laboratory optimum is shown in fig. 17. Of the total of 673 tests, 41 (6 percent) had densities and/or water contents outside the desired limits as follows: 34 samples (5 percent) had adequate densities but water contents were outside specified limits; 6 samples (1 percent) had acceptable water contents but were below the desired minimum percent compaction; and only one sample failed to meet both the water content and density criteria. Two areas had originally failed to meet requirements, but were subsequently proven satisfactory after reworking and retesting. Six areas that failed to meet water content and/or density criteria were reworked but not retested. Those samples failing to meet water content and/or density requirements were dispersed randomly within the impervious fill.

19. The statistical analyses of control data from the impervious zone of the dam (excluding the cofferdam) were based on 667 samples. The retest data were substituted for the original data in the case of the two areas that were reworked and retested. Since the areas that were reworked only did not represent the final state of compaction, those six data sets were excluded from the statistical analyses. A plot of actual fill dry density versus fill water content for the minus No. 4 fraction for the 667 samples is shown in plate 4. Excluding the areas which were reworked only, the mean water content was 10.4 percent and the mean dry density was 127.6 pcf.

Water content

20. The physical and statistical data for fill water content for the impervious zone of the dam (excepting the cofferdam portion) 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 5. The observed data exhibit slightly more central tendency than a normal distribution, since 69.7 percent of the values fall within plus or minus one standard deviation from the mean. Pearson's first skewness coefficient is 0.60.

Percent compaction

21. The physical and statistical data for percent compaction for the impervious zone of the dam (excepting the cofferdam portion) are summarized in table 3. The frequency histogram and percentage ogive for the variation of percent compaction are shown in plate 6. With 63.6 percent of the total data within plus or minus one standard deviation from the mean, the observed array is somewhat less concentrated toward the mean than a normal case. Furthermore, the actual distribution is negatively skewed with a Pearson's first coefficient of minus 0.26. The coefficient of variation was 1.80 percent.

Impervious Fill, Dike Embankment

22. Data for the impervious zone of the dike embankment were obtained from field density sampling between sta 20+90 to sta 28+60 and from el 544 to el 593, i.e., from foundation level to the top of the dike. A plot of fill percent compaction versus variation of fill water content from laboratory optimum is shown in fig. 18. Of the 80 total tests, 6 (8 percent) had water contents outside the specified limits. All other samples met the desired standards. A total of three areas had originally failed to meet requirements, but were subsequently proven satisfactory after reworking and retesting. Examination of the field data indicated that those samples that failed to meet water content specifications were dispersed at random within the dike impervious zone.

23. The statistical analyses of the field data from the impervious zone of the dike are based upon 80 test values. For the three areas that were reworked and retested, the retest data were substituted for the original values. A plot of fill dry density versus fill water content for these 80 samples is shown in plate 7. From plate 7, it is seen that the mean placement water content of the minus No. 4 fraction was 11.7 percent and the mean dry density was 124.1 pcf.

Water content

24. The water content data and statistical parameters for the impervious zone of the dike are summarized in table 2. The frequency histogram and cumulative frequency distribution for the variation of fill water content of the minus No. 4 fraction from laboratory optimum water content for the impervious zone of the dike are shown in plate 8. A normal distribution curve is shown with the histogram in plate 8. The actual distribution is significantly more concentrated toward the mean than the normal case, since 78.8 percent of the samples are contained within plus or minus one standard deviation from the mean. The actual array exhibits negative skewness (Pearson's first coefficient = -0.3) as well as an observed peakedness with respect to the normal curve (leptokurtosis).

Percent compaction

25. The physical and statistical compaction results for the impervious zone of the dike are summarized in table 3. The frequency histogram and percentage ogive for the variation of percent compaction for the dike impervious zone are shown in plate 9. The histogram of plate 9 is fitted with a normal distribution curve. The actual distribution tends to approach the normal case, although exhibiting less central tendency as evidenced by the fact that only 58.8 percent of the samples are contained within plus or minus one standard deviation (+ 1.7 percentage points) of the mean. Pearson's first coefficient of skewness is small (+ 0.1), indicating that the observed distribution exhibits no significant asymmetry. The coefficient of variation was 1.7 percent.

Impervious Backfill, Dam Embankment (Hand-Compacted)

26. Data for the impervious backfill material of the dam embankment were obtained from field density sampling between sta 1+20 to sta 14+80 and from el 400 to el 581. This included fill on the foundation and

around structures. The plot of fill percent compaction versus variation of fill water content from laboratory optimum for the minus No. 4 fractions of the field samples is shown in fig. 19. Of the 60 test values, 11 (18 percent) did not meet the water content specifications and/or the desired density. Among these, 6 samples (10 percent) had acceptable densities but were outside the water content limits; 4 samples (7 percent) had satisfactory water contents but had densities below the desired; and 1 sample (2 percent) did not meet either water content or density criteria. One of the 11 areas in which tests gave unsatisfactory results was reworked but not retested. A total of two areas had originally failed to meet requirements but were acceptable after reworking and retesting. Tests failing to meet water content specifications were scattered within the fill.

27. The statistical analyses of the data for the impervious backfill areas of the dam are based on 59 samples of the total of 60. The original data from the two areas that were reworked and retested were replaced by the retest values. The data for the single area which was reworked only were excluded. A plot of fill dry density versus fill water content of the minus No. 4 fraction for the 59 samples is shown in plate 10. The mean fill water content was 11.2 percent, and the mean fill dry density was 123.9 pcf.

Water content

28. The physical and statistical results for fill water content are summarized in table 2. The frequency histogram and cumulative frequency distribution curve for the variation of fill water content from laboratory optimum for the impervious backfill of the dam are shown in plate 11. A normal distribution curve is superimposed over the histogram in plate 11. The actual distribution tends to approach the normal case, although somewhat more concentrated toward the mean. Negative skewness or asymmetrical displacement to the right (Pearson's first coefficient = - 0.4) and some leptokurtosis of the actual distribution are apparent.

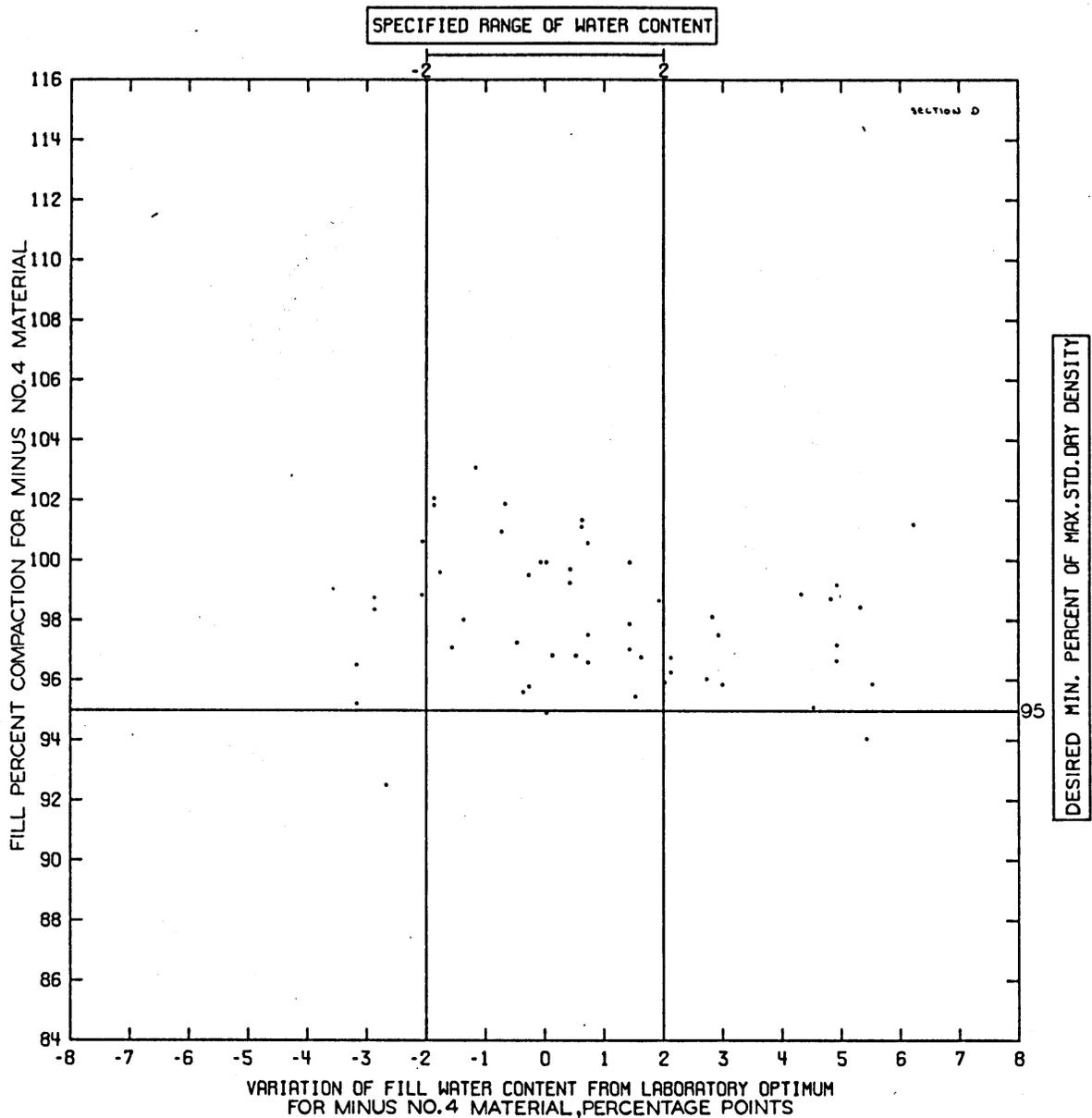
Percent compaction

29. The density results and statistical data for the impervious backfill of the dam are summarized in table 3. The frequency histogram and percentage ogive of fill percent compaction for the impervious backfill of the dam are shown in plate 12. The normal frequency curve best fitting the observed data is shown with the histogram in plate 12. The data exhibit some tendency to approach the normal curve, although slightly more concentrated toward the mean and positively skewed (Pearson's first coefficient = 0.9). The coefficient of variation was 2.4 percent.

Type I Random Fill, Dam and Dike

29. The random fill material placed in the dam and dike consisted of both Type I and Type II random soils. These soil groups were treated separately in the compaction-control procedure, and are therefore discussed separately in this report. Samples from the dike zone are combined with those from the dam for both the types of materials to obtain a more satisfactory population for the statistical analyses.

30. The analyses of the Type I random material are based upon 18 samples from sta 22+50 to sta 27+10 and el 550 to el 580 of the dike embankment and 38 samples between sta 7+00 to sta 11+00 and el 446 to el 516 of the dam. The plot of fill percent compaction versus variation of fill water content of the minus No. 4 fraction from laboratory optimum is shown in fig. 20. Of the total of 56 samples, 27 (48 percent) did not meet compaction and/or water content standards. Of these, 24 samples (43 percent) had adequate densities but did not meet water content requirements; 1 sample (2 percent) was of satisfactory water content but was below the desired density; and 2 samples (3 percent) did not meet either water content or density criteria. A plot of fill dry density versus fill water content for the minus No. 4 fractions of the 56 samples of this material is shown in plate 13.



NO. TESTS 56

TESTS OUTSIDE DESIRED LIMITS

<u>W.C. ONLY</u>	<u>DEN. ONLY</u>	<u>W.C. AND DEN.</u>	<u>TOTAL</u>
24	1	2	27

Fig. 20. Variation of test values with respect to desired limits,
Type I random fill

Water content

31. The physical and statistical results for fill water content are summarized in table 2. The frequency histogram and percentage ogive of the variation of fill water content from laboratory optimum for the minus No. 4 fractions of the Type I random samples are shown in plate 14. The actual distribution, with 64.3 percent of the water content values within plus or minus one standard deviation from the mean, is less concentrated toward the mean than the normal distribution. The observed array is relatively well balanced, with a Pearson's first coefficient of skewness of + 0.1. Although a number of differences are apparent in the test data distribution, the normal distribution curve in plate 14 appears to be a reasonable representation of the actual variation of fill water content.

Percent compaction

32. The fill density results for the Type I random material are summarized in table 3. The frequency histogram and percentage ogive of fill percent compaction for the Type I random materials are shown in plate 15. A normal distribution curve is superimposed over the histogram in plate 15. The actual array is very nearly normal in respect to central tendency, with 67.9 percent of the values falling within plus or minus one standard deviation from the mean. Although the actual distribution is slightly flattened in respect to the normal curve (platykurtic) and possesses negative skewness, the normal curve is a reasonable representation of the variation of fill percent compaction.

Summary of Physical and Statistical Values for Impervious Materials

33. The pertinent physical and statistical results for the impervious fill, impervious backfill, and Type I random fill materials shown in plates 1-15 are summarized in tables 2 and 3. This summary provides the basis

for the following observations:

- a. Average placement water contents varied only 1.9 percentage points among the five impervious embankment zones, while the maximum variation of placement water contents from optimum water contents between the different zones was only 0.8 percentage point.
- b. The fill in the cofferdam portion of the impervious fill of the dam was placed at an average water content 1.3 percentage points wetter than the remainder of the impervious zone. The average variation from optimum water content for the cofferdam segment exceeded that for the remainder of the impervious fill by 0.8 percentage points on the wet side. The difficulties encountered in the water content control of this area probably derived from the regular occurrence of rain during the period of fill placement from August to mid-October 1963.
- c. The average percent compaction varied 0.8 percentage point among the five impervious embankment areas listed in table 3.
- d. The percent compaction results for the cofferdam portion of the impervious fill of the dam were more variable than those for the remainder of the impervious zone as evidenced by higher values of the standard deviation and the coefficient of variation.
- e. The largest variation in overall compaction control among the five impervious areas occurred in the Type I random material. In respect to water content, this is evidenced by the highest standard deviation, and the highest percentage of samples not meeting specifications. In respect to percent compaction, this material had the highest standard deviation as well as the highest coefficient of variation. Variability of materials appears to be the cause of the major portion of the differences in control of the impervious zones. A wider variety of soil types made up the Type I random materials in comparison to the soils used in the other three zones. The range of placement water content in percentage points of dry weight and the range of in situ dry density are useful in indicating the variability of the materials. However, the total range of the data may often be misleading because of the occurrence of unusually high or low values. For this reason, the 95 percentile range or the range within which 95 percent of the test values fall is employed in table 4, which is a summary of the

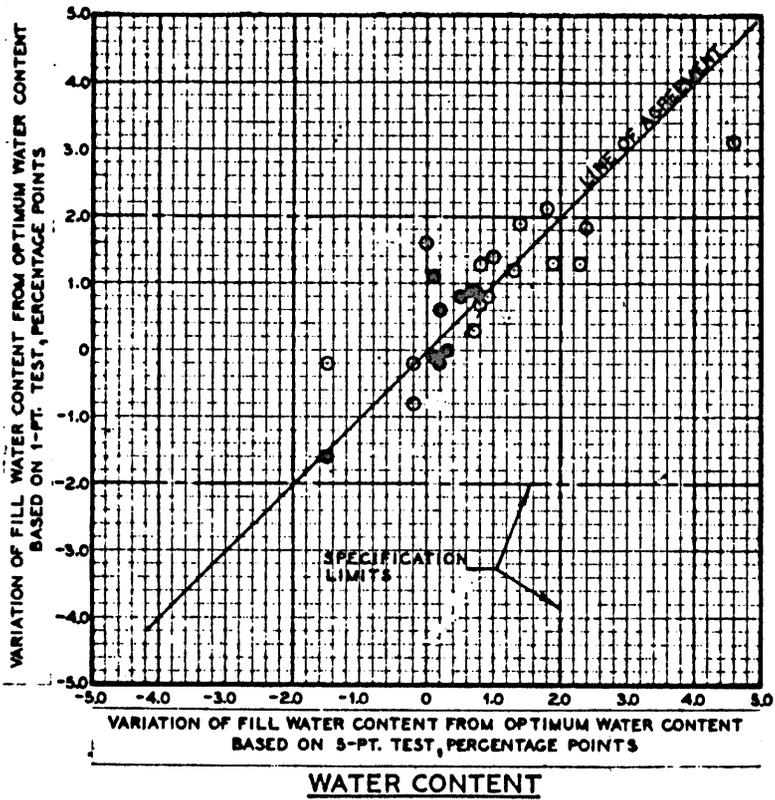
ranges of fill water content and fill dry density for the four impervious embankment areas. As can be seen from table 4, the Type I random material displays the largest water content and dry density ranges of the 95 percentile.

- f. Although the impervious backfill, unlike the other impervious fills, was compacted by hand-operated equipment in thin layers, the statistical results for the backfill bear resemblance to those for the other fill zones.

Record Sample Data

34. During construction of Littleville Dam, 30 conventional field density tests were made immediately adjacent to record sack samples obtained from the impervious fill, impervious backfill, and random fill zones of the dam. Of these samples, 25 were taken from the impervious zone, 2 were taken from the impervious backfill, and 3 were taken from the Type II random fill. The locations of field density tests and sack samples and the results of laboratory tests are listed in table 5. The analyses of the impervious zone data are described below:

- a. Eight record samples taken from the impervious zone of the dam from July to November 1964 were tested by the NED, including mechanical sieve analyses, standard effort compaction tests, and Q triaxial shear tests on the remolded minus No. 4 fractions. For the remaining record samples, only the values of maximum dry density and optimum water content obtained from 5-point compaction tests were furnished by the division. The eight full compaction curves and the remaining 17 optimum points are shown with the family of compaction curves in fig. 14. In fig. 21 water content and density test results are compared for the 25 record samples and the corresponding field density samples from the impervious zone. The maximum dry densities and optimum water contents of the record samples were obtained from 5-point standard effort compaction tests on the minus No. 4 fractions. The optimum values for the minus No. 4 fractions of the associated field density samples had been extrapolated using the compaction control procedure (see paragraph 11a and fig. 15) prior to the record sample testing.
- b. Graphical comparisons of the values of maximum dry density and optimum water content extrapolated from the 1-point standard effort control procedure with the optimum values



NOTE: SOLID SYMBOLS ARE FOR SAMPLES FOR WHICH 5-PT. COMPACTION CURVES ARE PRESENTED IN FIG. 14

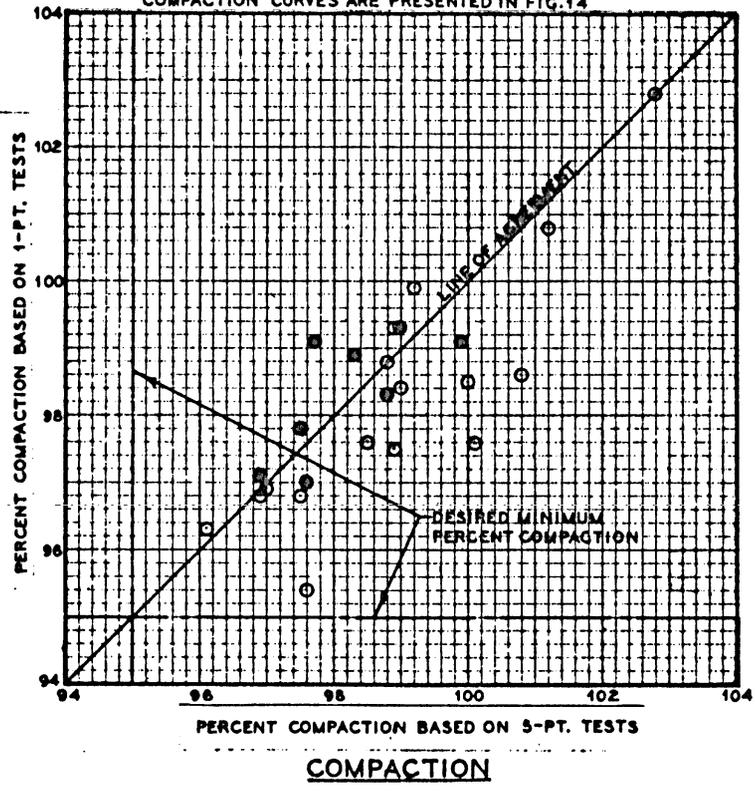


Fig. 21. Comparison of optimum values extrapolated by 1-point control procedure with those obtained by 5-point compaction tests

obtained from the 5-point standard effort compaction tests are shown in fig. 21. Assuming that the 5-point compaction tests on the record samples established the true optimum values, the variation from the true value of optimum water content of the 25 impervious samples ranged from 1.6 percentage points dry to 1.5 percentage points wet, with a mean variation very close to zero. The variation from true maximum dry density ranged from 1.9 pcf below to 3.5 pcf above the true value. From fig. 21 it is seen that the water contents for two tests (302 and 345) fell within the specified water content limits based on the value of optimum water content extrapolated by the 1-point procedure, but were outside the specifications based on the value of optimum water content obtained from the 5-point compaction test. Similarly, one value of percent compaction (for sample 1184) was above the desired minimum value based on the 1-point extrapolated maximum dry density but was below the desired minimum based on the 5-point compaction test result. However, three values of percent compaction (for samples 211, 214, and 253), which were below the desired minimum percent compaction on the basis of the 1-point procedure, were above the minimum on the basis of the 5-point test. In general, the comparisons shown in fig. 21 are in fairly good agreement, especially for the variation of fill water content. The standard deviations for variation of fill water content and maximum dry density (based on the 5-point tests) were 0.7 percentage point and 1.3 pcf, respectively.

- c. As indicated by the data in table 5, the soils of the impervious zone were of very low plasticity, with plasticity indexes (PI) ranging from 3 to 6 percent. Since these data were small in number and of very little variation in value, no attempt was made to correlate maximum dry density, optimum water content, and the Atterberg limits.

Type II Random Fill

35. The analyses of the Type II random material are based upon 21 samples taken between sta 23+00 to sta 28+25 and from el 565 to el 584 of the dike embankment and 17 samples between sta 7+50 to sta 18+00 and el 439 to el 595 of the dam. Of the total of 38 samples, only one failed to meet the desired minimum density of 95 percent of Providence vibrated

density. One sample had originally failed the density standard, and the area was reworked; however, no retest was reported, and the original value was excluded from the analyses. One other sample failed to meet specifications initially, but the area was subsequently proven satisfactory upon reworking and retesting.

36. The physical and statistical compaction results for the Type II random material are summarized in table 6. The frequency histogram and percentage ogive for the variation of percent of Providence vibrated density for the random pervious material are shown in plate 16. A normal distribution curve is shown with the histogram in plate 16. The observed distribution is somewhat more concentrated toward the mean than a normal sequence, since 76.3 percent of the values fall within plus or minus one standard deviation from the mean. Furthermore, the actual array exhibits leptokurtosis and significant negative skewness. The sample size is relatively small, and it is possible that with a larger population, the actual distribution would show a greater tendency to approach the normal case.

Pervious Fill

Inclined drain, dam embankment

37. General. Analyses of the pervious fill of the inclined drain of the dam are based upon 74 samples between sta 3+10 and sta 41+00 and from el 445 to el 581. Of the total samples, only 3 (4 percent) failed to meet the desired minimum density of 95 percent of Providence vibrated density. Results of one test were discarded since the area tested had been reworked but not retested. One other area originally failed the density standard, but was subsequently proven satisfactory.

38. Percent Providence vibrated density. The fill density results for the pervious zone of the dam are summarized in table 6. The frequency

histogram and percentage ogive for the variation of percent Providence vibrated density are shown in plate 17. The actual distribution is slightly more concentrated toward the mean than the normal curve shown with the histogram in plate 17, since 70.3 percent of the values fell within plus or minus one standard deviation from the mean. Minor leptokurtosis and positive skewness are evident, but the normal curve is a reasonable representation of the variation of the data.

Horizontal drainage blankets,
dam and dike embankments

39. General. Analyses of data from horizontal drainage blankets are based on the combination of 69 samples of sand fill from the dam and dike and 10 samples of processed sand fill from the dam. Of the 69 sand fill samples, 9 were taken between sta 23+65 to sta 25+75 and from el 543 to el 557 of the dike and the remaining 60 samples were taken between sta 5+00 to sta 12+75 and from el 413 to el 509 of the dam. The 10 processed sand fill samples were taken between sta 9+10 to sta 10+50 and from el 435 to el 443 of the dam. Of the total population of 79 samples, 8 (10 percent) failed to meet the minimum desired density of 95 percent Providence vibrated density. Three samples were rejected as they represented areas that had been reworked only. Four samples were from areas that originally failed to meet the expected density but were subsequently acceptable after reworking and retesting.

40. Percent Providence vibrated density. The fill density results and statistical parameters for the sand fill zones of the dam and dike are summarized in table 6. The frequency histogram and percentage ogive for the variation of percent Providence vibrated density for the sand and processed sand fill of the dam and dike are shown in plate 18. The observed distribution exhibits both leptokurtosis and positive skewness, while being more concentrated toward the mean than a normal distribution, with 73.4 percent of the values contained within plus or minus one standard deviation of the mean. Since Pearson's first coefficient of skewness with a value of

+ 0.7 is relatively high and since the number of samples should be sufficient to indicate the true tendencies of the observed data, it was apparent that a normal distribution curve was not an appropriate representation of the variation. Consequently, the actual distribution of the data obtained by smoothing the ogive is shown with the histogram in plate 18.

Gravel fill, dam and dike embankments

41. The samples from the gravel fill zones of the dam and dike were too few in number (14) to justify extensive statistical analyses. Two of the samples were taken from the dike, while the remaining 12 samples were taken between sta 7+15 to sta 14+80 and from el 430 to el 458 of the dam. The fill density results are summarized in table 6.

Summary of Physical and
Statistical Values for Pervious and Type II Random Materials

42. The pertinent physical and statistical results for the Type II random, pervious, sand and processed sand, and gravel fill zones shown in plates 16-18 are given in table 6. Inspection of that summary and those for the individual zones prompts the following observations:

- a. The mean values of percent Providence vibrated density varied only 1.2 percentage points.
- b. Because of the small number of tests for the gravel fill, the statistical values shown in table 6 are of limited significance. However, despite the small sample population, the results are generally consistent with those of the other pervious areas.
- c. There is an apparent tendency as observed from table 6 for an increase of variation in compaction results with an increase in the permeability of the material. Both the value of the standard deviation and the coefficient of variation increase progressively from the Type II random fill to the gravel fill. The values of mean percent Providence vibrated density exhibit a reverse trend, with the highest value of the mean occurring in the least pervious of the material.

PART IV: SUMMARY OF RESULTS

43. The water content and compaction results are summarized below:

a. Fill water content

- (1) The impervious fill of the cofferdam portion was placed 1.3 percentage points wetter on the average than the remainder of the impervious zone of the dam. The average deviation from optimum water content for the cofferdam exceeded that for the remainder of the impervious zone by 0.8 percentage points on the wet side.
- (2) The fill in the impervious and Type I random zones was generally placed wet (0.3 to 1.1 percentage points) of optimum water content. The extreme variations from optimum generally fell within 6 percentage points above optimum to 5 percentage points below optimum.
- (3) Test locations for which the water content specifications were not met occurred in a random fashion within the impervious, impervious backfill, and Type I random zones.

b. Fill density

- (1) The average values of fill percent compaction for the impervious, impervious backfill, and Type I random zones generally exceeded the desired minimum percent compaction by 3 percentage points.
- (2) The percent of samples with test values below the minimum desired 95 percent compaction ranged from 1.0 to 8.5 percent among the impervious, impervious backfill, and Type I random zones. Only 2 percent of the 1185 samples had percent compactions less than 95 percent.
- (3) Minor percentages of the total samples from the Type II random, pervious, sand fill, and gravel fill zones did not meet the desired minimum of 95 percent of Providence vibrated density; the average values for these zones generally exceeded this minimum value by at least 2 percentage points.
- (4) Test locations for which the values of percent Providence vibrated density fell below the 95 percent desired minimum were dispersed at random within the fill zones.

44. The statistical results for variation of fill water content from optimum water content and variation of fill percent compaction or percent Providence vibrated density are summarized below:

a. Variation of fill water content

- (1) The frequency distributions for the variation of fill water content from laboratory optimum water content for the impervious zones of the dam and dike and the impervious backfill zone of the dam tend to approach the normal probability curve, although generally more concentrated toward the mean than the normal distribution.
- (2) The frequency distribution for the variation of fill water content from laboratory optimum for the Type I random fill is considered to approach the normal distribution while exhibiting less central tendency than a normal array.

b. Variation of percent compaction or percent Providence vibrated density

- (1) The frequency distributions for the variation of percent compaction for the impervious fill and backfill zones of the dam tend to approach a normal distribution, although slightly more concentrated toward the mean.
- (2) The frequency distributions for the variation of percent compaction for the Type I random material of the dam and dike and for the impervious materials of the dike resemble a normal array while being slightly less concentrated toward the mean.
- (3) The frequency distributions for the variation of percent Providence vibrated density for the Type II random material of the dam and dike and for the pervious material of the dam can be represented by normal distribution curves, although they exhibit more central tendency.
- (4) The frequency distributions for the variation of Providence vibrated density for the sand and processed sand fill exhibit significant leptokurtosis and positive skewness. A normal distribution curve is not deemed appropriate as a representation of the actual variation.

45. The discussions in paragraph 34b provide some indication of the

validity of the 1-point standard effort control procedure, expressed in terms of deviations of the extrapolated optimum parameters from values based on 5-point compaction tests. The family of compaction curves in fig. 14 indicates that variability of materials was probably the primary source of the variations of the extrapolated optimum values from true optimum values, as described in paragraph 34b. Based on the 25 field density samples and the corresponding record samples taken from the impervious zone of the dam, the mean variation of optimum water content from the true values was essentially zero, while the mean variation of extrapolated maximum density from its true value was only 0.3 pcf larger.

PART V: CONCLUSIONS

46. The following are conclusions concerning the compaction control of Littleville Dam:

a. Fill water content

- (1) The impervious fill in the cofferdam portion was generally placed at a higher water content than the impervious fill for the rest of the embankment.
- (2) The impervious material used as backfill was placed slightly drier than that of the cofferdam area but wetter than the remainder of the impervious fill.
- (3) The percent of samples within specified water content limits for the impervious and Type I random zones is apparently related to the variability of materials. The soils placed in the impervious zones of the dam and dike and in the impervious backfill zone of the dam were taken from the same borrow areas. These materials were less variable in respect to gradations and soil types than materials taken from required excavations and placed in the Type I random zone.
- (4) The frequency distributions for the variation of fill water content from laboratory optimum for the impervious soils of the dam and dike and Type I random soils of the dam tend to approach normal distributions.

b. Fill density

- (1) The mean values of percent compaction indicate no significant differences among the dam impervious and Type I random zones and dike impervious zone with respect to relative degrees of density.
- (2) The frequency distributions of fill percent compaction for all the pertinent zones of Littleville Dam tended to approach the normal case.
- (3) It is not practical to compare the mean values of percent Providence vibrated density for the more pervious material of the dam since each zone represents different soil classification obtained from both commercial sources and local borrow. However, there appears to be a trend toward

increasing variability of compaction results with increasing permeability of the materials. This observation is supported by the fact that the coefficient of variation tends to increase as the permeability of the zones increases.

(4) It cannot be stated that the frequency distribution of percent Providence vibrated density for the drainage blanket material of the dam tended toward a normal distribution. However, the same distributions for the Type II random and inclined drain soils of the dam did exhibit normal tendencies.

c. For the impervious zone of the dam, the 1-point compaction test control procedure appears to be reliable if the results of testing on the 25 record samples are assumed to be representative of the entire zone.

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2. U. S. Army Engineer Division, New England, "Littleville Dam and Reservoir, Site Geology," Design Memorandum No. IV, August 1961, Waltham, Mass.
3. U. S. Army Engineer Division, New England, "Littleville Dam and Reservoir, Embankments and Foundations," Design Memorandum VII, December 1961, Waltham, Mass.
4. U. S. Army Engineer Division, New England, "Littleville Dam, Specifications for the Construction of Dam and Appurtenant Structures," vol I, March 1962, Waltham, Mass.
5. Duncan, A. J., Quality Control and Industrial Statistics, new ed., Irwin, Inc., Homewood, Ill., 1959.

Table 1

Fill Materials and Compaction Control Criteria, Littleville Dam

Type of Fill	Soil Classification	Max. Particle Size in.	Percent Material > #4 range	Fill Volume, cu. yd.		Number of Field Density Tests	Cubic yd of Fill per Density Test	Specified Placement Water Content* %	Desired Minimum Density %	Field Compaction Procedure	Procedure for Correlation of Field Density with Laboratory Density
				Dam	Dike						
Impervious Fill	SM,SM-SC, ML,ML-CL	5	10 - 35	1,400,000	80,000	1086	1360	-2 to +2	95+	6 passes sheepsfoot roller, 8-in. loose layer.	Impervious and Random Impervious: In-place density, corrected for plus No. 4 material (assuming plus No. 4 as single voidless stone), is correlated with maximum dry density based on results of one-point standard effort compaction test and family of compaction curves on minus No. 4 material. Water content of minus No. 4 determined by direct measurement and total sample water content calculated using percent of plus No. 4 and its absorption. PerVIOUS: Providence vibrated density test performed on material from each field density test.
Impervious Backfill**	SM,SM-SC, ML,ML-CL	3	10 - 20	3,900	-	56	70	0 to +3	95+	Power hand tampers, 2-in. loose layers.	
Random Fill, Type I	SM,SP-SM, GP,GP-GM, ML	8	15 - 55	106,000	45,000	56	1610	-2 to +2	95+	Same as impervious or 4 passes 50-ton pneumatic roller, 12-in. loose layers.	
Random Fill, Type II	SP,SP-SM, GP,GP-GM					38			95++	4 passes 50-ton pneumatic roller, 12-in. loose layers.	
PerVIOUS Fill (Inclined drain)	SP,SP-SM, GP,GW	6	30 - 70	73,000	-	75	1010	-	95++	Major portion: 8 coverages of tread of crawler tractor, 6-in. loose layers; minor portion: 4 passes 50-ton pneumatic roller, 12-in. loose layers.	
Gravel Fill	GP,SP	4	30 - 60 0	17,500	1,500	14	1360	-	95++		
Sand Fill Processed Sand Fill (Horizontal drainage blankets)	SP,SP-SM No. 4	3 0	15 - 40 0	65,000 6,000	8,000 -	79 10	925 600	- -	95++ 95++	Major portion: 6 coverages of tread of crawler tractor, 6-in. loose layers; minor portion: 4 passes 50-ton pneumatic roller, 12-in. loose layers.	

* With respect to standard optimum for minus No. 4 material

** Placed around conduits and against steep surfaces of walls and bedrock

† 95% of standard maximum dry density of minus No. 4 fraction

†† 95% of Providence vibrated density, equivalent to a relative density of about 90%

Table 2
Fill Water Content Data, Impervious Zones

PHYSICAL DATA											
Embankment Zone	No. Tests	Fill Water Content %		Optimum Water Content %		Variation of Fill Water Content from Laboratory Optimum Percentage Points		Specified Limits with Respect to Optimum Percentage Points	Percent of Total Samples with Respect to Specified Limits		
		Range	Mean	Range	Mean	Range	Mean		Below	Within	Above
Dike, Impervious	80	8.3 to 15.9	11.7	9.2 to 14.1	10.9	- 3.9 to + 2.8	+ 0.7	- 2.0 to + 2.0	1.2	92.5	6.3
Dam, Impervious, Cofferdam Portion	315	8.2 to 15.9	11.7	8.8 to 14.2	10.6	- 1.7 to + 4.4	+ 1.1	- 2.0 to + 2.0	0.0	84.1	15.9
Dam, Impervious, Excluding Cofferdam	667	7.1 to 14.8	10.4	7.0 to 13.0	10.1	- 2.3 to + 3.8	+ 0.3	- 2.0 to + 2.0	0.6	94.8	4.6
Dam, Impervious Backfill	59	8.1 to 16.1	11.2	9.3 to 15.2	10.8	- 3.6 to + 4.4	+ 0.5	0.0 to + 3.0	32.2	64.4	3.4
Dam and Dike, Type I Random	56	7.2 to 19.3	12.3	9.1 to 15.1	11.5	- 4.3 to + 6.2	+ 0.8	- 2.0 to + 2.0	28.6	55.3	16.1

	STATISTICAL DATA						Pearson's First Coefficient of Skewness
	Standard Deviation (σ) Percentage Points	Percent of Test Values					
		1 σ (68.3)*	2 σ (95.5)*	3 σ (99.7)*	Above +1 σ (wet side)	Below -1 σ (dry side)	
Dike, Impervious	1.05	78.8	95.0	98.8	6.2	1.2	- 0.26
Dam, Impervious, Cofferdam Portion	0.97	70.2	95.6	99.7	13.3	16.5	- 0.36
Dam, Impervious, Excluding Cofferdam	0.95	69.7	95.2	99.7	15.5	14.8	+ 0.60
Dam, Impervious Backfill	1.35	79.6	94.9	98.3	10.2	10.2	- 0.40
Dam and Dike, Type I Random	2.70	64.3	100.0	100.0	19.6	16.1	+ 0.11

* Figures in parentheses are values for normal frequency curve

Table 3
Fill Density Data, Impervious Zones

PHYSICAL DATA										
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		Percent	Percent
Dike, Impervious	80	112.2 to 132.3	124.1	118.0 to 131.2	126.3	95.1 to 101.5	98.3	95.0		0.0
Dam, Impervious, Cofferdam Portion	315	113.6 to 134.3	126.1	117.8 to 133.0	128.2	94.5 to 103.7	98.4	95.0		2.8
Dam, Impervious, Excluding Cofferdam	667	115.3 to 138.6	127.6	120.8 to 134.5	130.2	94.4 to 107.5	98.0	95.0		1.0
Dam, Impervious Backfill	59	111.1 to 132.8	123.9	114.8 to 132.4	126.9	92.2 to 103.3	97.6	95.0		6.8
Dam and Dike, Type I Random	56	105.9 to 130.0	119.4	110.3 to 130.8	121.6	92.5 to 103.1	98.2	95.0		5.4

	STATISTICAL DATA							
	Standard Deviation (σ) Percentage Points	Percent of Test Values					Coefficient of Variation (σ/m) %	Pearson's First Coefficient of Skewness
		Within			Above + 1 σ (heavier)	Below - 1 σ (lighter)		
		1 σ (68.3)*	2 σ (95.5)*	3 σ (99.7)*				
Dike, Impervious	1.67	58.8	100.0	100.0	15.4	16.2	1.70	+ 0.12
Dam, Impervious, Cofferdam Portion	2.17	68.5	97.5	100.0	13.3	18.1	2.20	0.00
Dam, Impervious, Excluding Cofferdam	1.76	63.6	97.4	99.7	24.7	11.7	1.80	- 0.26
Dam, Impervious Backfill	2.30	69.5	93.2	100.0	15.2	15.3	2.36	+ 0.91
Dam and Dike, Type I Random	2.33	67.8	96.4	100.0	16.1	16.1	2.37	- 0.36

* Figures in parentheses are values for normal frequency curve

Table 4
Summary of Water Content and Density Ranges
Impervious Materials

<u>Embankment Zone</u>	<u>Fill Water Content, %</u>		<u>Fill Dry Density, pcf</u>	
	<u>Total Range</u>	<u>95 Percentile Range</u>	<u>Total Range</u>	<u>95 Percentile Range</u>
Dam, Impervious (cofferdam)	7.7	4.7	20.0	11.2
Dam, Impervious (excluding cofferdam)	7.7	4.9	23.3	12.0
Dike, Impervious	7.6	5.3	20.1	12.8
Dam, Impervious Backfill	8.0	5.7	21.7	13.9
Type I Random	12.1	10.6	24.1	20.4

Table 5

Record Sample Data, Impervious Fill, Random Fill, and Impervious Backfill

Sample No.		Station	Offset* ft	Elevation ft msl	Dam Embankment Zone	Field Density & Water Content		Results of Field Compaction Control Procedure on -No. 4 Fractions of the Field Samples				Standard Compaction Test on - No. 4 Fraction		Atterberg Limits			Remarks
CP-NO.	DM-D NO.					Ydry pcf	w %	Results of 1-pt Std. Comp. Test		Extrapolated Optimums		Yd max	w opt	Yd max	w opt	LL	
10	47	10+00	265 us	440	Impervious	131.2	9.5	127.4	9.9	127.9	10.3	129.3	9.7	22	19	3	
8	118	8+20	300 us	457	"	121.6	12.6	125.7	11.2	125.7	11.2	124.6	11.6	23	20	3	
9	121	9+50	250 us	456	"	126.6	12.0	124.5	9.2	126.8	10.8	127.5	10.7	21	18	3	
10	124	10+60	0	427	Imp. Backfill	124.7	14.4	128.6	9.9	128.8	10.0	126.6	11.0	21	18	3	
7	135	7+90	40 ds	432	Impervious	122.6	13.7	125.4	9.6	127.1	10.6	127.4	9.1	23	19	4	
10	180	10+50	325 us	464	"	124.5	12.0	126.1	8.5	128.5	10.1	128.6	10.6	21	19	2	
7	189	7+50	225 us	450	"	127.8	11.4	126.4	8.0	129.3	9.8	126.9	11.4	21	18	3	
8	211	8+75	150 us	44.7	"	128.0	11.3	130.7	9.5	131.3	10.0	127.8	10.5	21	19	2	
8	214	8+75	380 us	465	"	127.2	12.3	128.7	9.1	130.7	10.2	128.8	10.5	21	19	2	
9	221	9+30	140 us	44.8	"	125.5	12.7	126.7	11.3	126.8	11.4	126.5	10.8	nonplastic			
8	253	8+00	250 us	459	"	126.8	9.9	128.2	9.9	128.5	10.1	128.5	10.1	22	18	4	
10	255	10+00	310 us	468	"	122.5	10.0	127.8	10.0	128.3	10.2	125.4	11.5	22	19	3	
10	259	10+00	40 ds	444	Type II Random	135.3	6.4	TOTAL SAMPLE		137.8	PVD	118.8	12.2	nonplastic			
3	284	3+30	60 us	476	Impervious	129.1	10.9	128.4	8.7	130.8	10.1	129.2	10.0	21	18	3	
11	291	11+75	325 us	475	"	128.2	11.0	129.1	9.2	130.6	10.1	129.6	10.3	21	19	2	
6	302	6+90	230 us	471	"	129.4	11.6	128.5	9.7	130.1	10.3	131.0	9.3	21	18	3	
10	345	10+50	180 us	485	"	124.3	13.4	124.5	10.6	126.0	11.6	126.0	11.0	22	18	4	
8	385	8+00	160 us	499	"	124.5	11.6	125.5	9.8	128.2	10.9	128.2	10.8	22	18	4	
11	399	11+25	274 us	500	Imp. Backfill	125.4	11.3	127.1	9.7	128.7	11.0	125.4	11.8	24	19	5	
8	406	8+75	240 us	501	Impervious	130.1	11.0	127.5	9.6	129.2	10.7	128.7	10.3	22	16	6	
8	413	8+75	90 us	458	Type II Random	133.7	5.8	TOTAL SAMPLE		139.9	PVD	111.7	11.1	nonplastic			
7	415	7+50	60 us	458	Type II Random	137.6	6.8	TOTAL SAMPLE		142.4	PVD	115.7	12.2	nonplastic			
8	783	8+50	130 ds	500	Impervious	128.9	10.3	130.0	8.5	131.0	9.2	130.2	10.2	18	17	1)	
11	863	11+50	135 us	510	"	125.7	10.6	126.5	8.0	129.6	9.7	128.8	9.9	18	17	1)	
12	1020	12+50	93 ds	532	"	126.6	11.2	128.3	10.0	129.4	10.6	129.8	11.0	nonplastic			
9	1094	9+50	148 us	540	"	129.2	10.1	129.2	9.2	130.3	10.1	129.6	9.8	20	18	2)	
6	1138	6+00	112 us	552	"	129.1	9.8	130.7	9.8	130.8	10.0	131.5	9.6	19	17	2)	
10	1184	10+00	70 ds	562	"	128.6	9.5	129.7	9.5	129.8	9.6	131.7	9.4	20	16	4)	
6	1234	6+00	40 ds	573	"	127.3	8.3	127.1	8.3	131.2	9.9	131.3	9.8	20	18	2)	
9	1266	9+00	20 us	585	"	129.4	10.2	129.6	8.9	130.4	9.4	130.8	9.7	19	17	2)	Compaction curves shown in fig 14

* Offset referenced to centerline of dam; us = upstream and ds = downstream

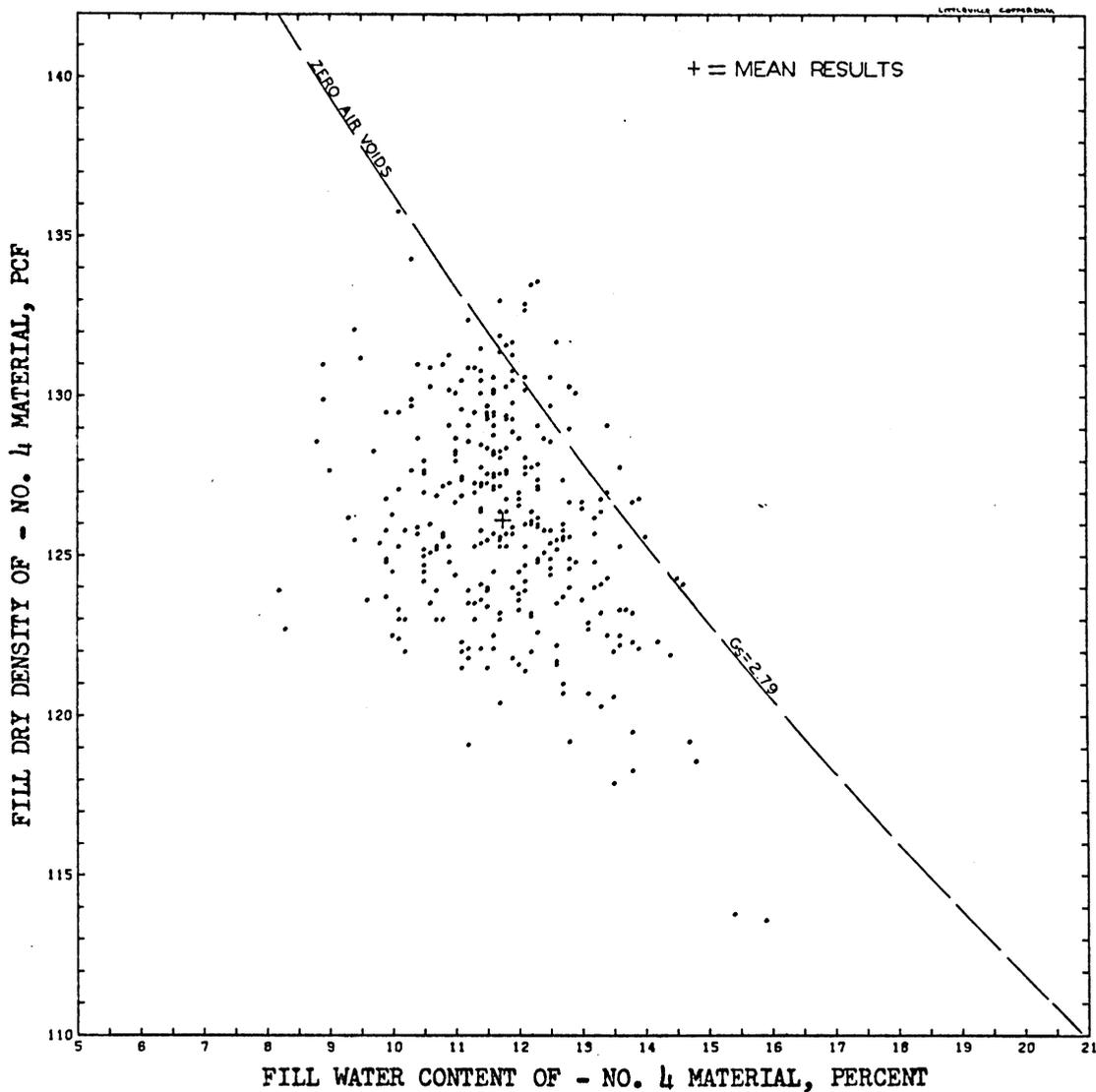
Table 6

Fill Density Data, Type II Random Fill and Pervious Zone Material

PHYSICAL DATA										
Embankment Zone	No. Tests	Fill Dry Density, γ_d pcf		Providence Vibrated Density (PVD) pcf		Fill Percent Providence Vibrated Density, pcf		Desired Minimum Percent PVD	Percent Test Values Below Desired Percent PVD	
		Range	Mean	Range	Mean	Range	Mean			
Dam and Dike, Type II Random	38	104.2 to 150.8	129.4	107.9 to 147.7	131.6	94.9 to 102.3	98.3	95.0	2.6	
Dam, Inclined Drain	74	116.6 to 151.4	137.8	118.0 to 152.6	141.0	94.7 to 105.6	97.8	95.0	3.8	
Dam and Dike, Horizontal Drainage Blanket	79	121.4 to 148.2	132.9	125.7 to 146.2	137.1	94.1 to 103.2	97.1	95.0	10.1	
Dam and Dike, Gravel Blanket	14	129.1 to 144.9	136.8	135.4 to 150.8	141.8	95.0 to 102.7	97.4	95.0	0.0	

STATISTICAL DATA									
	Standard Deviation (σ) Percentage Points	Percent of Test Values					Coefficient of Variation (σ/m) %	Pearson's First Coefficient of Skewness	
		Within			Above + 1 σ (heavier)	Below - 1 σ (lighter)			
		1 σ (68.3)*	2 σ (95.5)*	3 σ (99.7)*					
Dam and Dike, Type II Random	1.85	76.3	97.4	100.0	5.3	18.4	1.88	- 0.65	
Dam Inclined Drain	1.99	70.3	97.3	98.6	12.1	17.6	2.04	+ 0.16	
Dam and Dike, Horizontal Drainage Blanket	2.17	73.4	94.9	100.0	17.7	8.9	2.23	+ 0.73	
Dam and Dike, Gravel Blanket	2.22	No distribution Computed						2.28	

* Figures in parentheses are values for normal frequency curve



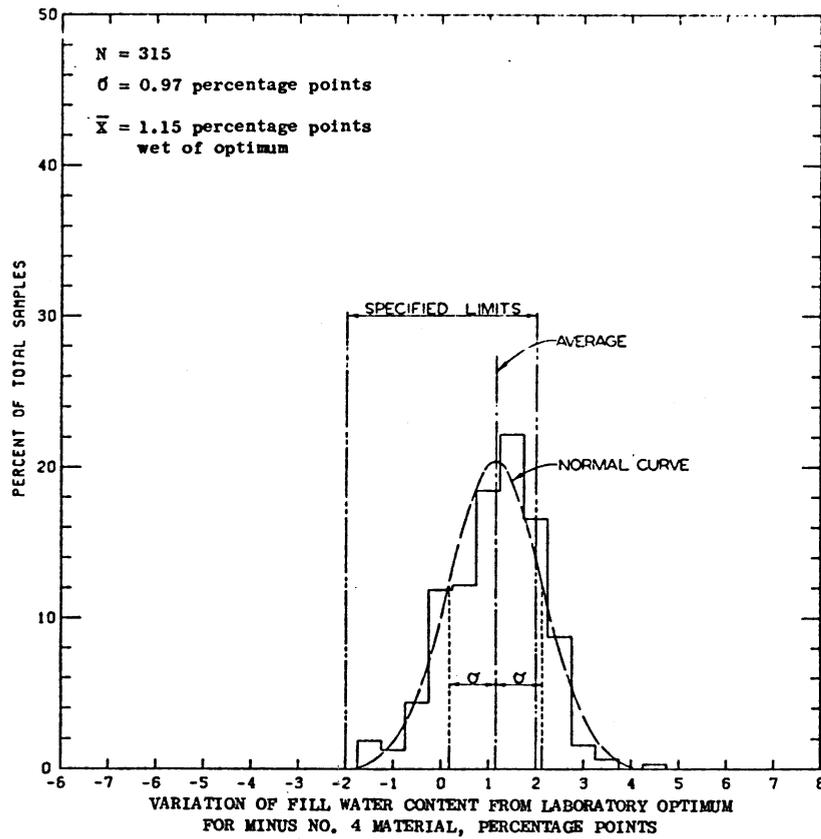
NO. TESTS 315

MEAN FILL WATER CONTENT
OF MINUS NO. 4 MATERIAL 11.72 percent.

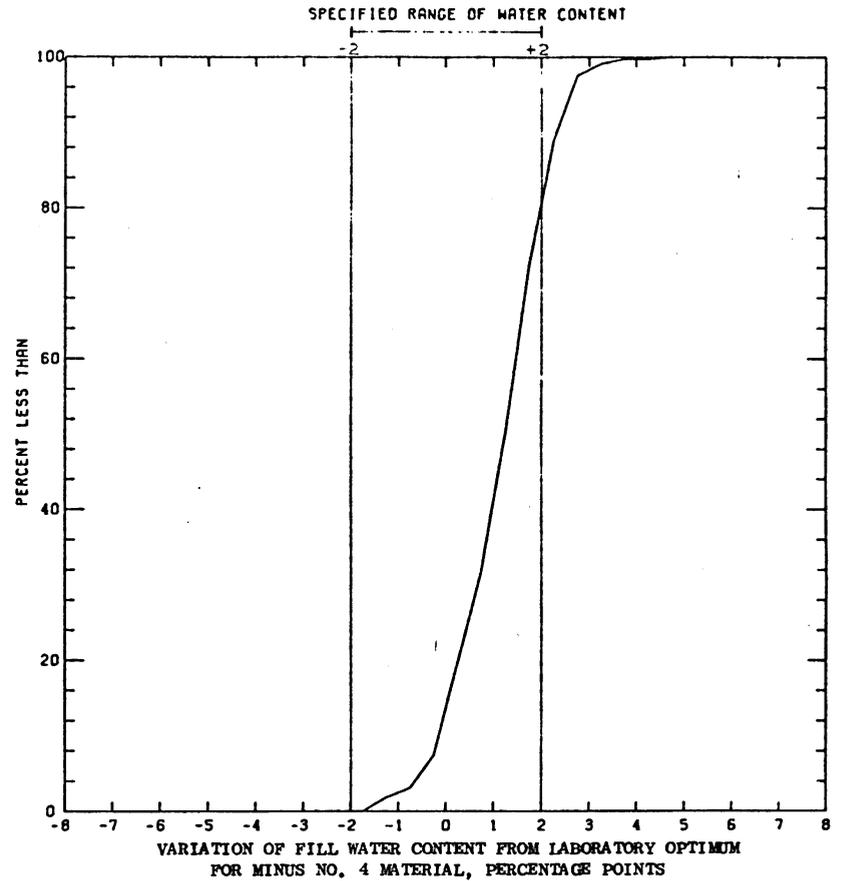
MEAN FILL DRY DENSITY OF
MINUS NO. 4 MATERIAL 126.12 pcf

FILL DRY DENSITY VERSUS FILL
WATER CONTENT, DAM IMPERVIOUS
FILL (COFFERDAM PORTION)

PLATE 2

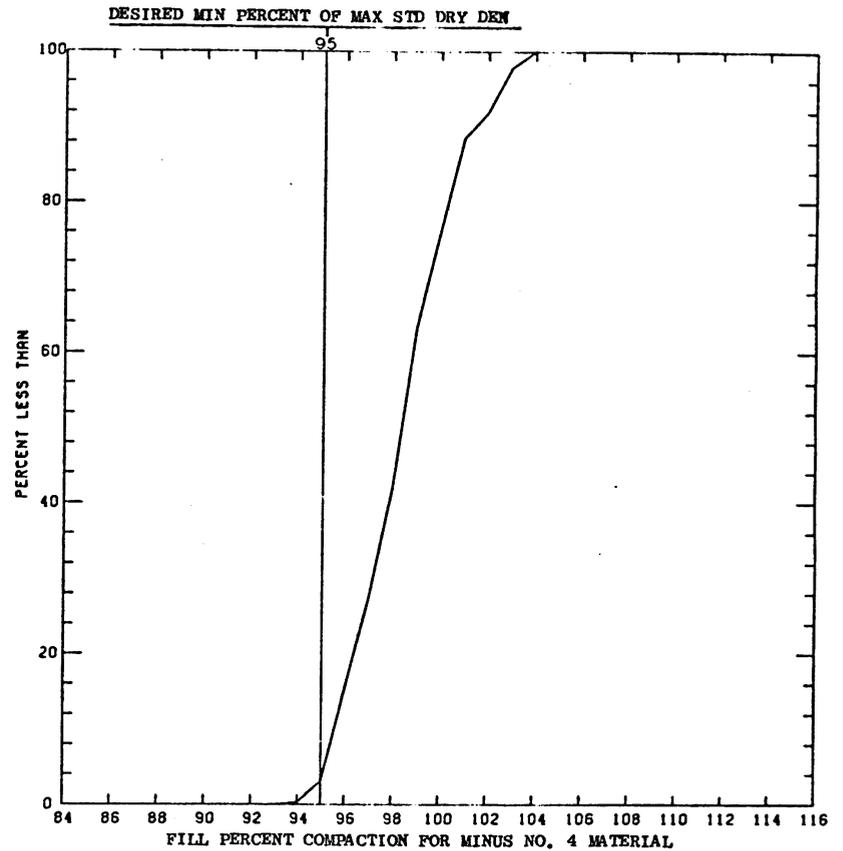
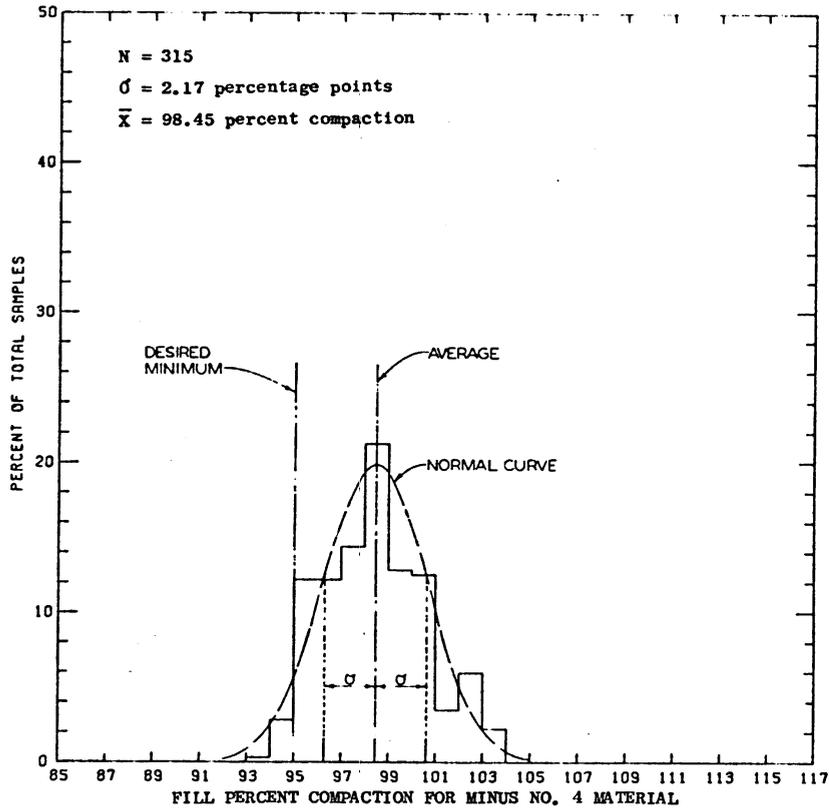


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
16.51	70.16	13.33

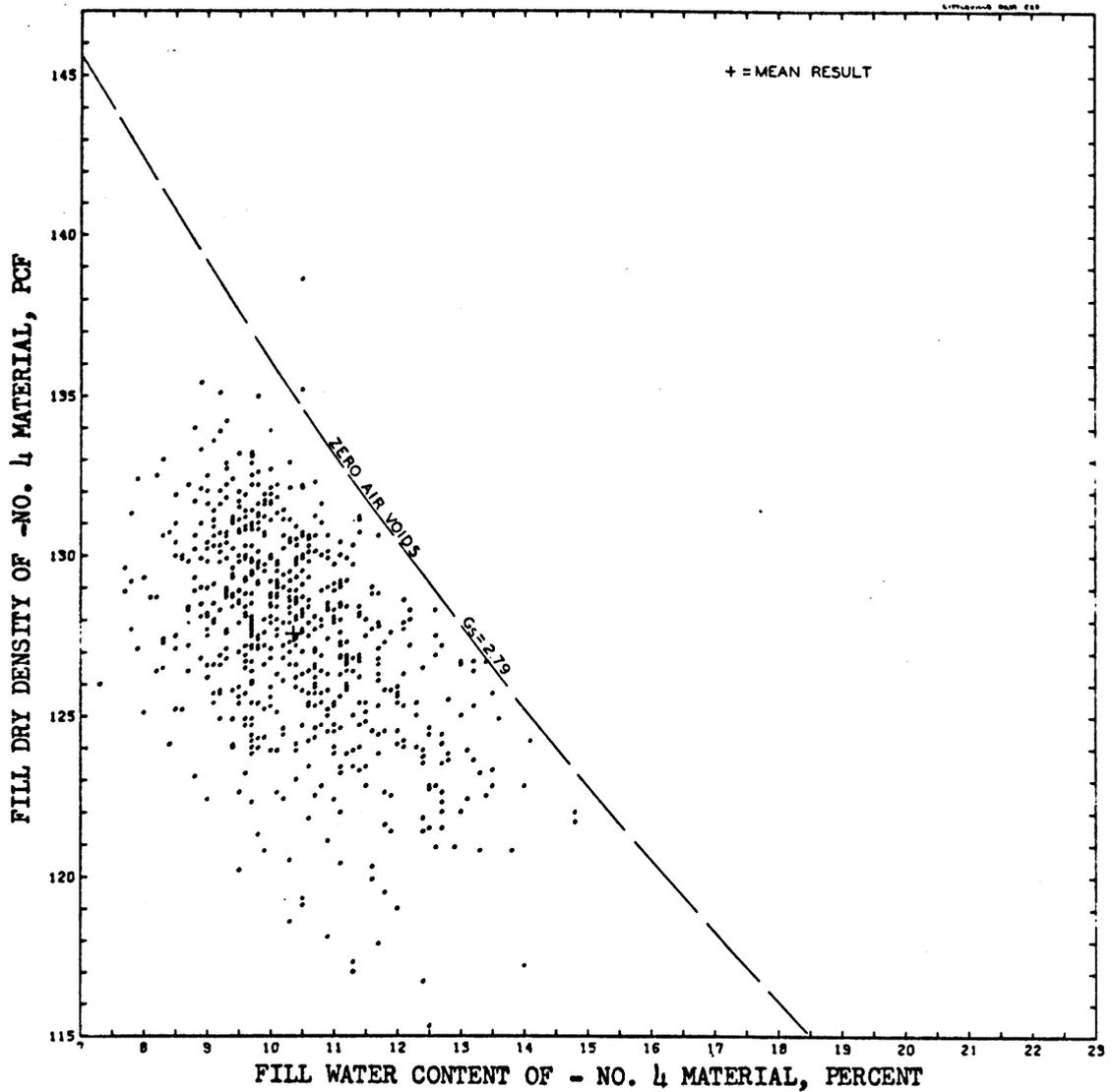


PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS		
BELOW	WITHIN	ABOVE
0.00	84.13	15.87

FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF FILL WATER CONTENT, DAM IMPERVIOUS FILL (COFFERDAM)



FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION
 OF FILL PERCENT COMPACTION, DAM IMPERVIOUS FILL (COFFERDAM)

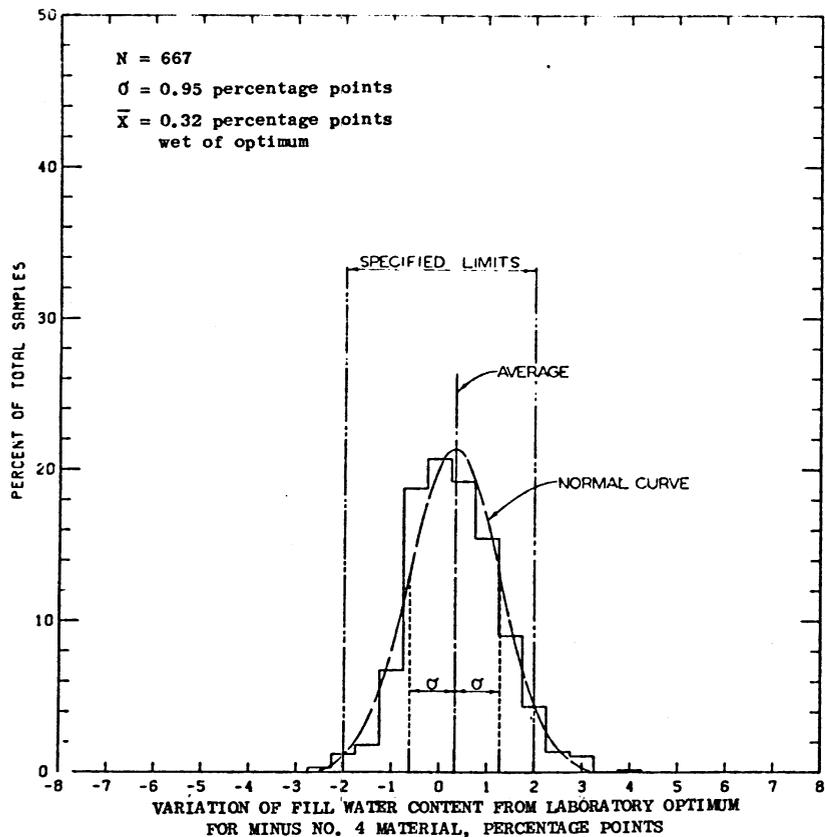


NO. TESTS 667

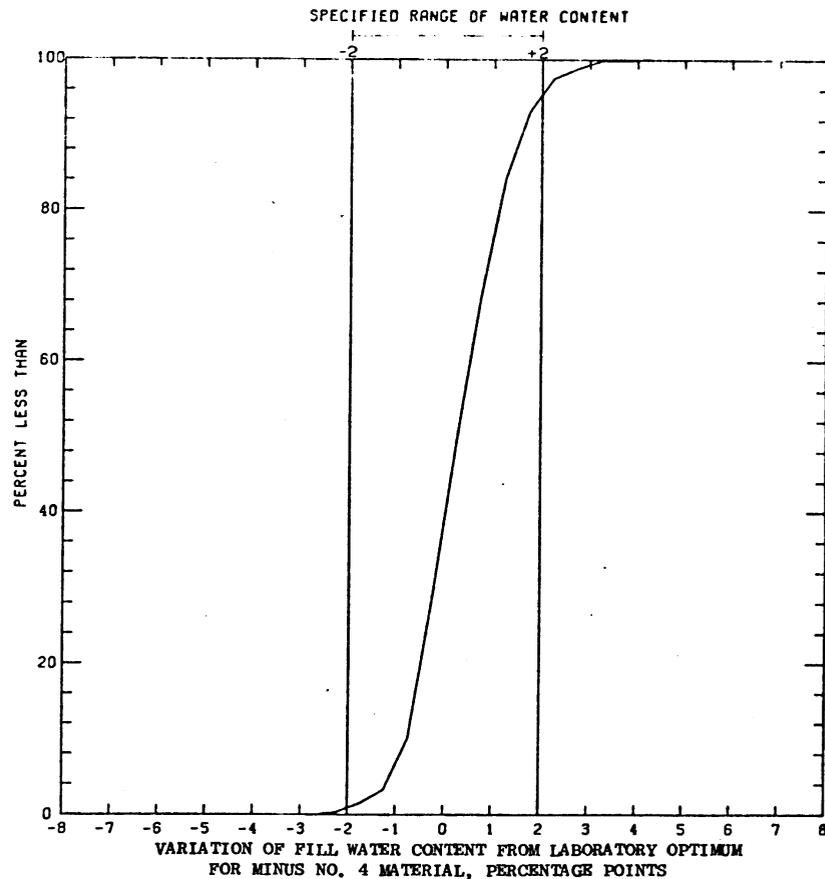
MEAN FILL WATER CONTENT
OF MINUS NO. 4 MATERIAL 10.4 percent

MEAN FILL DRY DENSITY OF
MINUS NO. 4 MATERIAL 127.6 pcf

FILL DRY DENSITY VERSUS FILL
WATER CONTENT, DAM IMPERVIOUS
FILL (EXCLUDING COFFERDAM)

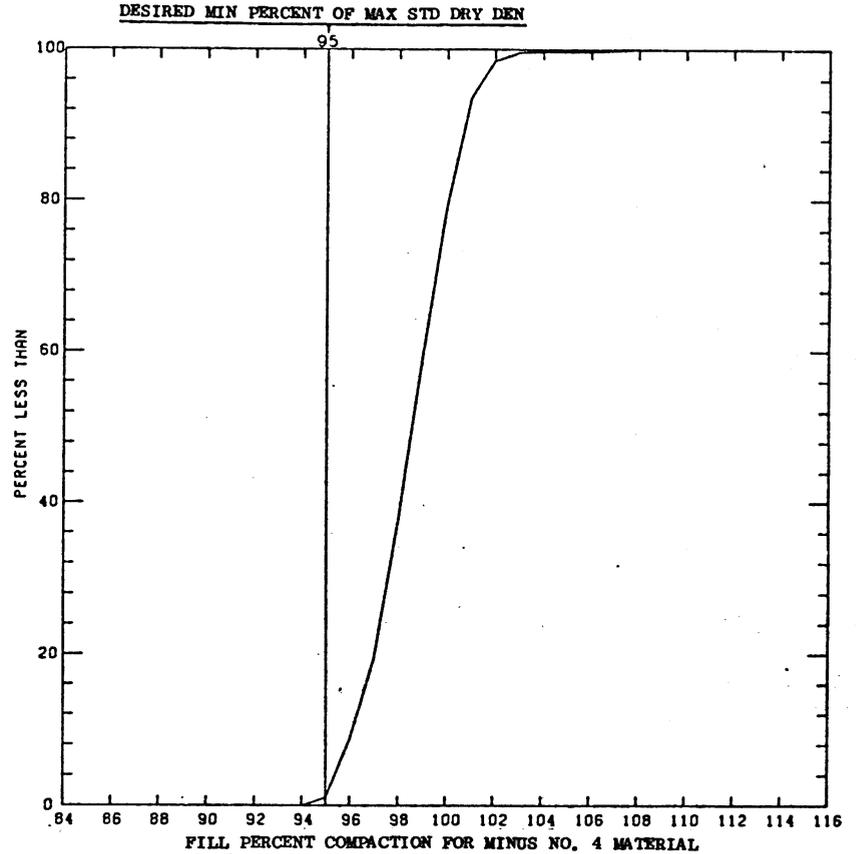
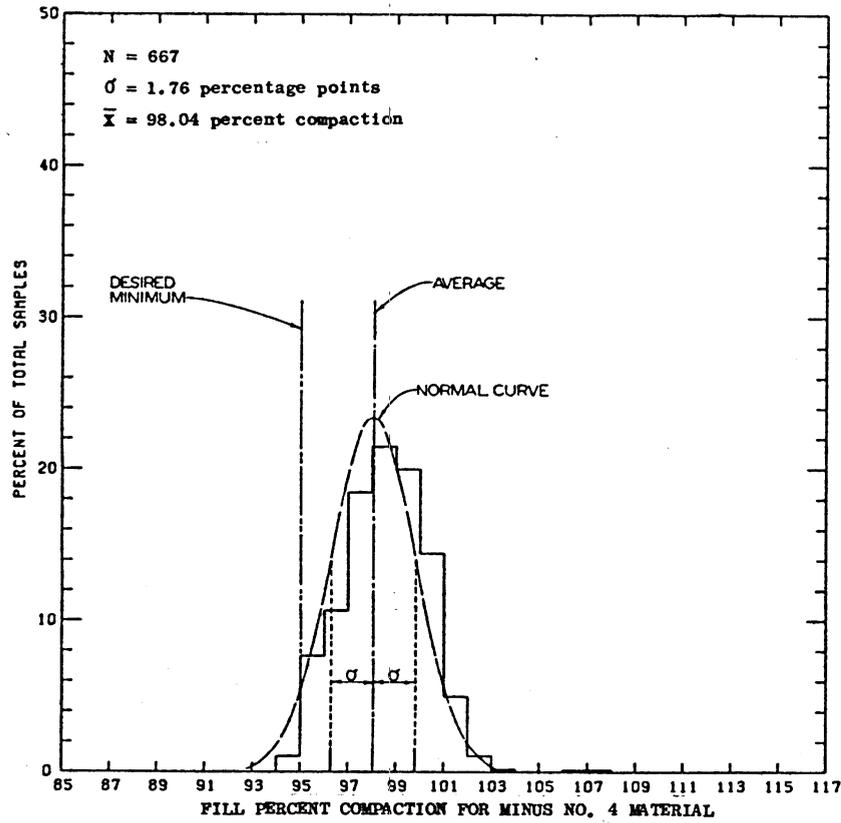


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
14.77	69.72	15.51

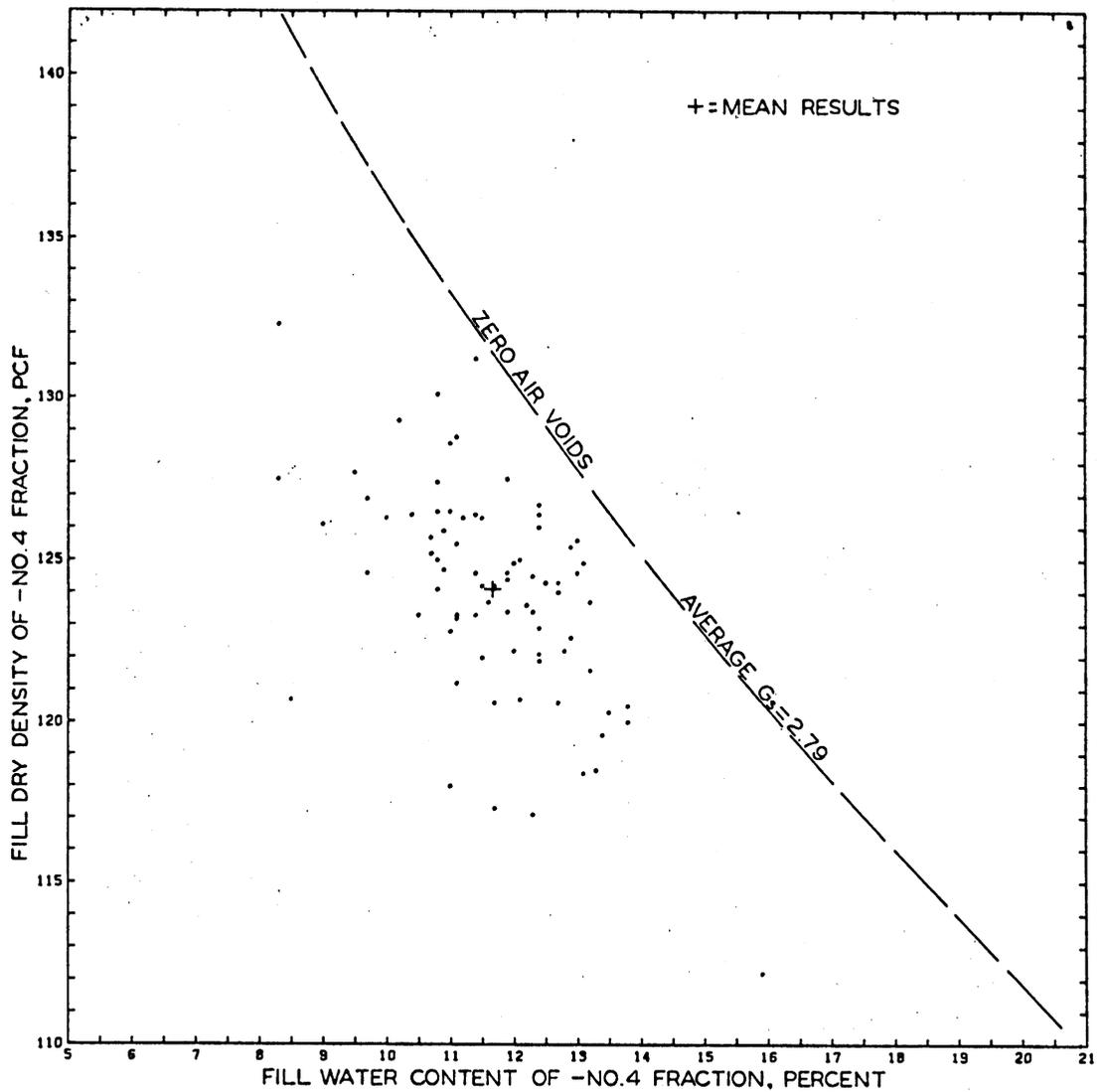


PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS		
BELOW	WITHIN	ABOVE
0.60	94.75	4.65

FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF FILL WATER CONTENT, DAM IMPERVIOUS FILL (EXCLUDING COFFERDAM)



FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF FILL PERCENT COMPACTION, DAM IMPERVIOUS FILL (EXCLUDING COPFERDAM)

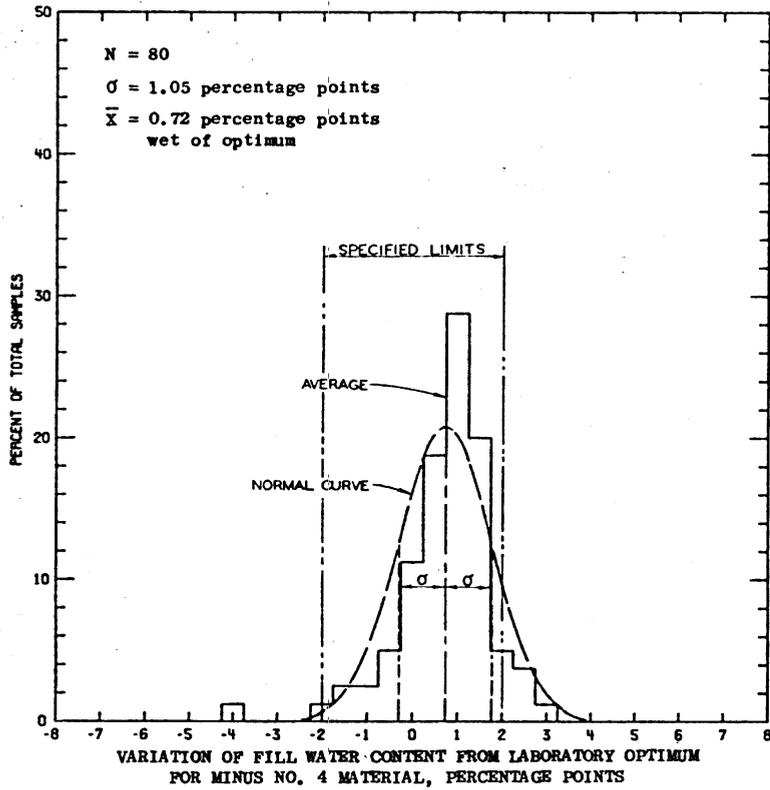


NO. TESTS 80

MEAN FILL WATER CONTENT
OF MINUS NO. 4 FRACTION 11.7 percent

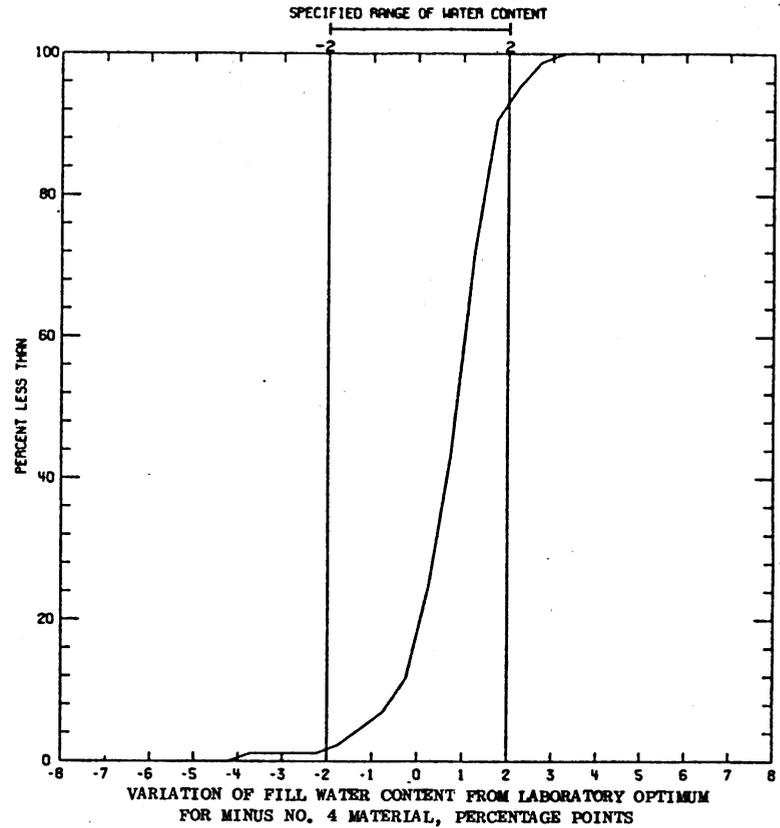
MEAN FILL DRY DENSITY OF
MINUS NO. 4 FRACTION 124.1 pcf

FILL DRY DENSITY
VERSUS FILL WATER
CONTENT, DIKE
IMPERVIOUS ZONE



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

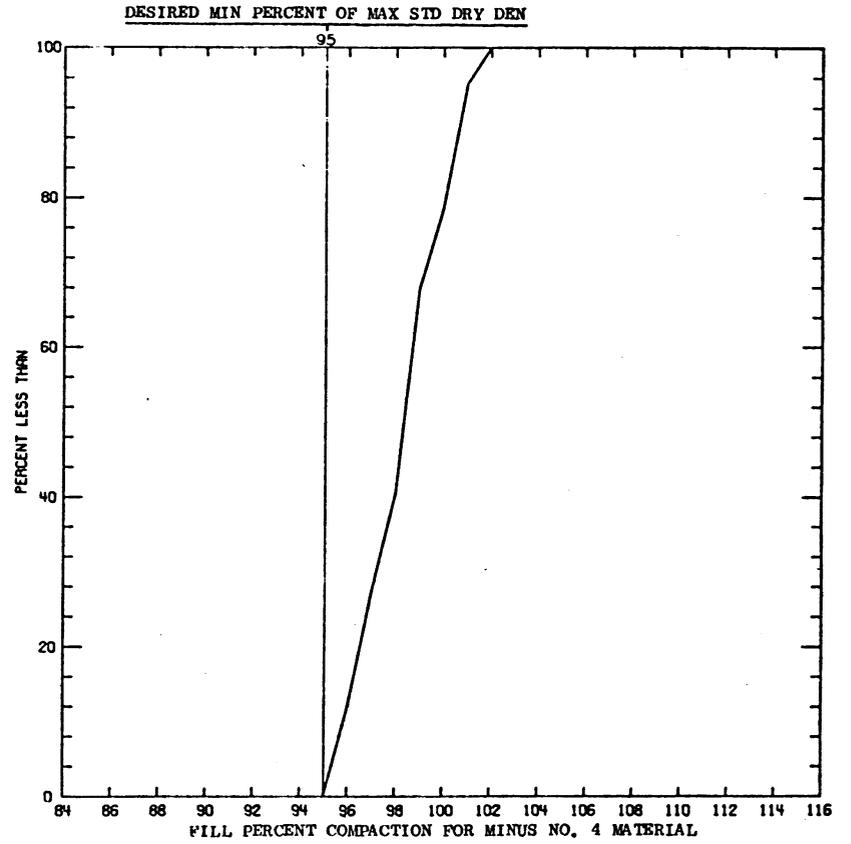
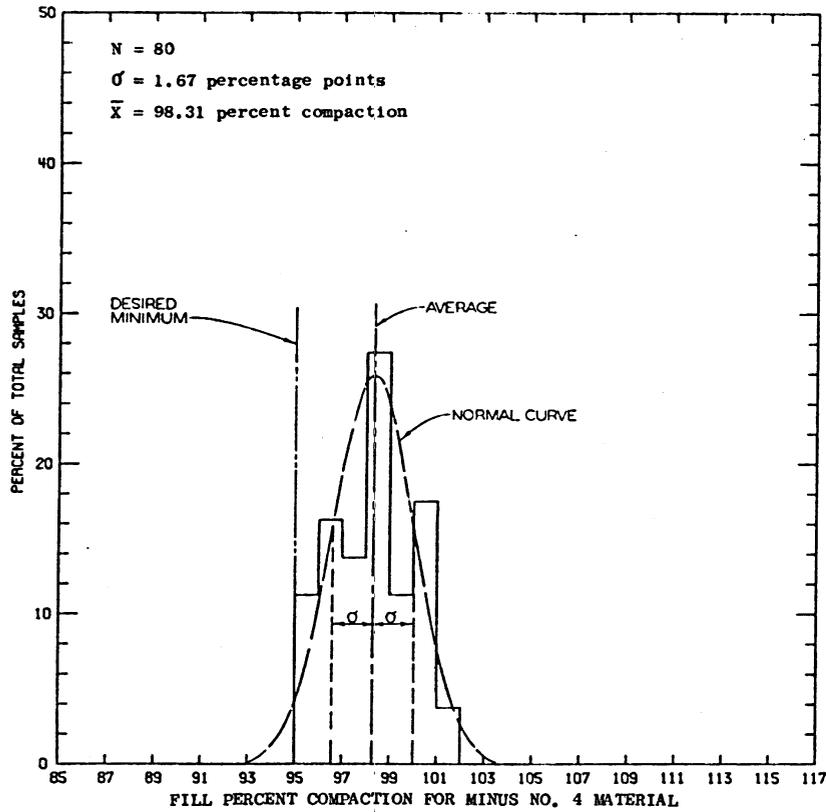
BELOW	WITHIN	ABOVE
12.50	78.75	8.75



PERCENT OF TOTAL SAMPLES WITH
RESPECT TO SPECIFIED LIMITS

BELOW	WITHIN	ABOVE
1.25	92.50	6.25

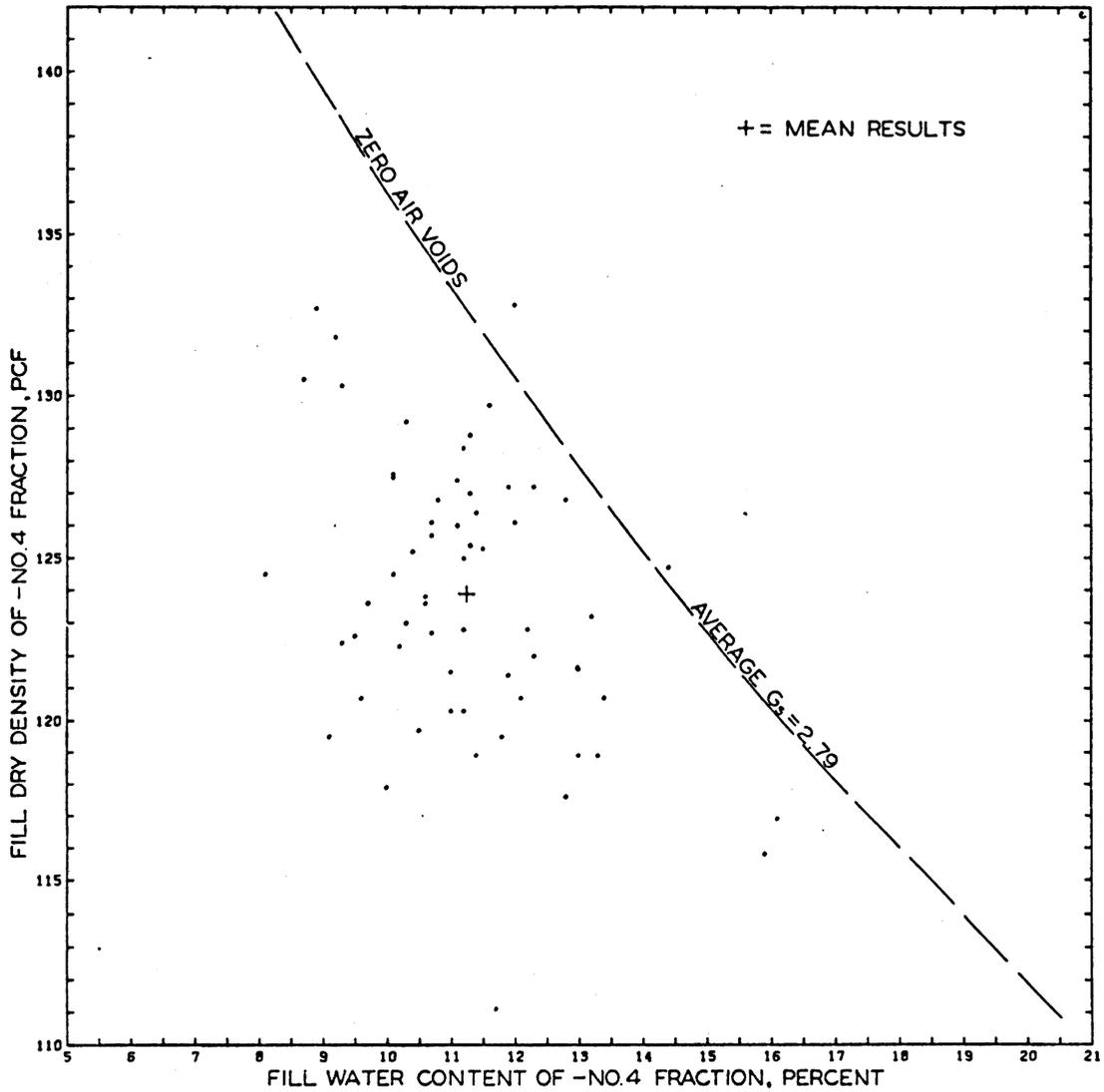
FREQUENCY HISTOGRAM AND CUMULATIVE
FREQUENCY DISTRIBUTION OF FILL WATER
CONTENT, DIKE IMPERVIOUS FILL



PERCENT OF TOTAL SAMPLES WITH
 RESPECT TO DESIRED % COMPACTION

BELOW	ABOVE
0.00	100.00

FREQUENCY HISTOGRAM AND CUMULATIVE
 FREQUENCY DISTRIBUTION OF FILL PERCENT
 COMPACTION, DIKE IMPERVIOUS FILL

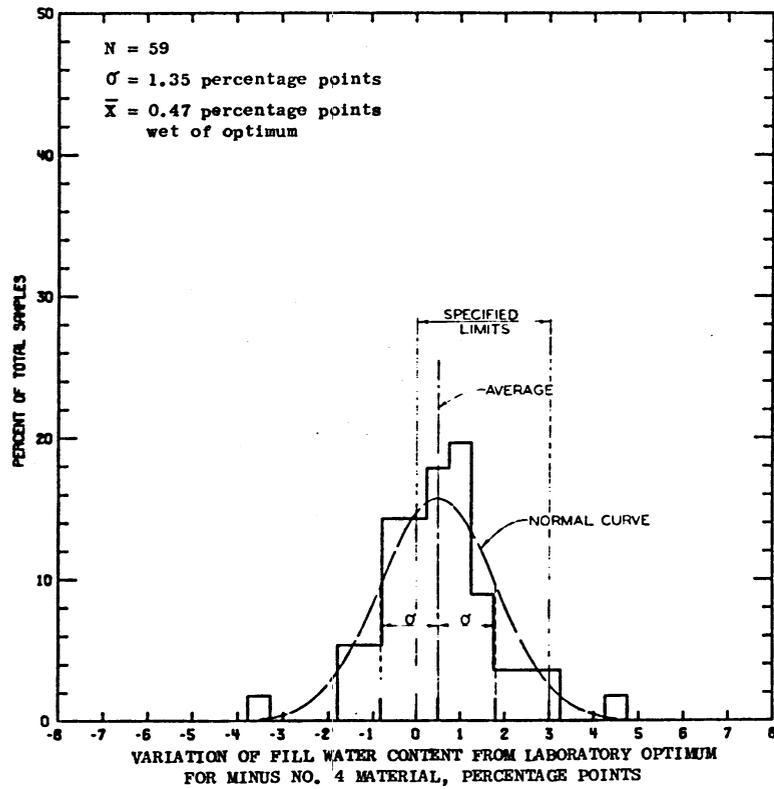


NO. TESTS 59

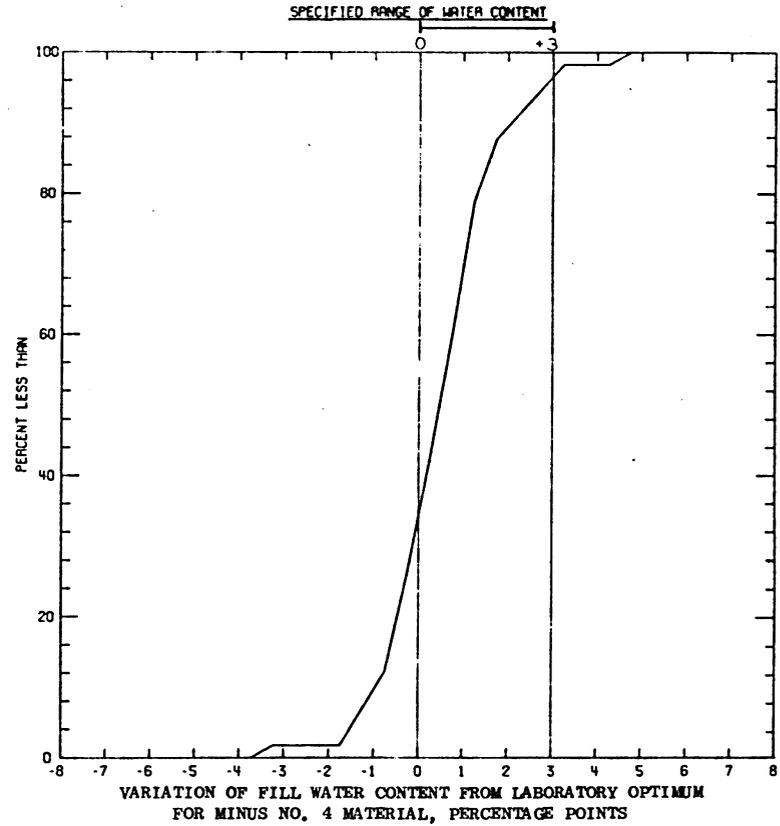
MEAN FILL WATER CONTENT
OF MINUS NO. 4 FRACTION 11.2 percent

MEAN FILL DRY DENSITY OF
MINUS NO. 4 FRACTION 123.9 pcf

FILL DRY DENSITY
VERSUS FILL WATER
CONTENT, DAM IM-
PERVIOUS BACKFILL

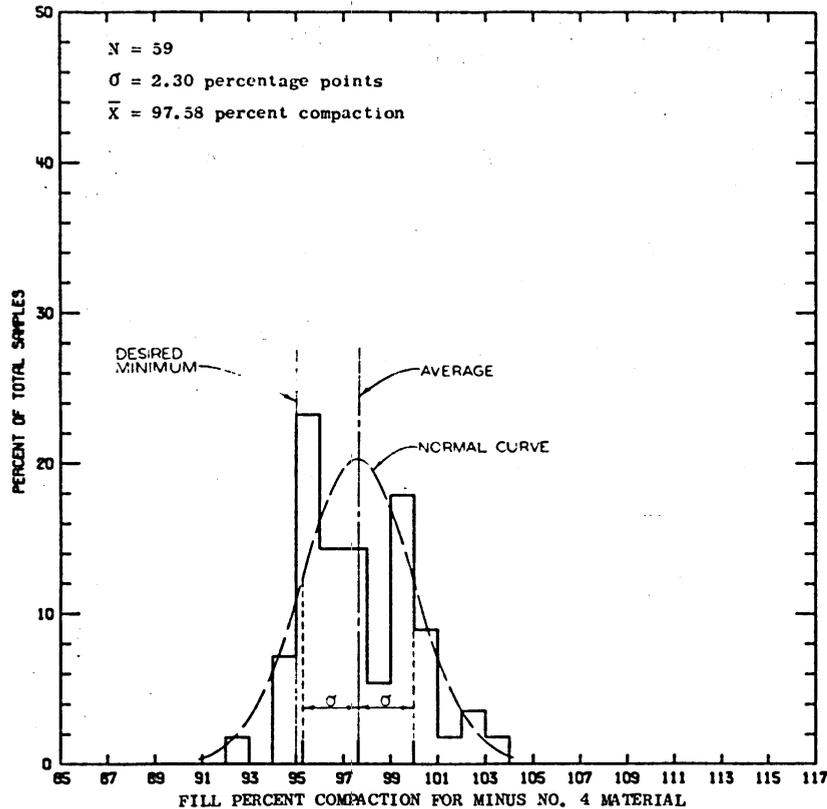


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
10.17	79.66	10.17

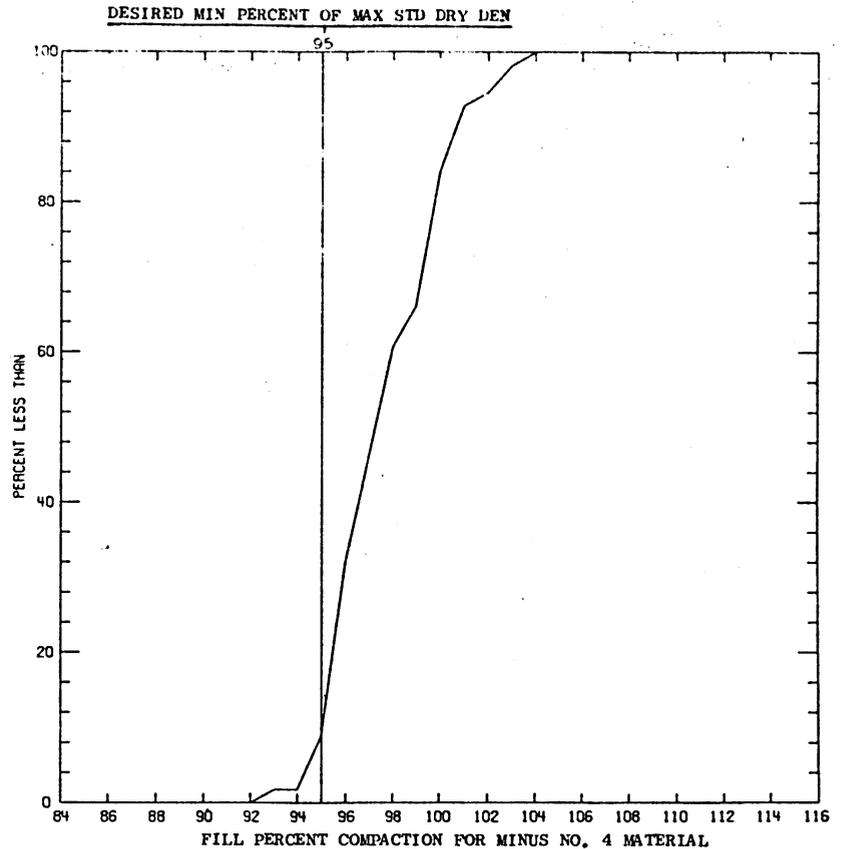


PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS		
BELOW	WITHIN	ABOVE
32.20	64.41	3.39

FREQUENCY HISTOGRAM AND CUMULATIVE
 FREQUENCY DISTRIBUTION OF FILL WATER
 CONTENT, DAM IMPERVIOUS BACKFILL

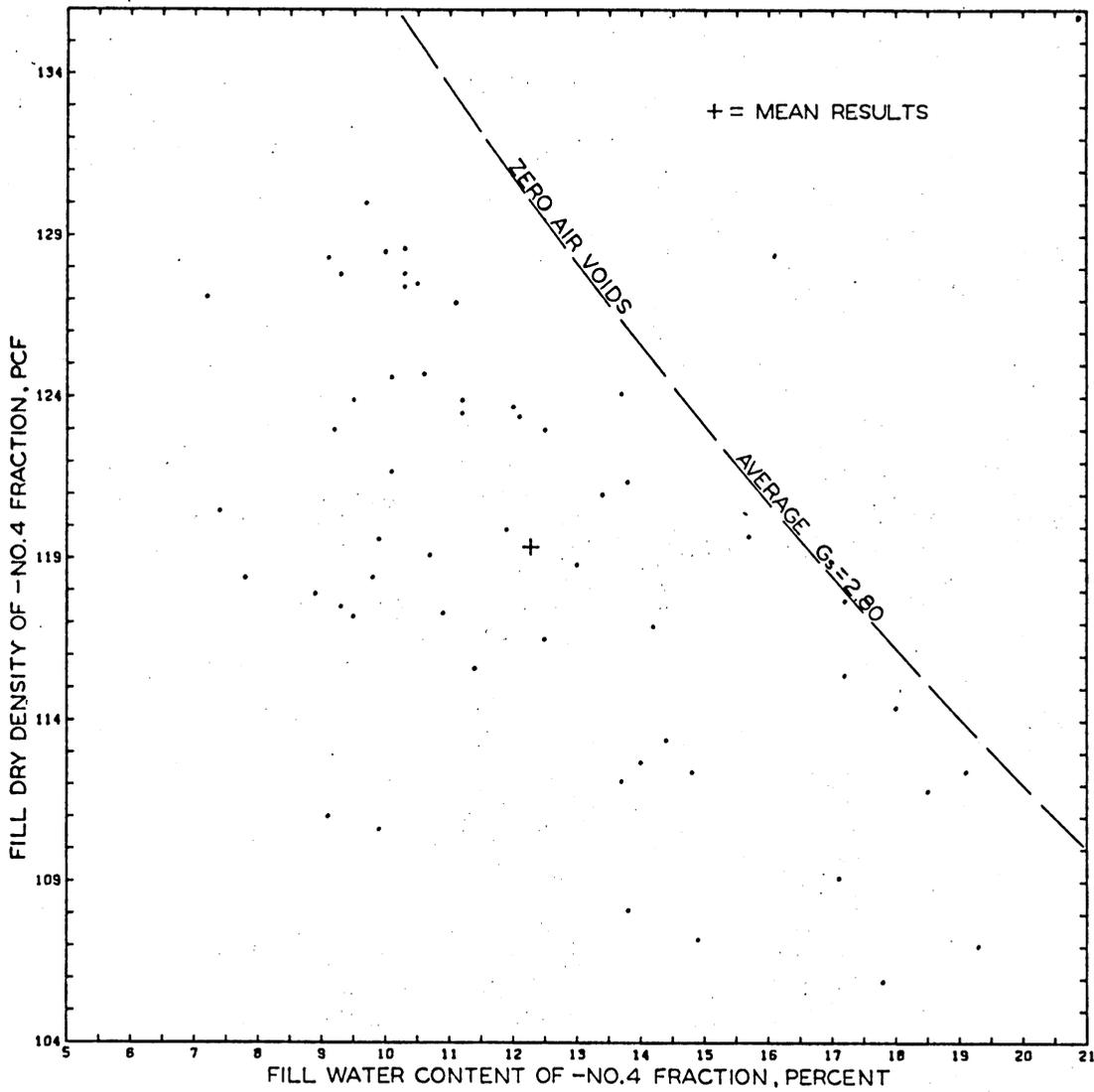


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
15.25	69.50	15.25



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION	
BELOW	ABOVE
8.47	91.53

FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF FILL PERCENT COMPACTION, DAM IMPERVIOUS BACKFILL

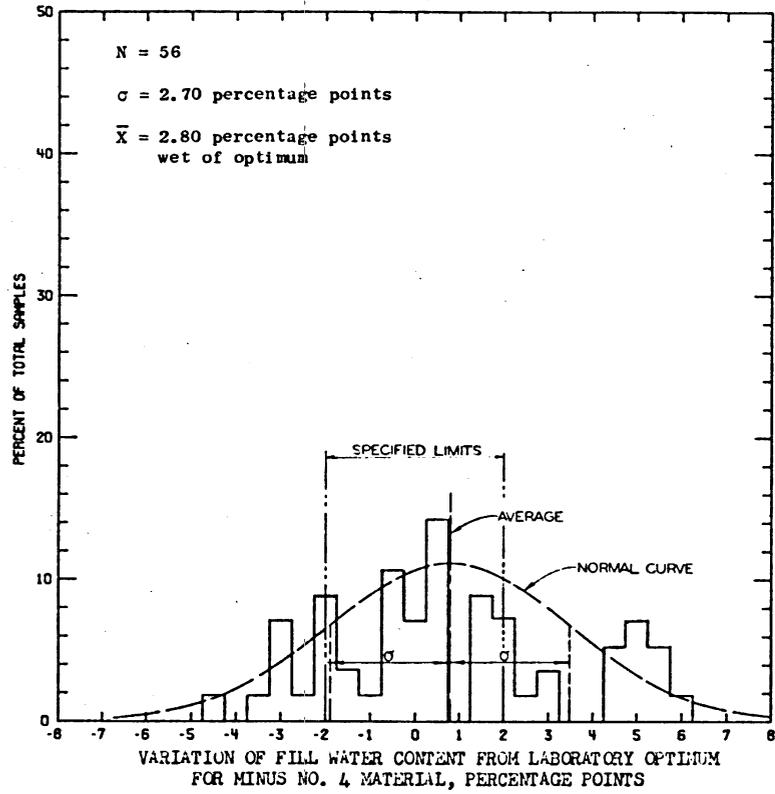


NO. TESTS 56

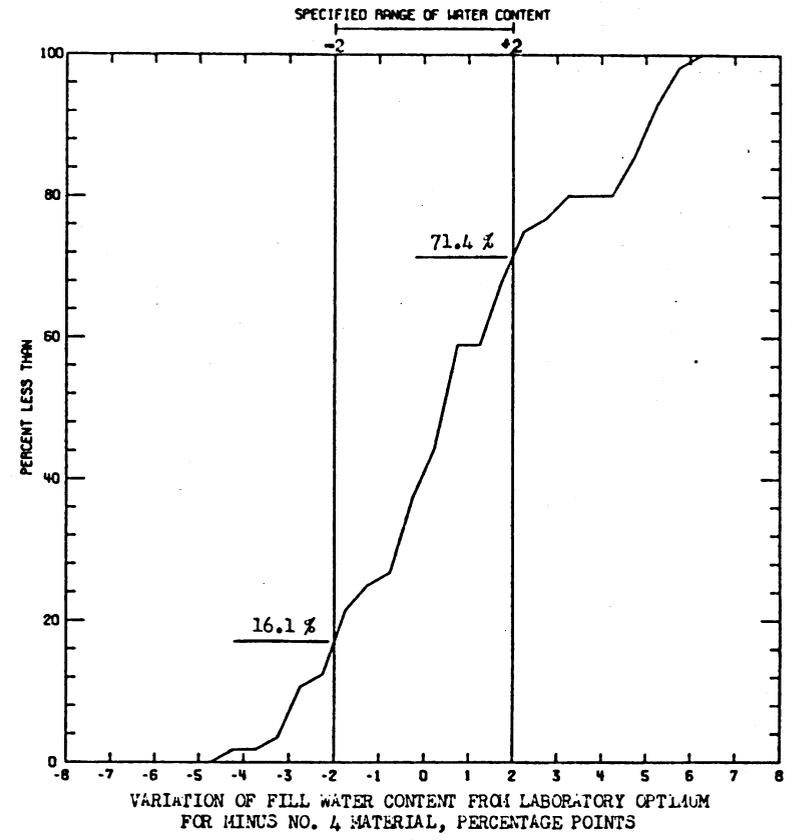
MEAN FILL WATER CONTENT
OF MINUS NO. 4 FRACTION 12.3 percent

MEAN FILL DRY DENSITY OF
MINUS NO. 4 FRACTION 119.4 pcf

FILL DRY DENSITY VERSUS
FILL WATER CONTENT, DAM
AND DIKE, TYPE I RANDOM FILL

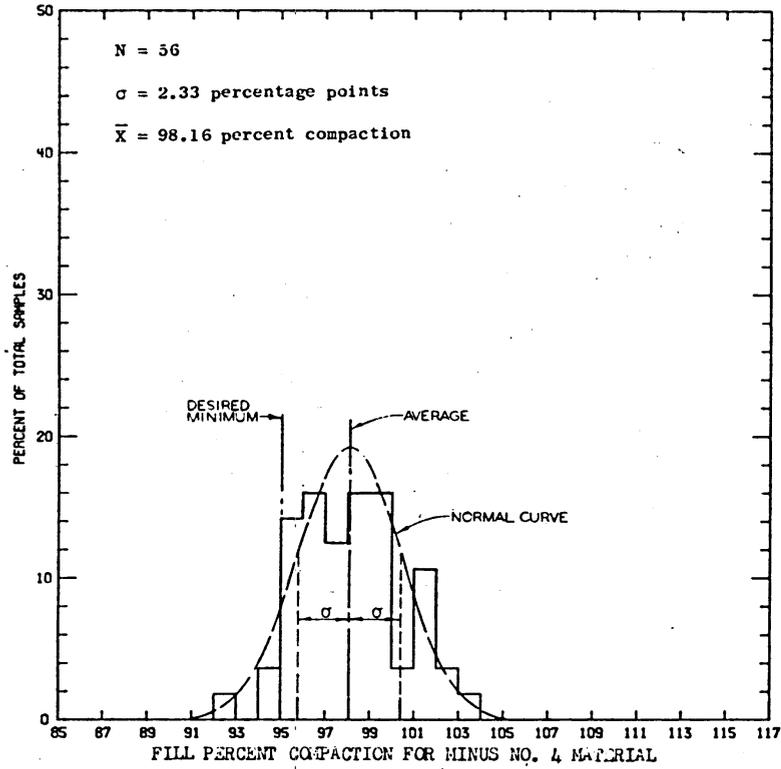


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
16.07	64.29	19.64

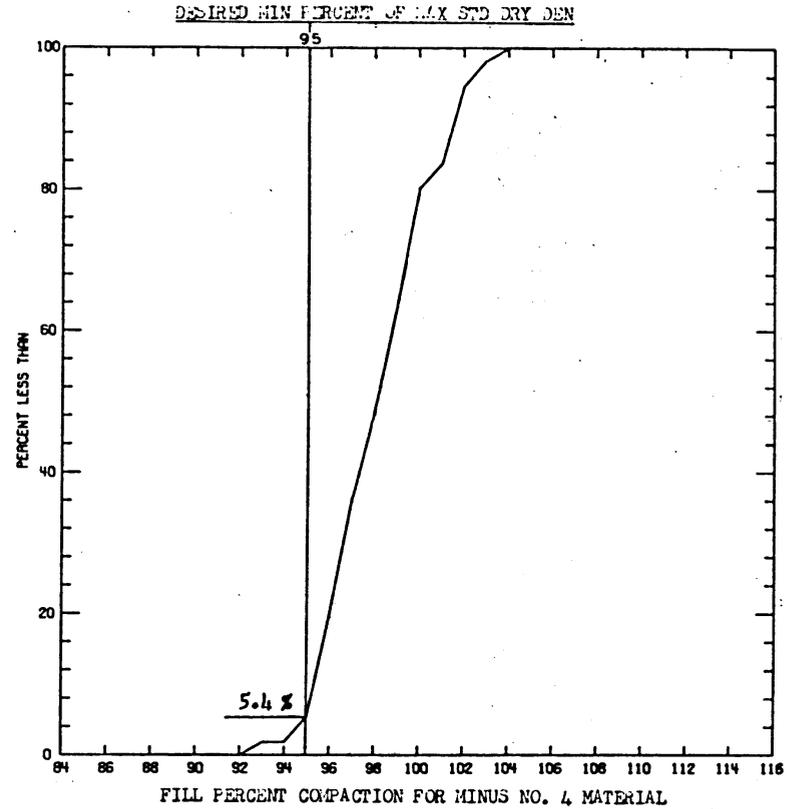


PERCENT OF TOTAL SAMPLES WITH RESPECT TO SPECIFIED LIMITS		
BELOW	WITHIN	ABOVE
16.07	55.36	28.57

FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF FILL WATER CONTENT, DAM AND DIKE, TYPE I RANDOM FILL



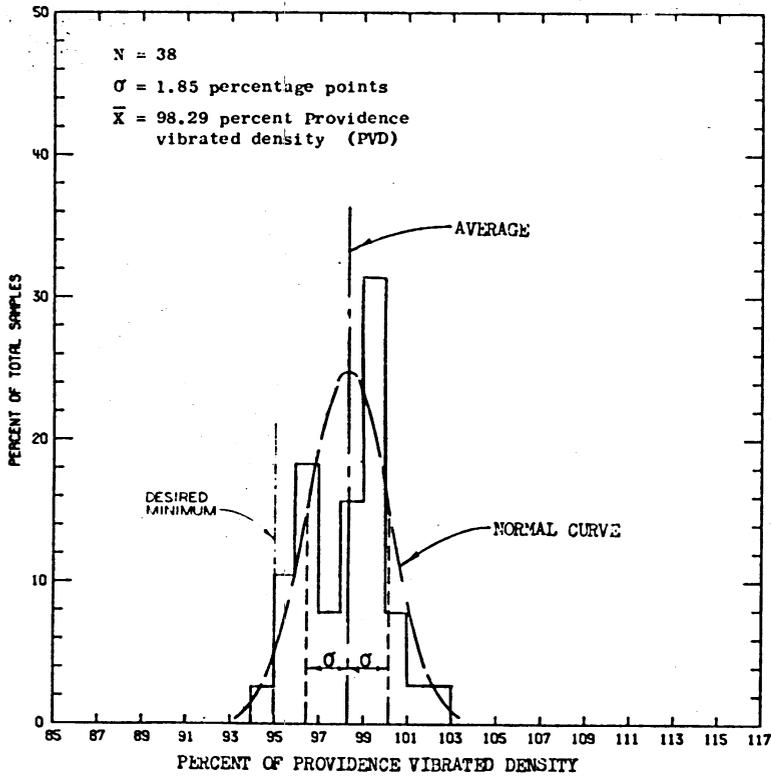
PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
<u>BELOW</u>	<u>WITHIN</u>	<u>ABOVE</u>
16.07	67.86	16.07



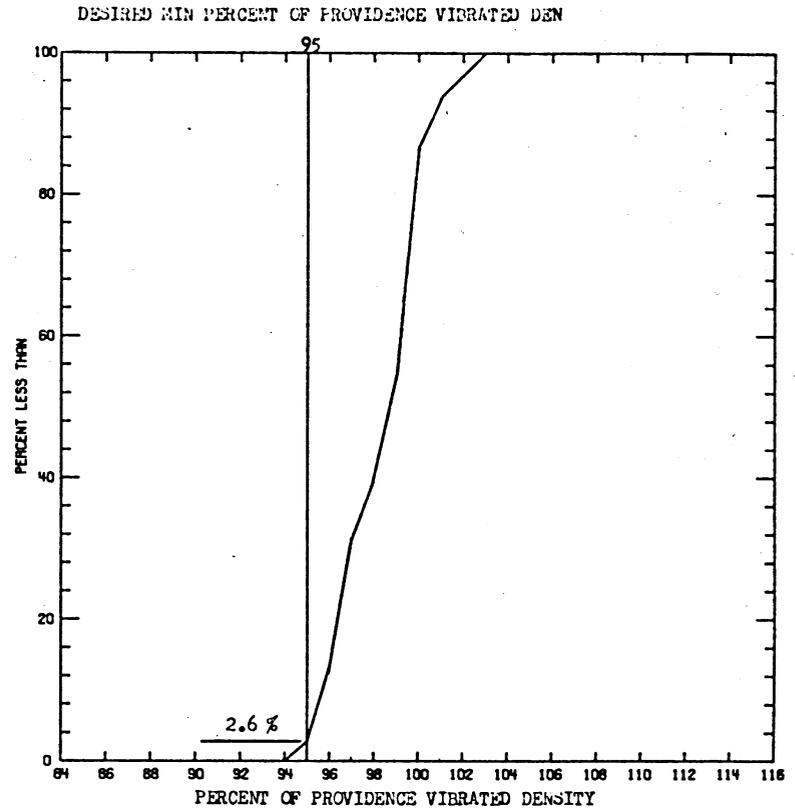
PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED % COMPACTION	
<u>BELOW</u>	<u>ABOVE</u>
5.36	94.64

FREQUENCY HISTOGRAM AND CUMULATIVE
 FREQUENCY DISTRIBUTION OF FILL PERCENT
 COMPACTION, DAM AND DIKE, TYPE I RANDOM FILL

PLATE 16

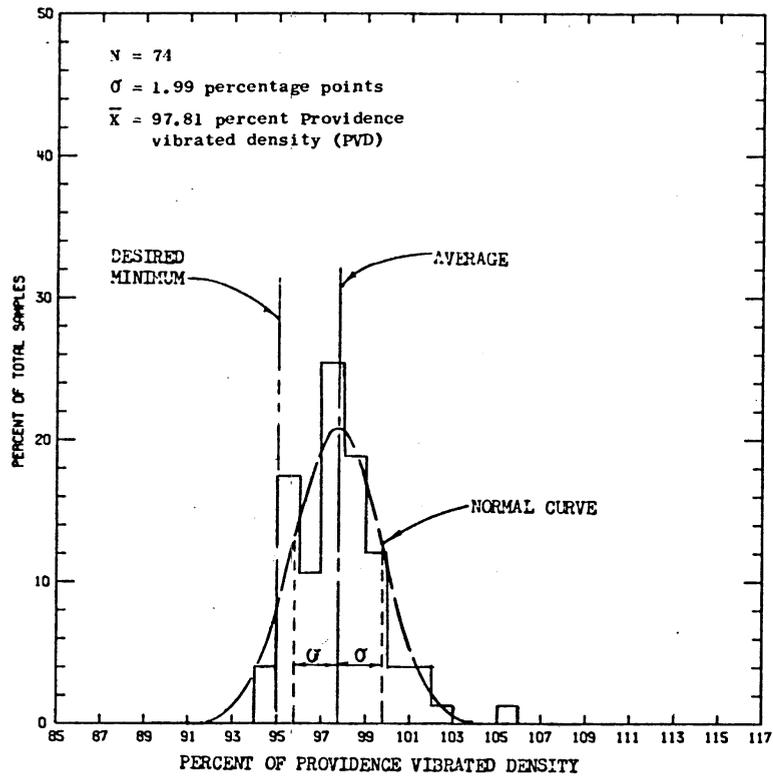


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
18.42	76.32	5.26

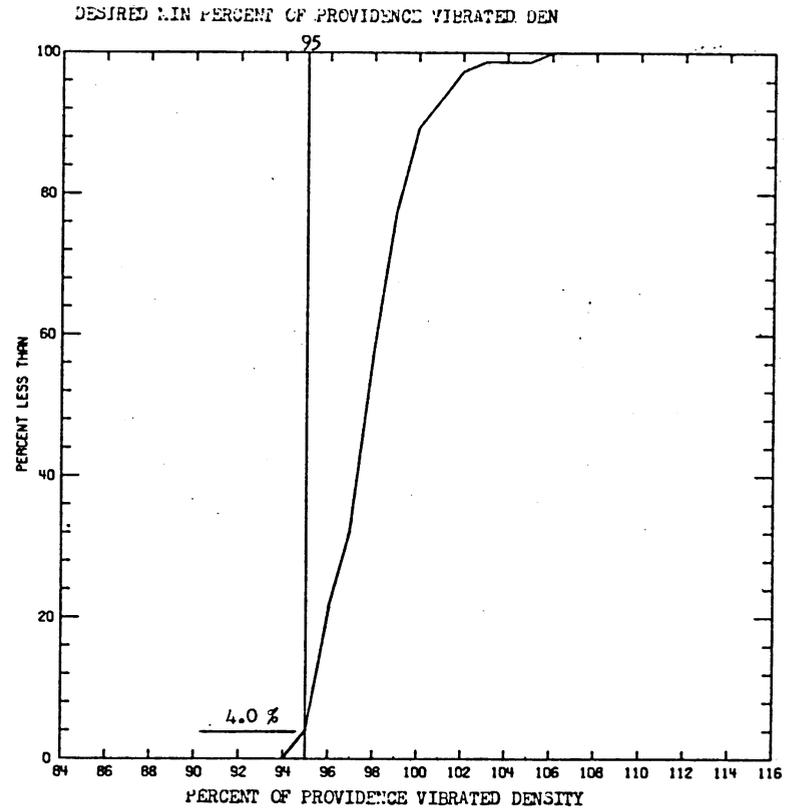


PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED PERCENT PVD	
BELOW	ABOVE
2.63	97.37

FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF PERCENT PROVIDENCE VIBRATED DENSITY, DAM AND DIKE, TYPE II RANDOM FILL

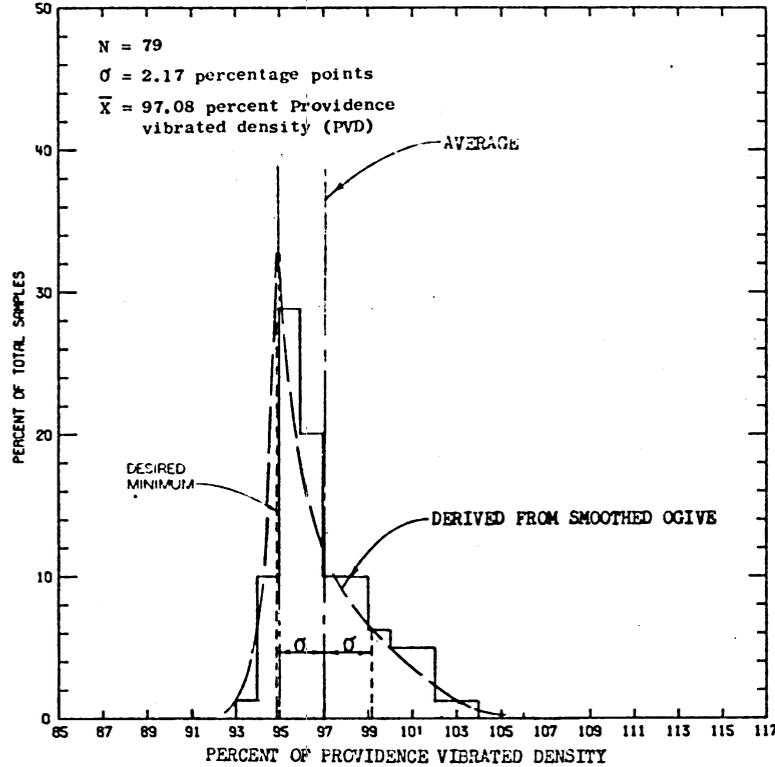


PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
17.57	70.27	12.16

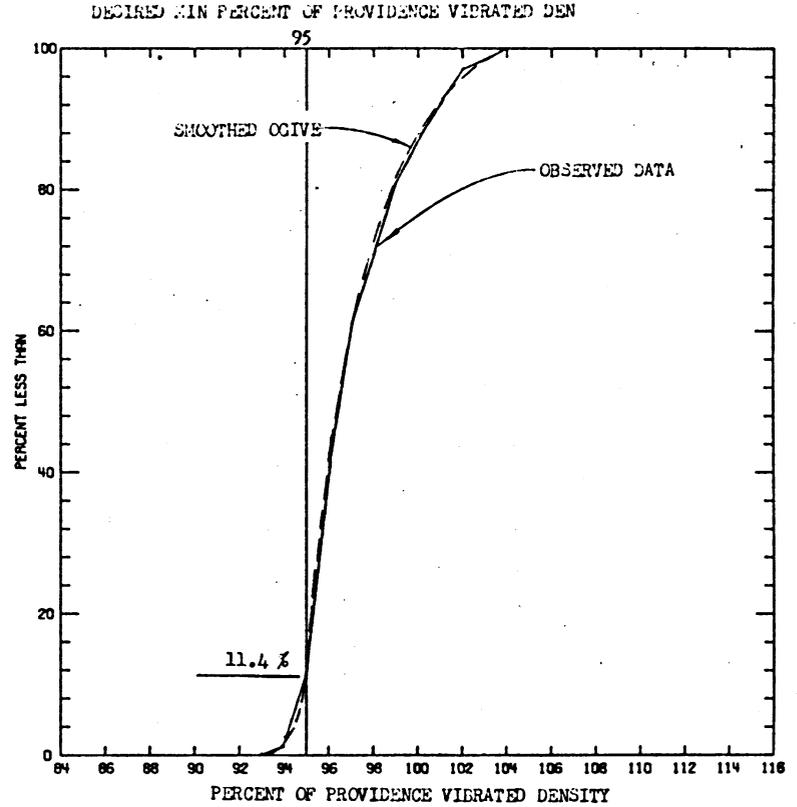


PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED PERCENT PVD	
BELOW	ABOVE
4.05	95.95

FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF PERCENT PROVIDENCE VIBRATED DENSITY, DAM PERVIOUS FILL (INCLINED DRAIN)



PERCENT OF TOTAL SAMPLES WITH RESPECT TO ONE STD. DEV. (σ)		
BELOW	WITHIN	ABOVE
8.86	73.42	17.72



PERCENT OF TOTAL SAMPLES WITH RESPECT TO DESIRED PERCENT PVD	
BELOW	ABOVE
11.39	88.61

FREQUENCY HISTOGRAM AND CUMULATIVE FREQUENCY DISTRIBUTION OF PERCENT PROVIDENCE VIBRATED DENSITY, DAM AND DIKE, PERVIOUS FILL (DRAINAGE BLANKETS)

APPENDIX A

DEFINITION OF BASIC TERMS

f Frequency, number of measurements in a given cell, class, or group

f_r Relative frequency, f/N

N Number of measurements, observations, or scores

R Range, the difference between the highest and lowest valued measurements in a given sample

σ Standard deviation or root-mean-square deviation for a given sample, $\sqrt{\sum (x - \bar{X})^2 / (N - 1)}$

C_v Coefficient of variation, $\frac{100\sigma}{\bar{x}}$, percent

x Individual value of a measurement, observation, or score

\bar{X} Arithmetic mean, $\frac{\sum_{i=1}^N x_i}{N}$

χ^2 chi square; a statistic which serves as a measure of the difference

between observed and expected frequencies, $\sum_{j=1}^k (O_j - E_j)^2 / E_j$

variation the extent to which numerical data tend to spread about an average value is called the variation or dispersion of the data

normal or Gaussian distribution a continuous probability distribution, often used to represent random variation for large samples ($N > 30$)

mode

that value which occurs most frequently in a set of numbers, i.e., it is the most common value; it may not be unique or even exist

skewness

a measure of the degree of asymmetry of a frequency distribution, Pearson's first coefficient = $(\text{mean} - \text{mode})/\sigma$

kurtosis

the degree of peakedness of a frequency distribution usually relative to a normal curve (termed mesokurtic). Distributions with a relatively high peak are termed leptokurtic, and those which are flat with regard to the normal case are termed platykurtic.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE ANALYSIS OF FIELD COMPACTION DATA; Report 2, LITTLEVILLE DAM, WESTFIELD RIVER, MASSACHUSETTS		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Report 2 of a series		
5. AUTHOR(S) (First name, middle initial, last name) Victor H. Torrey, III		
6. REPORT DATE December 1970	7a. TOTAL NO. OF PAGES 85	7b. NO. OF REFS 5
8a. CONTRACT OR GRANT NO.		8b. ORIGINATOR'S REPORT NUMBER(S) Miscellaneous Paper S-70-13, Report 2
a. PROJECT NO.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
c. ES 537		
d.		
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office, Chief of Engineers, U. S. Army Washington, D. C.
13. ABSTRACT This report is a review of the materials, specifications, procedures, equipment, and testing pertinent to construction and compaction control of the earth-fill embankment of Littleville Dam, Westfield River, Mass., constructed by the U. S. Army Engineer Division, New England. This report includes summation and analyses of the compaction control data submitted by the division to the U. S. Army Engineer Waterways Experiment Station. 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, 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.		

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1 NOV 65

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Compacting equipment Earth dams Embankments Littleville Dam Soil compacting						