STATISTICAL GEOTECHNICAL PROPERTIES OF GLACIAL LAKE EDMONTON SEDIMENTS

by

D. G. Fredlund and A. E. Dahlman

Department of Civil Engineering
University of Saskatchewan
Saskatoon, Saskatchewan
and
R. M. Hardy & Associates
Vancouver, B. C. Canada

Proceedings of the First International Conference on Applications of Statistics and Probability to Soil and Structural Engineering

Hong Kong, September 13 to 16, 1971

International Conference on Applications of Statistics and
Probability to Soil and Structural Engineering

STATISTICAL GEOTECHNICAL PROPERTIES OF GLACIAL LAKE EDMONTON SEDIMENTS

by

D. G. Fredlund and A. E. Dahlman

ABSTRACT

The geotechnical properties of proglacial Lake Edmonton sediments have been compiled and analysed statistically. On the basis of data from several hundred test holes, the lake sediment isopachs were first plotted. Due to the uniformity of the stratigraphy, the sediments were categorized and the soil properties were statistically evaluated with respect to depth below ground surface.

The results present the central and dispersion tendencies for the soil properties used in engineering. The statistical properties show relatively low dispersion tendencies except in the cases where the frequency distributions are multimodal. In these situations, more than one distinct soil type is incorporated into the sample, rendering most of the other statistical properties of limited value. However, most frequency distribution curves were unimodal. Several unimodal frequency distributions show consistent skewness. The most pronounced are the distribution curves for unconfined compression strength where the curves can be normalized by using the logarithm of compressive strength for the base scale.

The procedures for analysis used in this paper appear to satisfactorily establish the statistical variables associated with soil properties, provided proper attention is given to the stratigraphy of the area under consideration.

INTRODUCTION

The Edmonton city area is underlain by proglacial lake sediments ranging in thickness from a thin mantle to depths in excess of 50 feet. Glacial till lies below the lacustrine sediments. Boreholes for foundation investigations are generally carried through the lacustrine sediments and well into the glacial till. Over a period of years several hundred test holes have advanced through the Lake Edmonton sediments. Due to the similarity in the subsurface investigation procedure and laboratory testing programs, the results lend themselves to statistical analysis. However, there must first be a stratigraphic basis for grouping and analysing the laboratory test data.

Geological evidence indicates that lateral similarity of soil properties generally exists; however, this need not always be the case since local irregularities during deposition may result in significant variations. Even when performing a foundation investigation for one structure, lateral homogeneity is inferred which may not exist. The mode of deposition of the lacustrine deposit is such that the vertical variability of soil properties can be analysed on the basis of depth below ground surface, providing the depth of sediment does not vary significantly and distinct divisions within the stratigraphy do not occur.

Initially the Edmonton city area was divided into four quadrants and the soil properties analysed statistically for each area. However, the soil properties were not significantly different from a statistical standpoint and for this reason the entire city area was analysed as one unit. The statistical properties presented indicate the lateral and vertical variability of soil properties on an area basis.

Statistical evaluation of soil properties cannot be directly applied to foundation design or other soil mechanics problems; however, this type of presentation provides the engineer with a valuable indication of the "central" and "dispersion" tendencies of the soil deposit. Statistics applied to soil properties should NOT be considered an end in itself but rather an aid for arriving at valid assessments and relationships. There has been considerable application of statistics of surficial soils for highway engineering purposes (Hampton, 1961: Liu and Thornburn, 1964; 1965; Thornburn, Morse and Liu, 1966); however, few attempts have been made to apply statistics to entire soil strata of common geological origin (Lumb, 1966). Summaries of the engineering soil properties over a considerable area have been compiled by numerous research workers (Peck and Reed, 1954; Ladd and Luschev, 1965; Hooper and Butler, 1966). The application of the probability decision theory to soil mechanics problems (Folayan, Hoeg and Benjamin, 1970) requires an assessment of the variability of pertinent soil properties (i.e. sampling probability distribution). Folayan et al stated:

> "A necessary first step is to investigate the available data in an organized manner to assess the magnitude and the implications of the variability."

The statistical behavior of a sample can be described in terms of its central tendencies, dispersion tendencies, asymmetry (skewness) and peakedness. An attempt has been made to use the most common and widely accepted definition for each statistical property. When considering the dispersion tendencies of a soil deposit, attention should also be given to the dispersion tendencies involved in the reproducibility of the test performed in various laboratories by different technicians using supposedly "identical" soil samples (Hammitt, 1966). Table I has been reproduced for comparision with the dispersion tendencies observed in a natural deposit.

PHYSICAL FEATURES OF THE EDMONTON AREA

Climate - The climate of the Edmonton area can be classified as being between dry and moist sub-humid continental (Bowser et al, 1962). The mean summer temperature (May to September) is 56°F while the mean winter temperature (November to March)is 16°F.

The annual average precipitation is 17.5 inches with more than 50 percent of the precipitation occurring during the months of June, July and August. The precipitation from November to March is in the form of snow, totalling just over 50 inches.

Topography - The surface of the lake sediments is level to gently rolling, masking the underlying undulating till surface. The broad valley of the North Saskatchewan River, averaging 250 feet deep, runs in a north-easterly direction through the city, roughly following the central portion of the basin.

Pedology - Edmonton is located in the Black soil zone (Great Group). With the exception of the river valley, the area contains primarily Chernozemic soil (Malmo series) with a strip of Solonetzic soil (Wetaskiwin series) running north and south through the city (Bowser et al, 1962).

Geology - The surficial geology of the Edmonton area has been described by Bayrock and Hughes (1962), Bayrock and Berg (1966), Carlson (1966) and Thomson (1970). Figure 1 shows the major geomorphic units of the Edmonton district with the Metropolitan area centered in Lake Edmonton and bisected by the river valley. In the Edmonton city center area, the lake sediments are underlain by up to 100 feet of glacial till. The Saskatchewan Sands and Gravels occur between the till and the Edmonton Formation bedrock in most areas and can be in excess of 65 feet in thickness.

Proglacial Lake Edmonton was formed in contact with the ice during de-glaciation when the natural north-easterly drainage was blocked by ice. Water was impounded and the lacustrine sediments were deposited. Subsequently the lake was drained by outlets to the south of the city. During the later stages of the recession, the present North Saskatchewan river valley was eroded to drain Lake Edmonton. The valley has eroded through the lake sediments, glacial till, Saskatchewan Sands and Gravels and well into the Edmonton Formation bedrock.

SURFICIAL STRATIGRAPHY

The general surficial stratigraphy within the Edmonton Metropolitan area consists of a high plasticity silty clay near ground surface, becoming more silty and softer with depth. In areas where the sediments are deep, the lacustrine sediments grade into an outwash sand. There is often a water table in the lower silty and sandy portion of the profile perched on the till, which fluctuates throughout the year. The absence of water in the lower silty sands is generally related to drainage to the North Saskatchewan River through buried valleys. In some areas there is up to five feet of brown, alluvial, silty sand (at ground surface) overlying the silty clay.

Data was available from about 400 foundation investigations throughout the city. Approximately three or four test holes were drilled for each investigation. Typical test hole soil profiles (Figure 2) show the Atterberg limits and water contents at two locations; one where the sediments are of average thickness and the other where they are considerably thicker.

Isopachs outlining the thickness of the lake sediments show the general thickness trends of the deposit. Five foot isopachs were drawn for the Edmonton Metropolitan area by plotting the average thickness of glacial lake sediments at each site investigation (Figure 3).

The surface of the glacial till appears to be fairly erratic; however, the averaging over any one site tends to smooth the isopach lines. For example, variations in excess of ten feet have been noted within a horizontal distance of 100 feet. Therefore, the isopach map can only be used for general trends and not for specific depths. Also it should be noted that the frequency of investigations varies over the city. For example, investigations in the south-west portion of the city are far fewer than in the downtown area.

The isopach map shows the glacial lake sediments pinching out on the south-east side of the city and getting progressively thicker towards the river. The North Saskatchewan River runs through the approximate area of thickest sediments. The areas of thickest sediments also show the greatest variability in stratigraphy. Figure 4 shows a north-south and a northwest-southeast cross-section of the surficial stratigraphy.

PRESENTATION AND DISCUSSION OF SOIL PROPERTIES

The soil properties have been divided in four categories: classification, volume-weight relationships, volume change characteristics and shear strength.

Classification Properties

i) Color - The C-horizon of both the Malmo and Wetaskiwin series can be classified as a dark greyish brown (2.5Y 4/2) according to the Munsell color chart (Bowser, 1962). With depth, the profile may be grey or mottled with grey, while the silty zones are lighter and often brown in color.

ii) Mineralogical Composition and Exchange Capacities. Several X-ray diffraction tests, exchange capacities and exchangeable cation tests have been performed by the University of Alberta (Thomson, 1969) (Table II). The Lake Edmonton sediments can be classified as a calcium montmorillonite clay. Omitting the sample from the Wetaskiwin series, the soil has an average cation exchange capacity of 27 milliequivalents per 100 grams of dry soil.

iii)Particle Size Distribution - The results of 30 particle size distribution curves on the upper silty clay and 36 tests on the lower silts and sands are summarized in Table. III.

TABLE III

SUMMARY OF PARTICLE SIZE DISTRIBUTION CURVES*

Lake Edmonton Silty Clay

Average Depth (feet)	% Sand Sizes		% Silt Sizes		% Clay Sizes	
	Mean	Range	Mean	Range	Mean	Range
5	3		37		60	
10	3	0 to 10	42	35 to 50	55	40 to 65
15	7		58		35	

Transition to the silts and sands

Outwash Silts and Sands

Range of Depth (feet)	% Sand Sizes		% Silt Sizes		% Clay Sizes	
	Mean	Range	Mean	Range	Mean	Range
25 to 50	55	10 to 75	42	25 to 80	3	0 to 10

* MIT Grain Size Subdivision

The average uniformity coefficient of the lower silts and sands is 3.1; however, local clay lenses cause considerable variations.

iv) Atterberg Limits - Frequency distribution curves are shown for the 10 and 20 foot depths (Figure 5) and the statistical properties for all depths are summarized in Table A.1 (Appendix A). The mean liquid limits show a gradual decrease with depth. At 15 feet the frequency distribution becomes bimodal, indicating the combining of data from two distinct soil types. This is also depicted by the increased dispersion tendencies. The one soil profile is becoming more silty; however, its mode is still relatively close to the highly plastic range.

There is some skewness of the liquid limit frequency curves to the right and they are less peaked than a normal distribution curve.

The mean plastic limits are relatively constant with depth and their dispersion tendencies low. The upper frequency distribution curves are slightly skewed to the right while the lower curves are skewed to the left. The frequency distribution curves are more peaked than the liquid limit curves, approaching a normal distribution.

According to the plasticity chart (Figure 6) the lake sediments can be classified as a medium to high plasticity inorganic clay. A few test results also fall in the low plasticity, silt zone.

A limited number of tests performed on slurried samples indicated shrinkage limit values ranging from 15 to 17 percent. Several undisturbed samples from a depth of seven feet showed a shrinkage limit as low as 10 percent.

There is insufficient data (percent clay sizes and Atterberg limits) on identical samples to accurately assess the activity of the soil; however, average values from a depth of 10 feet give an activity of 0.66 or a relatively inactive clay.

Volume-Weight Properties

i) Specific Gravity - The results of 20 tests indicate that specific gravity varies from 2.72 to 2.79 with an average of 2.76. The higher values are more representative of the high plasticity clay whereas the specific gravity decreases with increasing silt and sand content.

ii) Water Content - Typical frequency distribution curves are shown in Figure 7 and a summary of the statistical properties is given in Table A.2. The mean water content increases to a depth of 12 feet and remains relatively constant below this depth. The low water content near ground surface shows the effects of evaporation and transpiration. The dispersion tendencies are high in the upper six feet whereas they have a consistent, relatively low coefficient of variation below this depth. The increased dispersion in the upper zone is probably related to seasonal variations. Below a depth of 14 feet there is a slight increase in the dispersion of the results, likely due to the variation in soil types previously mentioned.

All frequency distribution curves are slightly skewed to the left. Also, the curves for the upper four feet have a negative peakedness (flat) whereas below this depth peakedness is positive (i.e. a distribution curve more peaked than a normal distribution curve).

iii) Void Ratio - The void ratios for the statistical analysis are obtained from one-dimensional consolidation tests (Figure 8, Table A.4). The mean ratios are relatively constant to a depth of 15 feet and then decrease with depth. Examination of the frequency distribution curves reveals a bimodal distribution at the 15 foot depth and possibly a trimodal distribution at the 20 foot depth. However, the data is somewhat limited. It is note-worthy that the modes are most indicative of the number of distinct soil types involved.

iv) Degree of Saturation - Degrees of saturation were obtained from consolidation tests, and computed on the basis of sample dimensions and an assumed specific gravity (Figure 8, Table A.5). The difficulty in obtaining accurate measurements of both of these factors is illustrated by the numerous calculated degrees of saturation in excess of 100 percent. The frequency distributions all show only one mode, approaching 100 percent. There is a slight increase in variation of degrees of saturation near ground surface, probably due to varying environmental conditions.

v) Dry Density and Total Unit Weight - The dry density and total unit weights have not been analysed statistically since they show the same trend as the void ratios. Table IV shows mean values versus depth.

TABLE IV

MEAN DRY DENSITY AND TOTAL UNIT WEIGHTS

Depth (feet)	Dry Density (pounds per cubic foot)	Total Unit Weight (pounds per cubic foot)
5	91.0	118.3
10	90.5	120.1
15	90.6	122.6
20	98.8	133.1

vi) Consistency - During field drilling it is generally found that the soil is stiff and shows signs of desiccation near ground surface, but becomes progressively softer with depth. Comparing the natural water content with the Atterberg limits gives an indication of the consistency of the soil (Figure 9). Using mean values for the water content and Atterberg limits, the liquidity indices are 0.1 at 5 feet, 0.2 at 10 feet, 0.3 at 15 feet and 0.4 at 20 feet.

Volume Change Characteristics

An evaluation of the deformation measured in one-dimensional consolidation tests gives an indication of the stress history of the lake sediments. The compression curves from each five foot increment of depth have been analysed (Figure 10) without regard for other variables such as the Atterberg limits.

Compression at total loads less than one ton per square foot is negligible due to the swelling tendency of the soil (Fredlund, 1969). At loadings from one to ten tons per square foot (Table A.6) the slope of the void ratio versus logarithm of pressure curve, decreases slightly with depth but all values are in the low to medium compressible range.

The steepest portion of the consolidation curve (virgin compression branch) has been correlated with the liquid limit of the soil (Terzaghi and Peck, 1967). Since the highest load applied in the consolidation tests varied, it was difficult if not impossible to assess the compressive index of the virgin compression branch. However, the average slope between the one and ten tons per square foot loading (for approximately three percent increments of liquid limit) shows good correlation with the initial water content of the sample (Figure 12).

The mean swell index (slope of the rebound portion of the void ratio versus logarithm pressure curve) (Table A.8) is uniform for the upper 15 feet, decreasing below this depth. There is also increased dispersion of the swell index with depth.

The Lake Edmonton sediments show preconsolidation to a depth of approximately 15 feet. This depth is the location at which groundwater often comes to equilibrium in test holes. The amount of preconsolidation appears to be similar at the five and ten foot depths.

Shear Strength Properties

Although shear strength can be studied on the basis of various strength parameters, only the undrained strength obtained from unconfined compression tests is given consideration in this paper. The frequency distribution curves for compressive strength (Figure 12) are all unimodal and show a pronounced positive skewing (to lower strengths) at all depths. However, plotting the distribution curve versus the logarithm of strength, normalizes the curves. This is reasonable since the logarithm of compressive strength varies linearly with water content. The water content frequency distributions were slightly skewed to the left, therefore, a normal frequency curve for water content would probably have produced further positive skewness on the strength frequency distribution curves. Desiccation in the upper zone does not appear to have produced the skewness since skewness is similar with depth (Table A.9) and can be normalized in all cases by plotting strength on a log scale.

All frequency distribution curves (Figure 13) have one distinct mode. The soil shows increased strength at ground surface due to desiccation, the mean values decreasing exponentially with depth. The increased dispersion tendencies near ground surface are believed primarily due to increased variations in natural water content.

The logarithm of the unconfined compressive strength (for each ten percent range of liquid limit) was plotted versus the water content of the sample (Figure 14A). Although significant scatter occurs, only a few test results fall outside the band width of ten percent water content variation. A family of curves representing the best-fit lines for various liquid limit ranges can be plotted versus water content (Figure 14B) or liquidity index (Figure 14C). Mathematically the relationship between liquidity index and compressive strength can be expressed as follows:

$$q_u = 0.054 \times 10 \left(\frac{1 - I_L}{x}\right)$$

where

q_u = unconfined compressive strength

I_L = liquidity index

x = coefficient dependent on the plasticity of the clay

The test results for the samples with a liquid limit less than 40 percent show the effects of variation due to the inability of the sample to maintain its in-situ effective stress.

CONCLUSIONS AND RECOMMENDATIONS

First, it must be emphasized that the data presented is not meant to be applied directly for design purposes. Rather, it is meant to better equip the engineer to plan meaningful subsurface investigations by giving him ar indication of the nature and variation of the Lake Edmonton sediments.

No attempt has been able to interpret the statistical properties in the light of various soil problems. It is anticipated that this will be done on a limited, conservative basis by the individual engineer. As more similar studies are compiled on the soil deposits, the engineer will be able to make comparisons and the statistical properties will have more meaning.

The significance of the statistical parameters, based on the analyses in this paper, are as follows:

i) Central Tendencies - The mode is the first central tendency that should be examined. If the frequency distribution is unimodal, consideration should be given to the relationship of the mean and median to the mode. If more than one mode exists, there is more than one prime factor (soil type) involved and the mean and median are of limited significance. Similar class intervals should be used for each soil property and the frequency distribution curve plotted in all cases. Varying the boundaries of the class interval may assist in studying the modal behaviour of a sample.

ii) Dispersion Tendencies - The dispersion tendencies are considerably less than was initially speculated. It is interesting to note that standard deviations in the lake sediments is less, in some cases, than the measurement of that soil property by different technicians using an "identical" soil. The main factor causing increased dispersion is the "mixing" of soil from more than one soil type. Careful consideration should always be given to stratigraphy to ensure the correct basis of comparison.

iii) Skewness - When the frequency distribution curve is unimodal, the skewness is of significance. Skewness is believed related to the nonlinearity of the soil property, due either to its geological variability or its relationship to other soil properties. Since skewness is related to the third power of the difference between each observation and the mean, skewness can be heavily biased by a few erratic results. Therefore, obvious "outliers" should be omitted from the statistical analysis. This reasoning also applies to Kurtosis which depends on the fourth power and to a lesser extent, the standard deviation.

iv) Kurtosis - The peakedness of most of the Lake Edmonton sediment soil properties is greater than that of a normal distribution curve. (The main exception is the liquid limit frequency distribution.)

The above summary of the statistical properties reinforces the feasibilityof the application of statistics to soil properties within a unique soil strata. The statistical analysis has shown that further detailed analysis should be given to the strength characteristics of the Lake Edmonton Sediments (i.e. consolidated undrained traixial tests with pore pressure measurements). Also, the consolidation tests could be analysed in more detail, using subdivisions of liquid limit as well as depth.

Other soil deposits should be analysed and reported in order to develop a more complete understanding of the significance of the statistical parameters.

ACKNOWLEDGEMENTS

The authors are indebted to R. M. Hardy & Associates Ltd. (Edmonton, Alberta) for access to their files for soil test data. R. M. Hardy & Associates Ltd. should be congratulated, not only for the use of their test data, but for their encouragement and financial support of this project.

We also wish to acknowledge J. Hayes who was instrumental in initiating this study; H. L. Morrison, M. Berezowski and M. C. Harris who assisted in the analysis and review of this paper.

LIST OF REFERENCES

Bayrock, L.A. and Berg, T.E., (1966) "Geology of the City of Edmonton, Part 1: Central Edmonton", Research Council of Alberta Report 66-1.

Bayrock, L.A. and Hughes, G.M., (1962) "Surficial Geology of the Edmonton District, Alberta", Research Council of Alberta Preliminary Report 62-6.

Bowser, W.E., Kjearsgaard, A.A., Peters, T.W. and Wells, R.E. (1962) "Soil Survey of the Edmonton Sheet (83-H)", University of Alberta Bulletin #55-4, Alberta Soil Survey Report #21.

Carlson, V.A., (1966) "Bedrock Topography and Surficial Acquifers of the Edmonton District", Alberta Research Council Report #66-3.

Dahlman, A., (1965) "The Influence of Strain on the Strength Parameters of a Highly Plastic, Remoulded, Homionic Clay" Master's Thesis (Unpublished), University of Alberta.

Folayan, J.I., Höeg, K. and Benjamin, J., (1970) "Decision Theory Applied to Settlement Predictions", Journal of Soil Mechanics and Foundations Div., ASCE., July, p. 1127.

Fredlund, D.G., (1969) "Consolidometer Test Procedural Factors Affecting Swell Properties", Second International Conference on Expansive Soils, Texas A. & M.

Hammitt, G.M., (1966) "Statistical Analysis of Data from a Comparative Laboratory Test Program Sponsored by ACIL", U.S. Army Engineers Waterways Experimental Station, Corps of Engineers, Vicksburg, Mississippi.

Hampton, D., (1961) "Statistical Analysis of Soil Variability", Ph.D. Thesis, Purdue, Illinois.

Hausmann, M.R., (1965) "Technology of Some Alberta Soil Series", M.Sc.Thesis, University of Alberta.

Hooper, J.A. and Butler, F.G., (1966) "Some Numerical Results Concerning the Shear Strength of London Clay", Geotechnique, Vol. 16, p. 282-304.

Ladd, C.C. and Luscher, U. (1965) "Engineering Properties of the Soils Underlying the M.I.T. Campus", Publication #185, Massachusetts Institute of Technology.

Liu, K.T. and Thornburn, T.H., (1964) "Statistically Controlled Soil Survey", Project 1HR-12 Illinois Co-Operative Highway Research Program.

Liu, K.T. and Thornburn, T.H., (1965) "Engineering Index Properties of Some Surficial Soils in Illinois", University Experiment Station Bulletin #477, University of Illinois.

Locker, J.G., (1963) "The Influence of Pore Water Salt Content on the Shear Strength of a Remoulded Nomionic Clay", Master's Thesis (unpublished), University of Alberta.

Lumb, P., (1966) "The Variability of Natural Soils", Canadian Geotechnical Journal, Vol. III, No.2.

Peck, R. B. and Reed, W.C., (1954) "Engineering Properties of Chicago Subsoils", Eng. Experiment Station Bulletin #423, University of Illinois.

Spiegel, M.R., (1961) "Theory and Problems of Statistics", Schaum Publishing Co., New York.

Taylor, D.W., (1948) "Fundamentals of Soil Mechanics", John Wiley & Sons, New York.

Terzaghi, K. and Peck, R.B., (1967) "Soil Mechanics for Engineering Practice", 2nd Edition, John Wiley & Sons, New York.

Thomson, S., (1969) "A Summary of Laboratory Results on Lake Edmonton Clay", Unpublished, Internal Note: SM2, University of Alberta, Edmonton, Alberta.

Thomson, S., (1970) "Riverbank Stability Study at the University of Alberta, Edmonton", Canadian Geotechnical Journal, Vol. 7, No. 2.

Thornburn, T.H., Morse, R.K. and Liu, T.K., (1966) "Engineering Soil Report, Livingston County, Illinois", University Experiment Station, Bulletin #482, University of Illinois.

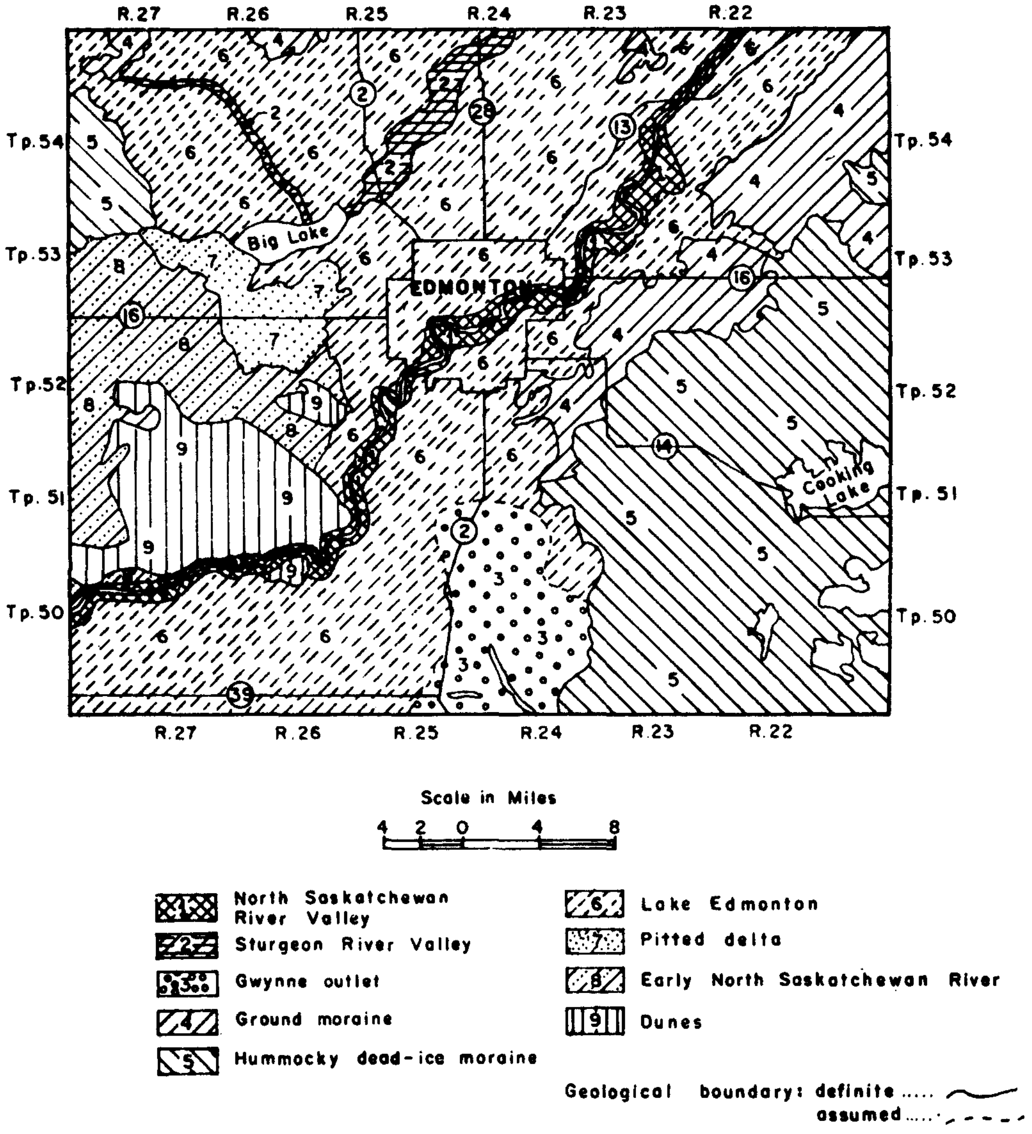

FIG. 1 GEOMORPHIC UNITS OF THE EDMONTON DISTRICT. (After Bayrock and Hughes, 1962)

TABLE I

STATISTICAL ANALYSIS OF SOIL TESTS PERFORMED ON IDENTICAL SOIL SAMPLES

Distributed by the American Council of Independent Laboratories*

G. M. Hammitt, 1966

	Highly Plastic Soil		Medium Plastic Soil		Low Plastic Soil	
Type of Test	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
LL	54.3	5.4	32.7	2.3	27.0	1.7
PL	22.2	3.4	22.4	2.8	23.6	2.4
PI	32.0	5.7	10.4	3.6	3.8	2.1
Specific Gravity	2.63	0.115	2.66	0.060	2.69	0.054
Grain Size % Finer Than						
0.076 mm	95.6	6.8	97.9	2.4	94.9	6.9
0.015 mm	68.6	8.8	43.9	10.6	30.2	6.7
0.002 mm	38.5	7.4	17.9	4.7	8.6	3.2

* The statistical properties of an "identical" soil tested in various laboratories by different technicians.

TABLE II

SUMMARY OF MINERALOGICAL COMPOSITION, EXCHANGE CAPACITIES AND EXCHANGEABLE CATIONS FOR LAKE EDMONTON SEDIMENTS

			Hausmann (1964)**			
Property	Locker (1963)*	Thomson (1963)	Malmo	Wetaskiwin	Dahlman (1965)	Phyzool (1965)
Mineralogical Composition of Material less than 2 microns (percent)						
Montmorillonite	30 to 40			70		50 to 55
Illite	30 to 40			20		27 to 32
Chlorite-Kaolinite	20 to 30			10		10 to 20
Cation Exchange Capacity (milliequivalents per 100 grams dry weight of soil)	27.0	28.2	21.4	50.8	29.3	27.5
Total Exchange Capacity	82.7	100.0	34.4	59.7	95.0	97.0
Exchangeable Cations						
Magnesium	--	14.2	4.5	14.9	18.0	2.5
Calcium	88.2	84.5	29.4	31.0	74.9	93.0
Potassium	1.3	0.8	0.3	0.5	1.2	0.5
Sodium	0.8	0.5	0.2	13.3	0.9	1.0
Salt Content	55.7	73.6	13.0	8.9	65.7	69.5

* Average of three trials
** Samples from C-horizon

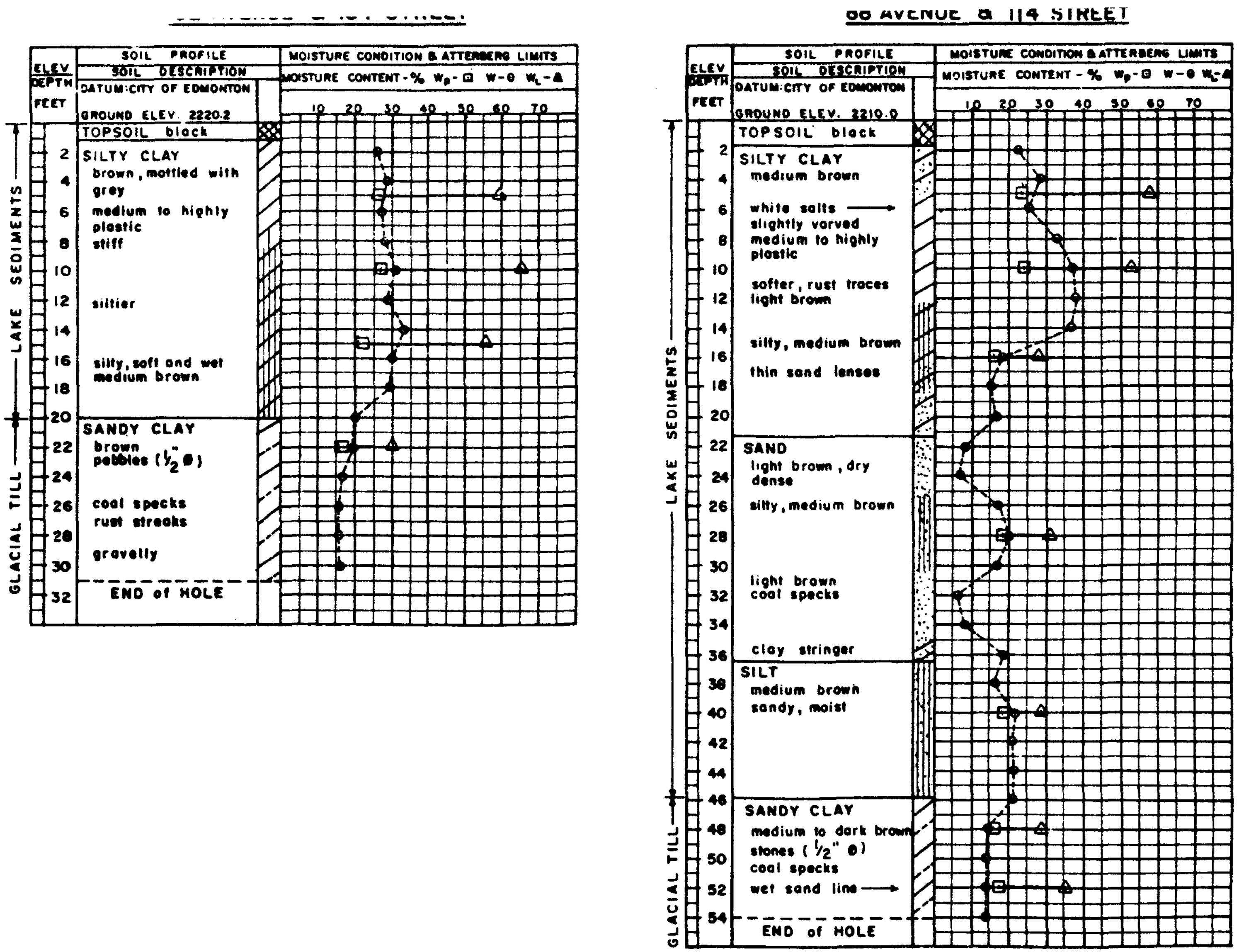

FIG. 2 TYPICAL TEST HOLE BORINGS

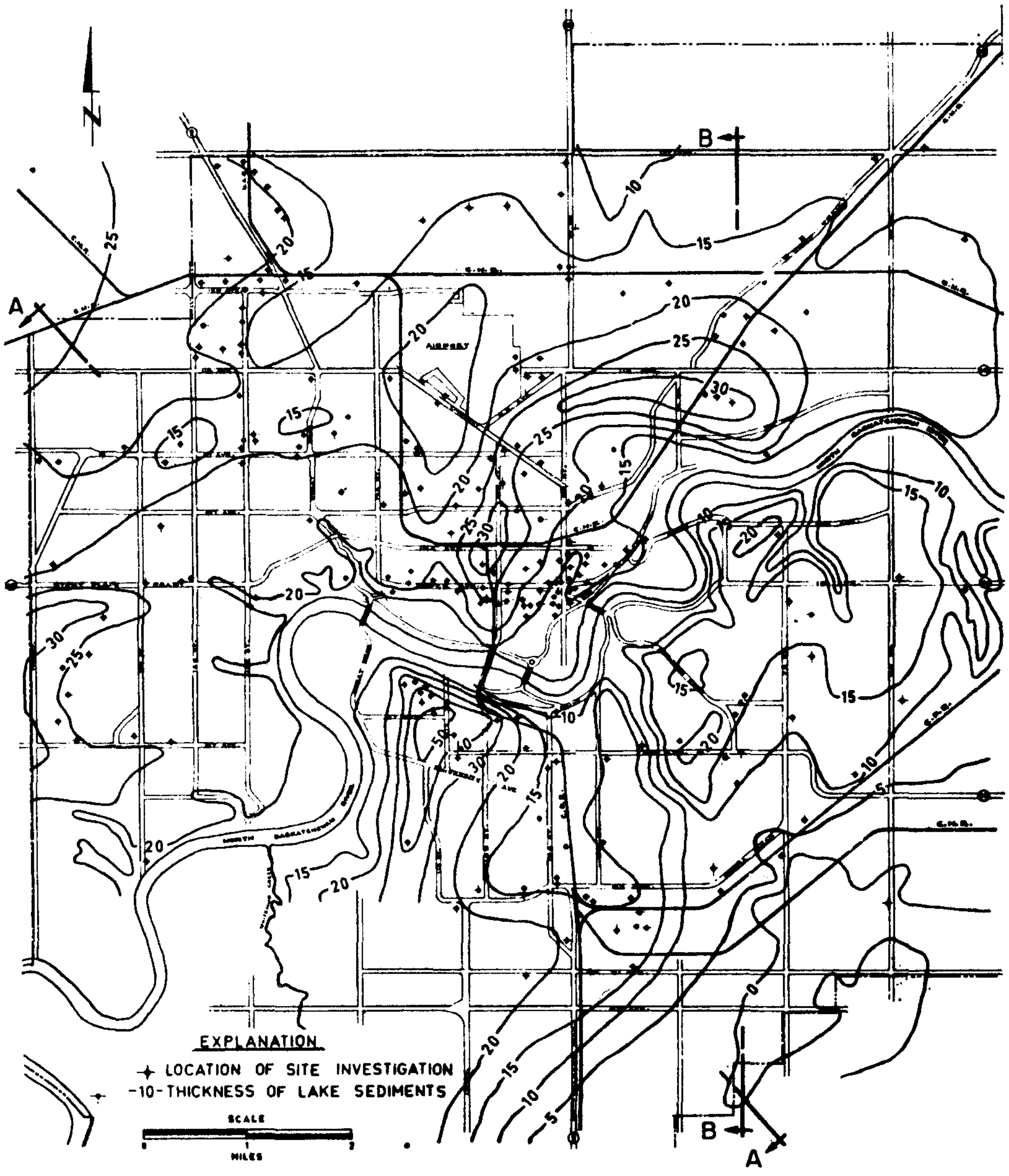

Fig. 3 Site Investigation Locations and Isopachs of Glacial Lake Sediments for Metropolitan Edmonton,

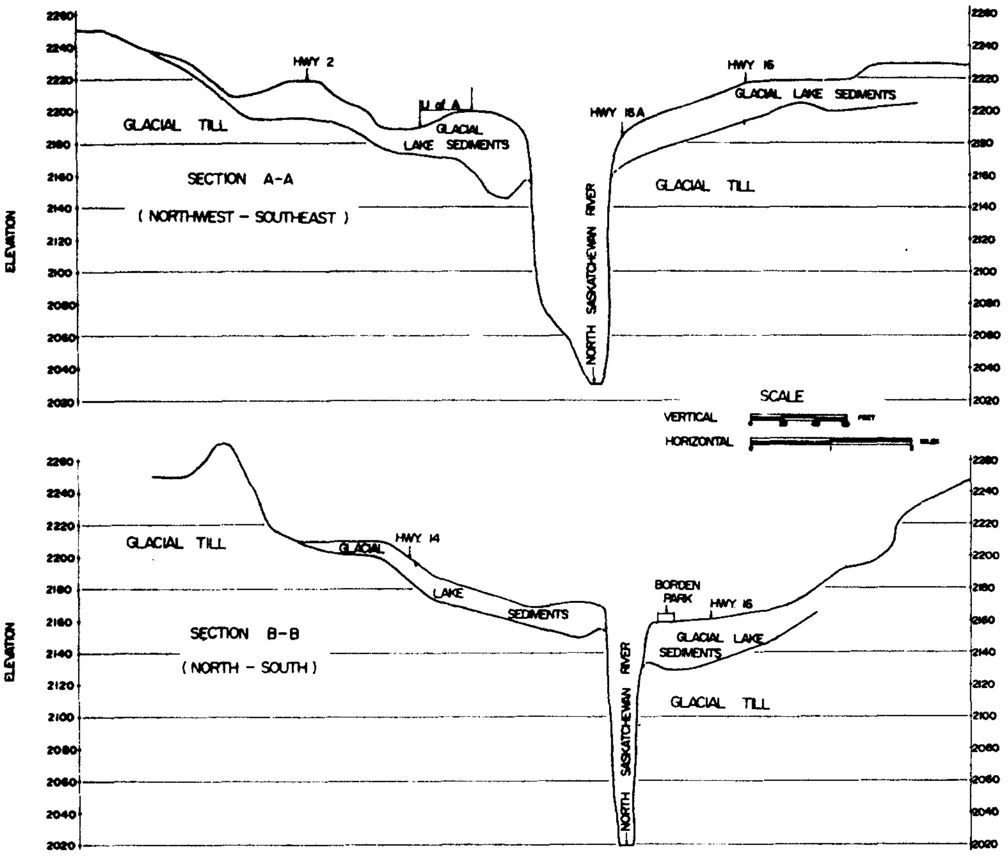

FIGURE 4 TYPICAL CROSS - SECTIONS

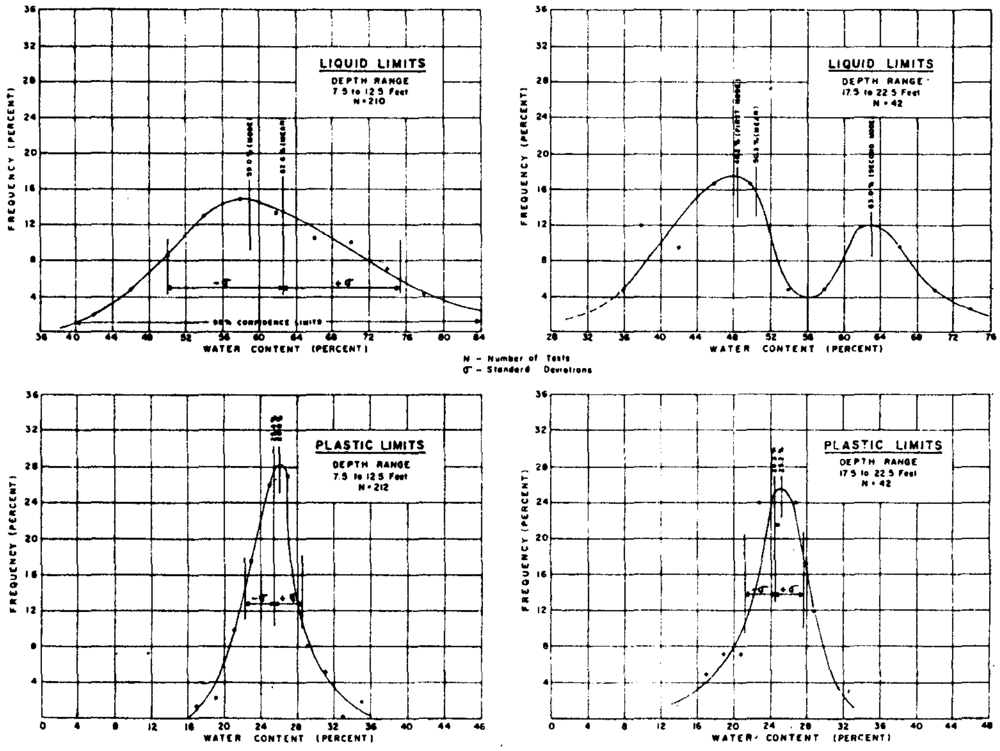

FIG. 5 TYPICAL FREQUENCY DISTRIBUTION CURVES FOR ATTERBERG LIMITS

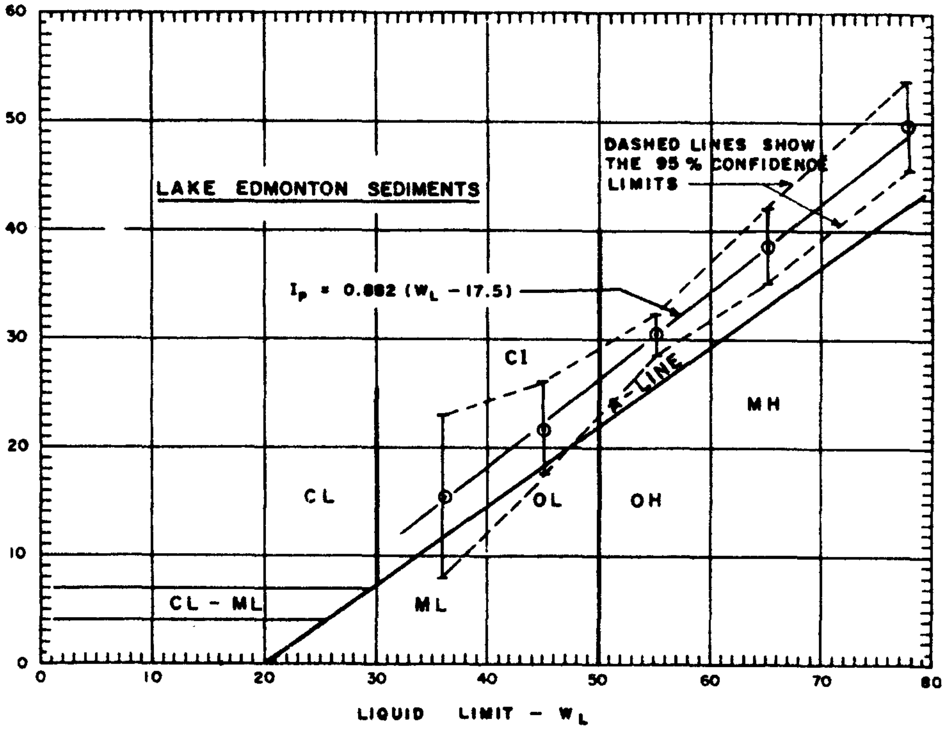

FIG. 6 PLASTICITY CHART. Circles shown represent mean values for ten percent liquid limit ranges.

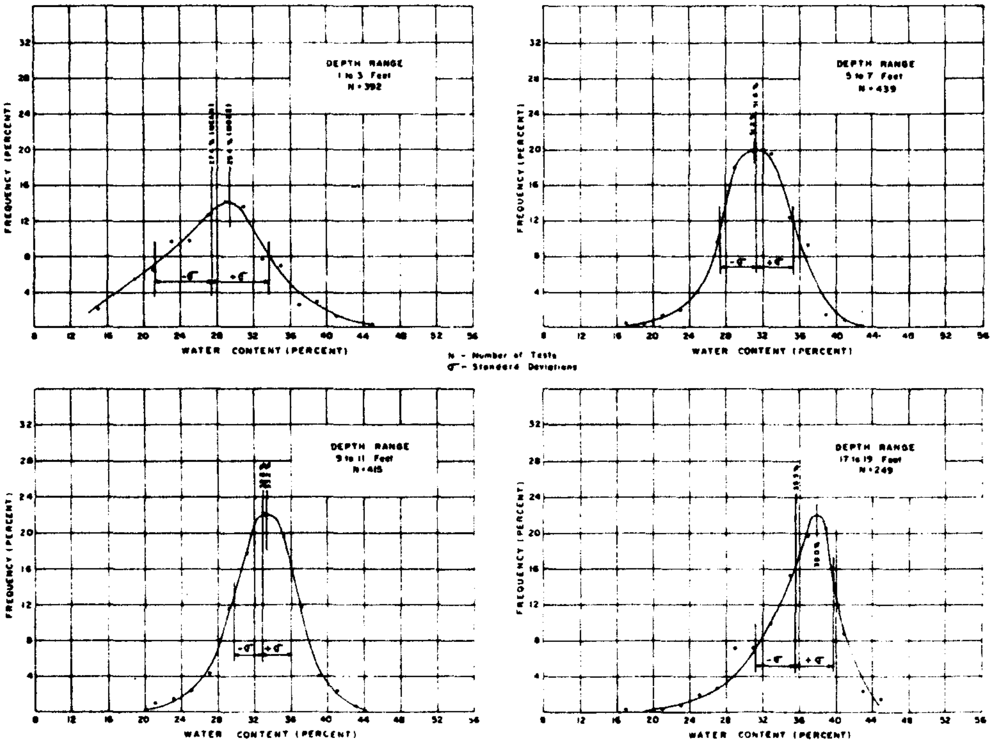

FIG. 7 TYPICAL FREQUENCY DISTRIBUTION CURVES FOR WATER CONTENTS

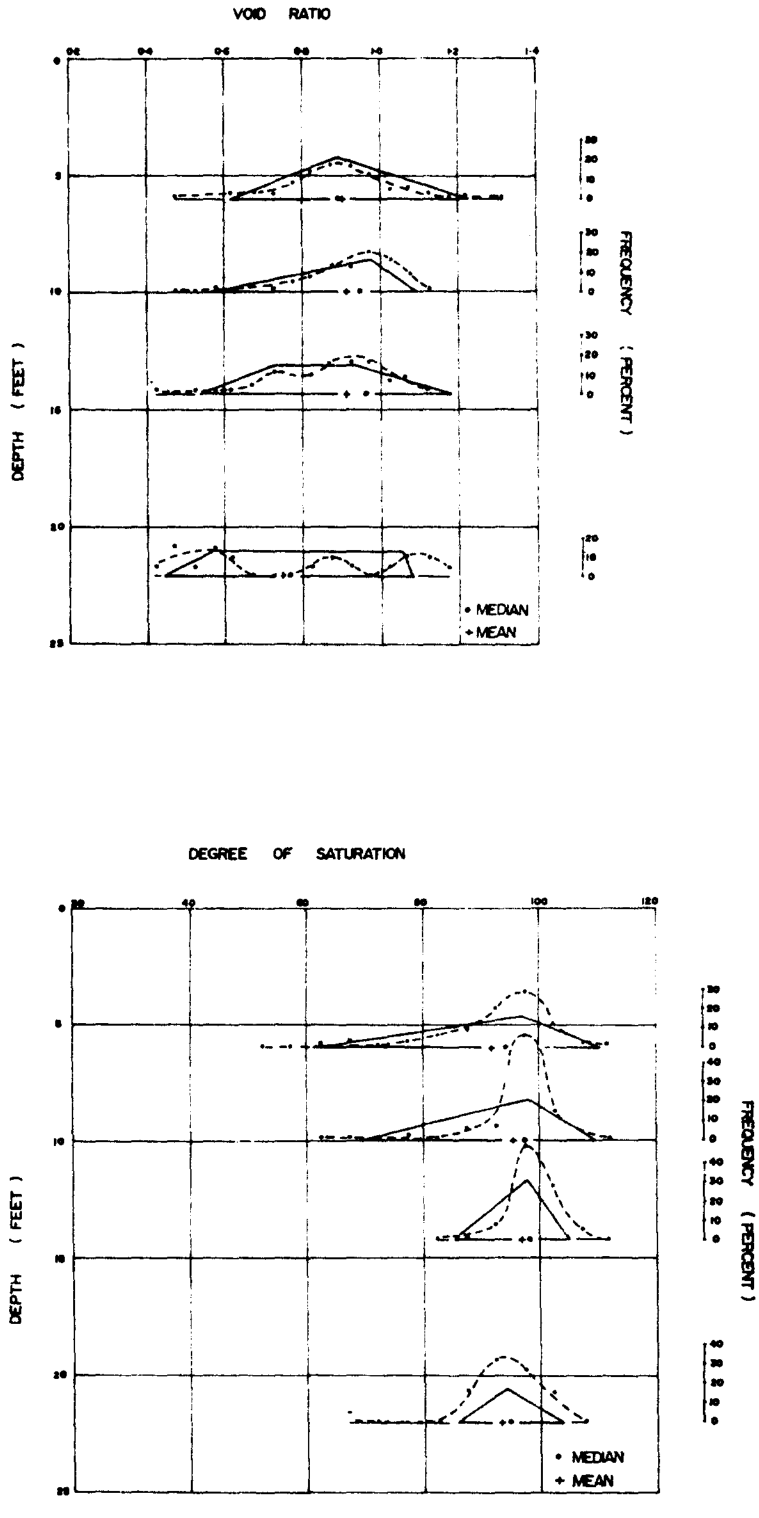

Fig. 8 Graphical Representation of Frequency Distribution Curves for Void Ratio and Degree of Saturation

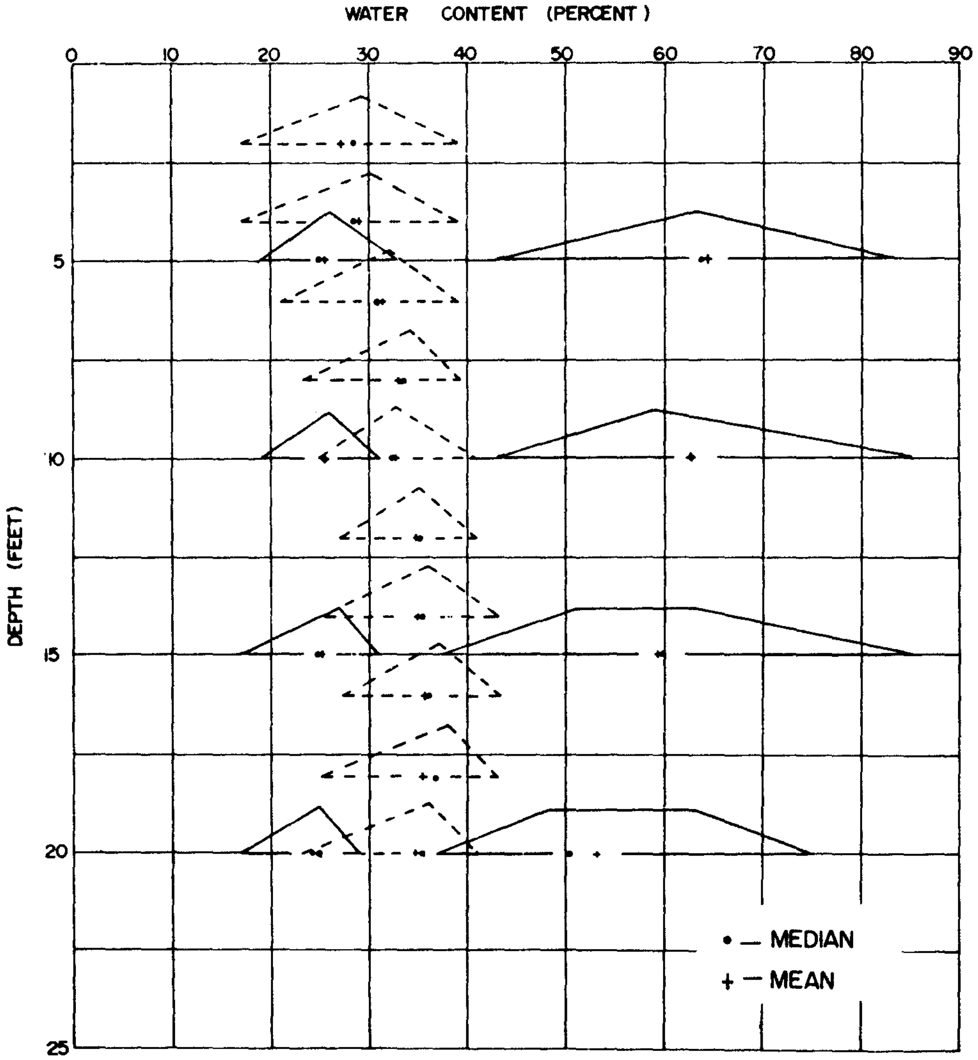

FIG. 9 RELATIONSHIP BETWEEN NATURAL WATER CONTENT AND ATTERBERG LIMITS

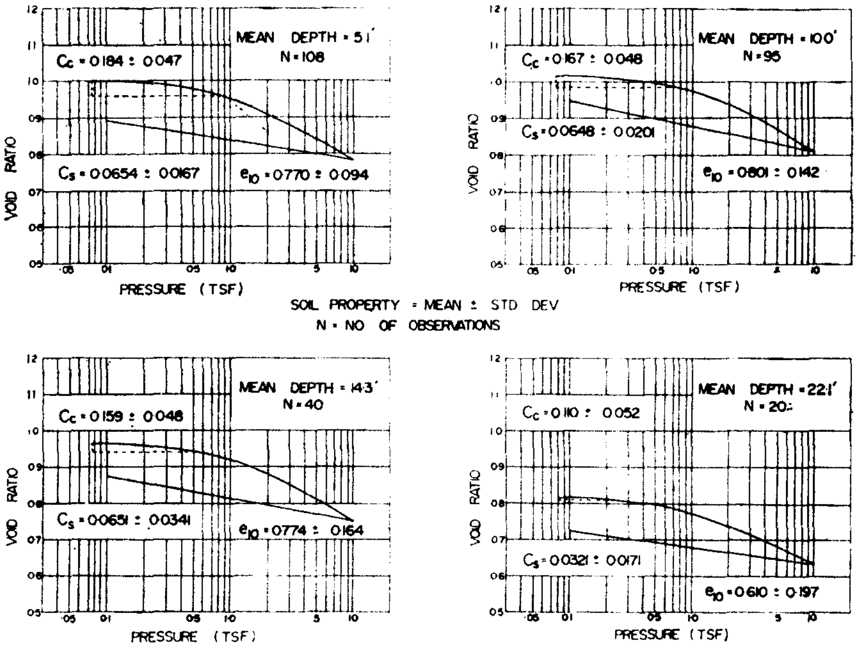

FIG. 10 MEAN CONSOLIDATION CURVES VERSUS DEPTH

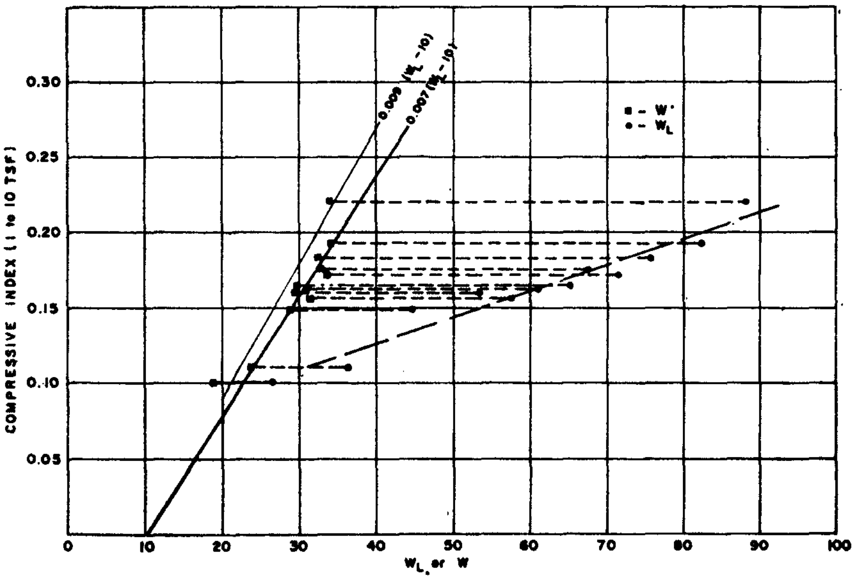

FIG. 11 RELATION BETWEEN COMPRESSIVE INDEX AND LIQUID LIMIT OR INITIAL WATER CONTENT

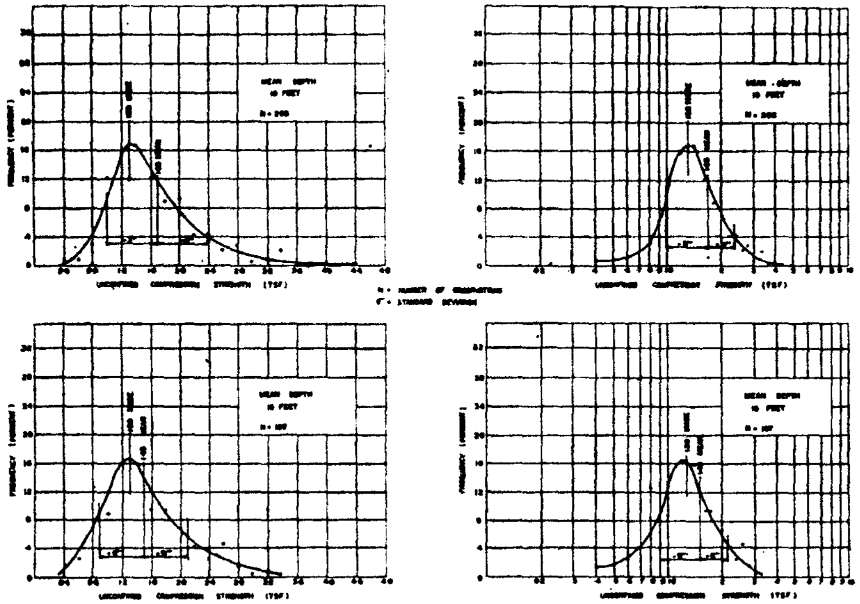

FIG. 12 -TYPICAL ARITHMETIC AND SEMI-LOG FREQUENCY DISTRIBUTION CURVES FOR UNCONFINED COMPRESSION TESTS

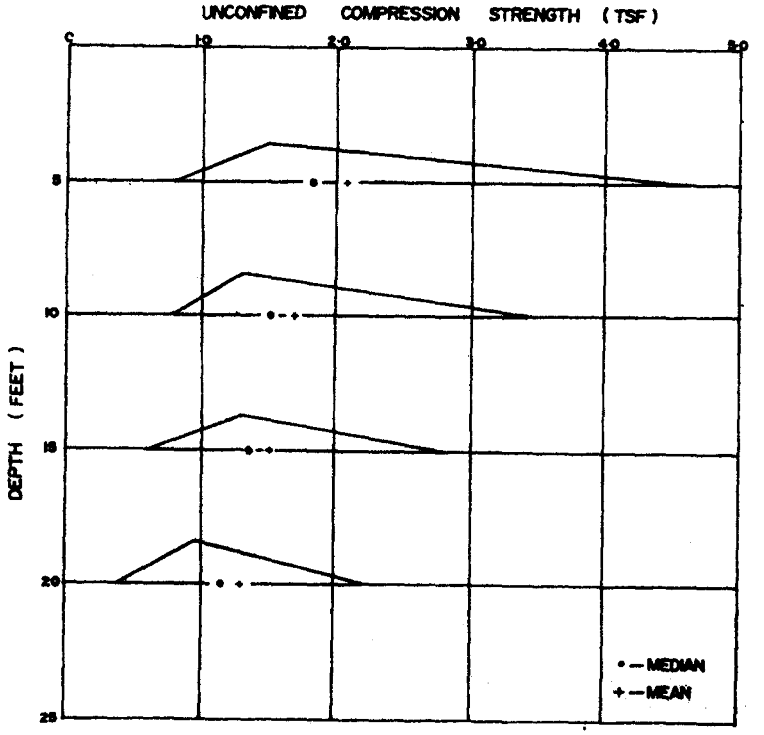

FIG. 13 UNCONFINED COMPRESSION STRENGTH VERSUS DEPTH

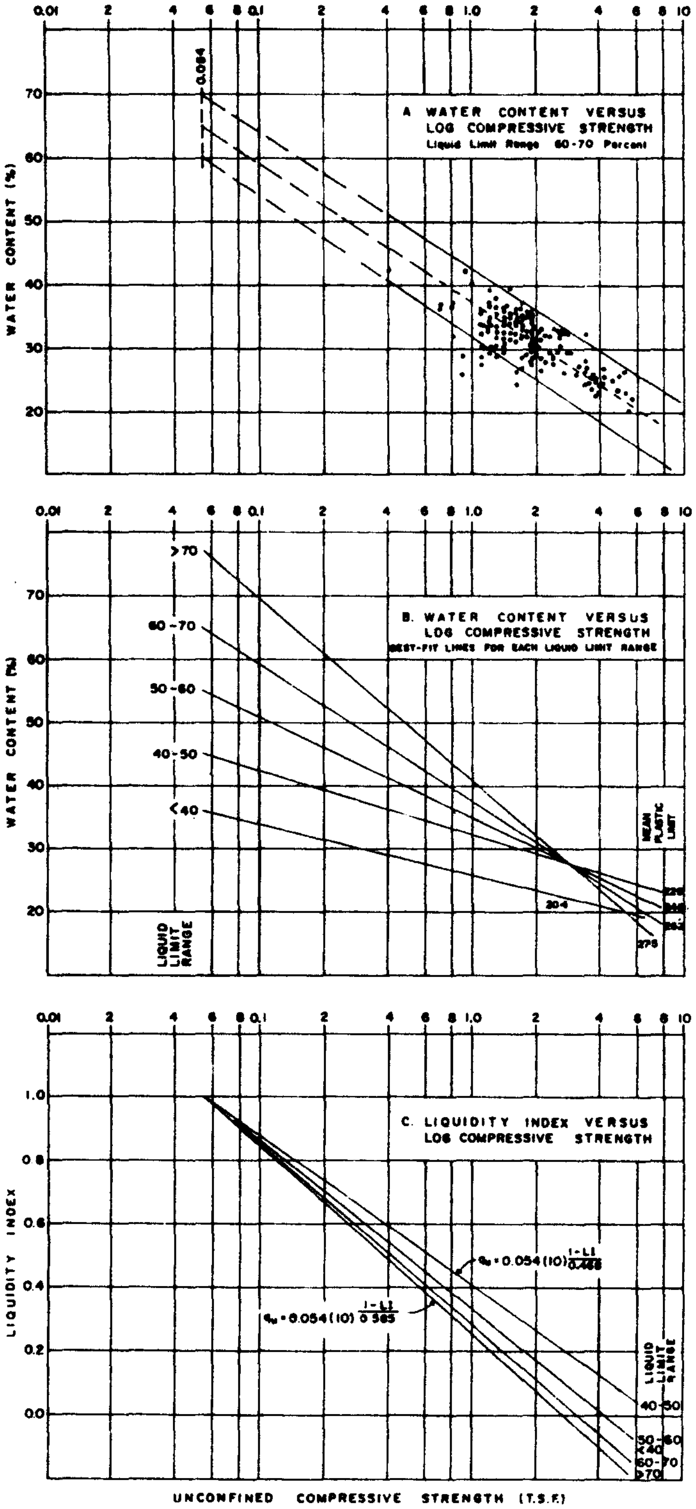

FIG. 14 RELATIONSHIPS BETWEEN UNCONFINED COMPRESSIVE STRENGTH AND WATER CONTENTS, LIQUID LIMIT AND LIQUIDITY INDEX

TABLE A.1

STATISTICAL PROPERTIES OF LIQUID LIMIT RESULTS

Average Depth (feet)	No. of Observations	Mean %	Mode %	Median %	Standard Deviation %	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.	202	64.1	63.	63.7	10.7	16.7	43.0	83.0	+ 0.06	- 0.47
10.	212	62.8	59.	62.8	11.4	18.2	43.0	85.0	+ 0.21	- 0.54
15.	143	59.2	51.0 63.0	59.4	13.1	22.2	37.0	85.0	+ 0.13	- 0.85
20.	40	53.0	48. 63.	50.1	11.2	21.1	37.0	75.0	+ 0.47	- 0.86

TABLE A.2

STATISTICAL PROPERTIES OF PLASTIC LIMIT RESULTS

Average Depth (feet)	No. of Observations	Mean %	Mode %	Median %	Standard Deviation %	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.	200	25.6	26.	24.9	3.4	13.3	19.0	33.0	+ 0.10	- 0.24
10.	212	25.4	26.	25.4	3.2	12.7	19.0	31.0	+ 0.31	- 0.53
15.	144	25.1	27.	24.9	3.8	15.0	17.0	31.0	- 0.24	- 0.11
20.	42	24.4	25.	25.0	3.2	13.3	17.0	29.0	- 0.52	- 0.46

TABLE A.3

STATISTICAL PROPERTIES OF NATURAL WATER CONTENTS

Average Depth (feet)	No. of Observations	Mean %	Mode %	Median %	Standard Deviation %	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
2.	392	27.4	29.	28.3	6.0	21.8	17.0	39.0	- 0.01	- 0.45
4.	430	28.9	30.	28.7	5.1	17.7	17.0	39.0	- 0.22	- 0.30
6.	439	31.2	32.	30.9	4.1	13.1	21.0	39.0	- 0.41	+ 0.69
8.	422	33.0	34.	33.4	4.1	12.4	23.0	39.0	- 0.57	+ 0.11
10.	415	32.8	33.	32.5	3.9	11.9	25.0	41.0	- 0.27	+ 0.37
12.	392	34.7	35.	35.1	3.5	10.1	27.0	41.0	- 0.38	+ 0.12
14.	362	35.0	36.	35.6	4.3	12.2	25.0	43.0	- 0.73	+ 0.15
16.	307	35.5	37.	35.9	4.3	12.2	27.0	43.0	- 0.12	+ 0.47
18.	249	35.5	38.	36.8	4.6	13.0	25.0	43.0	- 0.76	+ 0.76
20.	177	34.8	36.	35.1	4.6	13.2	23.0	41.0	- 0.89	+ 0.59

TABLE A.4

STATISTICAL PROPERTIES OF VOID RATIOS*

Average Depth (feet)	No. of Observations	Mean %	Mode %	Median %	Standard Deviation %	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.1	120	0.900	0.89	0.896	0.157	17.5	0.625	1.22	+ 0.83	+ 4.44
10.0	96	0.911	0.98	0.945	0.138	15.1	0.555	1.09	- 1.12	+ 1.03
14.3	47	0.909	0.72 0.93	0.961	0.186	20.4	0.535	1.18	- 0.54	- 0.13
22.1	21	0.749	0.57 0.83 1.05	0.765	0.236	31.6	0.449	1.08	+ 0.26	- 1.55

* From One-Dimensional Consolidation Tests (Computed on the basis of sample dimensions).

TABLE A.5

STATISTICAL PROPERTIES OF DEGREE OF SATURATION**

Average Depth (feet)	No. of Observations	Mean %	Mode %	Median %	Standard Deviation %	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.1	111	91.9	97.	94.1	12.1	13.2	60.7	110.5*	- 0.89	+ 1.59
10.0	90	95.6	98.	97.4	8.6	9.0	69.4	109.8*	- 1.71	+ 4.21
14.3	38	97.5	98.	98.4	8.4	8.6	85.5	105.1*	- 2.32	+10.6
22.1	19	93.3	94.	94.7	8.0	8.5	85.9	103.8*	- 1.30	+ 1.84

* These values cannot exist but are the result of insufficient knowledge of the specific gravity of the soil in each sample and inaccuracies in the volume measurement.

** From One-Dimensional Consolidation Tests. (Computed on the basis of sample dimensions).

TABLE A.6

STATISTICAL PROPERTIES OF COMPRESSIVE INDEX (1.0 to 10.0 tons per square foot)*

Average Depth (feet)	No. of Observations	Mean	Mode	Median	Standard Deviation	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.1	108	0.184	0.16	0.177	0.047	25.7	0.105	0.287	+ 0.75	+ 1.62
10.0	95	0.167	0.16	0.163	0.048	28.8	0.076	0.255	+ 0.38	- 0.15
14.3	40	0.159	0.13	0.147	0.048	30.1	0.096	0.283	+ 1.14	+ 1.00
22.1	20	0.110	0.07	0.088	0.052	47.1	0.047	0.213	+ 0.90	- 0.48

* From one-dimensional consolidation tests.

TABLE A.7

STATISTICAL PROPERTIES OF VOID RATIO AT 10 TONS PER SQUARE FOOT (CONSOLIDATION TESTS)*

Average Depth (feet)	No. of Observations	Mean	Mode	Median	Standard Deviation	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.1	108	0.770	0.79	0.784	0.094	12.1	0.538	0.920	- 0.79	+ 0.57
10.0	95	0.801	0.84	0.813	0.142	17.7	0.440	1.029	- 0.61	+ 0.48
14.3	40	0.774	0.93	0.831	0.164	21.2	0.434	1.001	- 0.48	- 1.09
22.1	20	0.610	0.47	0.545	0.197	32.3	0.393	0.967	+ 0.70	- 0.94

* From one-dimensional consolidation tests.

TABLE A.8

STATISTICAL PROPERTIES OF SWELLING INDEX (10 TO 0.1 TONS PER SQUARE FOOT)

Average Depth (feet)	No. of Observations	Mean	Mode	Median	Standard Deviation	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.1	27	0.0654	0.068	0.0662	0.0167	25.5	0.028	0.094	- 0.16	- 0.64
10.0	39	0.0648	0.065	0.0650	0.0201	31.1	0.025	0.097	+ 0.35	+ 0.01
14.3	27	0.0651	0.051	0.0604	0.0341	52.4	0.023	0.128	+ 0.69	- 0.63
22.1	14	0.0321	0.024	0.0255	0.0171	53.2	0.009	0.064	+ 0.83	- 0.57

TABLE A.9

STATISTICAL PROPERTIES OF UNCONFINED COMPRESSION TESTS

Average Depth (feet)	No. of Observations	Mean TSF*	Mode TSF	Median TSF	Standard Deviation	Coefficient of Variation (percent)	95% Confidence Limits		Skewness	Kurtosis
							Lower	Upper		
5.0	279	2.08	1.5	1.82	1.02	49.1	0.80	4.60	+ 1.24	+ 1.46
10.0	295	1.68	1.3	1.52	0.69	40.9	0.80	3.40	+ 1.40	+ 2.72
15.0	187	1.49	1.3	1.37	0.59	39.6	0.60	2.80	+ 0.69	+ 0.14
20.0	53	1.30	0.96	1.16	0.62	47.7	0.40	2.20	+ 1.21	+ 2.90

* TSF = Tons per square foot.