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CORPS OF ENGINEERS, U. S. ARMY

MISSISSIPPI RIVER COMMISSION

CORRELATION OF SOIL PROPERTIES WITH GEOLOGIC INFORMATION

REPORT NO. 1

SIMPLIFICATION OF THE LIQUID LIMIT TEST PROCEDURE

TECHNICAL MEMORANDUM NO. 3-286

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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PREFACE

In a memorandum to the President, Mississippi River Commission, dated 18 May 1948, subject "Special Projects for the Fiscal Year 1949," the Waterways Experiment Station proposed an investigation entitled "Correlation of Soil Properties with Geologic Information." The project was approved in the 1st Memo Indorsement dated 14 June 1948. This report is the first of a series to be published on this investigation.

The concept upon which this report is based was contributed by Dr. A. Casagrande, whose valuable assistance is hereby acknowledged. Acknowledgement is also made to the New Orleans, Vicksburg, and Memphis Districts, CE, for the use of their laboratory data files which aided materially in the accomplishment of the investigation.

The study was performed by the Embankment and Foundation Branch of the Soils Division, Waterways Experiment Station. Engineers connected with the study were Messrs. W. J. Turnbull, S. J. Johnson, A. A. Maxwell, S. Pilch and C. D. Burns. This report was prepared by Mr. Pilch.

CORRELATION OF SOIL PROPERTIES WITH GEOLOGIC INFORMATION

SIMPLIFICATION OF THE LIQUID LIMIT TEST PROCEDURE

PART I: INTRODUCTION

1. The general project of correlating soil properties with geologic information, one phase of which is described in this report, consists in comparing soil properties with soil types and with their geologic history and environment in order to determine what correlations are possible. If correlations are found to exist, it would be possible to reduce laboratory testing materially at sites where geologic information is available, and to obtain a better understanding of the behavior and properties of the soils. The purpose of this report is to present data and analyses from liquid limit tests, and correlations which may materially reduce the cost of performing this test.

2. Dr. Arthur Casagrande suggested that flow lines determined by liquid limit tests, plotting both water content and number of blows to a logarithmic scale, might have a constant slope for soils of the same geologic origin. The basis for the idea that a logarithmic plot would give a constant flow-line slope, which the currently-used semilogarithmic plot does not, is as follows: On a semilogarithmic plot, flow lines of higher liquid limit values have, in general, steeper slopes than flow lines of lower liquid limit values. However, a logarithmic plot reduces the slope of the higher liquid limit flow lines more than it does the lower, thus tending to make them equal as is clearly illustrated by figure 1.

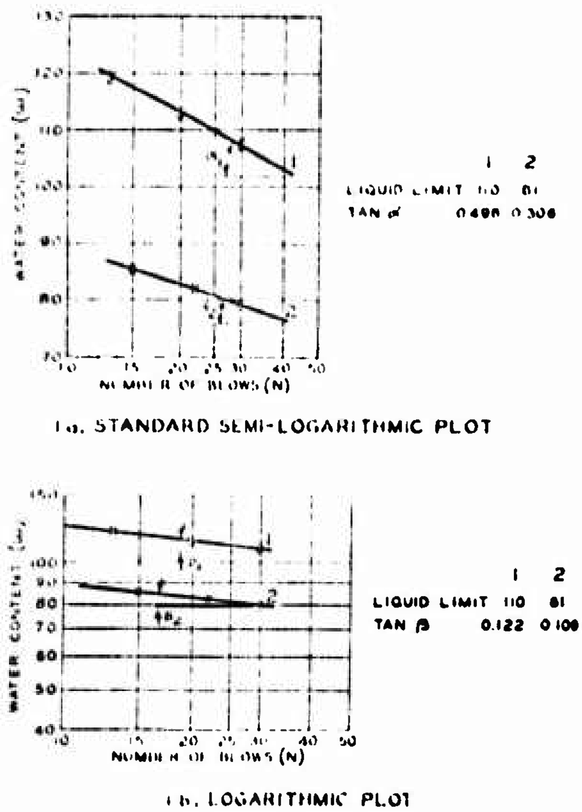

Fig. 1. Semi-logarithmic and logarithmic liquid limit flow line plots

3. It was apparent that this suggested procedure had practical possibilities that could be explored rather rapidly. Since the liquid limit test is a desirable but costly type of classification test, it was decided to determine the feasibility of using the liquid limit test procedure simplification suggested by Dr. Casagrande.

4. This report describes the results of analyses of 767 liquid limit tests. The tests were performed by the New Orleans, Vicksburg and Memphis Districts, and the Waterways Experiment Station, CE, in connection with various projects under the jurisdiction of the Mississippi River Commission and the Lower Mississippi Valley Division.

PART II: PRESENT AND PROPOSED LIQUID LIMIT TEST PROCEDURES

Present Test Procedure

5. The Atterberg liquid limit test has been standardized as to procedure and equipment*. The testing device consists essentially of a small brass dish which can be raised a distance of one centimeter by a cam arrangement and allowed to drop on a hard rubber base. The soil specimen is placed in this dish and a groove is cut in the specimen with a special grooving tool. The dish is then dropped on the base at a rate of two drops, or "blows," per second until a 1/2-in. length of the groove is closed by the flowing together of the soil on each side of the groove. The liquid limit is the water content of the soil when the groove closes with 25 blows. It would be too time-consuming to adjust the water content of a soil specimen so that the groove would close at exactly 25 blows. Hence the test is made at several water contents, and the water content at 25 blows is found by straight-line interpolation on a graph, plotting the number of blows on a logarithmic scale and water content on an arithmetic scale; figure 1-a is a typical plot. The line determined by the plotting of number of blows versus water content is called a flow line.

Proposed Method of Simplifying Test Procedure

6. It can be seen from figure 1-a that six points have been used to define a flow line on a semilogarithmic plot. If it can be shown

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* Casagrande, A., "Research on the Atterberg Limits of Soils," Public Roads, Vol. 13, No. 8, October 1932.

that the slope of the flow lines for soils in the same geologic formation is a constant on a logarithmic plot, then the liquid limit can be determined from one test point for each soil. The point can be plotted on logarithmic paper, and the flow line, with its predetermined slope, drawn through this point. The liquid limit would be the water content at the intersection of the flow line and the 25-blow line. A nomographic chart could also be made representing the relationship between the liquid limit, water content, and number of blows for a given flow line slope.

PART III: DATA ANALYSIS AND RESULTS

Sources of Data

7. The soils for which liquid limit test data were analyzed fall into three main geographical groups: the Alluvial Valley of the Mississippi River, the West Gulf Coastal Plain, and the East Gulf Coastal Plain. A few project locations lie outside of these groups and are listed as Miscellaneous. Plate 1 shows the locations of the projects from which data were analyzed.

8. Geologically, the soils tested fall within the following major groups: Recent (alluvium, backswamp, natural levee, channel filling, marsh, and marine), Pleistocene, Tertiary, and glacial till. Tables 1 and 2 show the locations and geologic types of soils at the projects from which data were used.

9. All of the tests were also classified as to their plasticity characteristics. For this purpose, Casagrande's plasticity chart of liquid limit versus plasticity index was used (plate 2). The plasticity charts for all the projects and tests used are presented on plates 3 to 7. The plasticity charts were consolidated according to the three major geographic groupings, and these charts are shown by plates 8, 9 and 10. In general, the soils analyzed were medium to highly plastic inorganic clays, and a few silts and sandy clays.

Conversion of Data

10. Data examined for this study were of the form shown on figure 1-a where the number of blows is plotted logarithmically and the water

content arithmetically. To determine the slope of a flow line on a fully logarithmic plot, it was not necessary to replot the data. The slope of a flow line on a logarithmic plot can be computed from the semilogarithmic plot by the following relationship:

$$\tan \beta = \frac{\log w_{10} - \log w_{30}}{\log 30 - \log 10} = \frac{\log \frac{w_{10}}{w_{30}}}{0.477}$$

where $\tan \beta$ = the slope of the flow line on a logarithmic plot with reference to the horizontal,

w_{10} = the water content at 10 blows) from flow line on
) semilogarithmic
w_{30} = the water content at 30 blows) plot

Ten and 30 blows were arbitrarily selected for convenience. This method is not theoretically exact, as a straight line (except a vertical or horizontal one) on a semilogarithmic plot will not be a straight line when plotted logarithmically. However, within the range in water contents and number of blows of a single flow line for the data utilized, the variation from a straight line is so small as to be of no consequence. Figure 1-b shows data from figure 1-a plotted logarithmically.

Methods Used in Analysis of Data

11. All of the data examined were used except for a few tests in which it was obvious that the test points were so erratic that a reasonably precise flow line could not be determined. The data were also limited to tests for which the liquid limit was less than 150.

12. It should be noted that liquid limit test results depend to a considerable extent on individual technique; and since the tests analyzed were performed by many technicians, some degree of control over the data

was lost. However, it is believed that the methods used in the analysis give results which accommodate a large part of the variations in the data due to differences in technique.

13. The large number of tests utilized made it necessary to adopt methods to present the data in a concise, yet complete form. To fill this need, statistical methods were used in analysis of the data and presentation of results. The statistical methods and nomenclature used are those recommended by the American Society for Testing Materials.*

Nomenclature and Definitions

14. For purposes of clarity, the nomenclature and definitions used in this study are given below:

$\tan\beta_1, \tan\beta_2, \tan\beta_3 \ldots\ldots\ldots \tan\beta_n$: observed values of $\tan\beta$; slope of flow line on a logarithmic plot.

n: the number of observations.

f: the frequency, the number of observations for a given value, or interval, of $\tan\beta$.

$\overline{\tan\beta}$: the arithmetic mean or average, referred to as the mean in this report.

$$\overline{\tan\beta} = \frac{\sum_{i=1}^{n} \tan\beta_i}{n}$$, where $\sum_{i=1}^{n} \tan\beta_i$ means the sum of all the values of $\tan\beta$ from $\tan\beta_1$ to $\tan\beta_n$, inclusive.

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* A.S.T.M. Manual on "Presentation of Data," April 1945 (reprint).

σ: the standard deviation, the most significant and efficient measure of dispersion of data about a mean. For a normal frequency curve, the mean plus and minus the standard deviation includes 68.3 per cent of the total number of observations.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (\tan \beta_i - \overline{\tan \beta})^2}{n}} .$$

v: the coefficient of variation, a measure of relative dispersion of data about a mean. Useful in comparing distributions with different means.

$$v\% = \frac{\sigma}{\overline{\tan \beta}} \times 100 .$$

k: Hazen's coefficient of skewness, a measure of the non-symmetry of a distribution about a mean. A positive value of k generally means that the observed values extend farther to the right of the mean than to the left; a negative value of k, vice versa. For a symmetrical normal frequency curve k = zero.

$$k = \frac{\sum_{i=1}^{n} (\tan \beta_i - \overline{\tan \beta})^3}{n \sigma^3} .$$

Normal frequency curve: the curve defined by the equation

$$f = \frac{n}{\sigma\sqrt{2\pi}} \left(e^{-\frac{(\tan \beta)^2}{2\sigma^2}} \right).$$

It is the familiar bell-shaped curve and represents a theoretically correct frequency distribution (see figure 2, page 10).

Analysis of Data with Respect to Geology

15. The individual values of tan β were computed to the nearest thousandth by the method discussed in paragraph 10. To show graphically the distribution of tan β for each geologic soil type within the projects, frequency histograms were plotted (plates 11-22). The frequency histograms have as their abscissas values of tan β grouped in classes with intervals of 15 thousandths, and as their ordinates, the frequency.

16. The mean tan β for each project was computed by the equation in paragraph 14. These means are listed in tables 1 and 2 and are plotted on the histograms; the means from all the various geologic types and projects range from 0.094 (White River Levee District, Recent alluvium, 25 tests) to 0.143 (Algiers Lock, Recent marine, 3 tests), a range of 0.049. The range of tan β within each geologic soil type averages about 0.1; maximum range 0.168 (Grenada Dam Tertiary, Eocene), minimum range 0.050 (Greenwood Protection Levee, Recent alluvium). The range of tan β within soil groups of the same geologic classification is greater than the range of the means of all geologic soil types. Also, an inspection of the means in tables 1 and 2 shows no tendency for each geologic type to group itself about a single mean tan β. From these observations it appears that, for the soil types studied, the slope of the flow line is not directly related to the geologic classification of the soil.

Analysis of the Data with Respect to Geography

17. The data were also analyzed by grouping the tests according to their geographical location: Alluvial Valley of the Mississippi River, West Gulf Coastal Plain, and East Gulf Coastal Plain. Histograms showing the distribution of tan β for the tests from these areas are shown in figures 2, 3, and 4. These histograms have as their abscissas values of tan β grouped in classes with intervals of 15 thousandths and as their ordinates, per cent frequency. The mean tan β, standard deviation, coefficient of variation, and skewness were computed for these areas and the results are listed in table 3 in addition to the number of tests and ranges in tan β and plasticity. The means range from 0.115 to 0.130, or

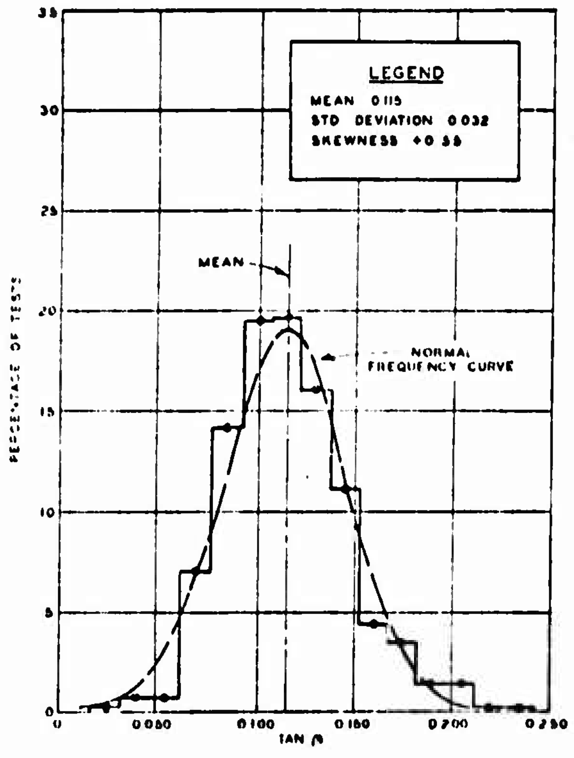


Fig. 2. Histogram of the Alluvial Valley of the Mississippi River -- 43[illegible] tests

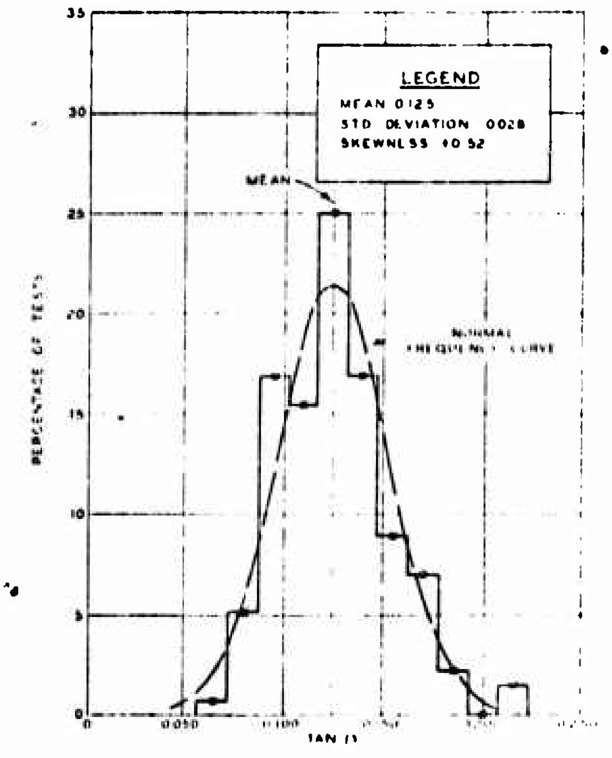


Fig. 3. Histogram of the West Gulf Coastal Plain -- 13[illegible] tests

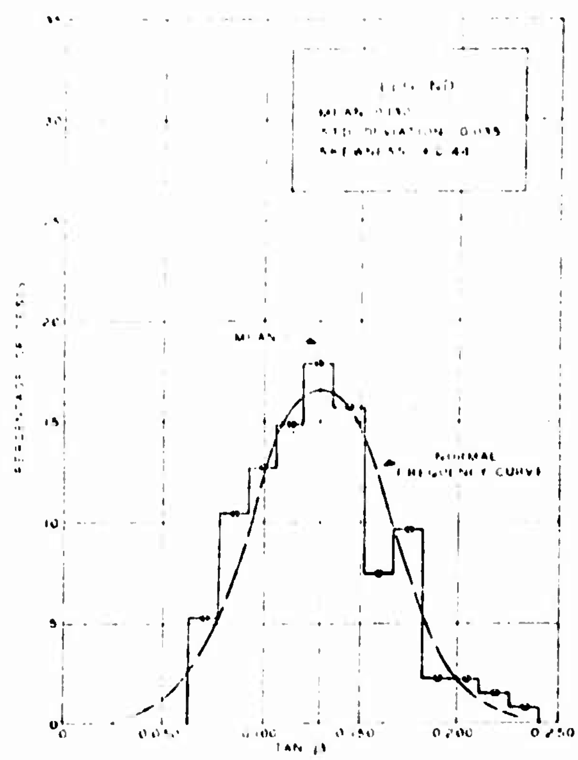


Fig. 4. Histogram of the East Gulf Coastal Plain -- 135 tests

expressed in degrees of β represent a range of 0.75 degrees. The standard deviations range from 0.028 to 0.035, and the coefficients of variation from 22.4 to 27.8 per cent. The skewnesses range from +0.42 to +0.55. All three histograms are skewed to the right, as indicated by the positive values of skewness. Using the means and standard deviations, it was possible to compute normal frequency curves which best fitted the distributions, and these curves are superimposed on the histograms of figures 2-4.

18. The means, standard deviations, coefficients of variation, and skewnesses were so close together for the three areas that it was believed that a more accurate representation of the data could be obtained by combining all 767 tests in one histogram, figure 5. This histogram contains, in addition to the tests from the Alluvial Valley

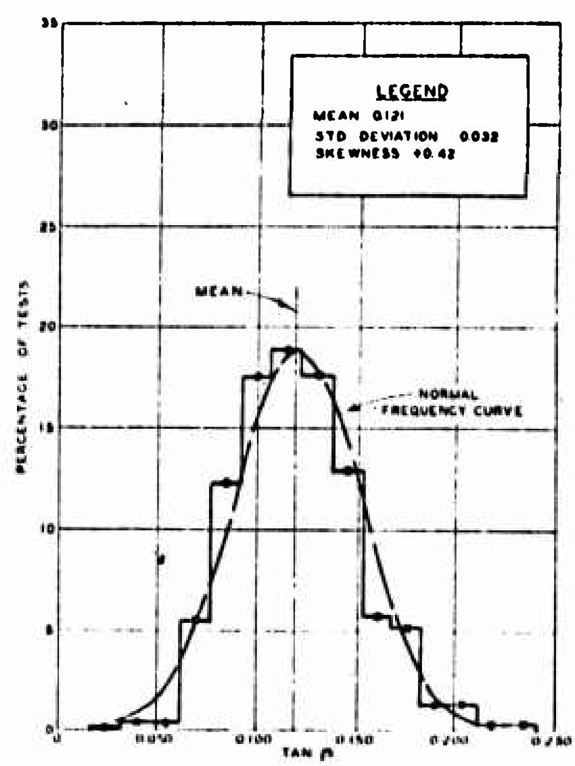


Fig. 5. Histogram of all 767 tests

of the Mississippi River and the East and West Gulf Coastal Plains, the tests from the two projects outside these three general areas: Garrison Dam, N.D., mean 0.123, and Blakely Mountain Dam, Ark., mean 0.1[illegible]3. The mean for all 767 tests is 0.121, the standard deviation 0.032, the coefficient of variation 26.4 per cent, and the skewness +0.42 (table 3). The normal frequency curve was computed and superimposed on the histogram, figure 5. This histogram best fits its normal frequency curve, as a comparison with the histograms of figures 2-4 shows. This was to be expected because of the large number of tests used in its development. The fact that the skewness coefficient is lower for the histogram of all the tests than for any of the three principal geographic areas is also indicative of a better fit to the normal frequency curve.

Analysis of Results

Equation for the liquid limit on a logarithmic plot

19. It can be shown that the value for the liquid limit using a logarithmic plot and one point on the flow line is determined by the equation:

$$LL = w_N \left(\frac{N}{25}\right)^{\tan\ \beta},$$

where LL = liquid limit,

w_N = water content at N blows from the liquid limit device,

$\tan\ \beta$ = slope of the flow line on a logarithmic plot.

Effect of variations in the slope of the flow line on the value of the liquid limit

20. The method of differentials is applicable to measuring the effect of variations in tan β on the value of the liquid limit. The expression for per cent change in the liquid limit is derived as follows:

$$LL = w_N \left(\frac{N}{25}\right)^{\tan \beta}$$

$$d\ (LL) = w_N \left(\frac{N}{25}\right)^{\tan \beta} \times \ln \frac{N}{25} \times d\ (\tan \beta)\ .$$

(ln refers to logarithms to the base e)

$$\text{and } \frac{d\ (LL)}{LL} = \ln \frac{N}{25} \times d\ (\tan \beta).$$

This may also be written as:

$$\frac{\Delta\ (LL)}{LL}\ \% = \ln \frac{N}{25} \times \Delta\ (\tan \beta) \times 100,$$

in which $\frac{\Delta\ (LL)}{LL}$ % is the per cent change in the liquid limit for a change Δ (tan β) in the slope of the flow line on a logarithmic plot. An inspection of this equation shows that the per cent change in the liquid limit is independent of the actual values of both the liquid limit and the slope of the flow line. It depends only on a given variation in the slope of the flow line and the number of blows. The above equation is plotted on figure 6 (page 14) for various values of N and Δ (tan β).

Comparison of mean slopes

21. The pertinent results determined for the geographical areas are summarized on the following page (from table 3):

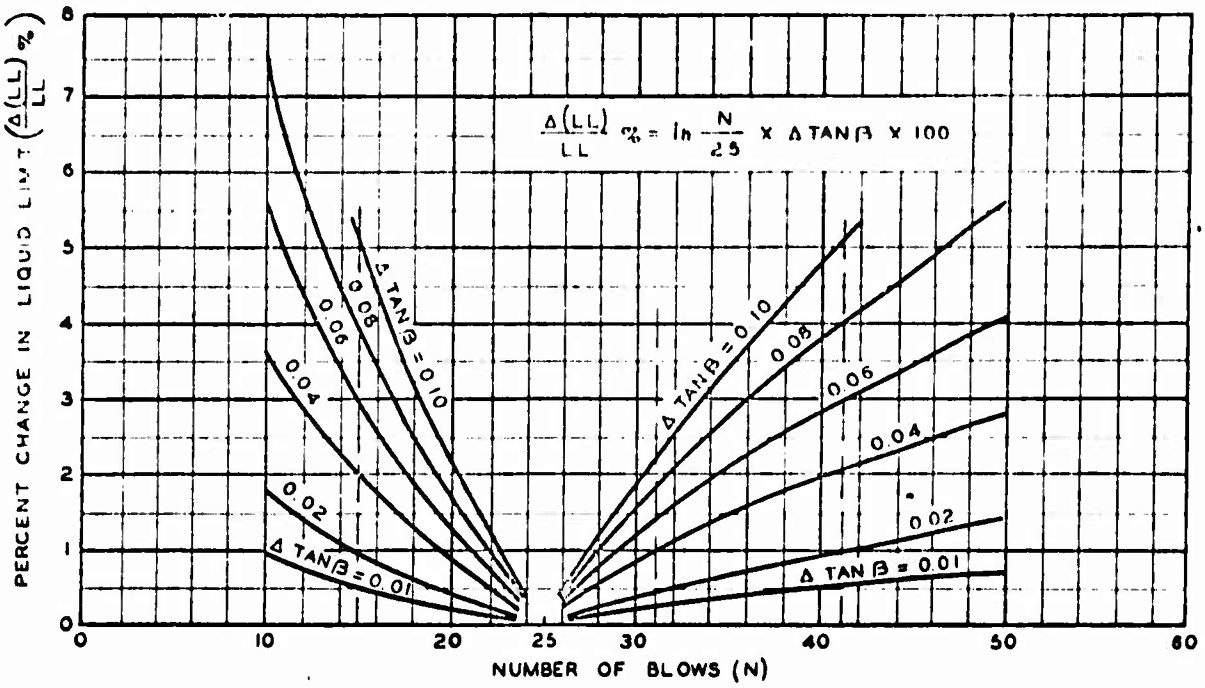


Fig. 6. Per cent change in liquid limit vs number of blows for changes in tan β

	No. Tests	Mean tan β	Standard Deviation	Coefficient of Variation (%)	Skewness
Alluvial Valley of the Mississippi River	432	0.115	0.032	27.8	+0.55
West Gulf Coastal Plain	136	0.125	0.028	22.4	+0.52
East Gulf Coastal Plain	135	0.130	0.035	26.9	+0.44
All tests (including 64 from the Miscellaneous Group)	767	0.121	0.032	26.4	+0.42

The magnitude of the differences between the mean for all tests and for the three principal geographic areas is best understood by reference to the change in the liquid limit due to these variations. The mean of all the tests, 0.121, differs from the mean of the Mississippi River Alluvial Valley, 0.115, by 0.006. This would make a difference in the liquid limit determination of 0.3 per cent, using 15 blows, Figure 6. This illustrates that the differences between the means in the above table are of an extremely small magnitude when referred to the differences that they would make in computing liquid limits. The means of the West Gulf Coastal Plain and the East Gulf Coastal Plain, although from relatively small numbers of tests, differ from the mean of 0.121 by 0.004 and 0.009, respectively. The dispersion of data about the four individual means is least for the West Gulf Coastal Plain, as is seen by an inspection of the coefficients of variation and standard deviations. This is not necessarily conclusive, however, as the smaller number of tests involved means a greater probability for a narrower range in tan β, which in turn results in a smaller coefficient of variation. For practical purposes the measures of dispersion and skewness are essentially the same for all groupings. Based on the above factors it is believed that the histogram of all the tests, figure 5, with its mean of 0.121 best represents all the data studied, and the remainder of this report will be referred to this value.

<u>Per cent error involved in liquid limit determinations using mean slope</u>

22. The histogram and normal frequency curve for all 767 tests were plotted on arithmetic probability graph paper, figure 7. The ordinates of this graph are so spaced

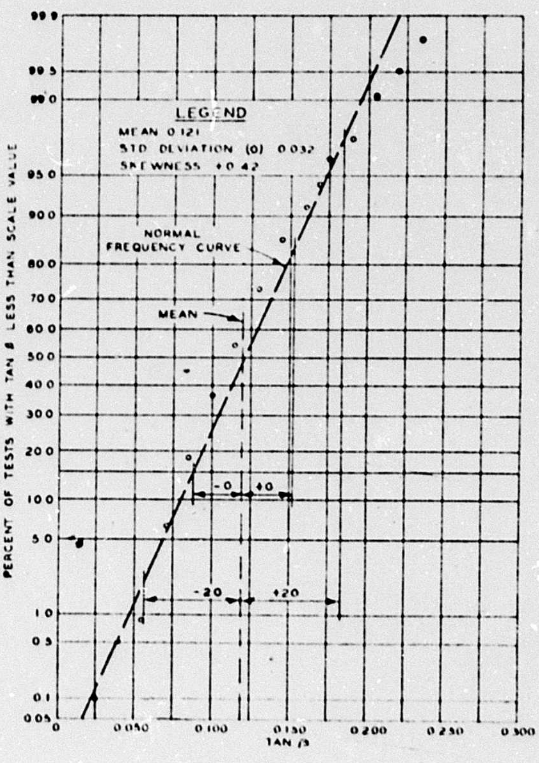


Fig. 7. Arithmetic cumulative frequency curve -- 767 tests

that a normal frequency curve will plot as a straight line when cumulative per cent frequency is used as the ordinate and the quality being measured as the abscissa. An inspection of figure 7 shows that the plotted points generally lie above the normal frequency curve and tend to define a smooth curve rather than a straight line. Both of these facts are indicative of the skewness to the right of the distribution.

23. This cumulative frequency graph facilitates the calculation of the per cent error involved in liquid limit determinations for a given per cent of the tests. The standard deviation, σ, is defined so that, for a normal frequency curve, the mean $\pm\sigma$ includes 68.3 per cent of the observations and the mean $\pm 2\sigma$ includes 95.5 per cent. The mean, $\overline{\tan\beta} = 0.121$, $\overline{\tan\beta} \pm \sigma$, and $\overline{\tan\beta} \pm 2\sigma$, ($\sigma = 0.032$), were plotted on the cumulative frequency curve, figure 7, making it possible to pick off actual percentages of observations included within the ranges noted in the table below. The per cent error in the liquid limit for tests within the given ranges was obtained from figure 6 where per cent change in liquid limit also means per cent error in liquid limit, and $\Delta(\tan\beta)$ is the variation of the mean slope from the true flow line slope. (Fifteen blows were used for the following table.)

Range in tan β		Percentages of Total Observations Lying Within Given Ranges (all 767 tests): Theoretical	Observed	Per Cent Error in Liquid Limit Using N = 15
$\overline{\tan\beta} \pm \sigma$	0.089-0.153	68.3	67.7	less than $\pm$ 1.5
$\overline{\tan\beta} \pm 2\sigma$	0.057-0.185	95.5	95.1	less than $\pm$ 3.3
min tan β - max tan β	0.027-0.235	99.9	100.0	less than + 4.8 ($\tan\beta = 0.027$) less than -5.8 ($\tan\beta = 0.235$)

Factors affecting the liquid limit determination using a mean slope

24. An examination of figure 6 shows that the per cent error in the liquid limit determination depends on the variation of the true slope from the mean slope and on the number of blows used to determine a point on the flow line. The preceding paragraph showed that the error due to variations in the slope of the flow line is small. To keep errors due to number of blows to a small magnitude, the desirability of keeping the number of blows as close as possible to 25 is readily apparent. For example, from the preceding table the error for $\overline{\tan\ \beta} \pm 2\sigma$ using 15 or 41 blows is less than 3.3 per cent for 95.1 per cent of the tests; if 20 or 31 blows were used the error would be reduced to less than 1.4 per cent. (41 and 31 blows give the same error as 15 or 20 blows respectively, figure 6.) The limiting of the number of blows to between 20 and 31 reduces the error to less than 2.5 per cent for all 767 tests as compared to less than 5.8 per cent for between 15 and 41 blows.

Discussion

25. In the analyses of the data it was found that the values of the slopes of the flow lines on a logarithmic plot exhibited a definite tendency to group themselves about a central value, in a distribution which is approximated by a normal arithmetic frequency distribution. While this is satisfactory for analysis of the data, it is pointed out that theoretically a normal frequency distribution cannot represent the data because the values of tan β cannot extend to $-\infty$ and to $+\infty$, but are limited to the range of 0 to $+\infty$. This in itself indicates that some skewness to the right in the observed distribution of values of tan β

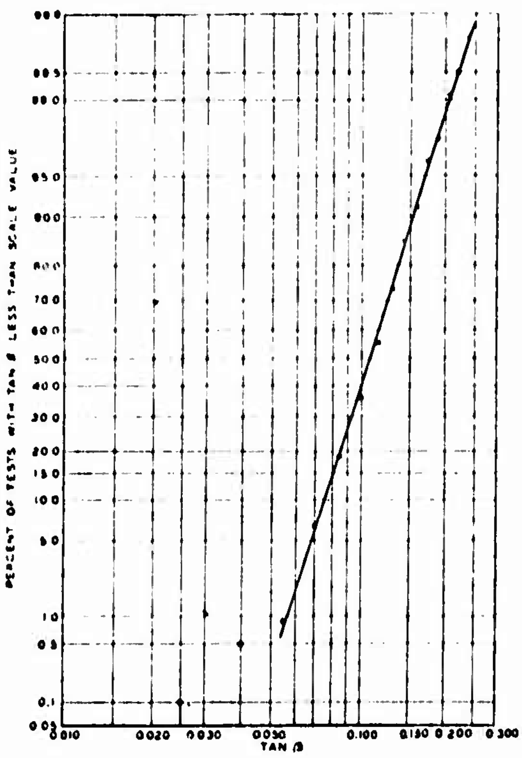


Fig. 8. Logarithmic cumulative frequency curve -- 767 tests

should be expected, and it is likely that the distribution may be better approximated by a logarithmically normal frequency distribution. As a check on this possibility, the data shown on figure 7 were plotted on logarithmic probability paper, figure 8 (identical to the arithmetic probability paper except for the substitution of a logarithmic scale for the arithmetic one). On this type of plot all the points, except those for tan β equal 0.025 and 0.040, lie on a straight line, indicating that the distribution of values of tan β is logarithmically normal rather than arithmetically normal. However, for the purpose of this investigation it was considered that an arithmetically normal frequency distribution could be used.

26. The observed variations of tan β from the mean may be due to a natural distribution of tan β as a property of the soils studied. However, the variations from the mean may also be due, in part, to errors involved in performing the tests rather than to any property of the soil itself. All technicians in the soils laboratory of the Waterways Experiment Station are, at intervals, requested to perform the liquid limit test on the same material. Study of the results so obtained indicates a variation in values of both the liquid limit and tan β, with a grouping

of the test results in such a way as to suggest that they follow a natural error distribution; a distribution of the same form as the normal frequency curve. However, this report is not concerned with which explanation best describes the observed variations, since the variations themselves are of limited significance.

27. The results obtained from the analyses described herein are not intended to apply to soils other than those tested, and no generalization to other soils is made. As regards the soils of the Alluvial Valley of the Mississippi River and the East and West Gulf Coastal Plains, however, sufficient tests have been analyzed to warrant consideration of a simplified liquid limit test procedure for work in the laboratories of the Mississippi River Commission and Lower Mississippi Valley Division. For soils from other areas the procedure may be just as applicable, but the values of tan β should first be determined by preliminary tests. To take full advantage of the fact that, for the soils studied, the dispersion of the flow line slopes is of such small magnitude that errors arising from the use of a mean slope are negligible, the liquid limit test procedure outlined in the following paragraphs is presented.

Recommended Simplified Liquid Limit Procedure

28. The simplified liquid limit procedure is as follows:

a. The test should be run in a humid room if the air is dry. Mix the soil to be tested with water to a consistency as close to the liquid limit as possible. A technician can, with experience, judge this very closely. Extreme care should be taken in the mixing to obtain a uniform water content throughout the sample.

b. Operate the liquid limit device and determine the number of blows necessary to close a 1/2-in. length of the groove.

Take a 15-20 gm wet weight sample at the closed groove for a water content determination. Water content weights should be accurate to 0.01 gm.

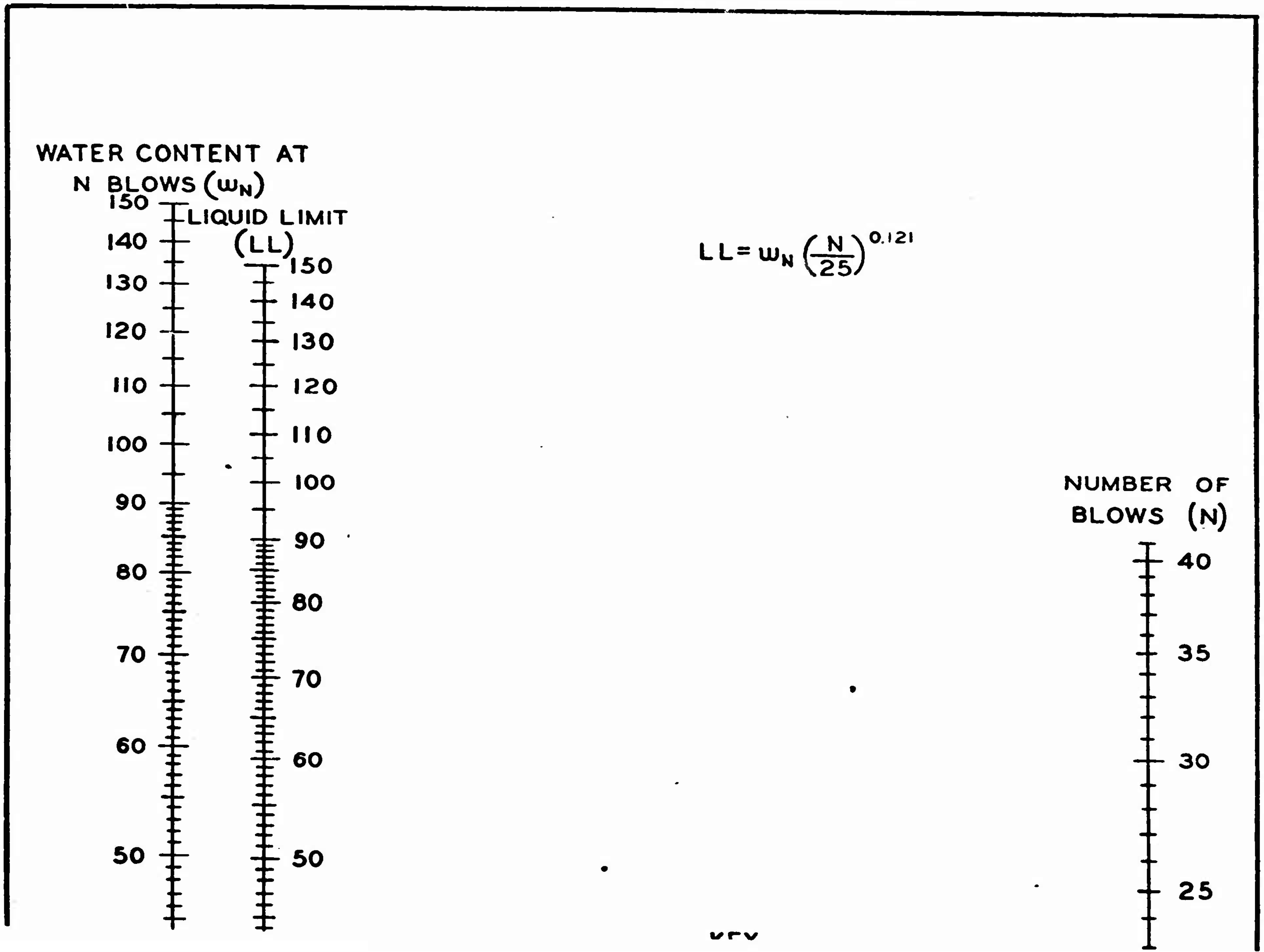
c. Add enough soil paste at the water content of step a to replace that removed, and remix the soil slightly in the liquid limit cup without the addition of water. Regroove and operate the device again. The number of blows necessary to close 1/2 in. of the groove should either be the same as before or not more than two blows different. (If it is not, it is a sign of insufficient mixing in step a, and the entire procedure should be repeated.) Take another sample at the closed groove for a water content determination.

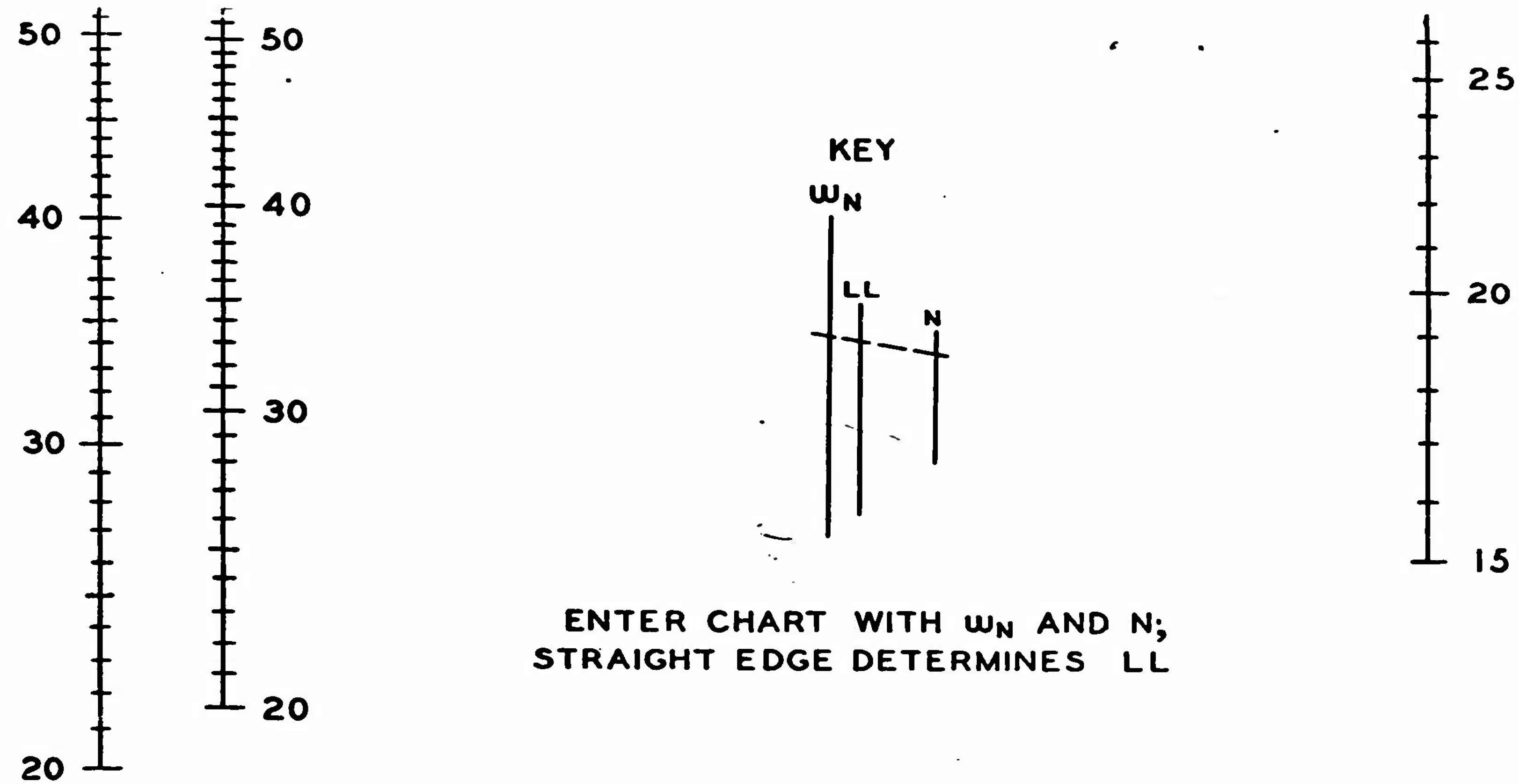
d. The liquid limit is determined from the equation:

$$LL = w_N \left(\frac{N}{25} \right)^{0.121}$$

where w_N is the water content at N blows. Figure 9 is a nomographic chart useful in solving this equation. A straightedge laid on a given water content at a corresponding number of blows determines the liquid limit. Two initial liquid limit values should be computed using the data from steps b and c. The average of the two is the final liquid limit. The difference between the two initial values should be less than 2 per cent of their average to consider the test valid.

29. If the liquid limit is being used for classification purposes, the number of blows should be kept between 15 and 41, but if the liquid limit is being used for quantitative correlation with other tests, e.g., consolidation, it is desirable that the number of blows be kept between 20 and 31.


WATER CONTENT AT N BLOWS (w_N)
LIQUID LIMIT (LL)
$LL = w_N \left(\frac{N}{25}\right)^{0.121}$
NUMBER OF BLOWS (N)
150
140
130
120
110
100
90
80
70
60
50
40
35
30
25



NOMOGRAPHIC CHART TO DETERMINE LIQUID LIMIT USING MEAN SLOPE METHOD

FIGURE 9

2

PART IV: CONCLUSIONS AND RECOMMENDATIONS

30. Based on the data and analyses presented in this report, the following conclusions are warranted for the soils studied -- namely, medium to highly plastic inorganic clays with liquid limits less than 150 from the Alluvial Valley of the Mississippi River and the East and West Gulf Coastal Plain areas.

a. The slopes of liquid limit flow lines, when plotted to a logarithmic scale, tend to group around a central value which appears to be independent of soil type and geologic classification.

b. The variations of the slopes of the flow lines for the soils studied, without regard to geologic origin, satisfactorily approximate a normal frequency distribution. This result makes it possible to use the simplified liquid limit procedure.

c. Liquid limits computed using a mean flow line slope of 0.121 and one liquid limit test point give results well within the accuracy required in normal work.

d. It is recommended that the simplified liquid limit procedure described in paragraphs 28-29 be adopted for soils from the Alluvial Valley of the Mississippi River and the East and West Gulf Coastal Plain areas. This procedure will result in a substantial reduction in the cost of liquid limit determinations.

TABLES

Table 1

SUMMARY OF DATA FROM THE ALLUVIAL VALLEY OF THE MISSISSIPPI RIVER

Project and Location	Geologic Description	No. Tests	Mean tan β	Range tan β Min	Range tan β Max	Range Liquid Limit Min	Range Liquid Limit Max	Range Plasticity Index Min	Range Plasticity Index Max
Upper St. Francis Levee District, vicinity mi 900 AHP rt bank	Recent alluvium	40	0.112	0.027	0.193	33	104	4	74
Reelfoot Levee District, vicinity mi 900 AHP lt bank	Recent alluvium	30	0.122	0.071	0.176	30	102	9	73
Tiptonville-Obion River Levee Extension, vicinity mi 850 AHP lt bank	Recent alluvium	25	0.107	0.061	0.130	59	147	35	97
Lower St. Francis Levee District, vicinity mi 750 AHP rt bank	Recent alluvium	25	0.123	0.071	0.186	34	94	7	69
Upper Yazoo Levee District, vicinity mi 700 AHP lt bank	Recent alluvium	25	0.122	0.063	0.176	35	106	14	80
White River Levee District, vicinity mi 650 AHP rt bank	Recent alluvium	25	0.094	0.069	0.130	43	107	22	77
Coldwater River Levee, Coldwater River, Mississippi	Yazoo River Basin, recent alluvium	15	0.097	0.069	0.130	50	99	31	73
Greenwood Protection Levee, Greenwood, Mississippi	Yazoo River Basin, recent alluvium	13	0.098	0.072	0.122	56	100	32	69
Bougere Levee, vicinity Natchez, Miss., rt bank	Recent alluvium	22	0.101	0.074	0.129	59	122	34	86
Bayou Cocodrie, vicinity Shaw, Louisiana	Lower Tensas Basin, backswamp and natural levee deposits	23	0.128	0.097	0.185	47	115	26	87
Morganza Floodway Area, Atchafalaya River Basin, La.									
Bayou Sorrel Lock, approx 10 mi SW Plaquemine, La.	Backswamp deposits	13	0.121	0.037	0.192	66	136	40	96
Texas & Pacific RR Embankment (Port Allen branch), runs NW fm Morganza, La., about 5 mi long	Backswamp deposits	49	0.127	0.070	0.202	28	122	6	90
N.O.T.& M. RR Embankment, runs between Krotz Springs & Cortableau, La.	Backswamp deposits	10	0.108	0.084	0.148	34	103	11	67
Morganza Control Structure, approx 5 mi north Morganza, La.	Backswamp deposits	55	0.128	0.063	0.222	30	117	3	79
	Channel filling deposits	13	0.123	0.080	0.228	30	115	5	88
Veterans Administration Hospital, New Orleans, La.	Recent marsh deposits	8	0.109	0.084	0.132	60	82	35	54
	Marine deposits	12	0.115	0.070	0.180	24	83	9	52
	Pleistocene-Prairie deposits	8	0.104	0.038	0.212	59	82	35	54
Algiers Lock, vicinity of Algiers, La.	Recent marsh deposits	18	0.100	0.070	0.171	58	99	37	71
	Marine deposits	3	0.143	0.128	0.154	54	66	38	44
	Alluvial Valley of Mississippi River	432	0.115	0.027	0.228	24	147	3	97

Table 2

SUMMARY OF DATA FROM THE EAST AND WEST GULF COASTAL PLAINS AND MISCELLANEOUS GROUP

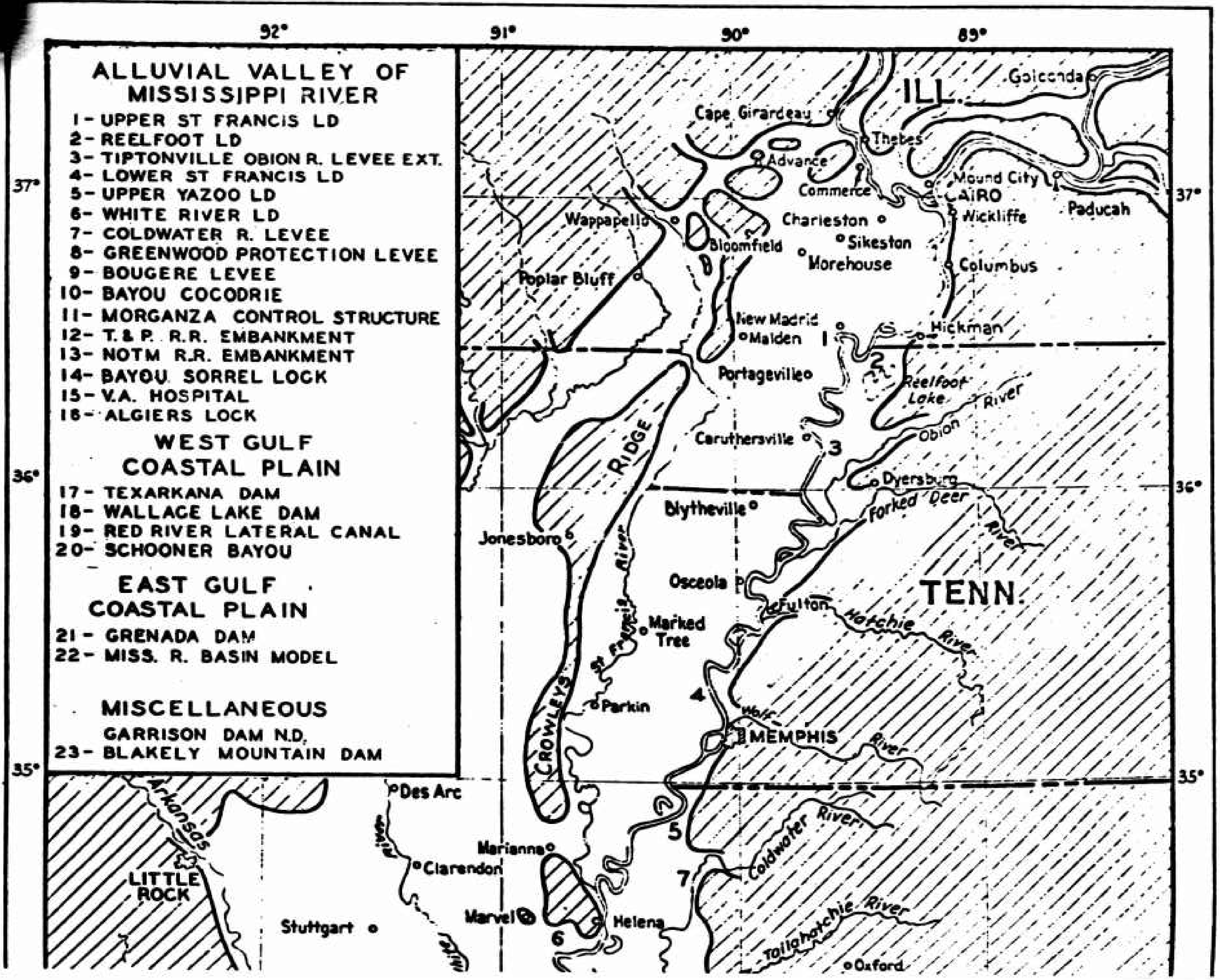
Project and Location	Geologic Description	No. Tests	Mean tan Φ	Range tan Φ Min	Range tan Φ Max	Range Liquid Limit Min	Range Liquid Limit Max	Range Plasticity Index Min	Range Plasticity Index Max
	WEST GULF COASTAL PLAIN								
Texarkana Dam, Sulphur River, vicinity Texarkana, Ark.	Pleistocene-Terrace deposits	106	0.12[illegible]	0.073	0.1[illegible]	[illegible]	[illegible]	9	76
Wallace Lake Dam, Red River, approx 15 mi south Shreveport, La.	Red River Valley, recent alluvium	13	0.12[illegible]	0.094	0.170	57	[illegible]	33	59
Red River Lateral Canal, vicinity of Marksville, La.	Red River Valley, recent alluvium	10	0.120	0.074	0.212	30	74	11	48
Schooner Bayou, approx 18 mi south Abbeville, La.	Pleistocene-Prairie deposits	7	0.133	0.065	0.210	31	83	5	48
	West Gulf Coastal Plain	136	0.125	0.065	0.212	25	99	5	76
	EAST GULF COASTAL PLAIN								
Grenada Dam, vicinity Grenada, Miss.	Yalobusha River Valley								
	Tertiary (Eocene)	69	0.133	0.067	0.235	17	100	2	73
	Recent alluvium	25	0.129	0.069	0.192	29	121	9	94
Mississippi River Basin Model, Clinton, Miss.	Tertiary (Eocene)	41	0.128	0.073	0.179	32	108	16	87
	East Gulf Coastal Plain	135	0.130	0.065	0.235	17	121	2	94
	MISCELLANEOUS								
Garrison Dam, vicinity Garrison, N. D.	Missouri River Valley								
	Recent alluvium	42	0.121	0.063	0.197	30	99	3	76
	Glacial till	7	0.138	0.100	0.207	26	40	10	22
	Average	49	0.123						
Blakely Mountain Dam, 10 mi NW Hot Springs, Ark.	Ouachita River Valley Residual and Alluvial	15	0.123	0.074	0.151	20	33	5	16
	Miscellaneous	64	0.123	0.063	0.207	20	99	3	76

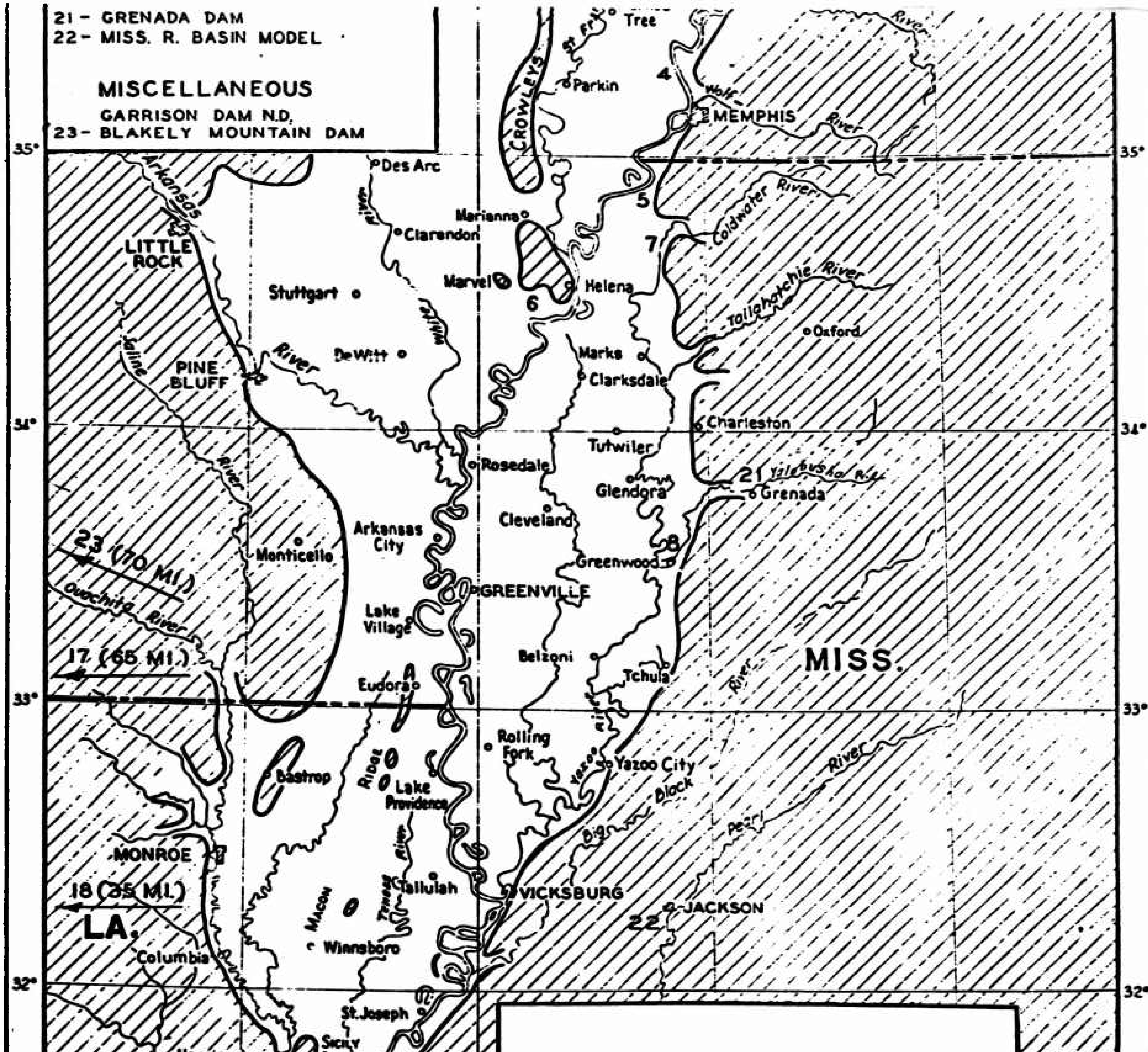
Table 3

CONSOLIDATED DATA FROM THE PRINCIPAL GEOGRAPHIC AREAS

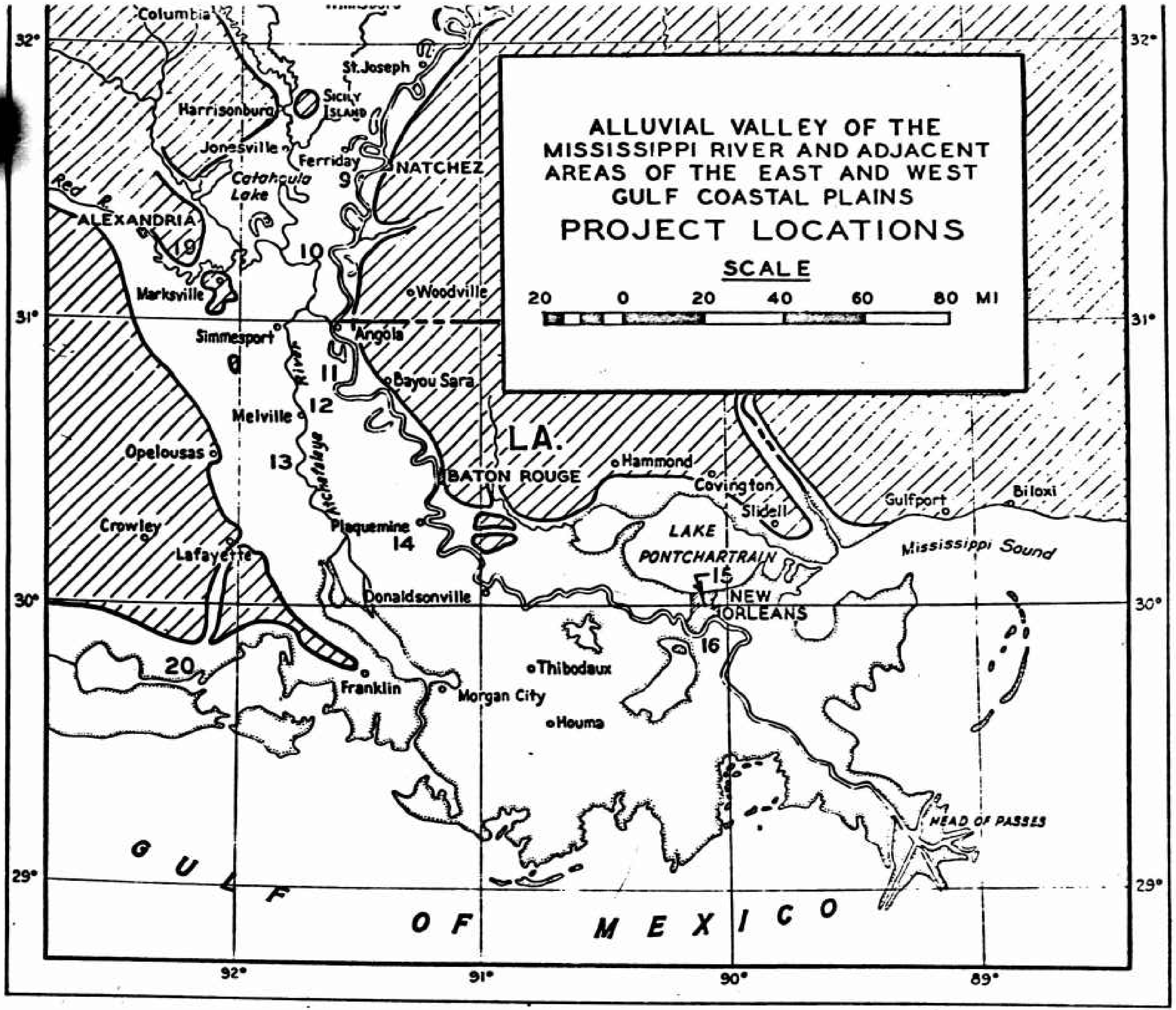
Area	No. Tests	Mean $\tan\beta$	Range $\tan\beta$ Min	Range $\tan\beta$ Max	Standard Deviation (σ)	Skewness (k)	Coefficient of Variation (v %)	Range Liquid Limit Min	Range Liquid Limit Max	Range Plasticity Index Min	Range Plasticity Index Max
Alluvial Valley of Mississippi River (Table 1)	432	0.115	0.027	0.228	0.032	+0.55	27.8	24	147	3	97
West Gulf Coastal Plain (Table 2)	136	0.125	0.065	0.212	0.028	+0.52	22.4	25	99	5	76
East Gulf Coastal Plain (Table 2)	135	0.130	0.065	0.235	0.035	+0.44	26.9	17	121	2	94
Miscellaneous (Table 2)	64	0.123	0.063	0.207	-	-	-	20	99	3	76
All Tests	767	0.121	0.027	0.235	0.032	+0.42	26.4	17	147	2	97

31067


ALLUVIAL VALLEY OF MISSISSIPPI RIVER
1 - UPPER ST FRANCIS LD
2 - REELFOOT LD
3 - TIPTONVILLE OBION R. LEVEE EXT.
4 - LOWER ST FRANCIS LD
5 - UPPER YAZOO LD
6 - WHITE RIVER LD
7 - COLDWATER R. LEVEE
8 - GREENWOOD PROTECTION LEVEE
9 - BOUGERE LEVEE
10 - BAYOU COCODRIE
11 - MORGANZA CONTROL STRUCTURE
12 - T. & P. R.R. EMBANKMENT
13 - NOTM R.R. EMBANKMENT
14 - BAYOU SORREL LOCK
15 - V.A. HOSPITAL
16 - ALGIERS LOCK
WEST GULF COASTAL PLAIN
17 - TEXARKANA DAM
18 - WALLACE LAKE DAM
19 - RED RIVER LATERAL CANAL
20 - SCHOONER BAYOU
EAST GULF COASTAL PLAIN
21 - GRENADA DAM
22 - MISS. R. BASIN MODEL
MISCELLANEOUS
GARRISON DAM N.D.
23 - BLAKELY MOUNTAIN DAM
92°
91°
90°
89°
37°
36°
35°
ILL.
TENN.
Cape Girardeau
Thebes
Advance
Commerce
Mound City
CAIRO
Paducah
Wickliffe
Charleston
Sikeston
Morehouse
Columbus
Wappapello
Bloomfield
Poplar Bluff
New Madrid
Malden
Hickman
Portageville
Reelfoot Lake
Obion River
Caruthersville
Dyersburg
Forked Deer River
Blytheville
Jonesboro
RIDGE
CROWLEYS
St. Francis River
Osceola
Fulton
Hatchie River
Marked Tree
Parkin
Wolf River
MEMPHIS
Des Arc
Marianna
Clarendon
Marvel
Helena
Coldwater River
Tallahatchie River
Oxford
Arkansas
LITTLE ROCK
Stuttgart

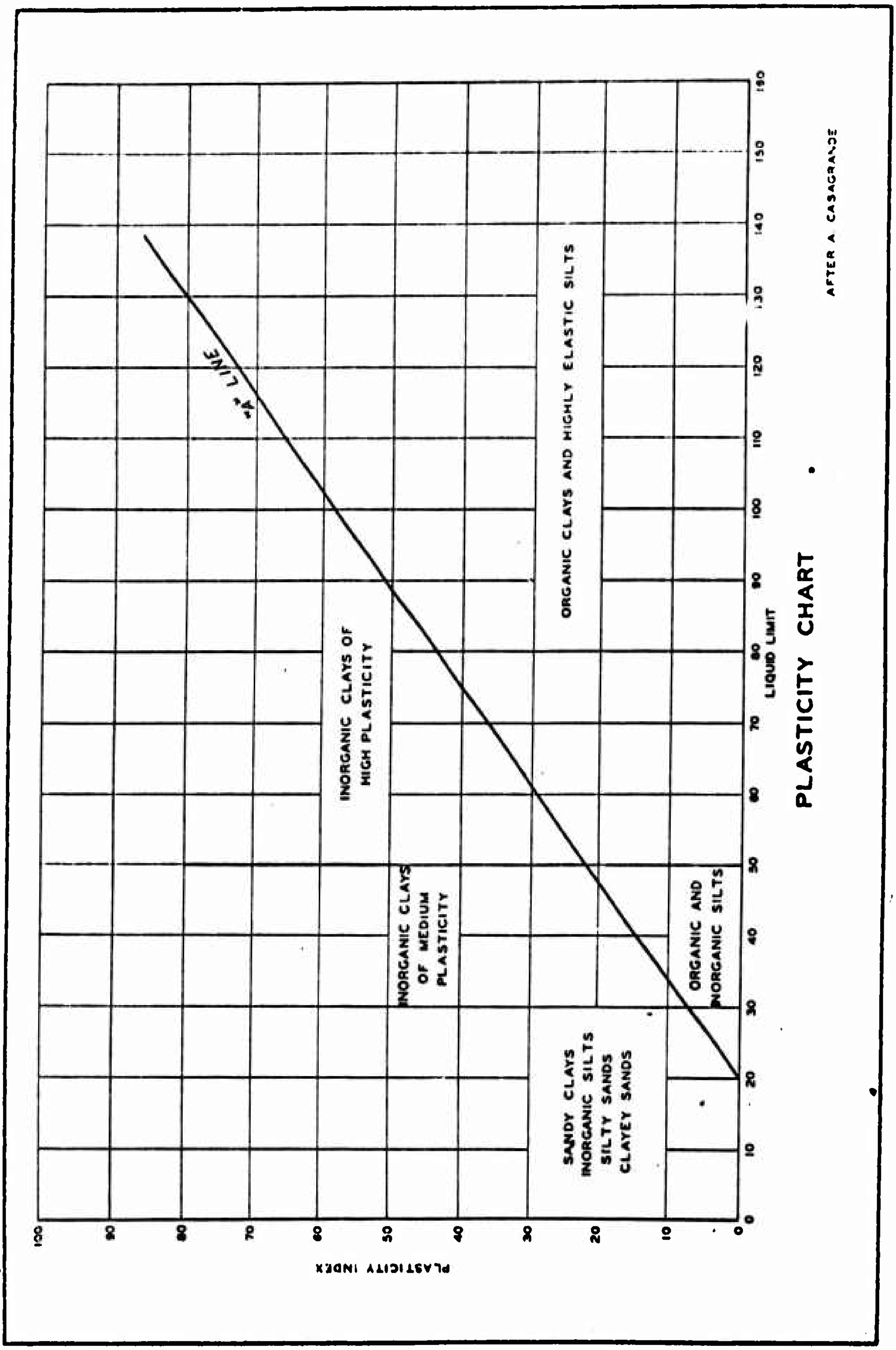

21 - GRENADA DAM
22 - MISS. R. BASIN MODEL
MISCELLANEOUS
GARRISON DAM N.D.
23 - BLAKELY MOUNTAIN DAM
35°
34°
33°
32°
MEMPHIS
Parkin
Tree
CROWLEYS
Des Arc
Marianna
Clarendon
Marvel
Helena
LITTLE ROCK
Arkansas
Stuttgart
DeWitt
PINE BLUFF
Saline
River
White
Marks
Clarksdale
Charleston
Tutwiler
Rosedale
Glendora
Grenada
Cleveland
Greenwood
Arkansas City
Monticello
GREENVILLE
Lake Village
Belzoni
Tchula
Eudora
Rolling Fork
Yazoo City
Bastrop
Lake Providence
MONROE
Tallulah
VICKSBURG
JACKSON
Macon
Winnsboro
Columbia
St.Joseph
LA.
MISS.
Oxford
Coldwater River
Tallahatchie River
Yalobusha R.
Wolf River
Ouachita River
Yazoo
Big Black
Pearl River
23 (70 MI.)
17 (65 MI.)
18 (35 MI.)
4
5
6
7
8
21
22

2



ALLUVIAL VALLEY OF THE
MISSISSIPPI RIVER AND ADJACENT
AREAS OF THE EAST AND WEST
GULF COASTAL PLAINS
PROJECT LOCATIONS
SCALE
20 0 20 40 60 80 MI
32°
31°
30°
29°
92°
91°
90°
89°
Columbia
St. Joseph
Sicily Island
Harrisonburg
Jonesville
Ferriday
NATCHEZ
Catahoula Lake
Red R.
ALEXANDRIA
Marksville
Woodville
Simmesport
Angola
Bayou Sara
Melville
Opelousas
Atchafalaya River
LA.
Hammond
BATON ROUGE
Covington
Slidell
Gulfport
Biloxi
Crowley
Lafayette
Plaquemine
LAKE PONTCHARTRAIN
Mississippi Sound
Donaldsonville
NEW ORLEANS
Thibodaux
Franklin
Morgan City
Houma
HEAD OF PASSES
GULF OF MEXICO
8
9
10
11
12
13
14
15
16
19
20

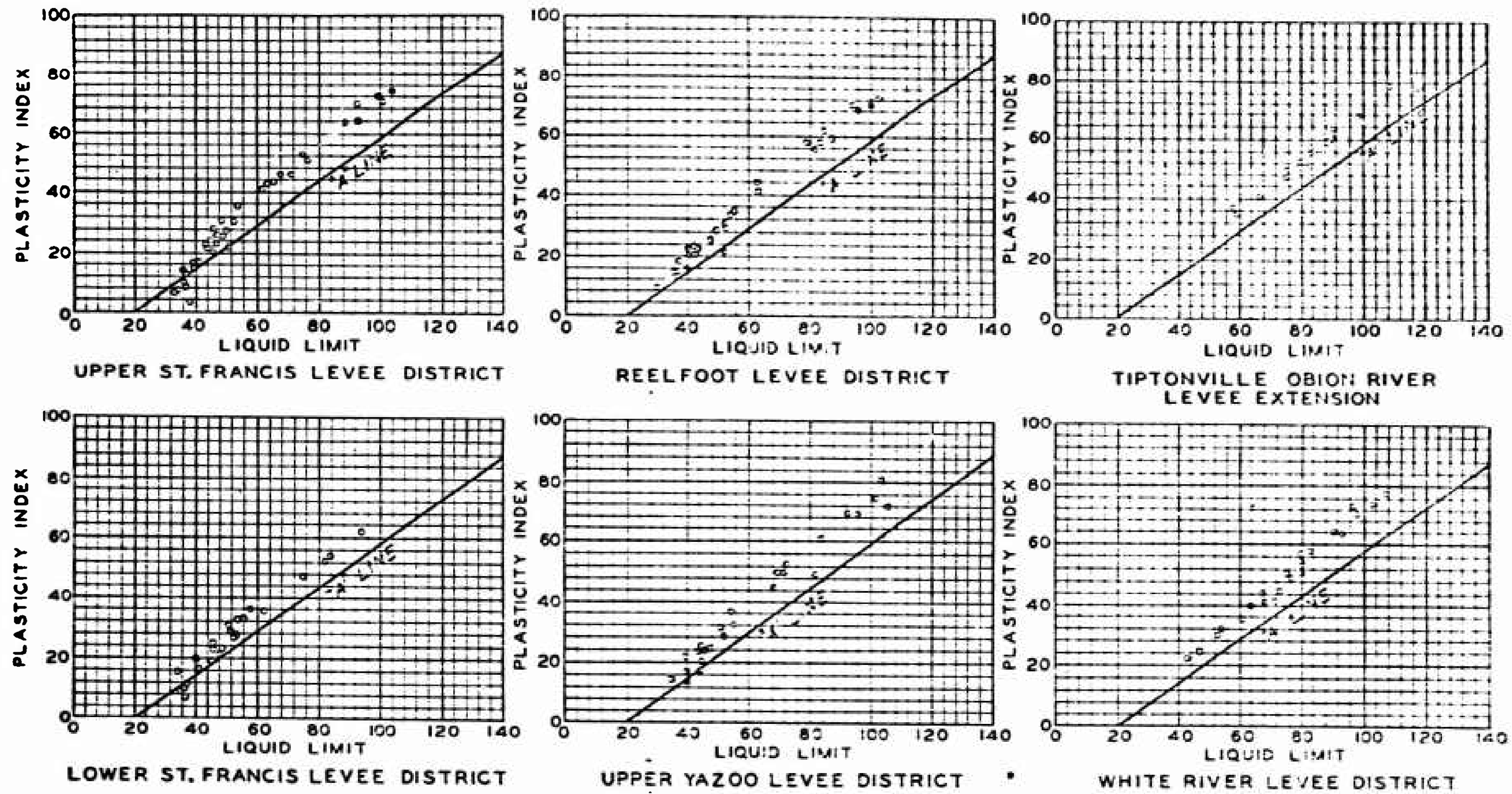
PLATE I



PLASTICITY CHART

AFTER A. CASAGRANDE

PLATE 2

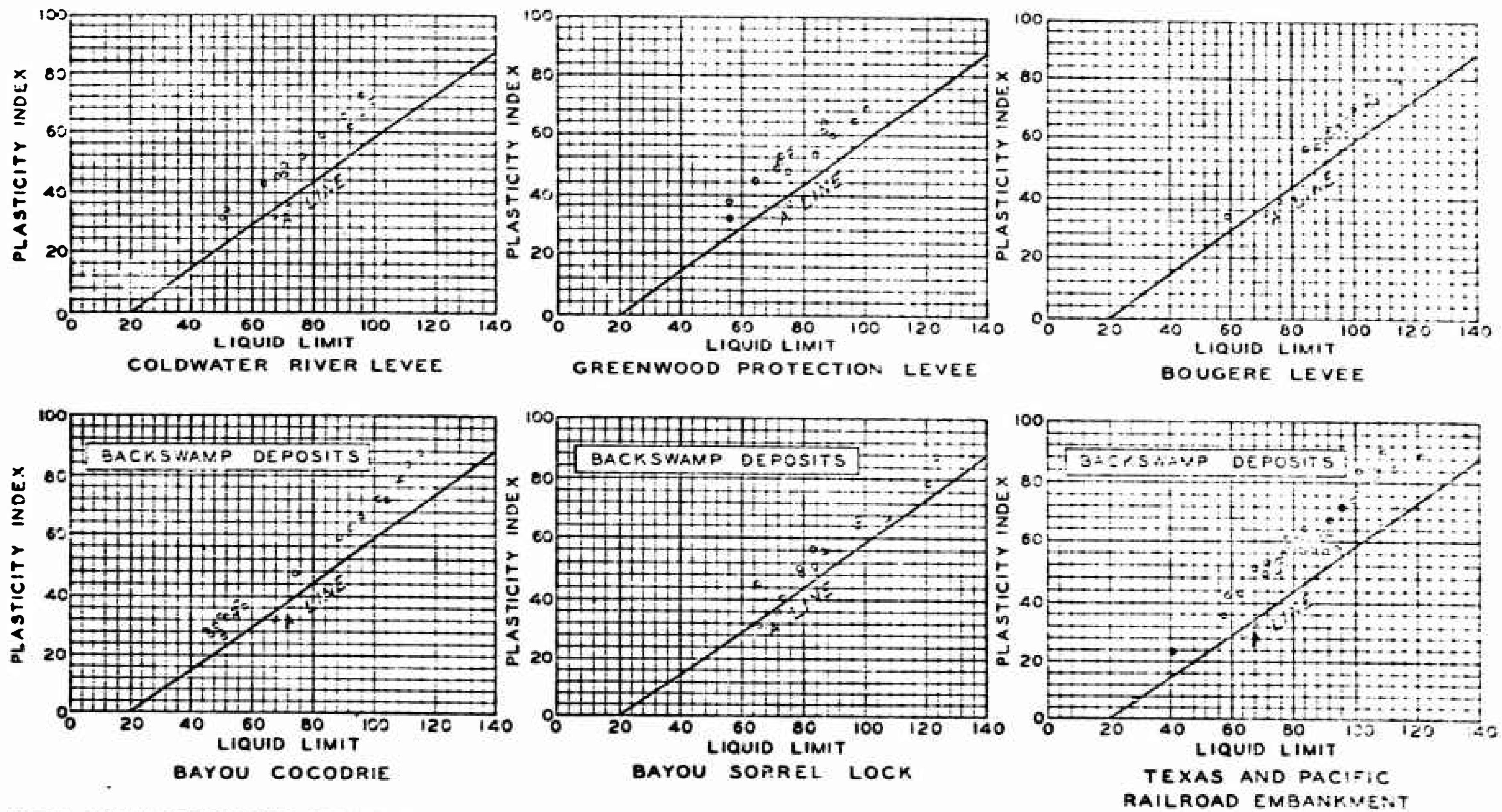


NOTE: ALL TESTS RECENT ALLUVIUM

PLASTICITY CHARTS

PROJECTS IN THE ALLUVIAL VALLEY OF THE MISSISSIPPI RIVER

PLATE 3

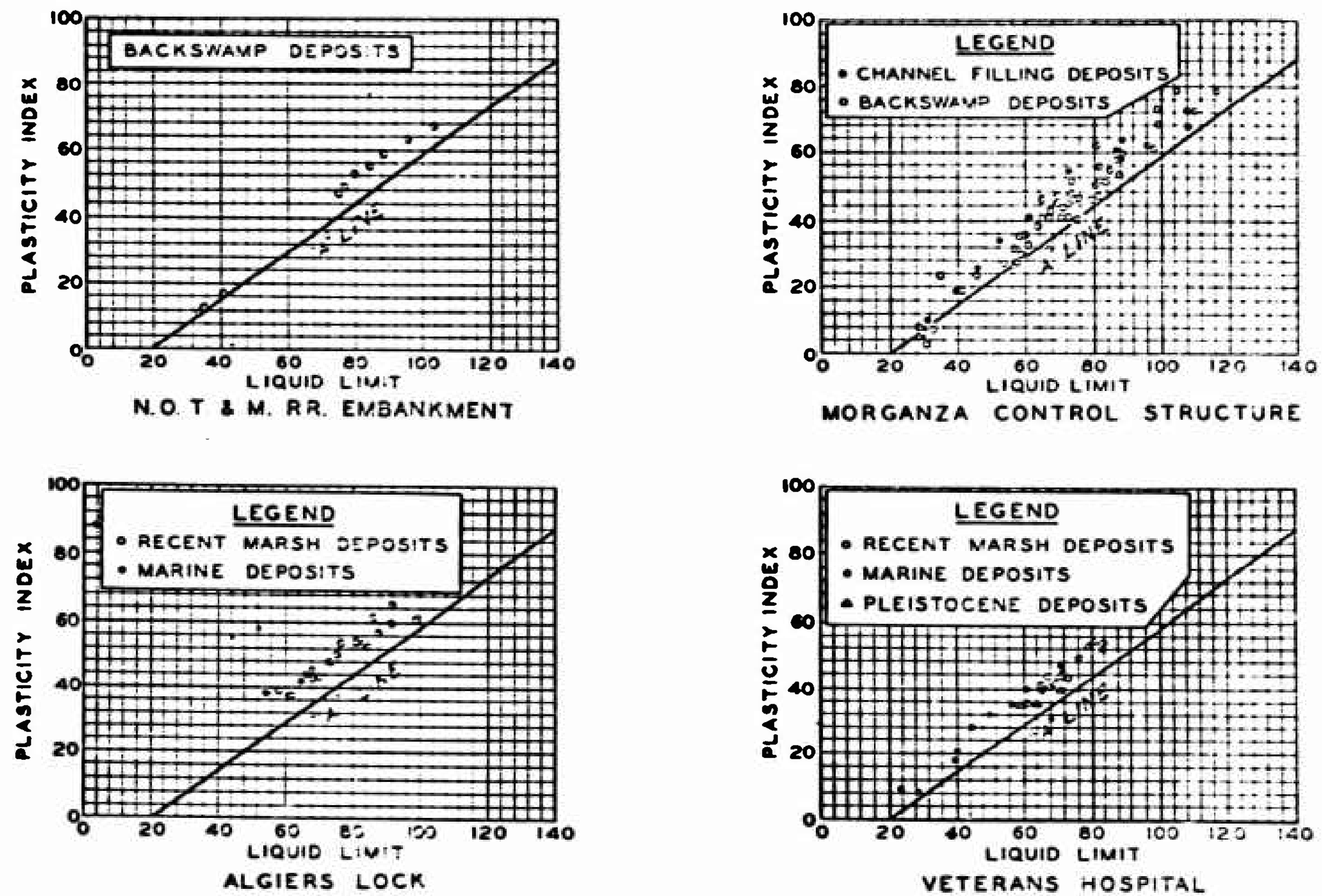


NOTE. ALL TESTS RECENT ALLUVIUM

PLASTICITY CHARTS

PROJECTS IN THE ALLUVIAL VALLEY OF
THE MISSISSIPPI RIVER

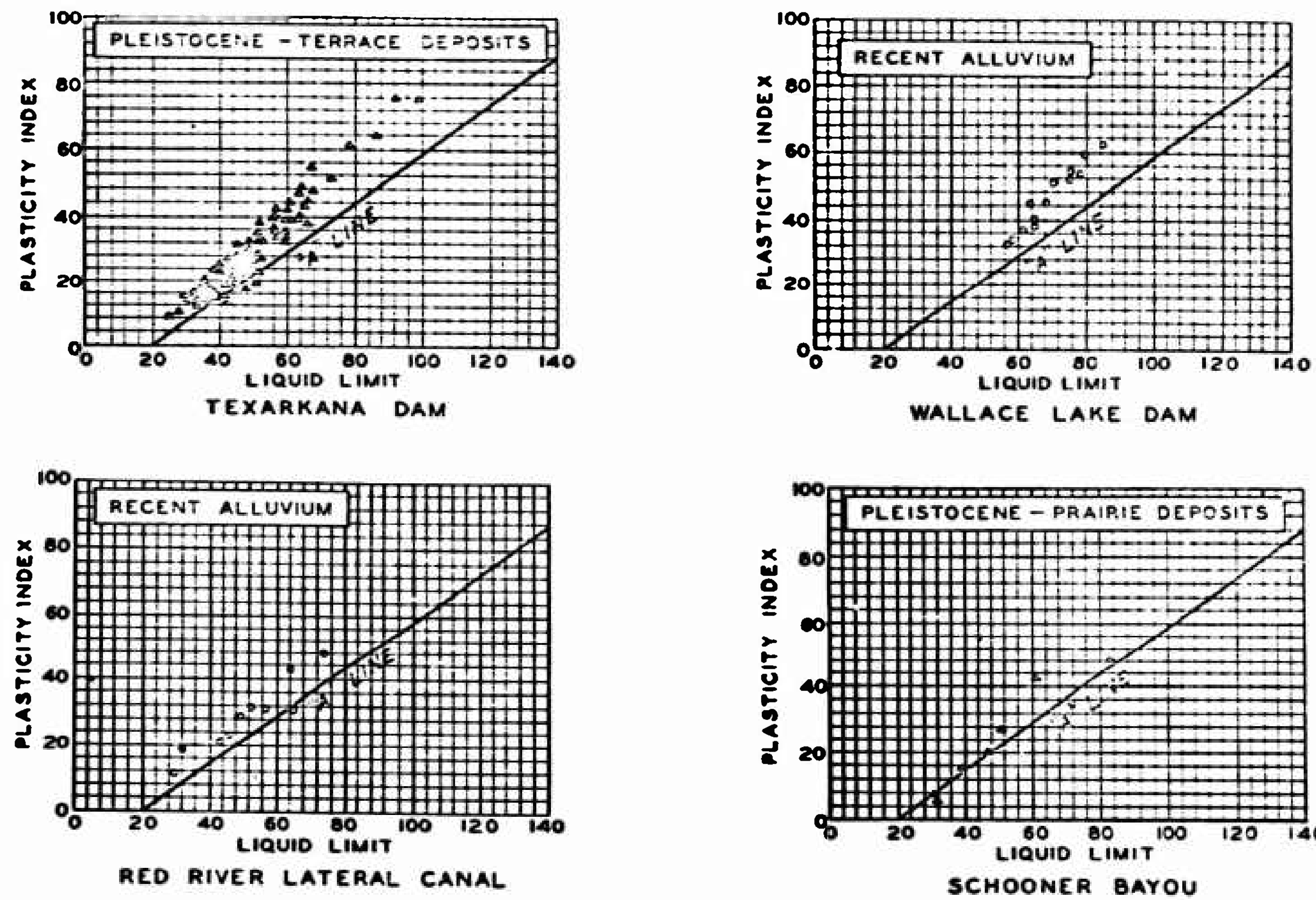
PLATE 4



PLASTICITY CHARTS

PROJECTS IN THE ALLUVIAL VALLEY OF
THE MISSISSIPPI RIVER

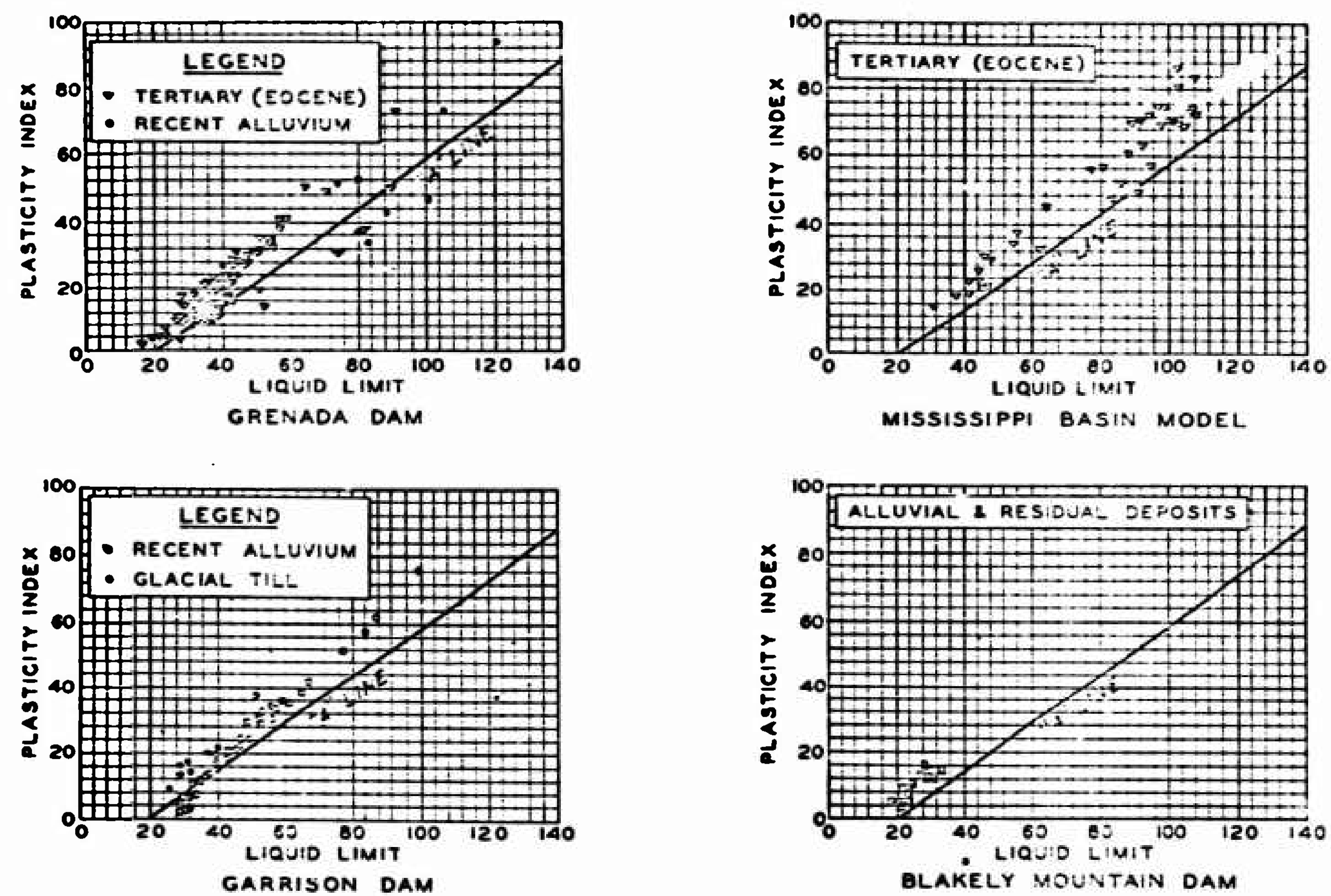
PLATE 5



PLASTICITY CHARTS

PROJECTS IN THE WEST GULF COASTAL PLAIN

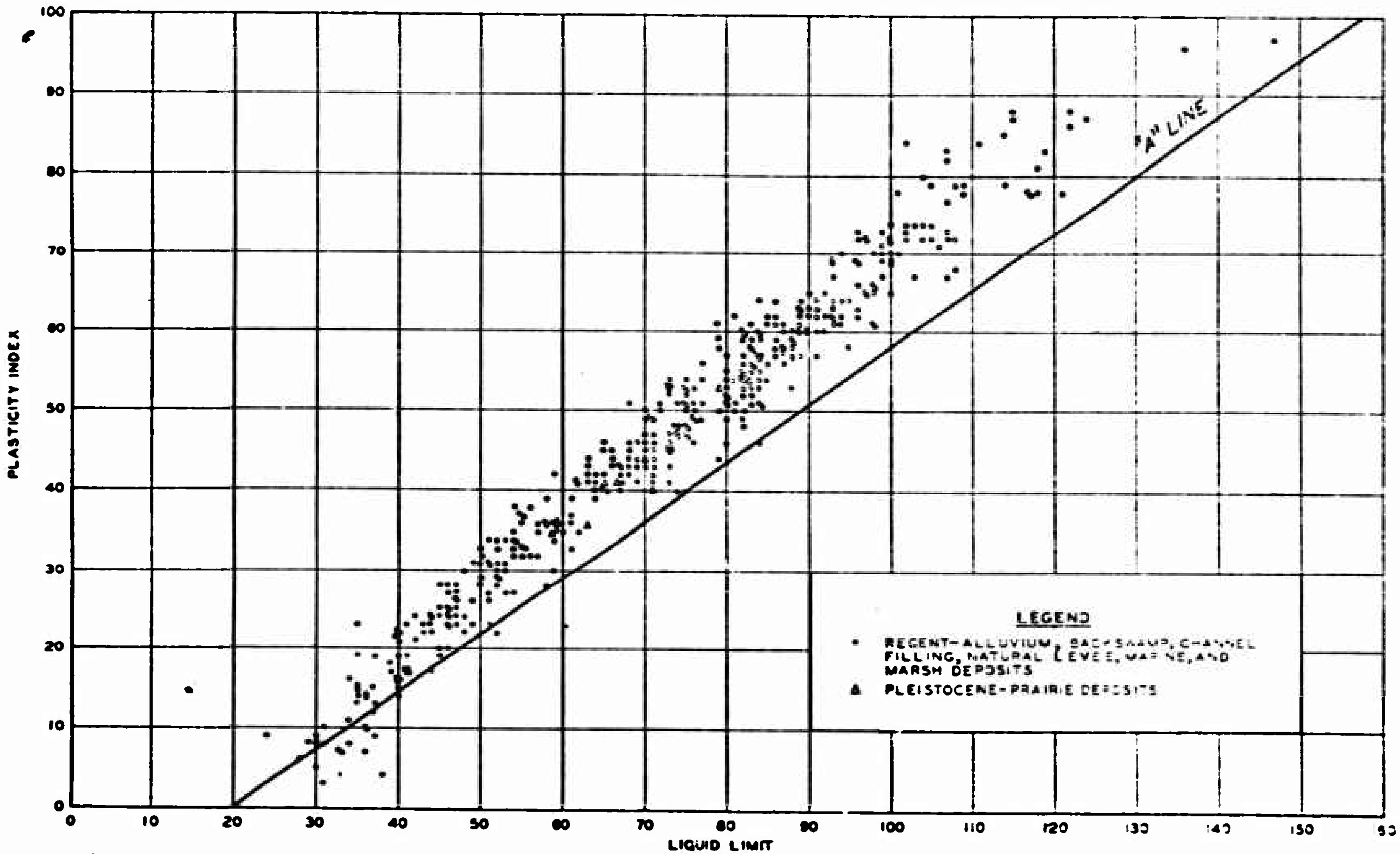
PLATE 6



PLASTICITY CHARTS

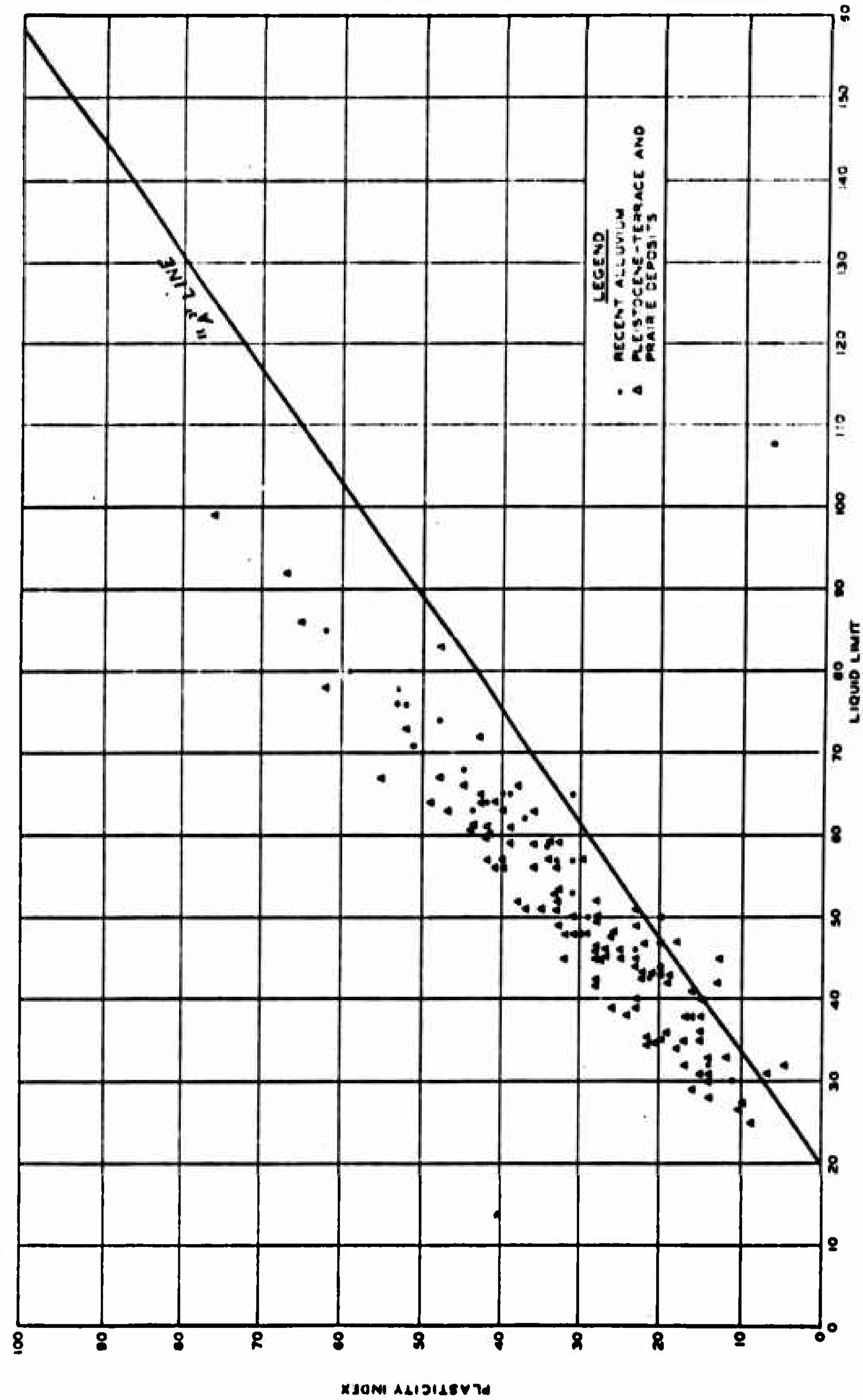
PROJECTS IN THE EAST GULF COASTAL PLAIN
AND MISCELLANEOUS GROUP

PLATE 7



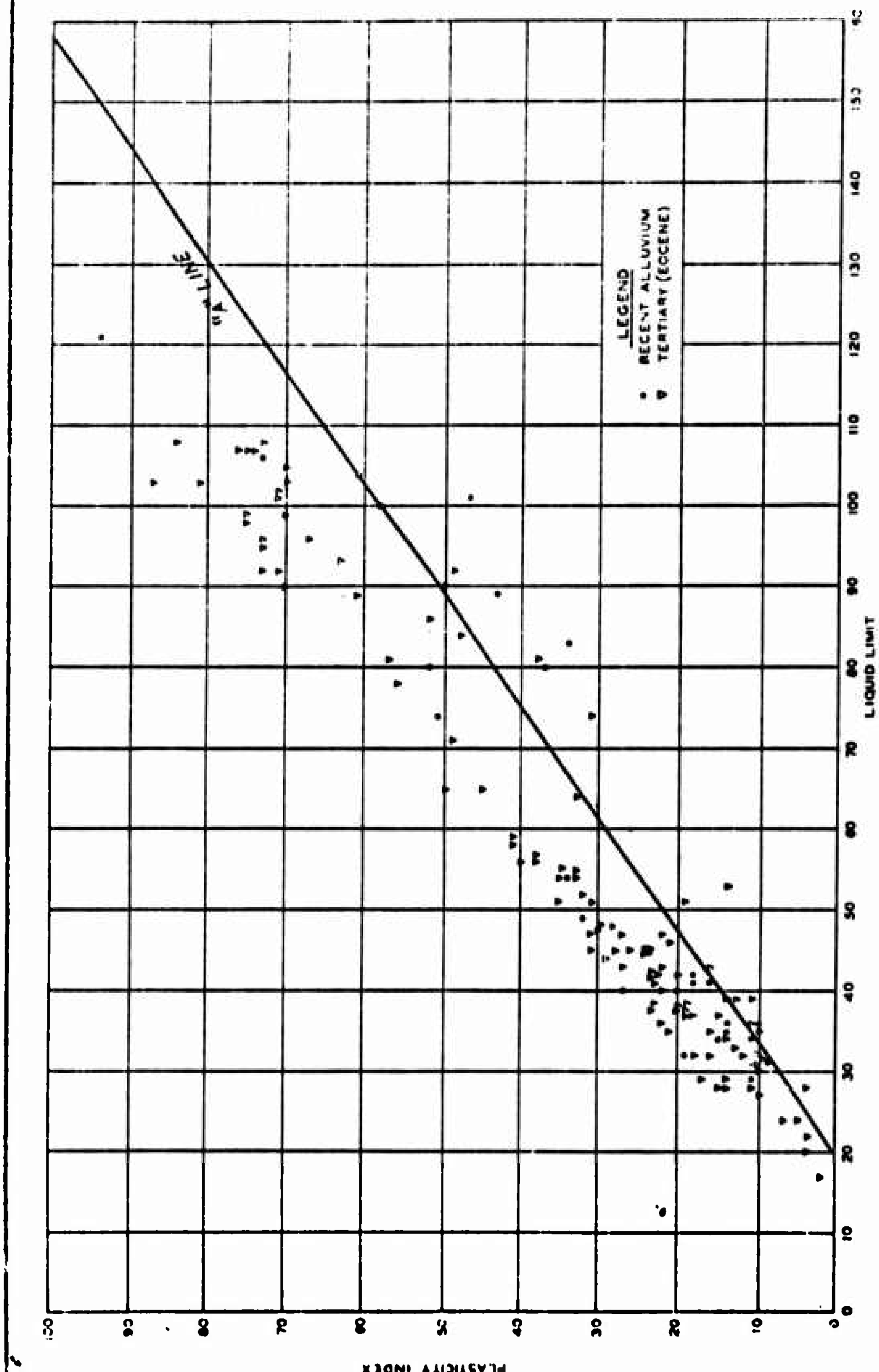
PLASTICITY CHART
ALLUVIAL VALLEY OF THE MISSISSIPPI RIVER-432 TESTS

PLATE 8



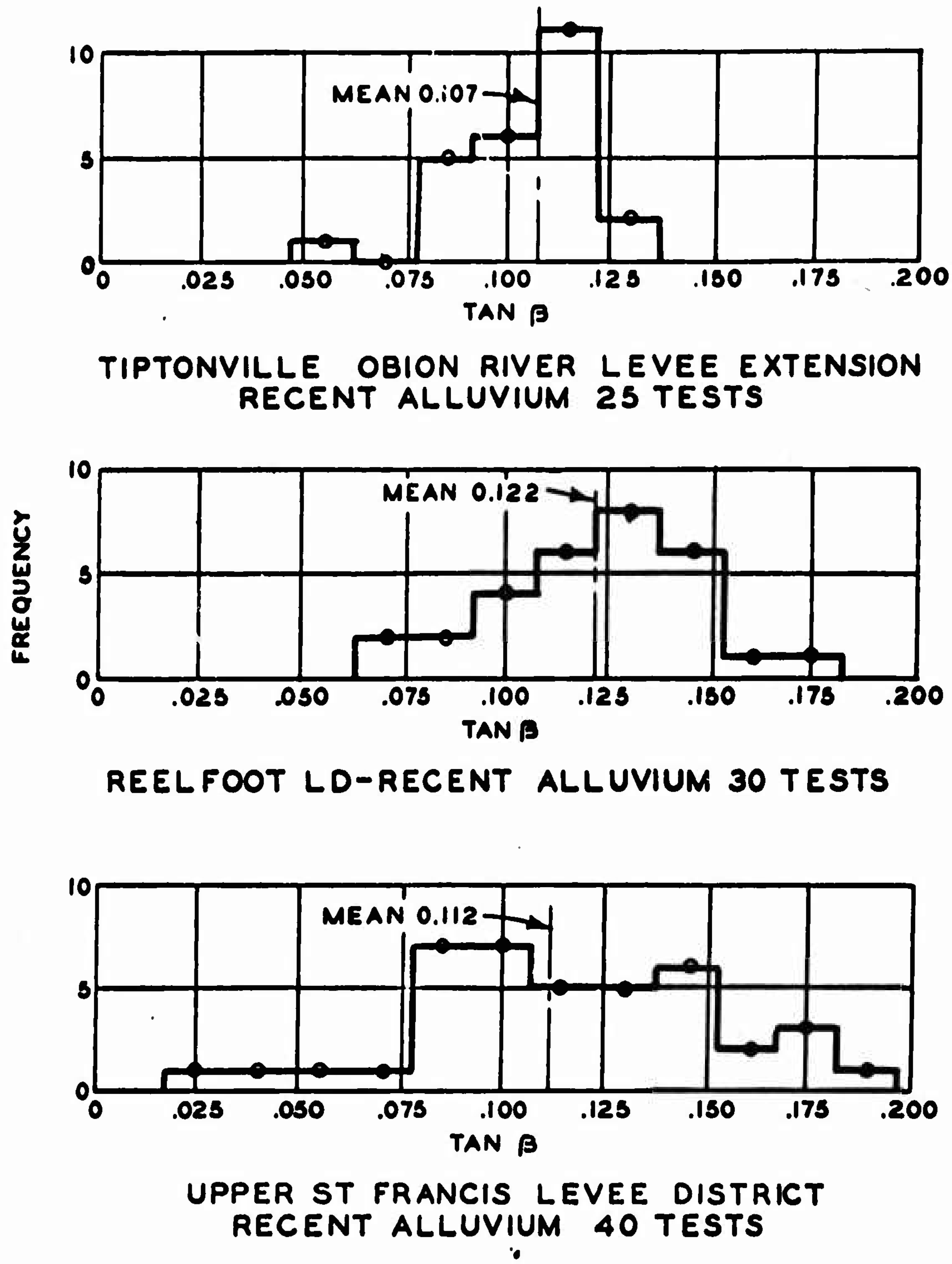
PLASTICITY CHART
WEST GULF COASTAL PLAIN
136 TESTS

PLATE 9

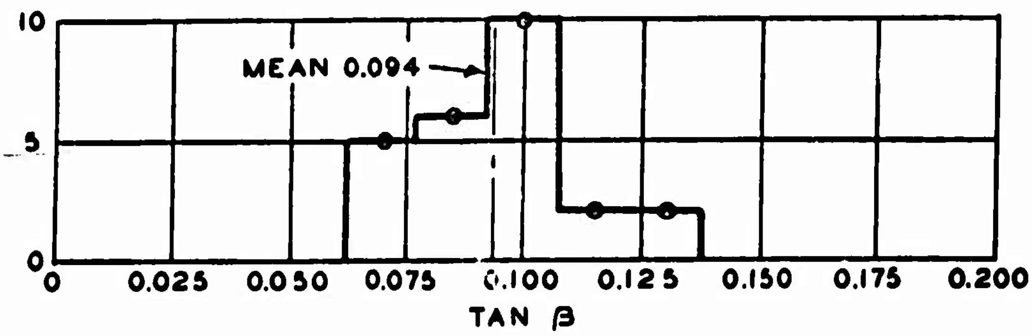


PLASTICITY CHART
EAST GULF COASTAL PLAIN
135 TESTS

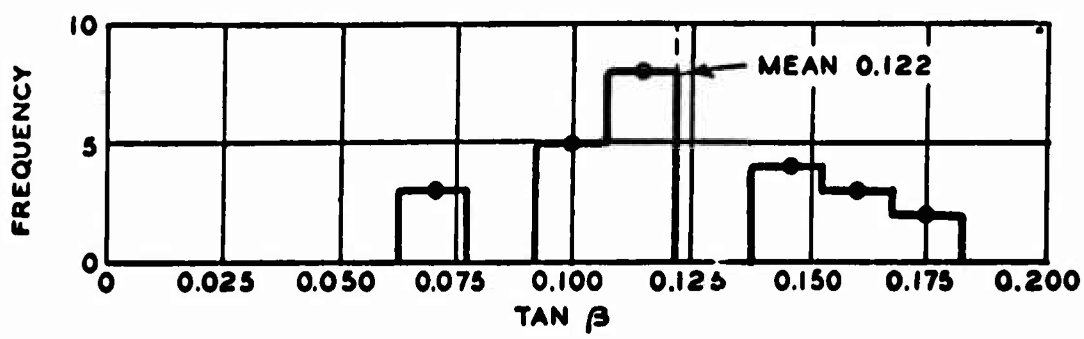
PLATE 10



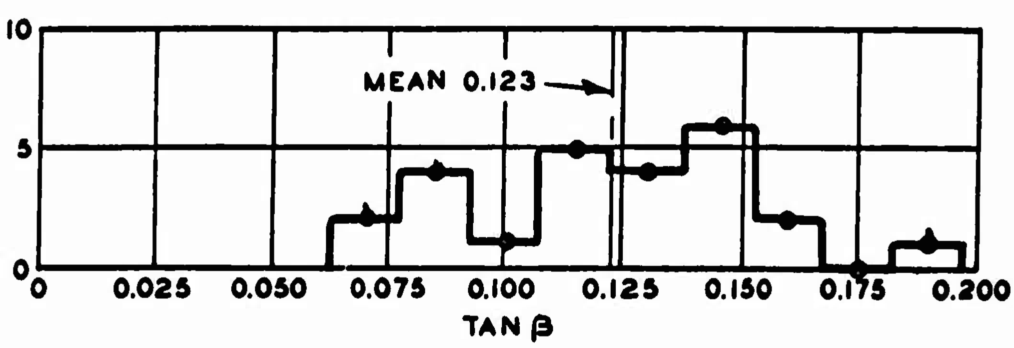
HISTOGRAMS OF GEOLOGIC SOIL TYPES



WHITE RIVER LEVEE DISTRICT
RECENT ALLUVIUM 25 TESTS

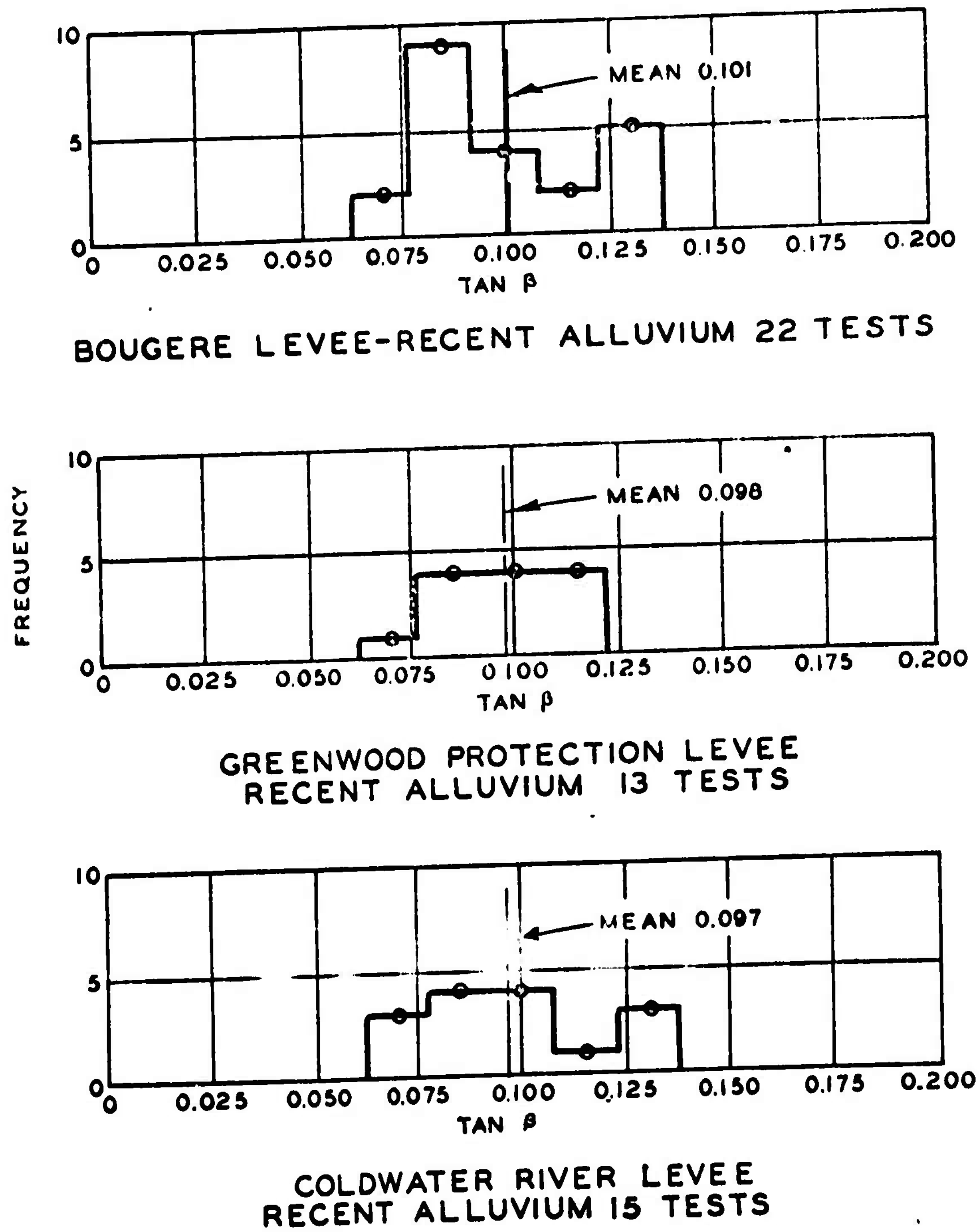


UPPER YAZOO LEVEE DISTRICT
RECENT ALLUVIUM 25 TESTS

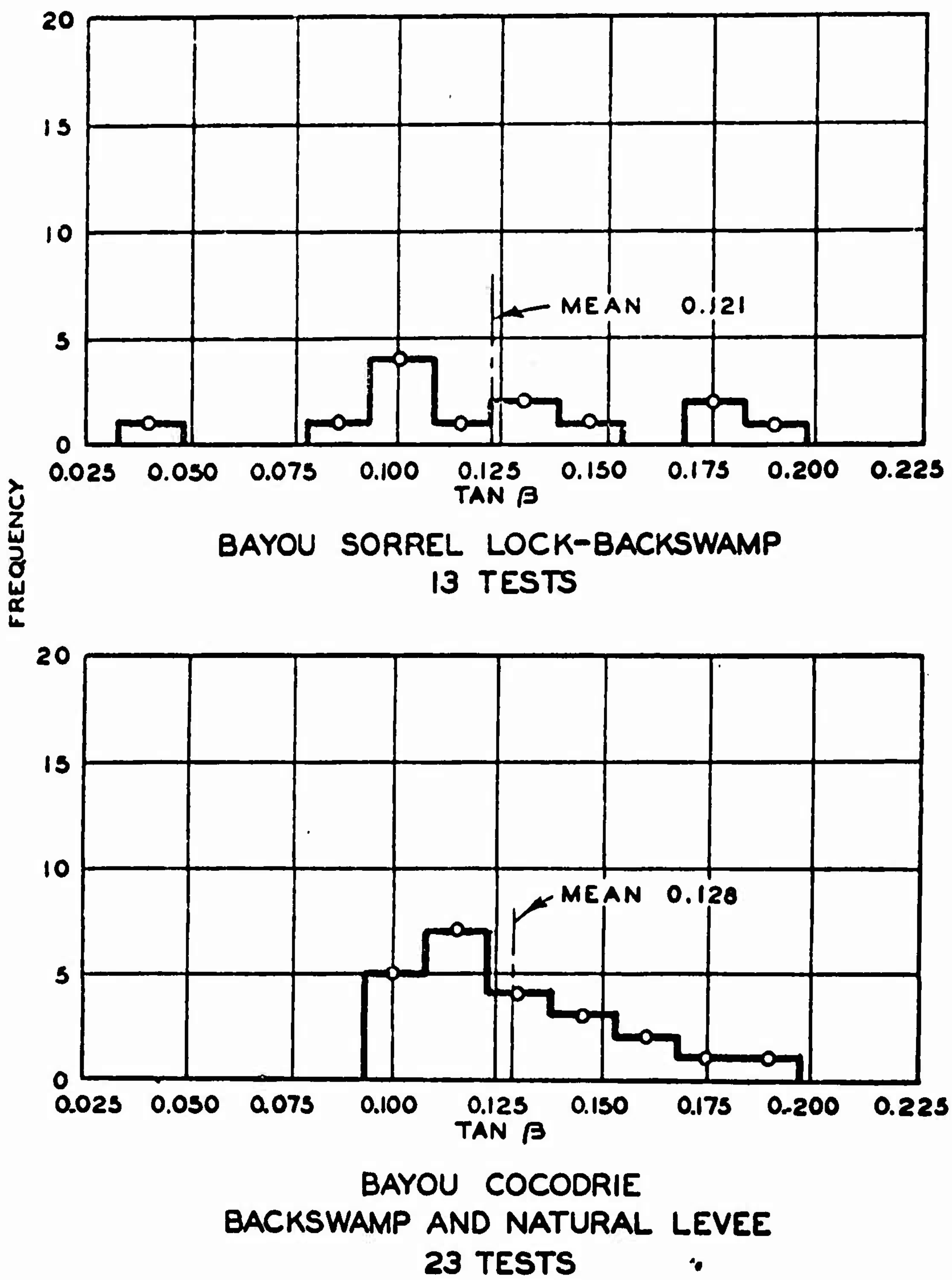


LOWER ST FRANCIS LEVEE DISTRICT
RECENT ALLUVIUM 25 TESTS

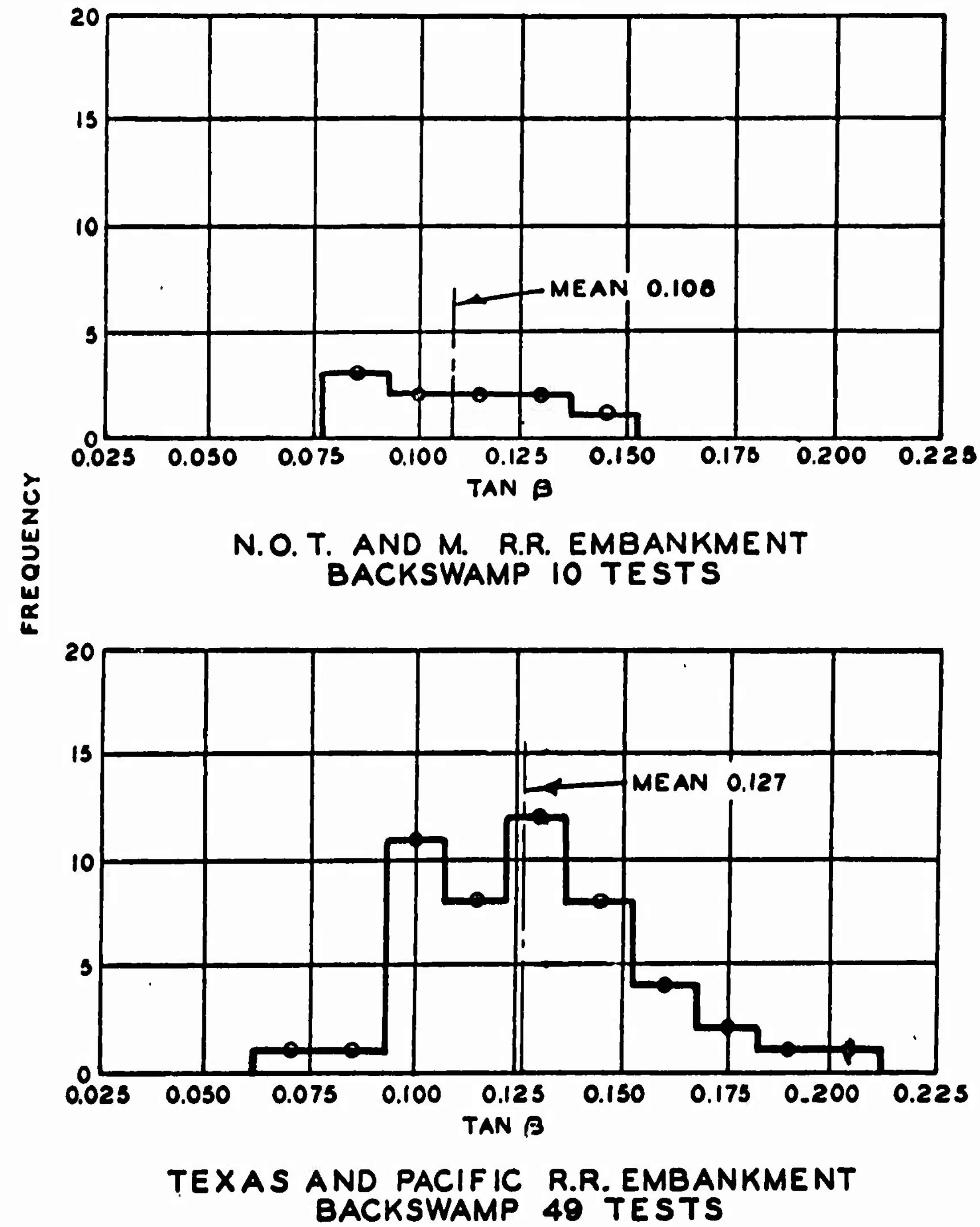
HISTOGRAMS OF GEOLOGIC SOIL TYPES



HISTOGRAMS OF GEOLOGIC SOIL TYPES

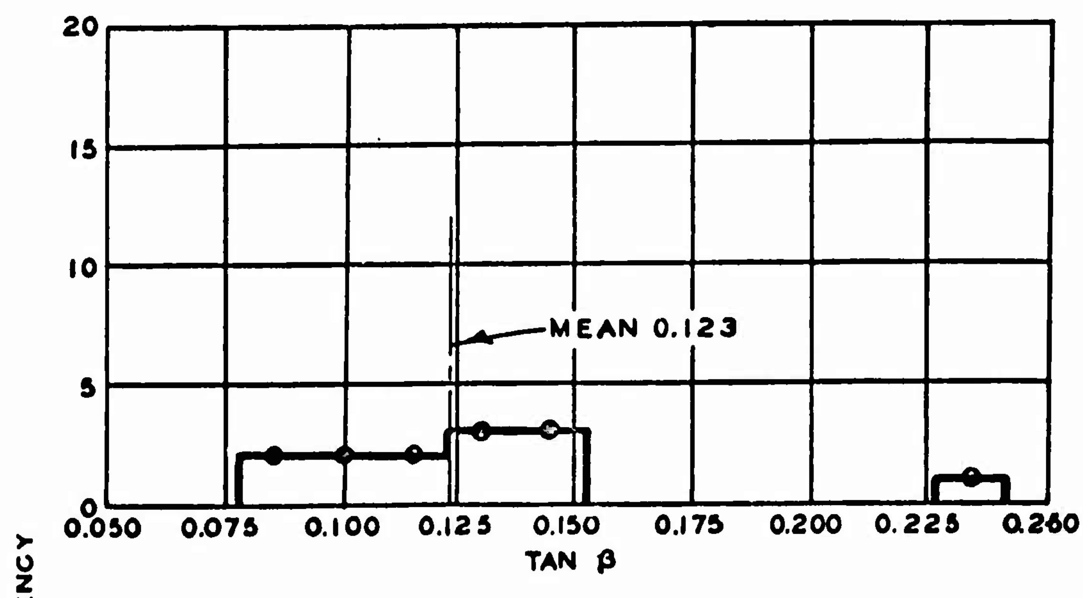


HISTOGRAMS OF GEOLOGIC SOIL TYPES

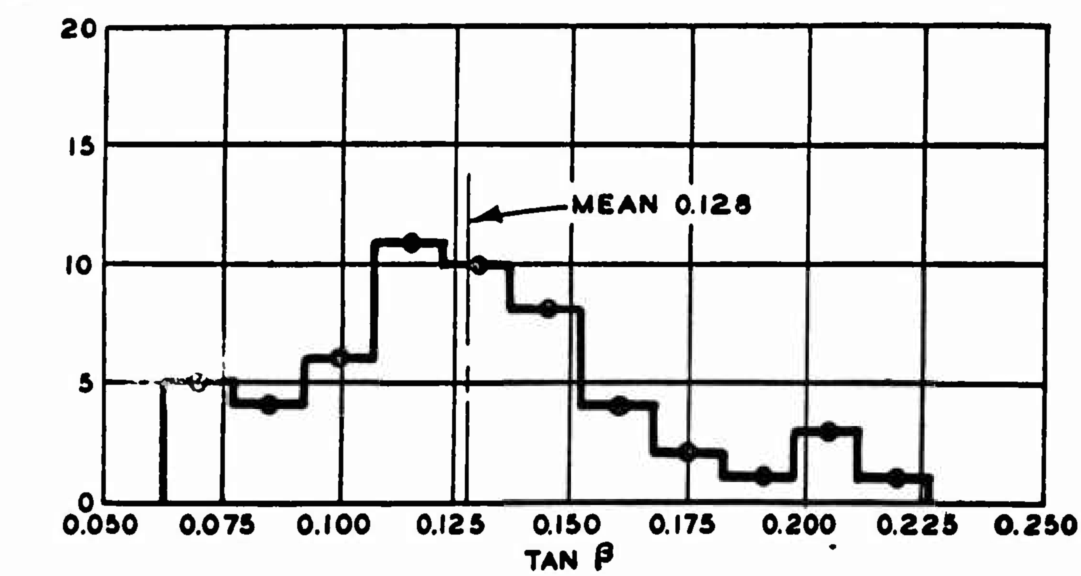


HISTOGRAMS OF GEOLOGIC SOIL TYPES

PLATE 15

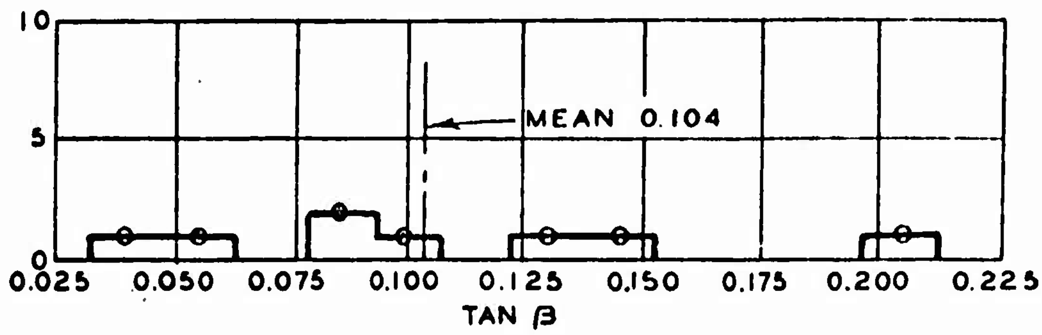


MORGANZA CONTROL STRUCTURE
CHANNEL FILLING 13 TESTS

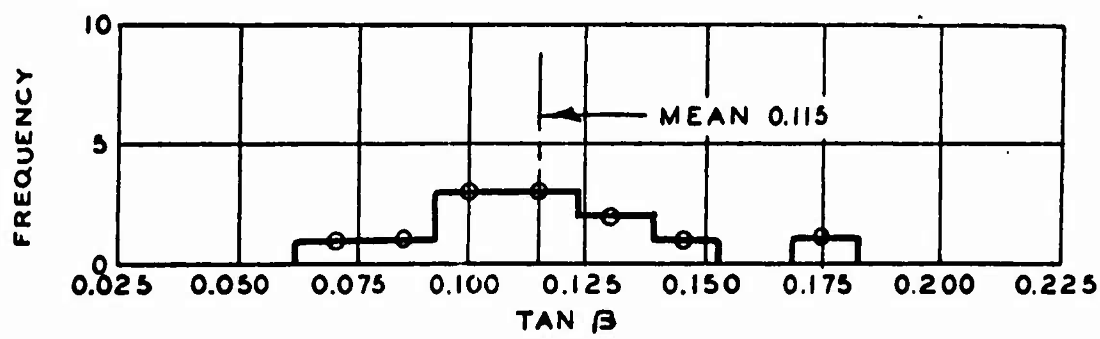


MORGANZA CONTROL STRUCTURE
BACKSWAMP 55 TESTS

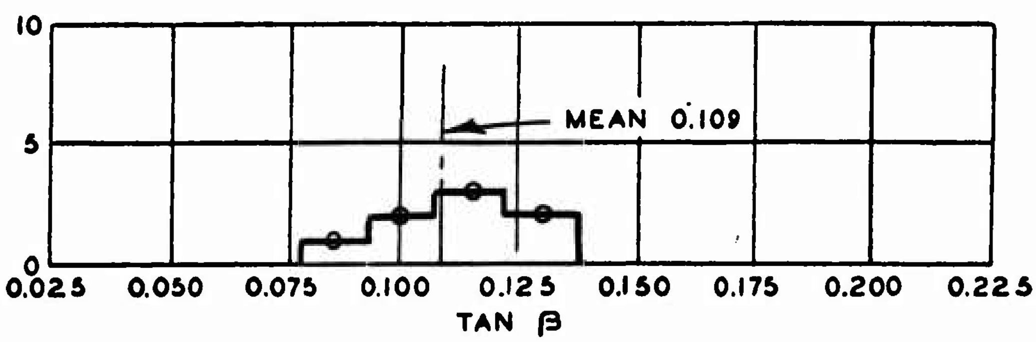
HISTOGRAMS OF GEOLOGIC SOIL TYPES



VETERANS ADMINISTRATION HOSPITAL
PLEISTOCENE PRAIRIE DEPOSITS 8 TESTS

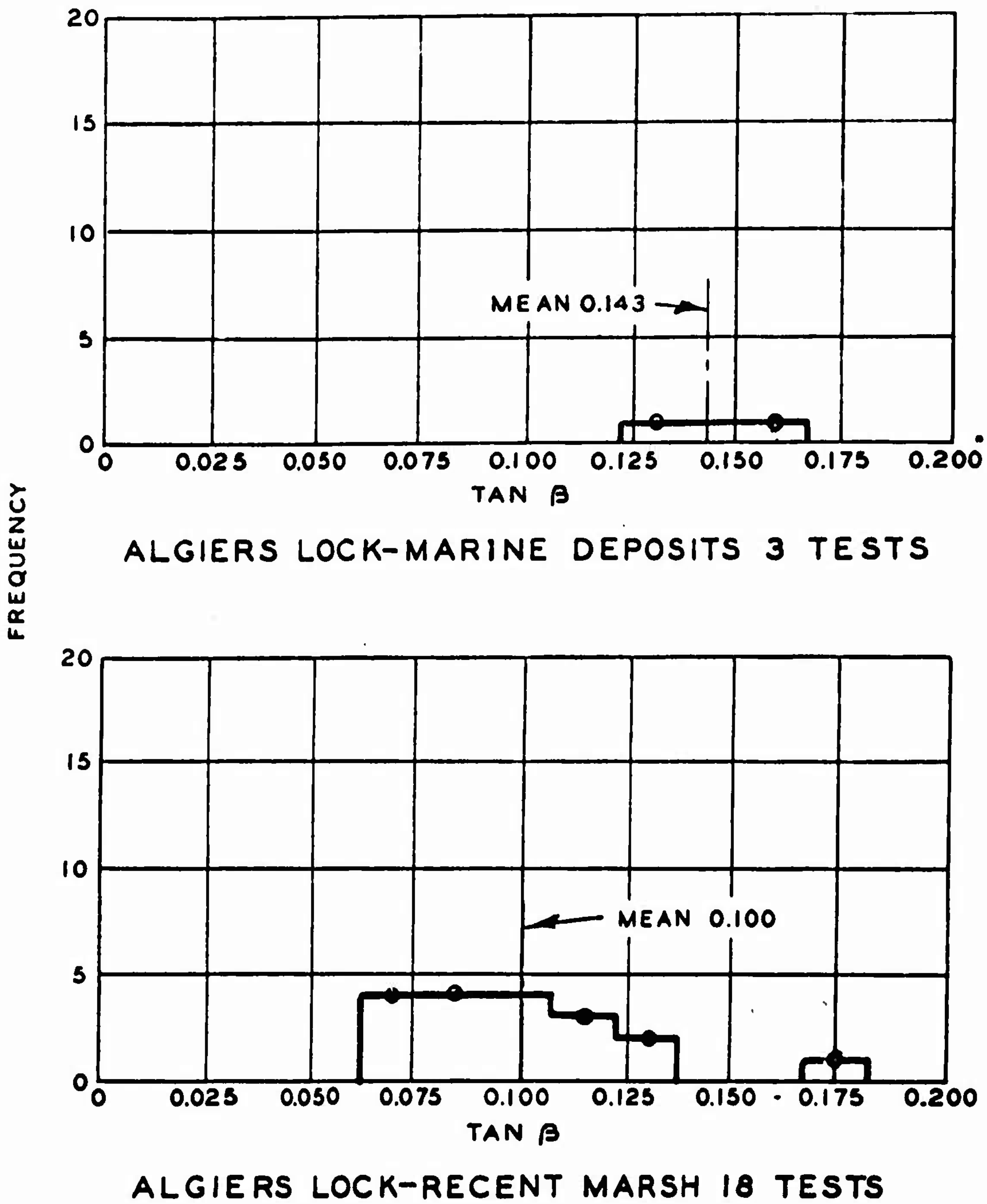


VETERANS ADMINISTRATION HOSPITAL
MARINE DEPOSITS 12 TESTS



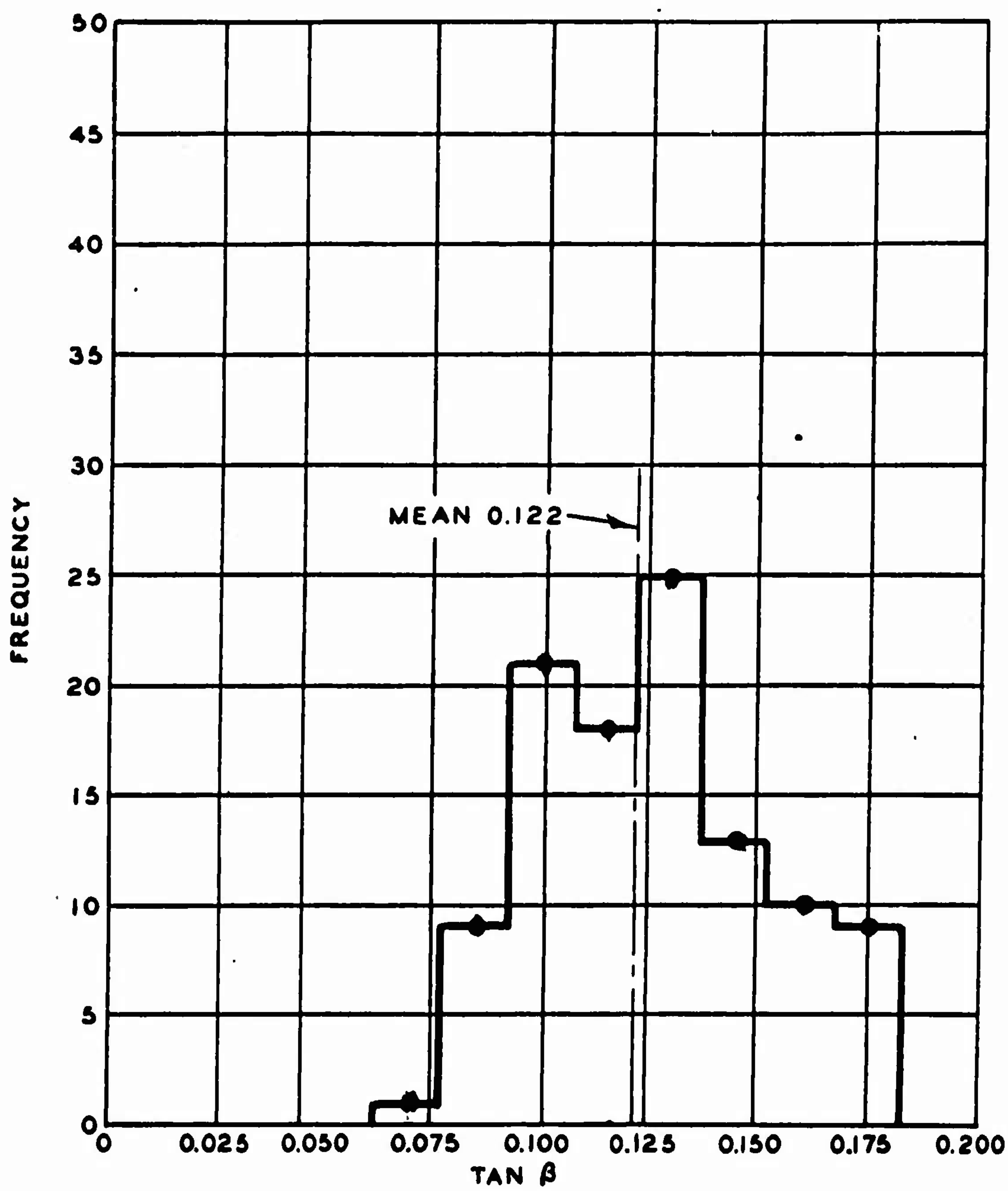
VETERANS ADMINISTRATION HOSPITAL
RECENT MARSH 8 TESTS

HISTOGRAMS OF GEOLOGIC SOIL TYPES



HISTOGRAMS OF GEOLOGIC SOIL TYPES

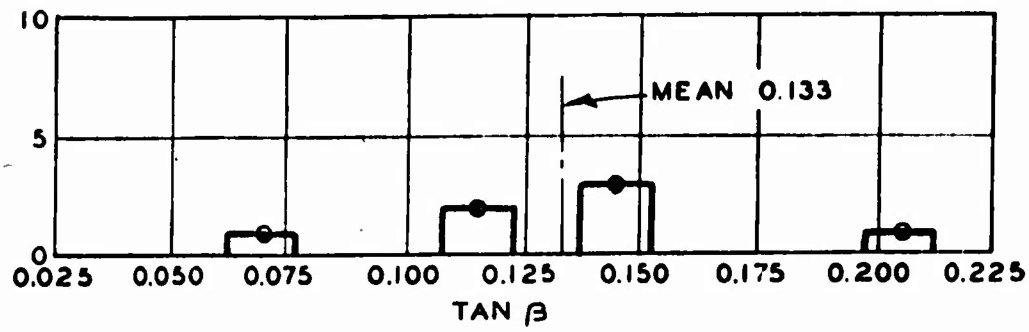
PLATE 18



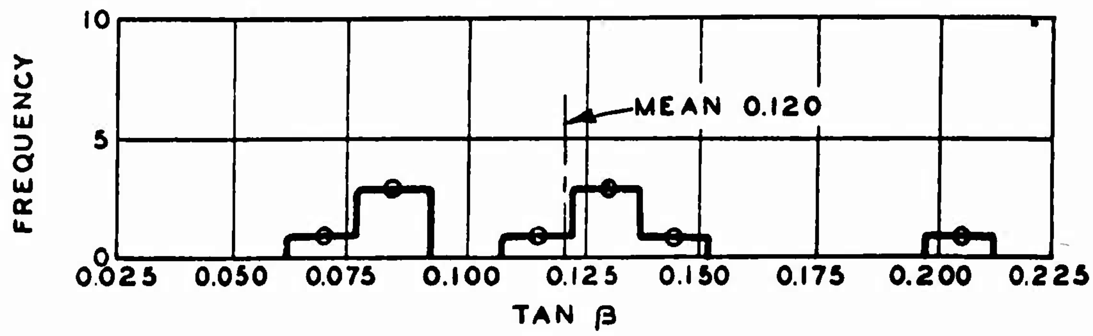
TEXARKANA DAM-PLEISTOCENE
TERRACE DEPOSITS 106 TESTS

HISTOGRAMS OF GEOLOGIC SOIL TYPES

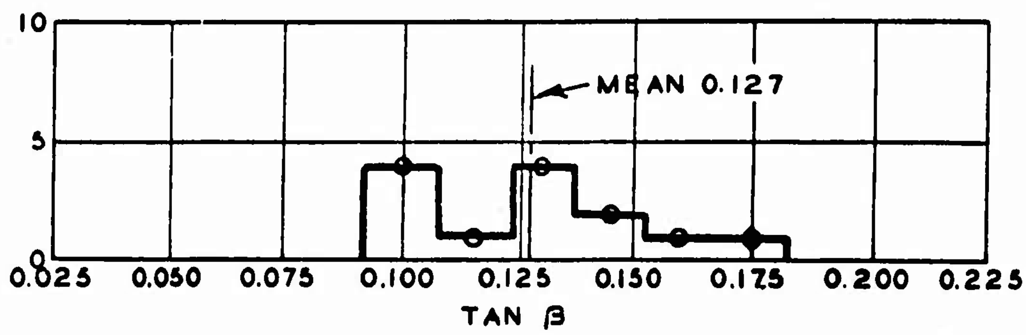
PLATE 19



SCHOONER BAYOU-PLEISTOCENE
PRAIRIE DEPOSITS 7 TESTS



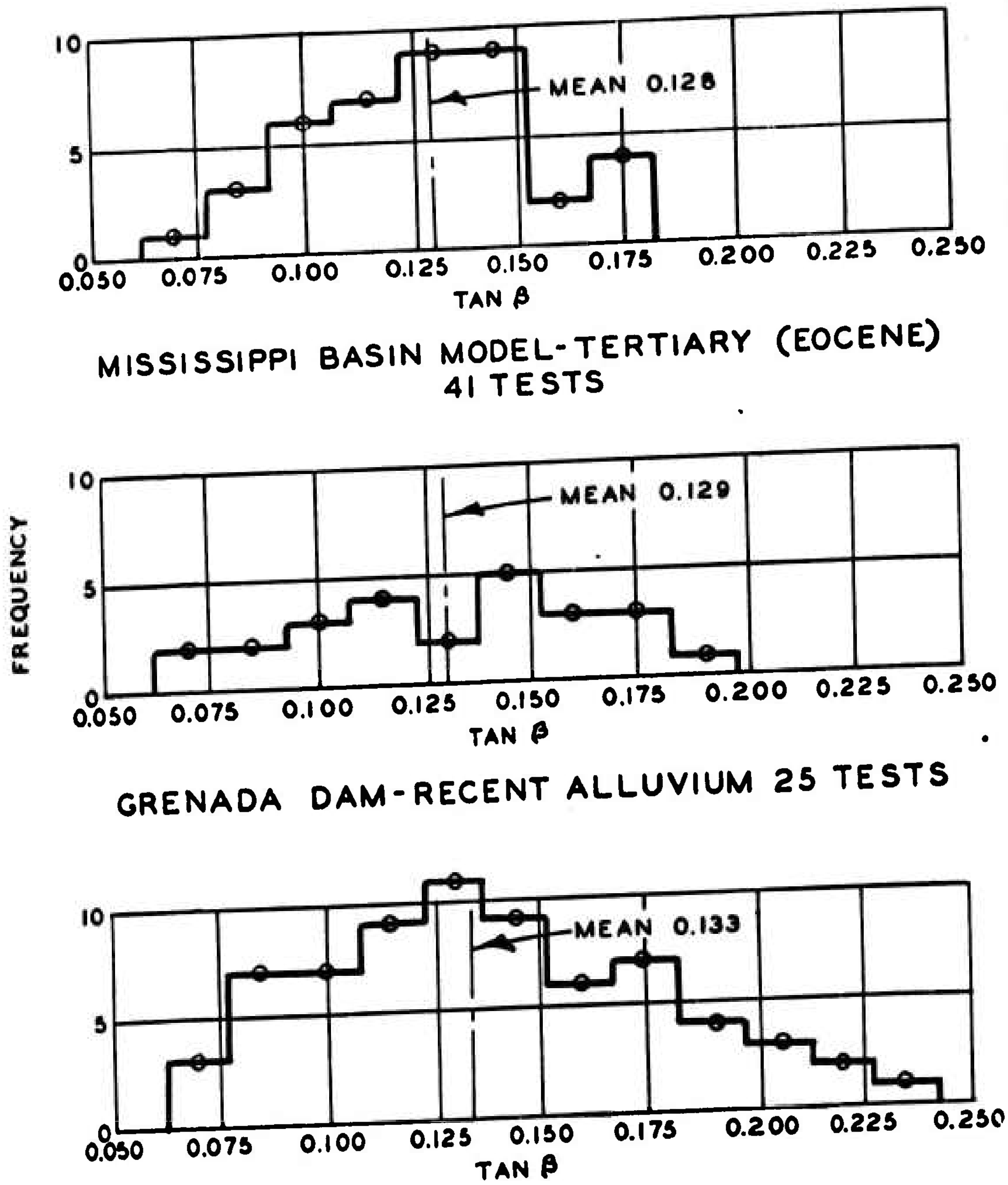
RED RIVER LATERAL CANAL
RECENT ALLUVIUM 10 TESTS



WALLACE LAKE DAM
RECENT ALLUVIUM 13 TESTS

HISTOGRAMS OF GEOLOGIC SOIL TYPES

PLATE 20

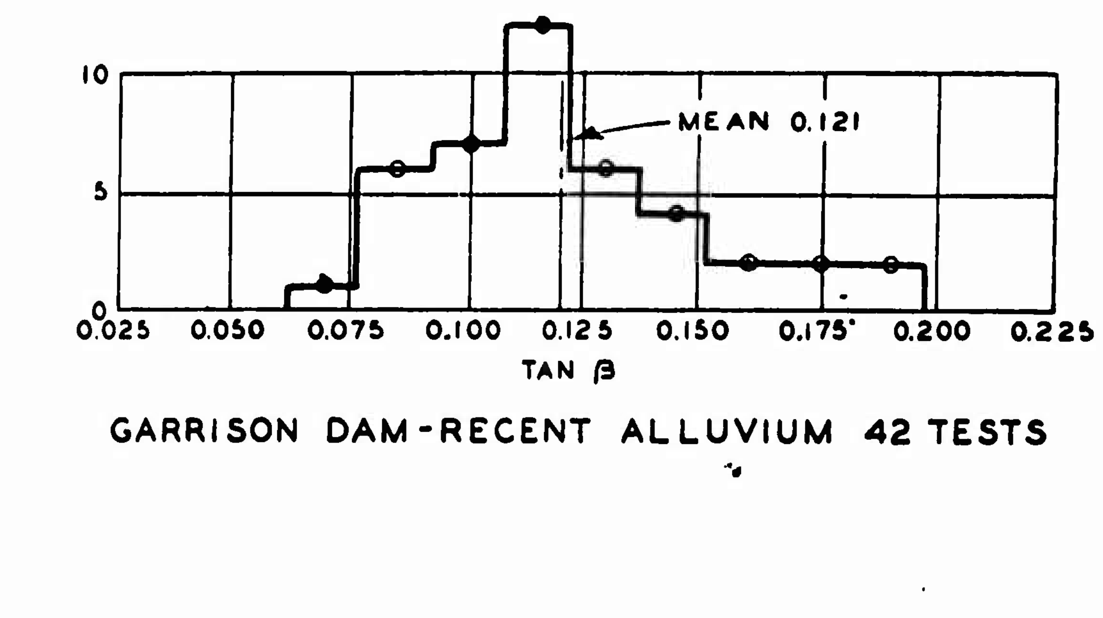


MISSISSIPPI BASIN MODEL-TERTIARY (EOCENE)
41 TESTS

GRENADA DAM-RECENT ALLUVIUM 25 TESTS

GRENADA DAM-TERTIARY (EOCENE) 69 TESTS

HISTOGRAMS OF GEOLOGIC SOIL TYPES



HISTOGRAMS OF GEOLOGIC SOIL TYPES

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