ONE POINT LIQUID LIMIT DETERMINATION
FOR OKLAHOMA CLAYS

By

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PREFACE

In June, 1949, the Corps of Engineers at the Waterways Experiment Station in Vicksburg, Mississippi published a technical memorandum on simplification of the liquid limit test procedure. The report showed that the liquid limit could be obtained by determining one point on the flow line of a soil. However, the analysis was for soils of the Alluvial Valley of the Mississippi River and the adjacent Coastal Plains, and no generalization for other soils was made.

Knowing the nature of Oklahoma soils, Professor J. V. Parcher suggested to the author that an analysis be made of the Pennsylvanian and Permian soil formations. As a result, this thesis was undertaken by the author to determine the mean slope of the flow line for Oklahoma soils, and to construct a formula and a nomographic chart which would be applicable for a one point liquid limit determination.

The author wishes to express his indebtedness and gratitude to the following individuals and organizations:

To Professor J. V. Parcher for his valuable guidance and assistance in the preparation of this thesis and for acting as the author's major adviser;

To Professor R. E. Means, the Corps of Engineers at Tulsa, and the Oklahoma State Highway Department for the use of their laboratory data files which aided materially in the accomplishment of the investigation;

To the Professors and Instructors in the Civil Engineering Department for their interest and friendship during the past year;

To his beloved wife, June, for her constant encouragement and patience, without which this work would not have been possible; and

To Mrs. Joan Kuhlman for her excellent work in typing and arranging this manuscript.

Brian L. Kilpatrick

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CHAPTER I

INTRODUCTION

General

The general project of correlating soil properties with geologic information, one phase of which is described in this thesis, 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.

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 Figures 1 and 2.

It was apparent that this suggested procedure had practical possibilities that could be explored rather rapidly. At the Waterways Experiment Station at Vicksburg, Mississippi, this has been carried out on soils of the Alluvial Valley of the Mississippi River and adjacent areas of the east and west Gulf Coastal Plains. Results obtained were shown to be satisfactory, and a nomograph was set up where the liquid limit could be obtained directly from one trial.

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, for the soils of Oklahoma.

Normal Liquid Limit Test Procedure

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. About 100 grams of moist soil are mixed thoroughly with distilled water to form a uniform paste and a portion of this paste is placed in the brass dish. The surface is smoothed off, and then a special grooving tool is drawn through the sample along the symmetrical axis of the

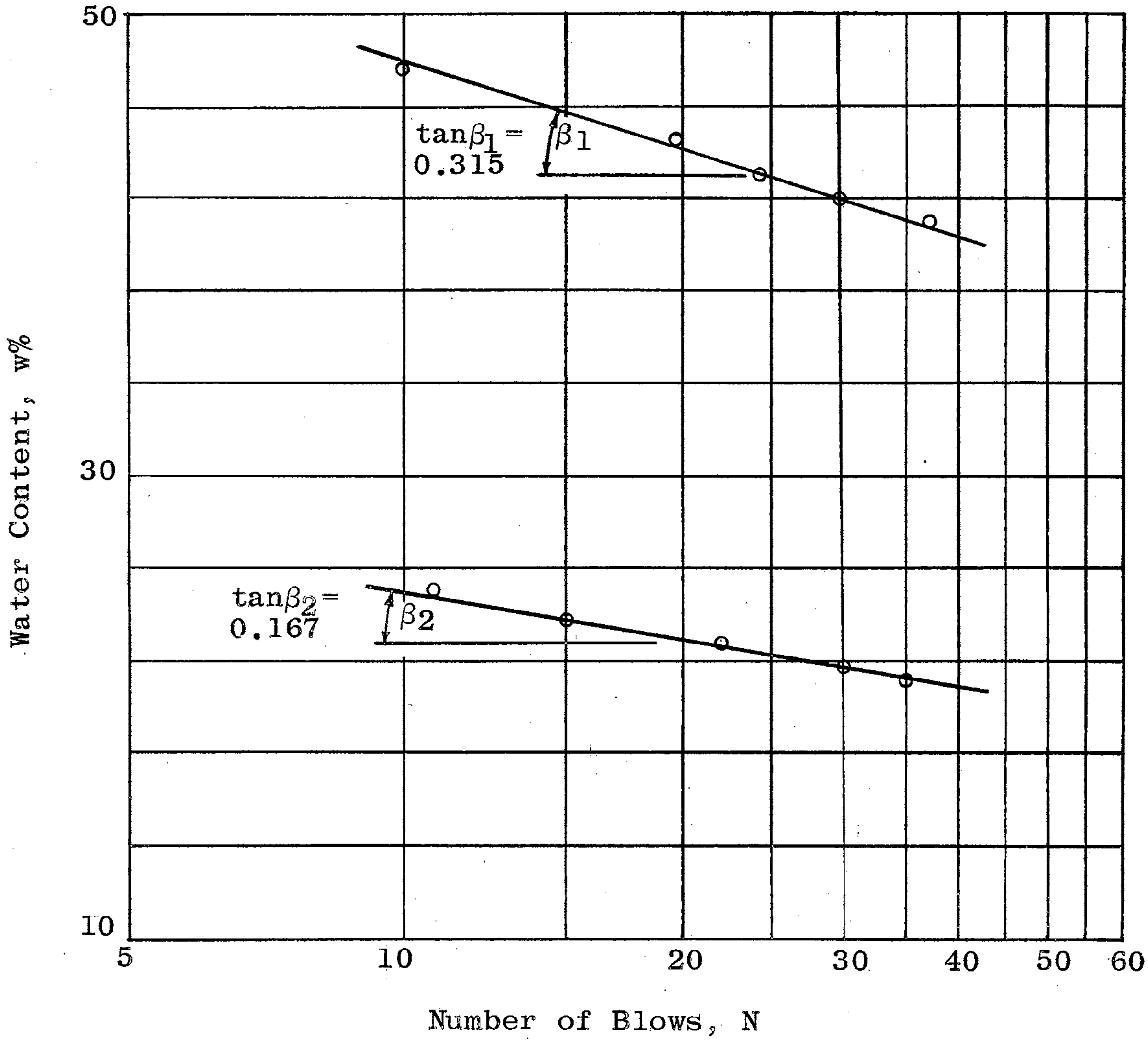

Figure 1

A Standard Semi-Logarithmic Liquid Limit Flow Line Plot

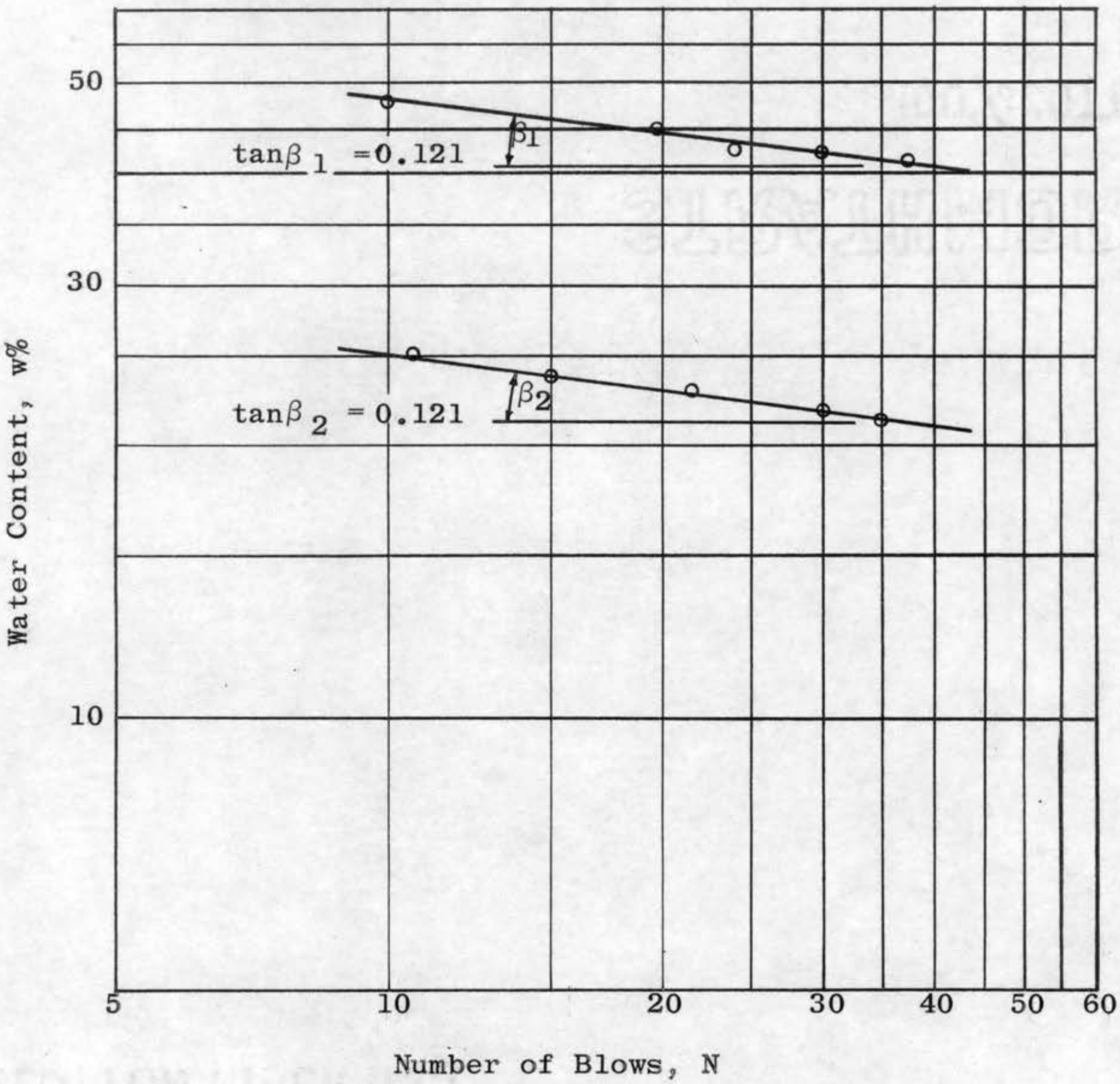

Figure 2

A Logarithmic Liquid Limit
Flow Line Plot

dish, holding the tool perpendicular to the dish at the point of contact. This grooving tool controls the maximum thickness of the soil at the groove. The dish is then dropped on the base at a rate of two drops, or "blows," per second until a half inch 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 four or five different water contents within a range of from ten to forty blows. 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. The line determined by the plotting of the number of blows versus water content is called a flow line.

Proposed Method of Simplifying Liquid Limit Test Procedure

It can be seen from Figure 1 that five points have been used to define a flow line on a semilogarithmic plot. If it can be shown 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.

CHAPTER II

SOIL PROPERTIES AND GEOLOGIC ORIGIN

Soil Properties

Shale is a rock made up of materials with grain sizes ranging between those of silt and clay. Although to the unaided eye shales appear to be composed of nearly uniformly sized material, the actual range of particle sizes is very large. Some shales consist exclusively of clay-sized particles, whereas others are mixtures of clay, silt, and even sand. This textural difference often endows the shale with distinct properties. Differences in shales, however, appear to consist primarily of differences in the behavior of the contained minerals. For example, shales composed primarily of illite or montmorillonite tend to be saturated with water and are soft and greasy to the touch. They lack hardness and strength, and they usually disintegrate when placed in water.

Clay originates through the breaking down of other rocks such as granite, syenite, anorthosite, gabbro, limestone, and dolomite. The individual particles of clay are the smallest produced in this breaking down or weathering process. This process is in part a chemical one, whereby the silicate or carbonate minerals composing the rock are decomposed by the gases of the atmosphere, water, carbon dioxide, oxygen, etc., and by the sub-surface water with its content of dissolved carbon dioxide, oxygen, and weak organic acids. The weathering process is also in part a physical or mechanical process brought about by volume changes induced by chemical weathering and possibly by temperature changes, the freezing of water in cracks, and the splitting and prying action of plant roots. The material remaining, after weathering has removed the soluble components, is a residual clay.

A residual clay, obviously, would rarely remain on steep slopes as rain wash would carry it into streams. The latter transports it to lower areas, where it is deposited as sedimentary or transported clay.

Clay is composed for the most part of clay minerals with minor quantities of quartz, limonitic material, feldspar, pyrite, organic matter, and a host of other minerals which for one reason or another have proven resistant to weathering.

The clay minerals are hydrous aluminum silicates, frequently with some replacement of the aluminum by iron and magnesium and with small quantities of calcium, sodium and potassium. According to the most common classification systems, the size of clay particles varies from .002 mm. to colloidal-sized material.

There are many clay minerals, the principal ones of which are contained in the following three groups:

1. The montmorillonite group, consisting of hydrous aluminum silicates, derives its name from the mineral montmorillonite, the principal mineral in the group. The

aluminum is sometimes replaced by magnesium or ferric iron. It is this presence of iron which gives the Oklahoma Permian clay its characteristic reddish color.

2. The kaolinite group consists of hydrous aluminum silicates. Like the preceeding group, it derives its name from the principal mineral in the group, kaolinite.

3. The illite group, which is similar to white mica, is composed of hydrous aluminum silicates carrying appreciable quantities of potash, iron, and magnesium.

Clays and shales are the most abundant minerals in the State. They crop out in all areas and belong to nearly all geological periods. They vary in color from red, gray, and bluish and greenish gray to grayish white.

Geologic Origin

As shown on Figure 3, the State of Oklahoma consists mainly of rocks and soils from two geologic periods; namely, Permian and Pennsylvanian.

The Pennsylvanian system occupies a broad L-shaped area in eastern Oklahoma. In the southern and eastern parts of this area the formations consist of sandstone and shale in alternate layers. The formations thin to the north, and limestones appear interbedded with the shales and sandstones. In the east-west limb of the L the formation is folded into broad arches and troughs which extend in a general northeast-southwest direction. Those of the north-south limb slope gently to the west and pass under the younger Permian system rocks above them.

Figure 3*

Geologic Map of Oklahoma

*Sheerar, Leonard Francis, The Clays and Shales of Oklahoma, p.77 , Oklahoma Engineering Experiment Station Publication No. 17, Oklahoma State University, Stillwater, 1932.

With few exceptions rocks and soils of Permian age outcrop over the entire western half of Oklahoma. The formations generally have a reddish-brown color. The line of separation between the red and the non-red formations passes about midway between Stillwater and Pawnee, thence southeastward to Stroud, then passes southwest of the east end of the Arbuckle Mountains. The line separating the Permian and Pennsylvanian formation enters the State near the northeast corner of Osage County and crosses the State bearing a little west of south to the west side of the Arbuckle Mountains. It should be noted that the line of color change does not coincide with the Pennsylvanian-Permian contact, but cuts the latter at an acute angle. Between these two lines there is a small area of red Pennsylvanian rocks. (1).

The beds of red Permian clay originated in a salt water sea which covered the area described in the preceding paragraph. Deposits of soil were carried from the mountains into the salt water sea by torrential rains of short duration. Towards the end of the Permian period the sea almost dried up three times, each time depositing gypsum and salt along with layers of clay and sandstone. These deposits were later covered with an overburden of several hundred feet which has since been removed by weathering. As a result, the Permian clays are highly preconsolidated.

CHAPTER III

DATA ANALYSIS

Sources of Data

The soils for which liquid limit test data were analysed fall into two distinct groups. Geologically, they are known as the deppsits of the Pennsylvanian period and the Permian period. Geographically, they can be divided into the eastern and western halves of Oklahoma. As stated previously, the line separating the Permian and Pennsylvanian formations enters the State near the northeast corner of Osage County and crosses the State bearing a little west of south to the west side of the Arbuckle Mountains. For convenience in this thesis, this imaginary line will also be used as the geographic boundary. Tables I and II show the locations and geologic types of soils of the samples from which data were used.

All of the tests, except the ones obtained from the Corps of Engineers at Tulsa, were classified as to their plasticity characteristics. These were plotted on Casagrande's plasticity chart and are shown on Figures 4 and 5. In general, the soils which were plotted were medium to highly plastic inorganic clays with a liquid limit greater than 20.

TABLE I

SUMMARY OF DATA FOR PENNSYLVANIAN SOILS

Location	Soil Description	No. of Tests	Mean $\tan\beta$	Range $\tan\beta$		Range Liquid Limit		Range Plasticity Index	
				Min.	Max.	Min.	Max.	Min.	Max.
Eufaula	Yellowish-Gray Clay	30	0.126	0.051	0.212	16.4	75.6	----	----
Keystone	Silty Clay	6	0.142	0.112	0.171	23.2	32.2	----	----
Oologah	Yellowish-Gray Clay	14	0.113	0.056	0.188	36.0	64.7	----	----
Tulsa	Yellowish-Gray Clay	5	0.106	0.038	0.185	46.0	68.7	20.3	43.0
Others (Miami, Pryor & Muskogee)	----------------	3	0.189	0.178	0.197	29.7	85.8	14.9	66.4

TABLE II

SUMMARY OF DATA FOR PERMIAN SOILS

Location	Soil Description	No. of Tests	Mean tanβ	Range tanβ Min.	Range tanβ Max.	Range Liquid Limit Min.	Range Liquid Limit Max.	Range Plasticity Index Min.	Range Plasticity Index Max.
Altus	Clay	25	0.133	0.088	0.198	21.1	44.1	----	----
Fort Sill	Clay	31	0.098	0.053	0.133	25.7	71.5	----	----
Guthrie	Reddish-Brown Silty Clay	3	0.128	0.118	0.136	24.0	25.4	7.2	8.4
Kingfisher County	Reddish-Brown Clay	23	0.133	0.056	0.229	21.0	58.6	3.0	33.0
Lake Carl Blackwell Dam	Reddish-Brown Clay	12	0.130	0.102	0.197	25.4	43.8	8.7	28.2
Lawton	Yellowish-Gray Clay	5	0.124	0.089	0.178	39.8	52.3	17.0	25.2
Stillwater	Reddish-Brown Clay	4	0.128	0.098	0.186	25.0	57.2	8.4	38.5
Tinker	Clay	20	0.125	0.063	0.215	21.1	56.8	----	----
Walters	Reddish-Brown Clay	3	0.130	0.078	0.148	47.0	51.1	29.1	31.0

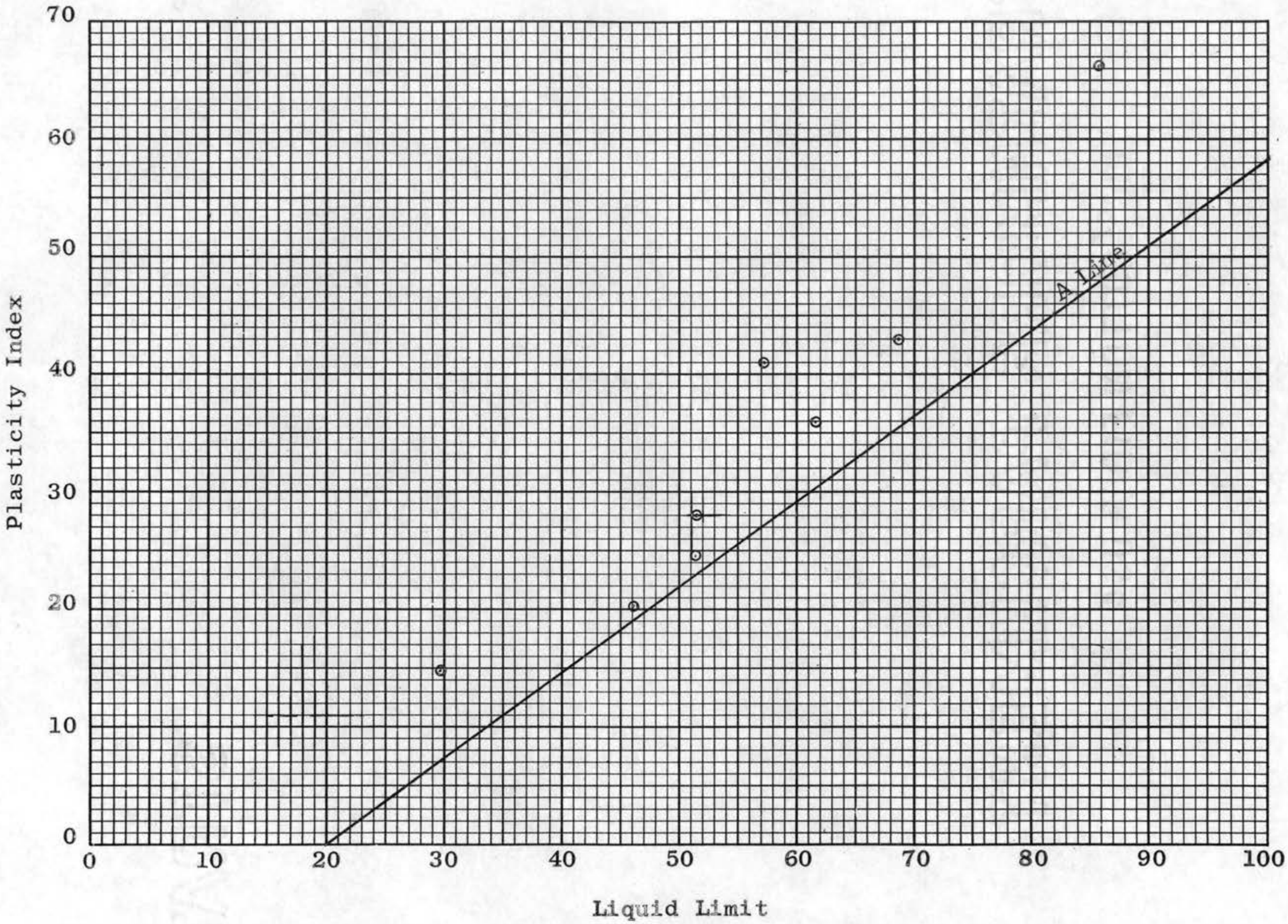

Figure 4. Plasticity Chart - Pennsylvanian Soils

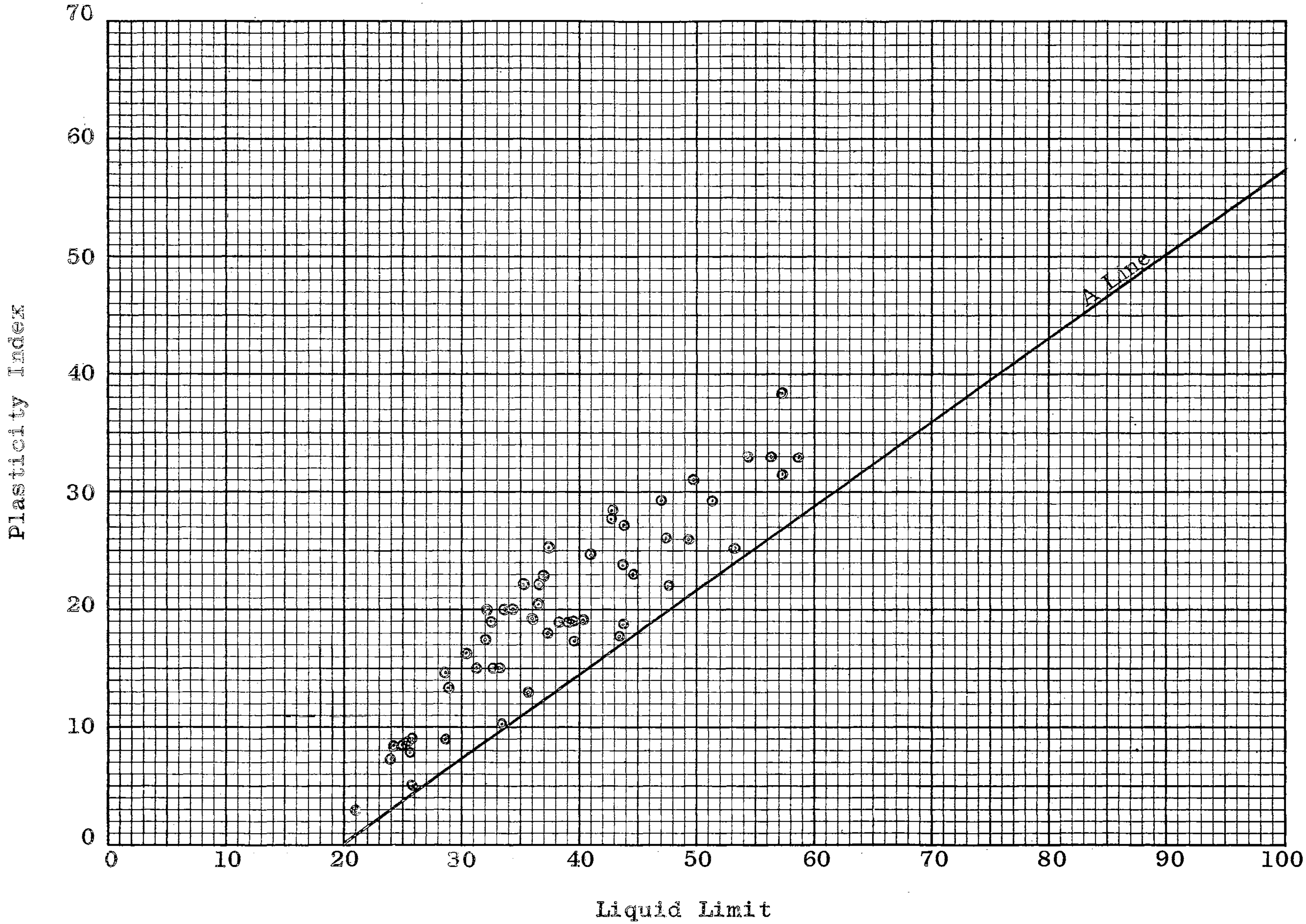

Figure 5. Plasticity Chart - Permian Soils

Conversion of Data

Data examined for this thesis was of the form shown in Figure 1 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 plot

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

Ten and thirty 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 it is of no consequence. (2). Figure 2 shows data from Figure 1 plotted logarithmically.

Methods Used in Analysis of Data

All of the data was 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 was also limited to tests for which the liquid limit was less than 100.

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 the author as well as many engineers and 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.

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 as was done in the United States Waterways Experiment Station Technical Memorandum 3-286. (2). The statistical methods and nomenclature used are those recommended by the American Society for Testing Materials. (3).

Nomenclature and Definitions

For purposes of clarity, the nomenclature and definitions used in this study are the same as those used in reference (2), and are given below:

$\tan\beta_1$, $\tan\beta_2$, $\tan\beta_3 \ldots\ldots \tan\beta_n$ = observed values of $\tan\beta$, the slope of the 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 thesis.

$$\overline{\tan\beta} = \frac{\sum_{i=1}^{n} \tan\beta_i}{n},$$ 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.

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. It is 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 nonsymmetry of a distribution about a mean. A positive value of k generally means that the observed values extend further to the right of the mean than to the left. A negative value of k generally means that the observed values extend further to the left of the mean than to the right. 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

$$f = \frac{n}{\sigma\sqrt{2\pi}}\left[e^{-\frac{1}{2}\left(\frac{\tan\beta}{\sigma}\right)^2}\right]$$

where $\tan\beta$ = the difference between the mean value and the value for which f is being calculated. It is the familiar bell-shaped curve and represents a theoretically correct frequency distribution.

Analysis of the Data with Respect to Geology

All of the individual values of $\tan\beta$ were computed to the nearest thousandth by the method discussed on Page 17.

To show graphically the distribution of $\tan\beta$ for each location in the State where samples were used, frequency histograms were plotted. These are shown in Figures 6 to 18 inclusive. The frequency histograms have as their abscissas values of $\tan\beta$ grouped in classes with intervals of 15 thousandths, and as their ordinates, the number of values in the class.

The mean $\tan\beta$ for each location was computed. These means are listed in Tables I and II and are plotted on the histograms. The means from all of the various geological soil types and locations range from 0.098 at Fort Sill to 0.189 at Miami, Pryor, and Muskogee, a range of 0.091. The range of $\tan\beta$ within each geologic soil type averages about 0.1; maximum range 0.173 at Kingfisher County, minimum range 0.018 at Guthrie. The range of $\tan\beta$ 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 Table I shows no tendency for each geologic type to group itself about a single mean $\tan\beta$. 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

The data was also analysed by grouping the tests according to their geographical location; Eastern Oklahoma and Western Oklahoma. Histograms showing the distribution of $\tan\beta$ for the tests from these areas are shown in Figures 19 and 20.

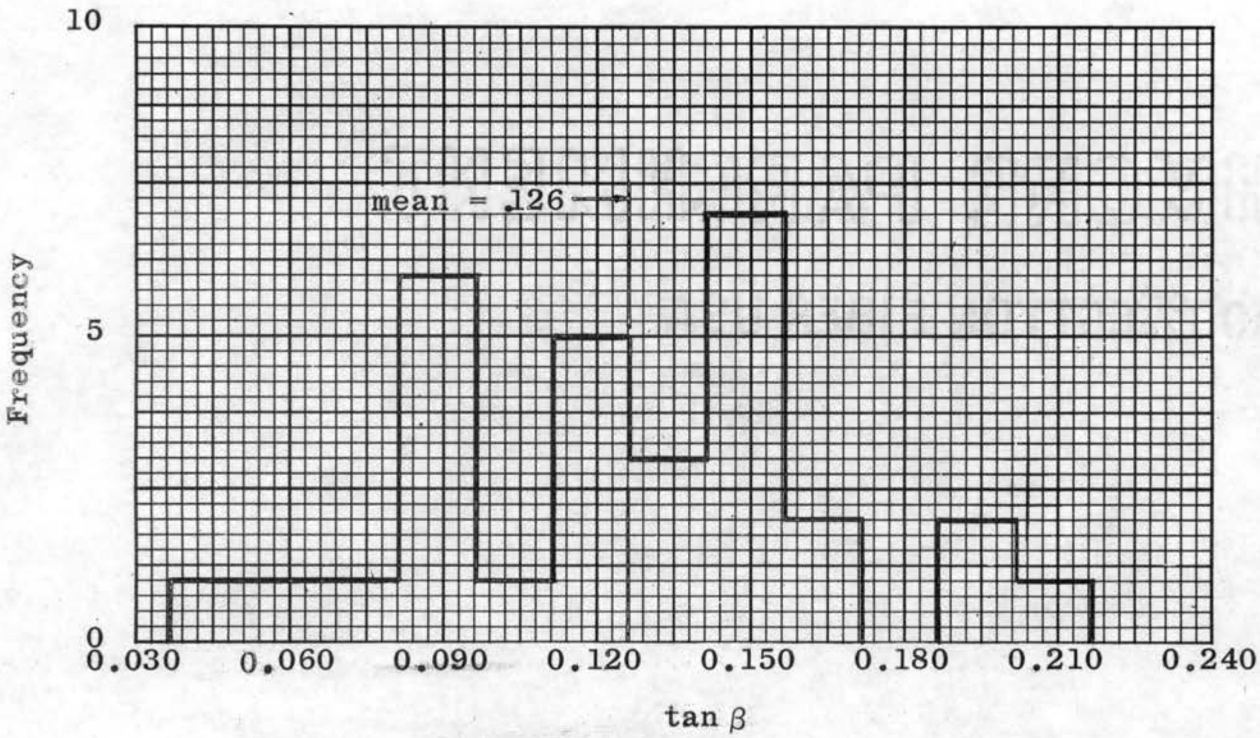

Figure 6

Frequency Histogram for Eufaula

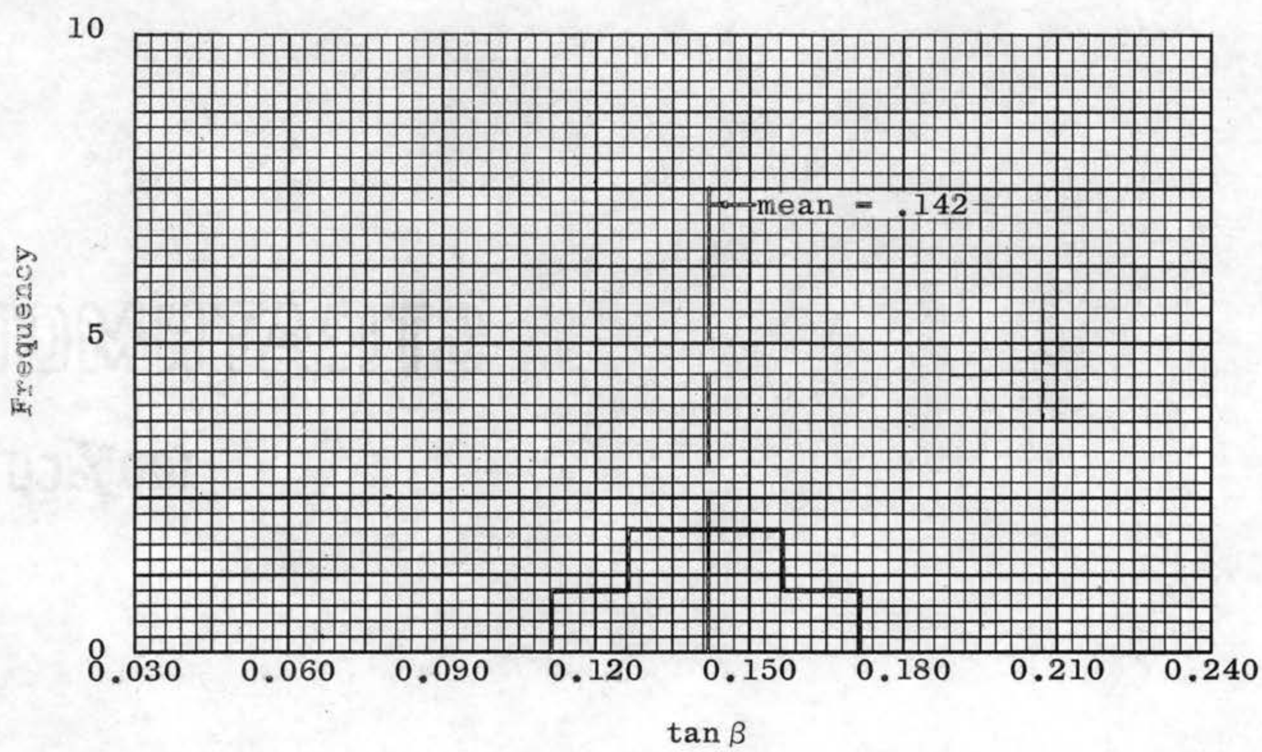

Figure 7

Frequency Histogram for Keystone

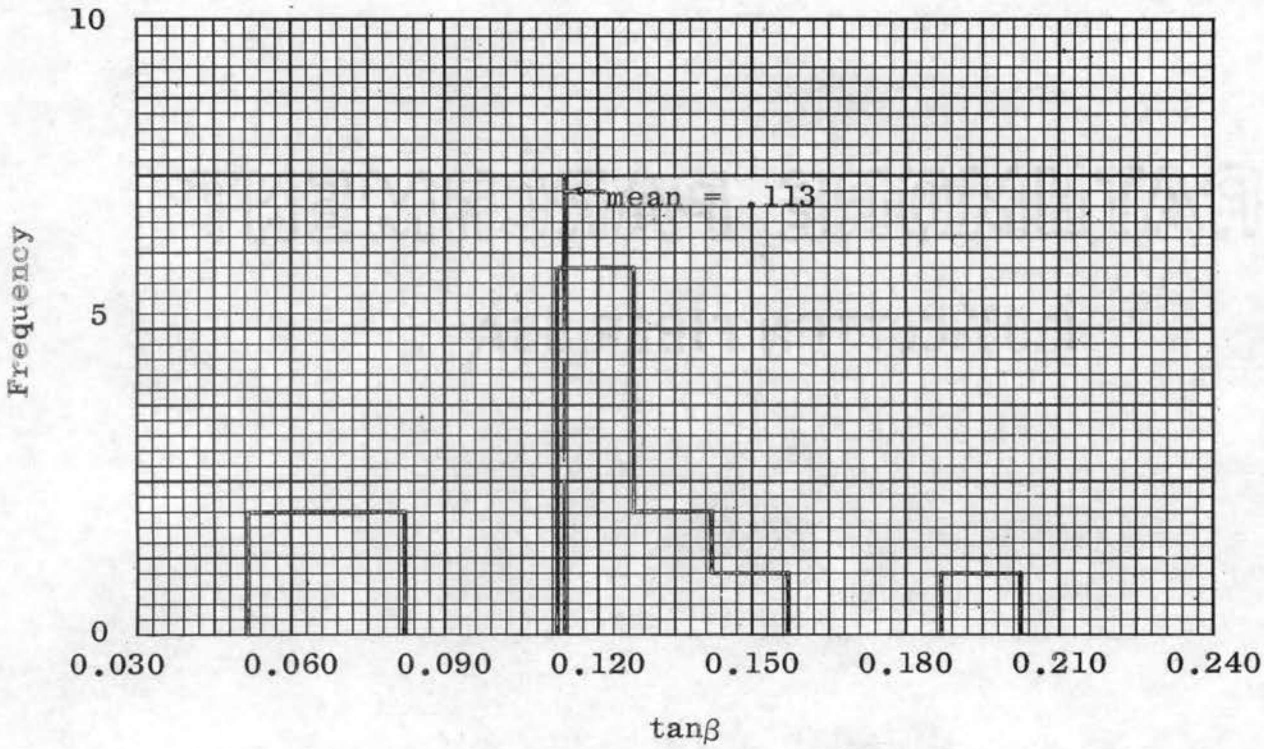

Figure 8

Frequency Histogram for Oologah

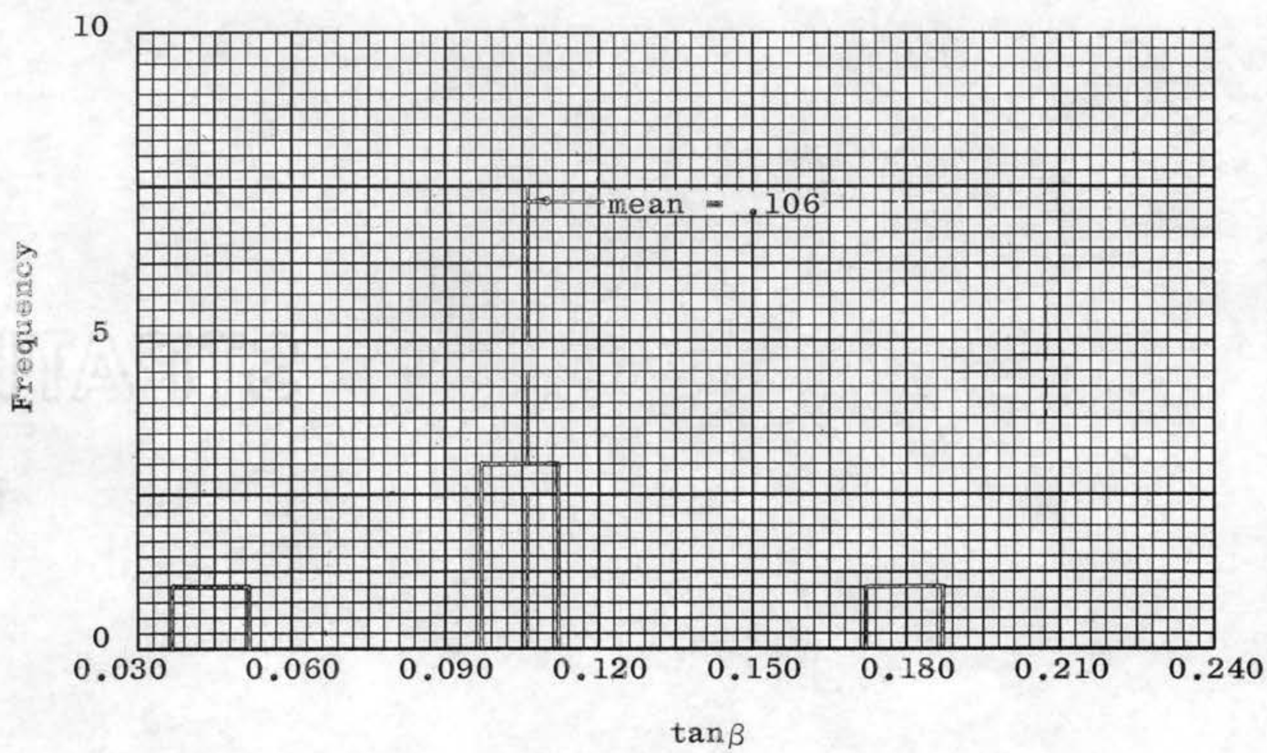

Figure 9

Frequency Histogram for Tulsa

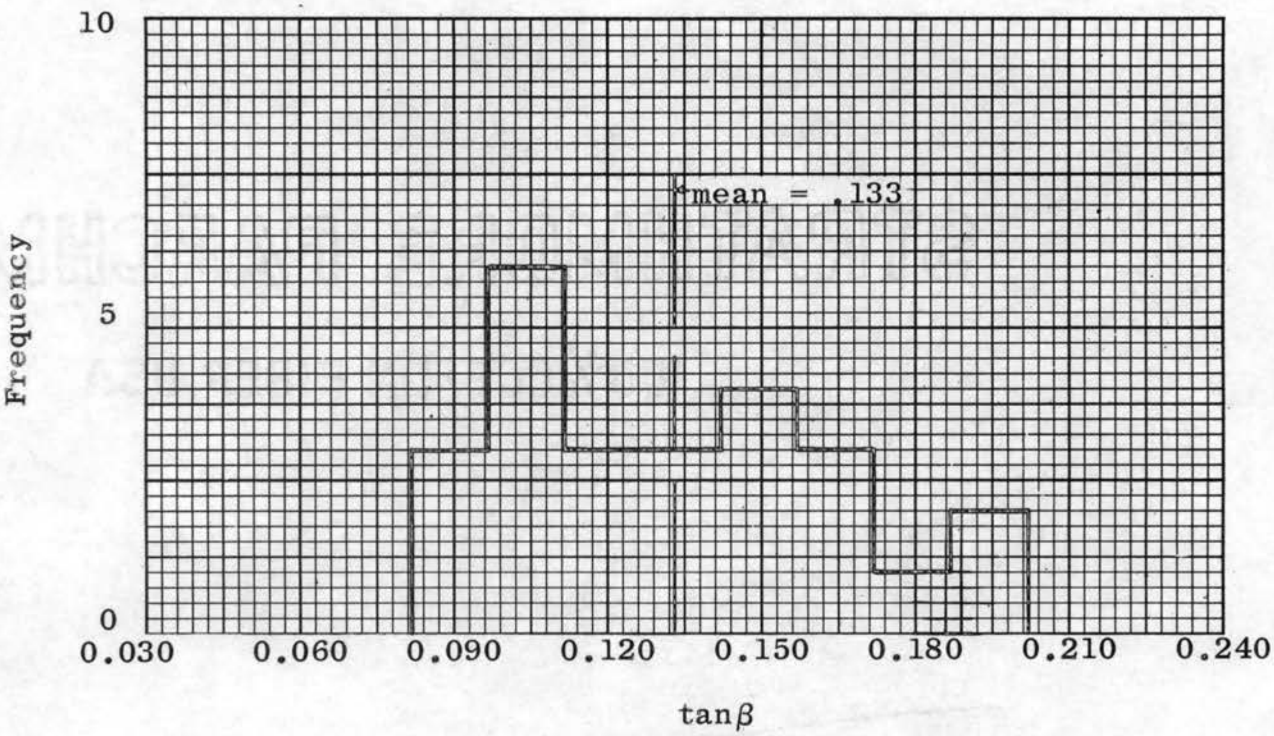

Figure 10

Frequency Histogram for Altus

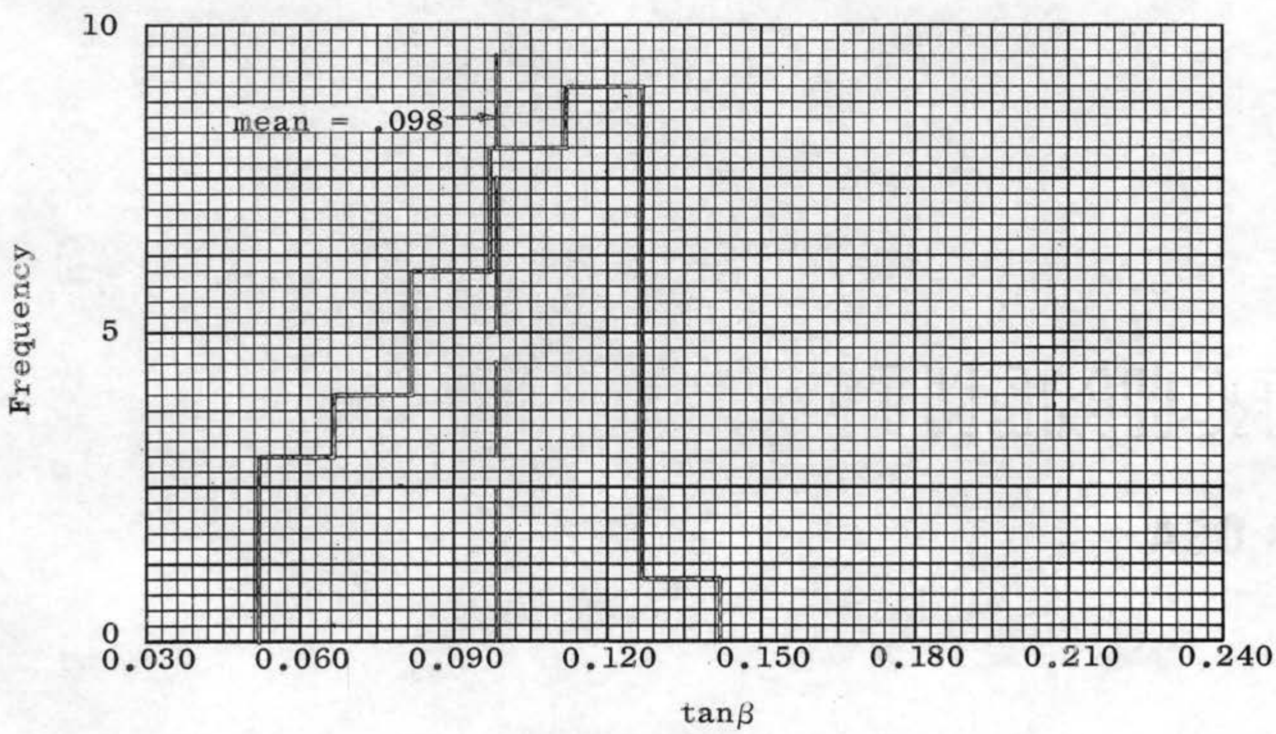

Figure 11

Frequency Histogram for Fort Sill

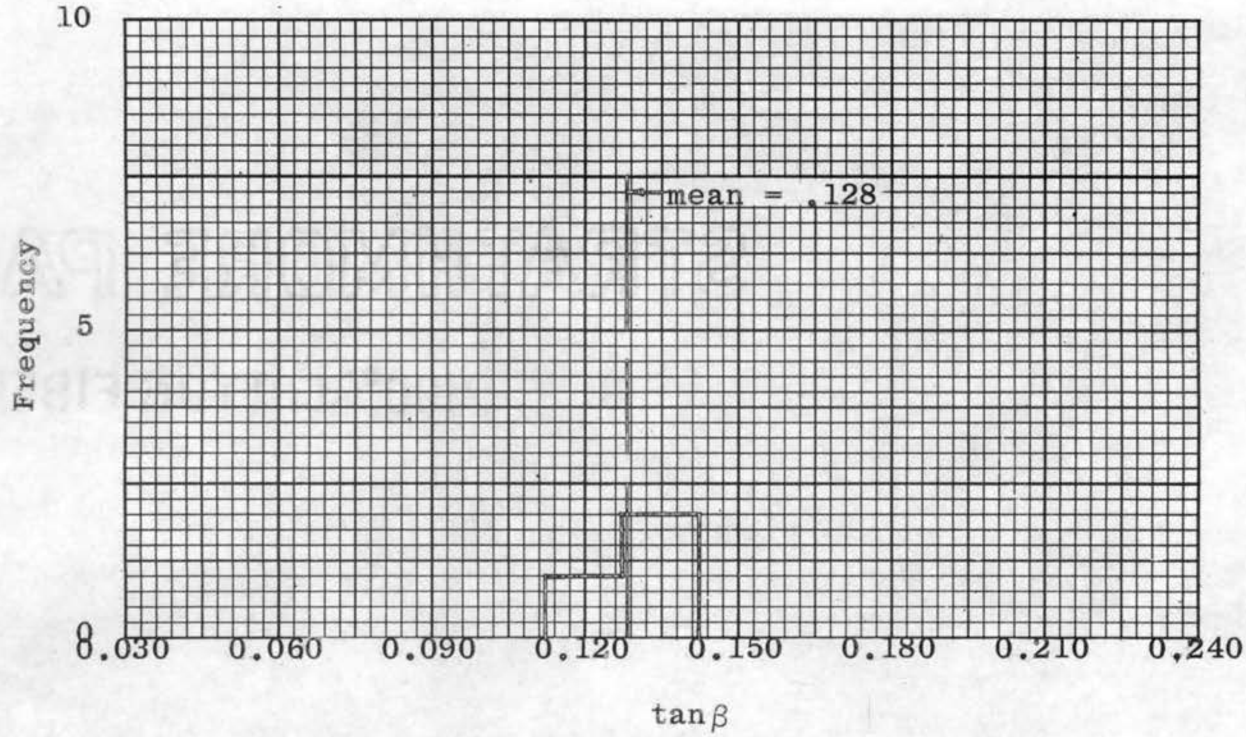

Figure 12

Frequency Histogram for Guthrie

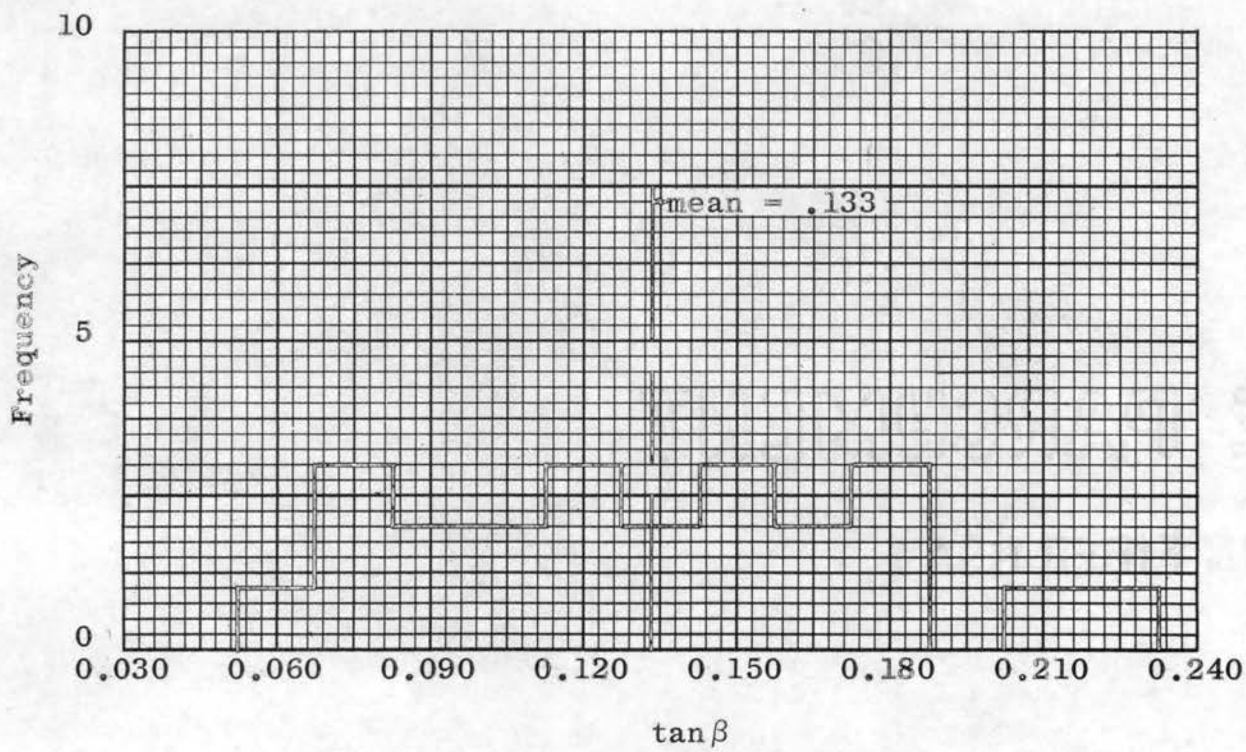

Figure 13

Frequency Histogram for Kingfisher County

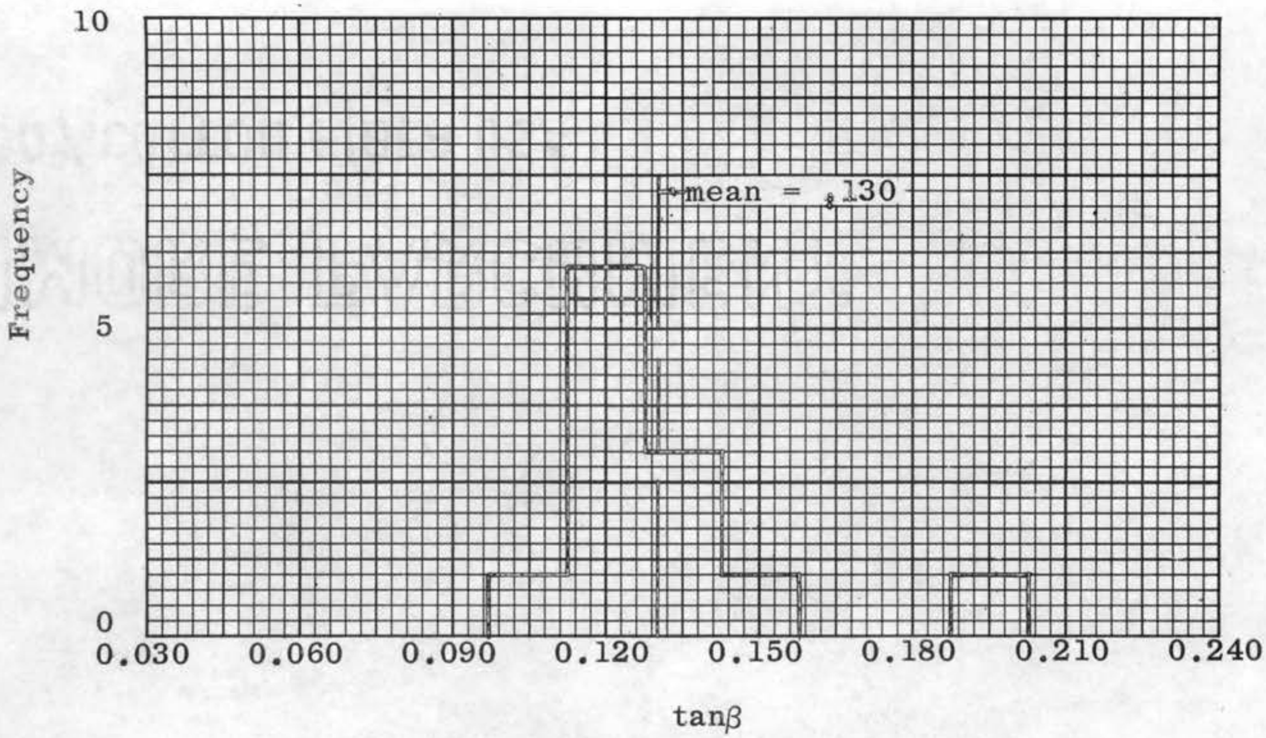

Figure 14

Frequency Histogram for Lake Carl Blackwell Dam

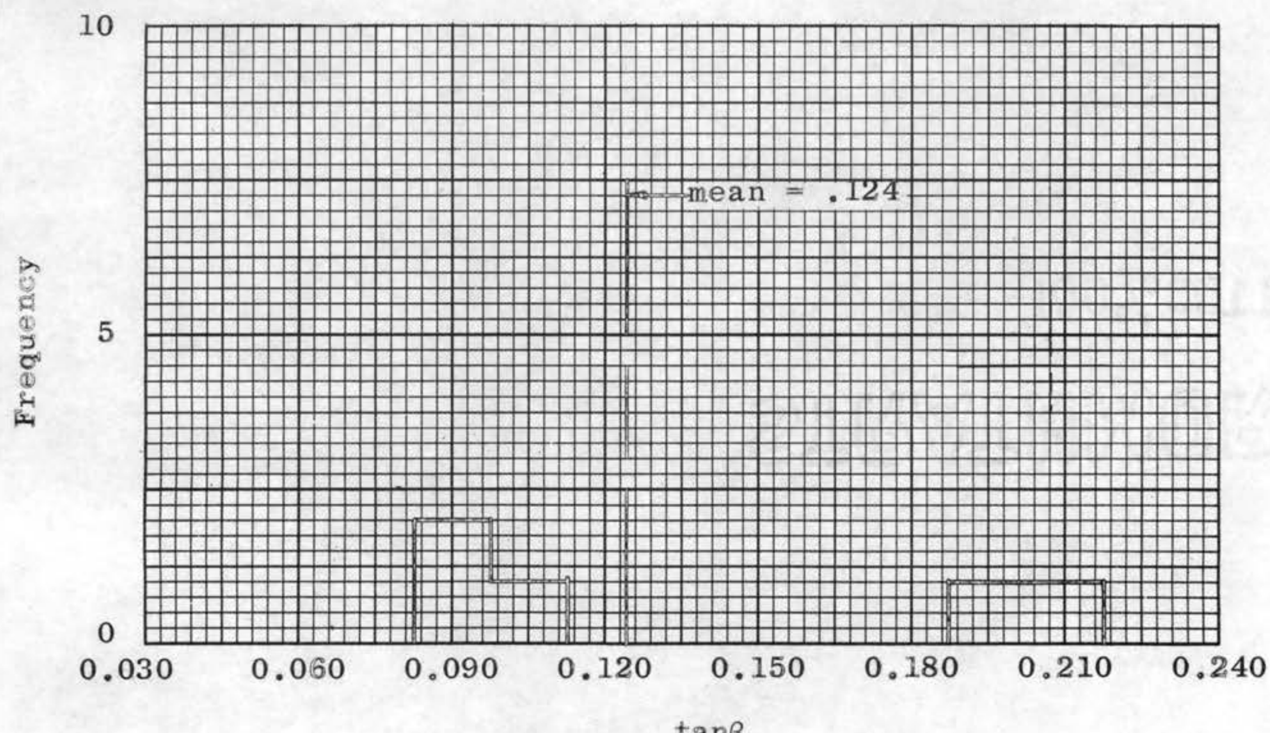

Figure 15

Frequency Histogram for Lawton

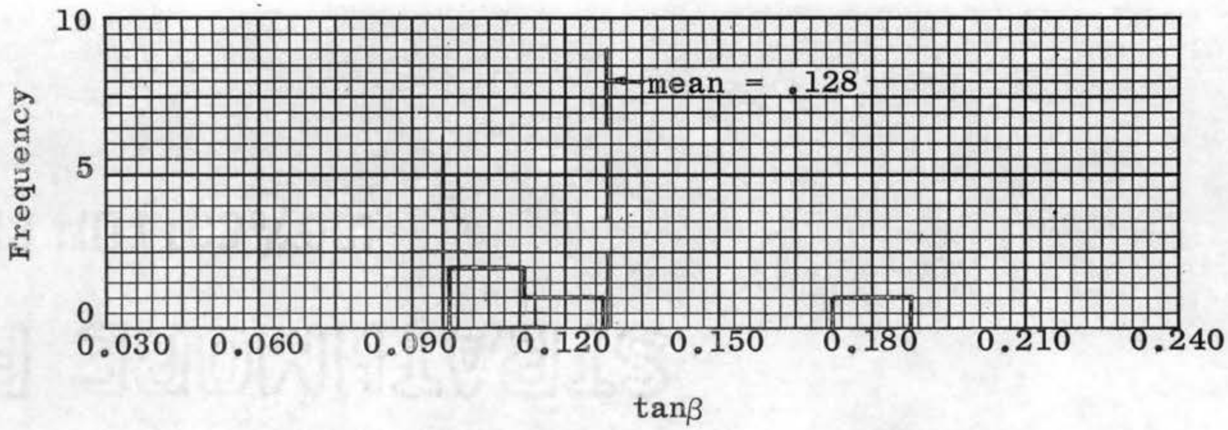

Figure 16

Frequency Histogram for Stillwater

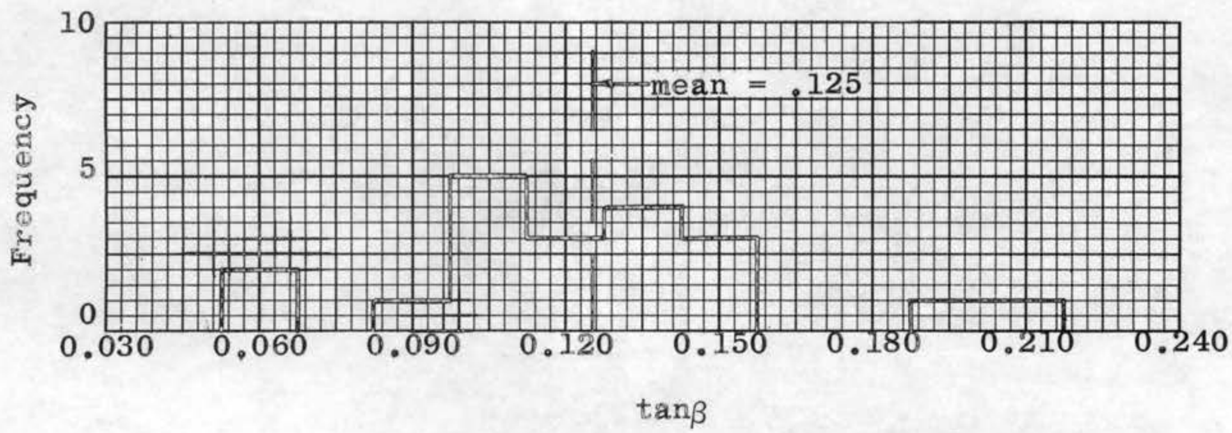

Figure 17

Frequency Histogram for Tinker Air Force Base

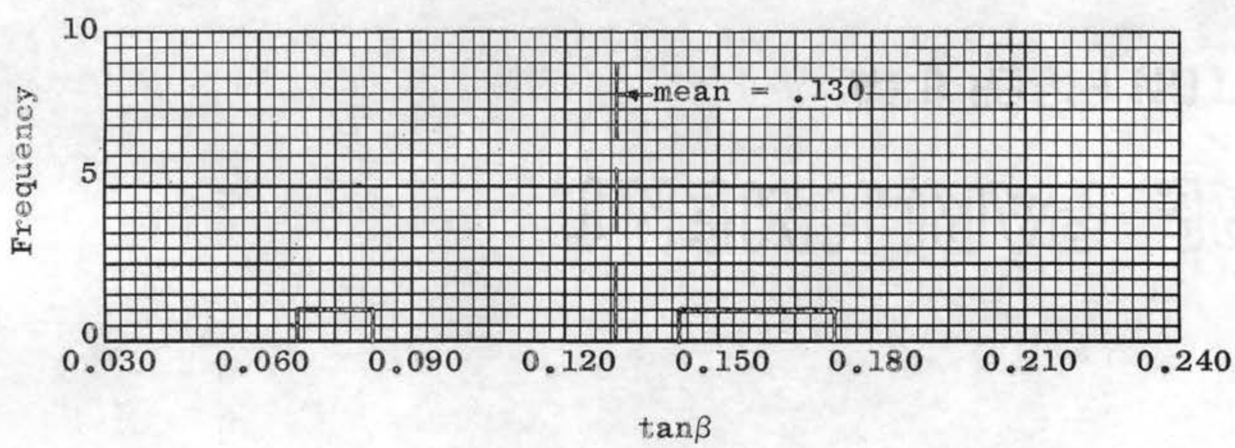

Figure 18

Frequency Histogram for Walters

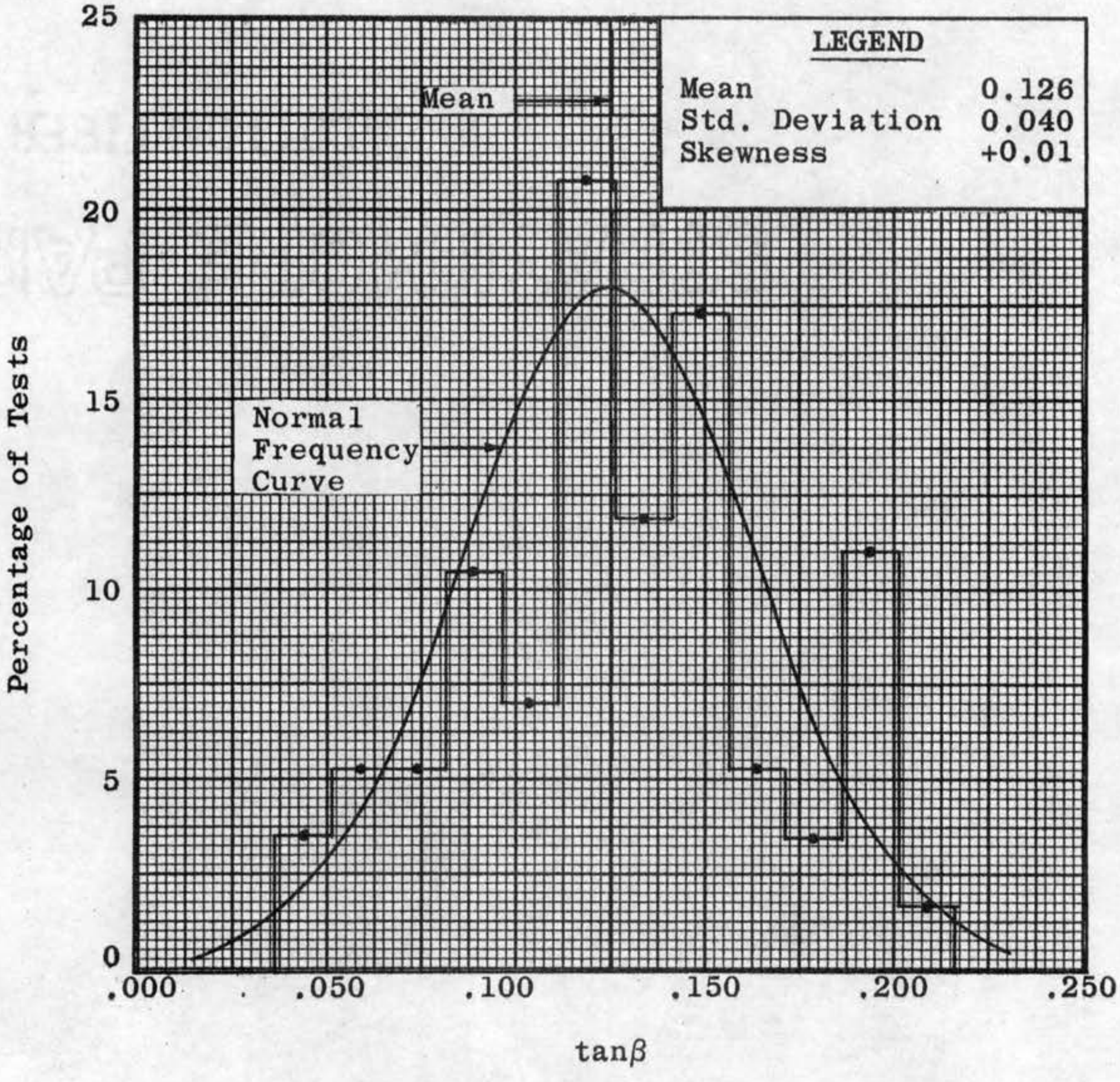

Figure 19

Histogram of Eastern Oklahoma - 58 Tests

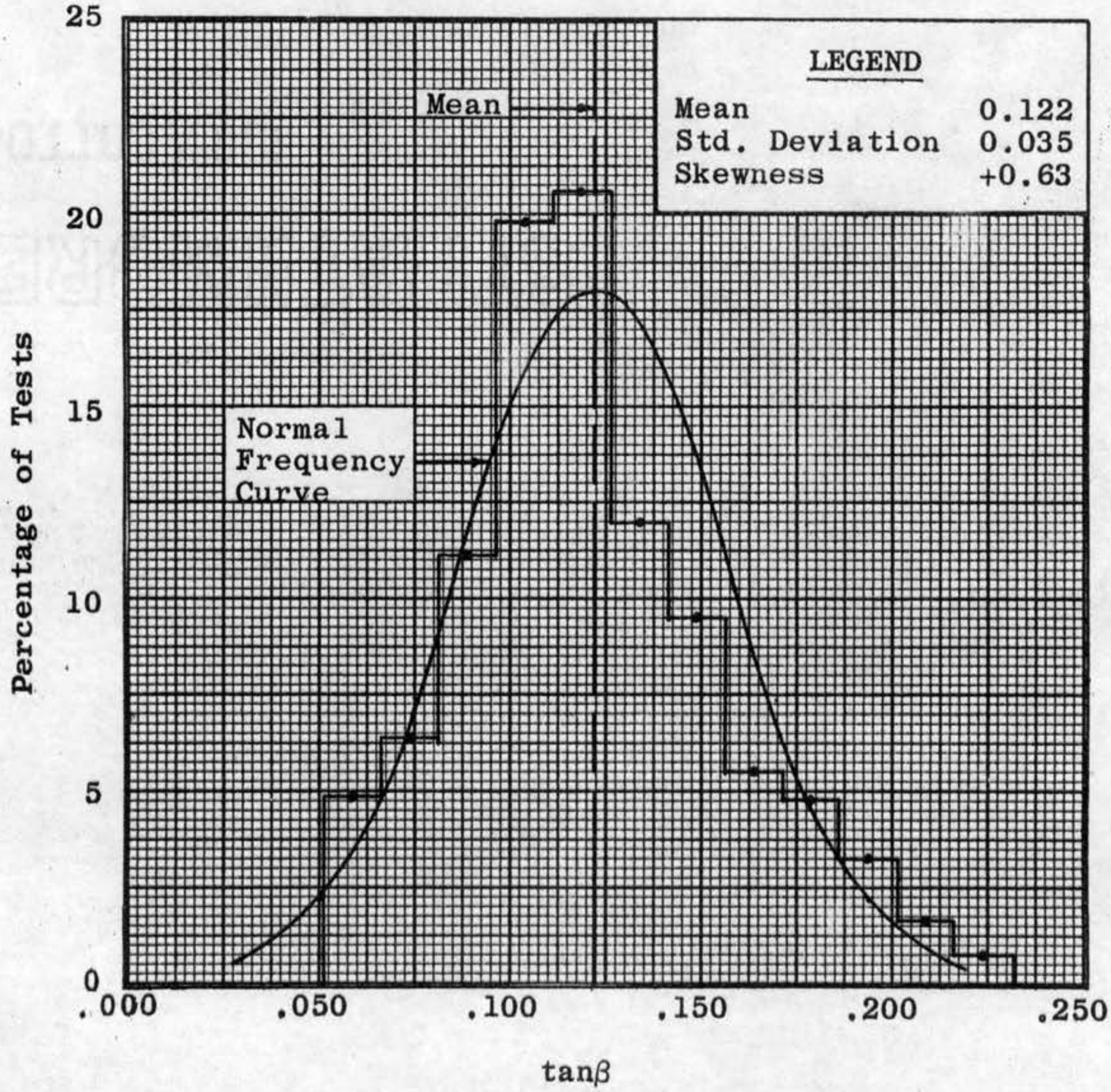

Figure 20

Histogram of Western Oklahoma - 126 Tests

These histograms also have as their abscissas values of $\tan\beta$ grouped in classes with intervals of 15 thousandths and as their ordinates, per cent frequency. The mean $\tan\beta$, standard deviation, coefficient of variation, and skewness were computed for these areas and the results are listed in Table III in addition to the number of tests and ranges in $\tan\beta$ and plasticity. The means were 0.122 and 0.126. Expressed in degrees of β, this represents a range of about 0.20 degrees. The standard deviations were 0.040 and 0.035, the coefficients of variation 31.75 and 28.69 per cent, and the skewnesses +0.01 and +0.63. Both 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 were superimposed on the histograms of Figures 19 and 20.

The means, standard deviations, and coefficients of variation were so close together for the two areas that it was believed that a more accurate representation of the data could be obtained by combining all 184 tests in one histogram (Fig. 21). The mean for all 184 tests was 0.123, the standard deviation 0.037, the coefficient of variation 30.01 per cent, and the skewness +0.37. The normal frequency curve was computed and superimposed on the histogram (Fig. 21). This histogram best fits its normal frequency curve, as a comparison with the histograms of Figures 19 and 20 shows. This was to be expected because of the larger number of tests used in its development.

TABLE III

CONSOLIDATED DATA FROM THE PRINCIPAL GEOGRAPHIC AREAS

Area	No. of Tests	Mean $\tan\beta$	Range $\tan\beta$		Std. Dev. (σ)	Skew. (k)	Coef. of Var. (v%)	Range L. L.		Range P. I.	
			Min.	Max.				Min.	Max.	Min.	Max.
Eastern Oklahoma (Pennsylvanian)	58	0.126	0.038	0.212	0.040	+0.01	31.75	16.4	85.8	14.9	66.4
Western Oklahoma (Permian)	126	0.122	0.053	0.229	0.035	+0.63	28.69	21.0	71.5	3.0	38.5
All Tests	184	0.123	0.038	0.229	0.037	+0.37	30.01	16.4	85.8	3.0	66.4

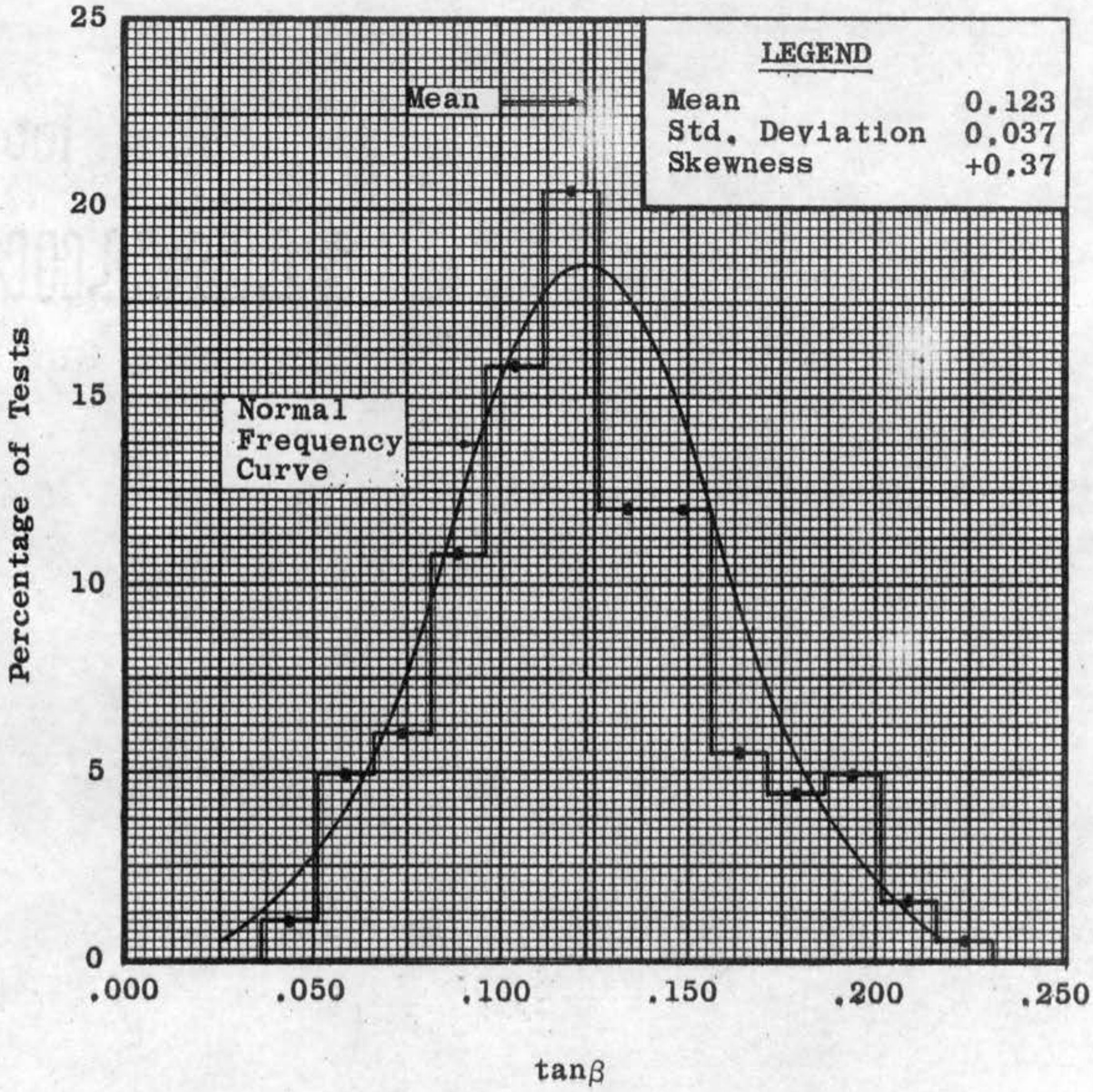

Figure 24

Histogram of All 184 Tests

CHAPTER IV

RESULTS AND DISCUSSION

Equation for the Liquid Limit on a Logarithmic Plot

From Figure 2 it can be shown that:

$$\frac{\log LL - \log W_N}{\log N - \log 25} = \tan\beta$$

$$\log \frac{LL}{W_N} = (\tan\beta) \cdot \log \frac{N}{25}$$

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

Taking the anti-log of both sides,

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

Where LL = Liquid Limit

W_N = Water content at N blows from the liquid limit device

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

This is the value for the liquid limit using a logarithmic plot and one point on the flow line.

Effect of Variations in the Slope of the Flow Line on the Value of the Liquid Limit

As shown in the Technical Memorandum 3-286 of the United States Waterways Experiment Station, the method of differentials is applicable to measuring the effect of variations in $\tan\beta$ on the value of the liquid limit. The expression for per cent change in the liquid limit is derived as follows:

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

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

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

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 $\Delta(\tan\beta)$ 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 22 for various values of N and $\Delta(\tan\beta)$. (2).

Comparison of Mean Slopes

The pertinent results determined for the geographical areas are summarized in Table IV.

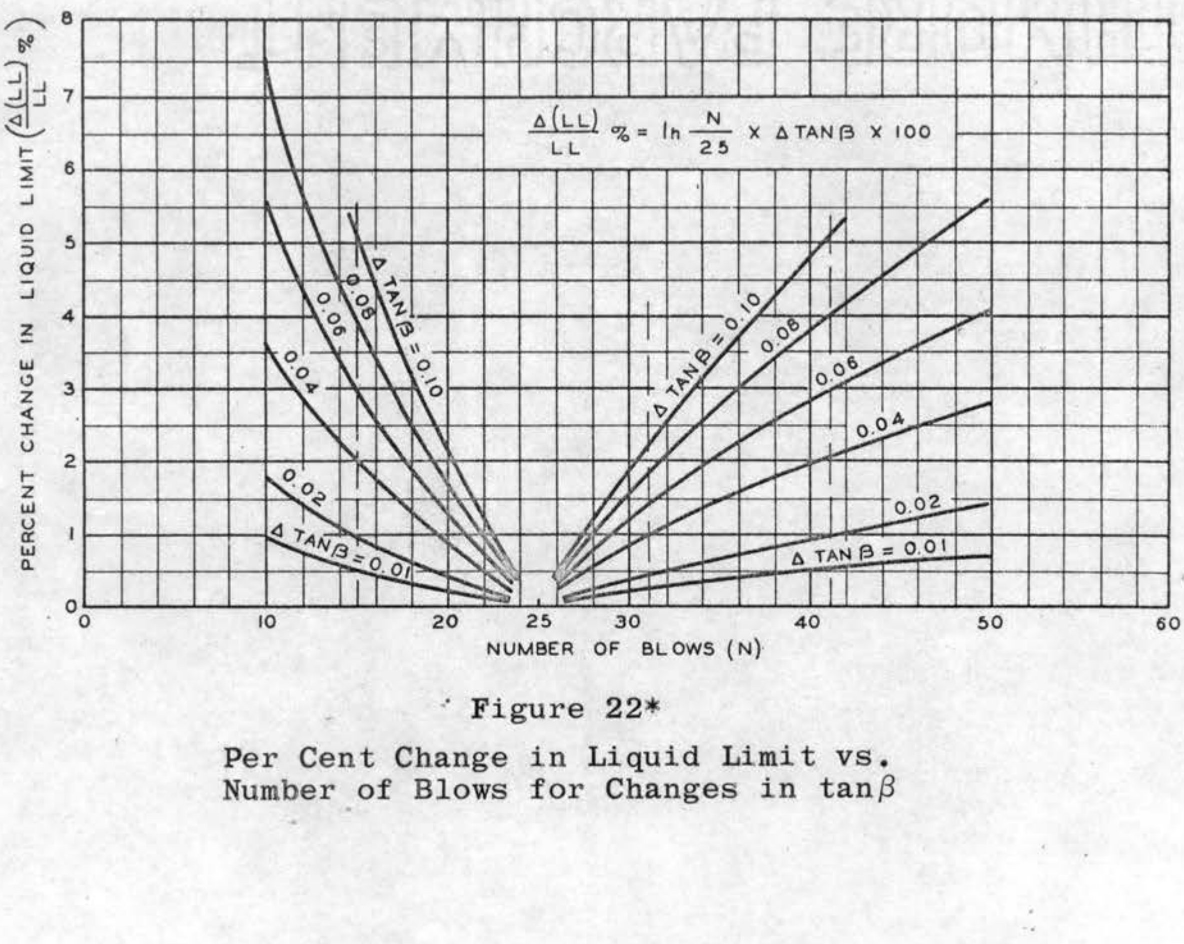

Figure 22*

Per Cent Change in Liquid Limit vs.
Number of Blows for Changes in tanβ

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*Pilch, S. et al, Simplification of the Liquid Limit Test Procedure, p. 14 (Fig. 6) Corps of Engineers, United States Army Technical Memorandum 3-286, Vicksburg, Mississippi, 1949.

TABLE IV

TABLE OF RESULTS FOR THE GEOGRAPHICAL AREAS

	No. Tests	Mean $\tan\beta$	Standard Deviation	Coef. of Var. (%)	Skew-ness
Eastern Oklahoma	58	0.126	0.040	31.75	+0.01
Western Oklahoma	126	0.122	0.035	28.60	+0.63
All Tests	184	0.123	0.037	30.01	+0.37

The magnitude of the differences between the mean for all tests and for the two 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, 0.123, differs from the means of Eastern Oklahoma and Western Oklahoma by 0.003 and 0.001 respectively. Using Figure 22 and 15 blows, this would only make a change of about 0.2 and 0.1 per cent respectively in the liquid limit. This illustrates that the difference between the means in the above table are of an extremely small magnitude when referred to the difference that they would make in computing liquid limits. The dispersion of data about the three individual means is least for Western Oklahoma, as is seen by an inspection of the coefficients of variation and standard deviations. 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, with its mean of 0.123, best represents all the data studied (Fig. 21).

Per Cent Error Involved Using the Mean Slope

The histogram and normal frequency curve for all 184 tests were plotted on arithmetic probability graph paper (Fig. 23). The ordinates of this graph are so spaced 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 23 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.

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. That 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, $\overline{\tan\beta} = 0.123$, $\overline{\tan\beta} \pm \sigma$, and $\overline{\tan\beta} \pm 2\sigma$, ($\sigma = 0.037$), were plotted on the cumulative frequency curve (Fig. 23) making it possible to pick off actual percentages of observations included within the ranges noted in Table V. The per cent error in the liquid limit for tests within the given ranges was obtained from Figure 22 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 Table V.) (2).

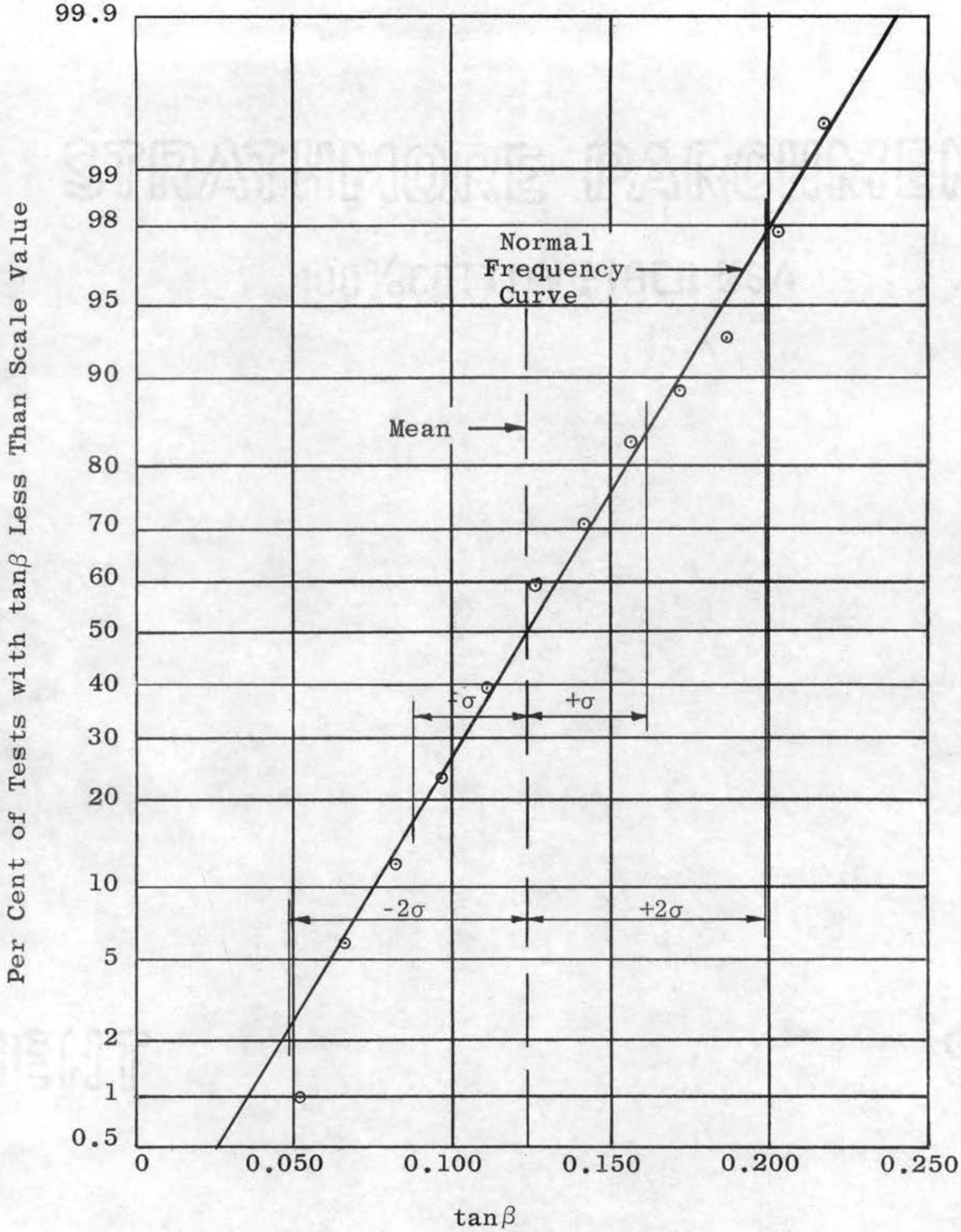


Figure 23

Arithmetic Cumulative Frequency Curve

TABLE V

PER CENT ERROR INVOLVED USING THE MEAN SLOPE

Range in $\tan\beta$		Percentages of Total Observations Lying Within Given Ranges (all 184 tests) Theoretical	Observed	Per Cent Error in Liquid Limit Using N = 15
$\overline{\tan\beta} \pm\sigma$	0.086-0.160	68.3	68.0	less than $\pm$ 1.9
$\overline{\tan\beta} \pm 2\sigma$	0.049-0.197	95.5	95.2	less than $\pm$ 3.8
Min. $\tan\beta$ to max. $\tan\beta$	0.038-0.229	99.9	100.0	less than + 4.4 ($\tan\beta$ = 0.038) less than - 5.5 ($\tan\beta$ = 0.229)

Factors Affecting the Liquid Limit Determination Using a Mean Slope

An examination of Figure 22 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 table showed that the error due to variations in the slope of the flow line is small. To keep errors due to the 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 3.8 per cent for 95.2 per cent of the tests; if 20 or 31 blows were used, the error would be reduced to less than 1.7 per cent. (41 and 31 blows give the same error as 15 or 20 blows respectively, (Fig. 22).) The limiting of the number of blows to between 20 and 31 reduces the error to less than 2.4 per cent for all 184 tests as compared to less than 5.5 per cent for between 15 and 41 blows.

Discussion

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 $\tan\beta$ 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 $\tan\beta$ should be expected. (2).

The observed variations of $\tan\beta$ from the mean may be due to a natural distribution of $\tan\beta$ 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.

CHAPTER V

SUMMARY AND CONCLUSIONS

Conclusions

Based on the data and analyses presented in this thesis, the following conclusions are warranted for the soils studied -- namely, inorganic clays with liquid limits less than 100 from the Permian deposits in Western Oklahoma and the Pennsylvanian deposits in Eastern Oklahoma.

1. 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 the soil type and geologic classification.
2. 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 outlined in the next part of this chapter.
3. Liquid limits computed using a mean flow line slope of 0.123 and one liquid limit test point give results well within the accuracy required in normal work.
4. 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.

5. It is recommended that the simplified liquid limit procedure be adopted for Oklahoma soils. This procedure will result in a substantial reduction in the cost of the liquid limit determinations.

The results obtained from the analyses described in this thesis are not intended to apply to soils other than those here in Oklahoma. For soils from other areas the procedure may be just as applicable, but the values of $\tan\beta$ 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 below is recommended.

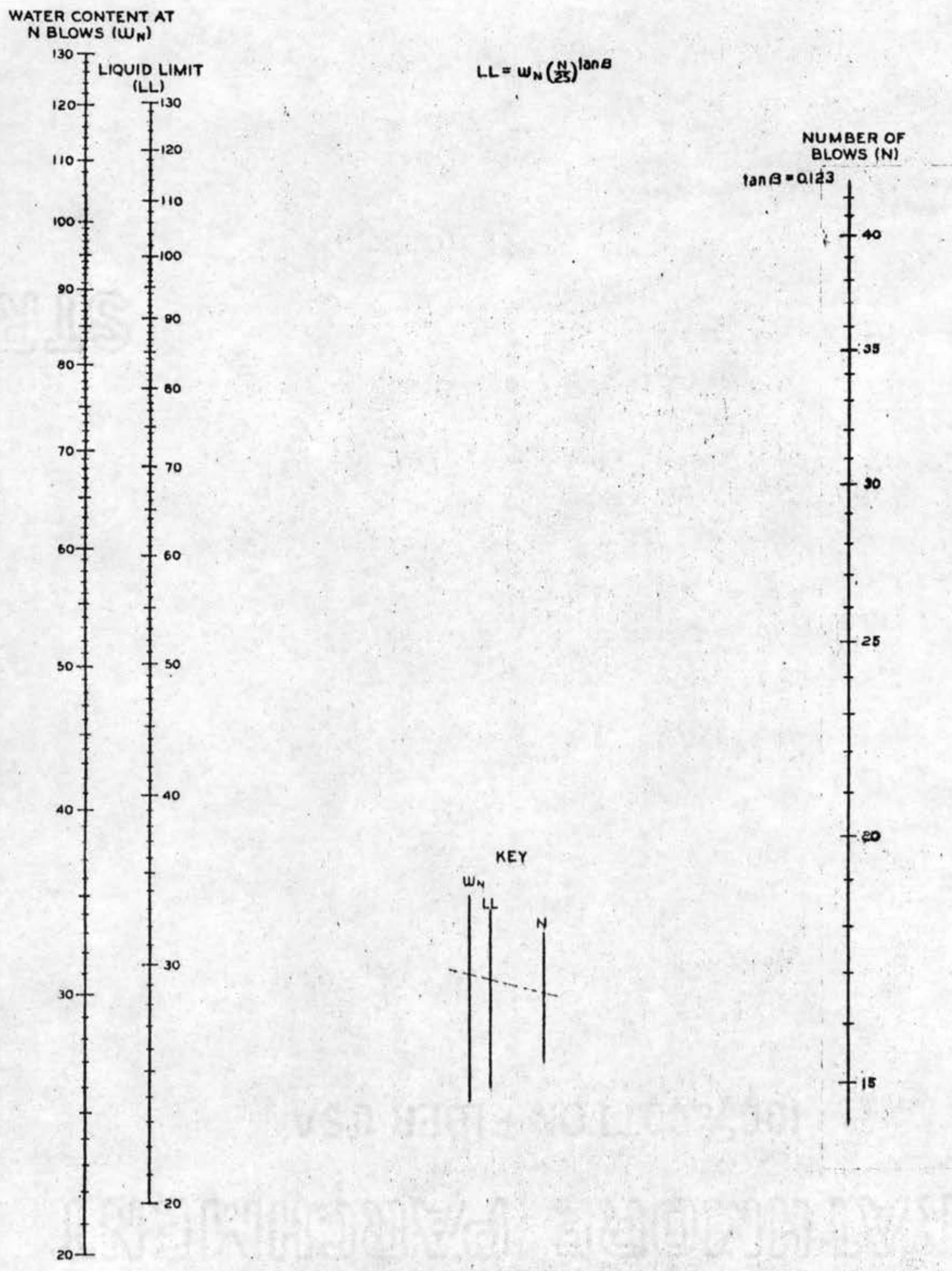
Recommended Simplified Liquid Limit Test Procedure

The simplified liquid limit test procedure should be carried out as follows. If possible, if the air is dry, the test should be conducted in a humid room. The soil to be tested is mixed with distilled water to a consistency as close to the liquid limit as possible. A soils engineer or technician, with experience, can judge this very closely. Extreme care should be taken in the mixing to obtain a uniform water content throughout the sample. Operate the liquid limit device and determine the number of blows necessary to close a half inch length of the groove. Remix and regroove the sample, and again determine the number of blows necessary to close a half inch length of the groove. If the number of blows required to close the groove differs from trial one, it is an indication of insufficient mixing of the sample. When two successive trials are obtained with the same number of blows required to close the groove, take about a ten gram sample of the soil for a water content determination.

The liquid limit is then determined from the equation:

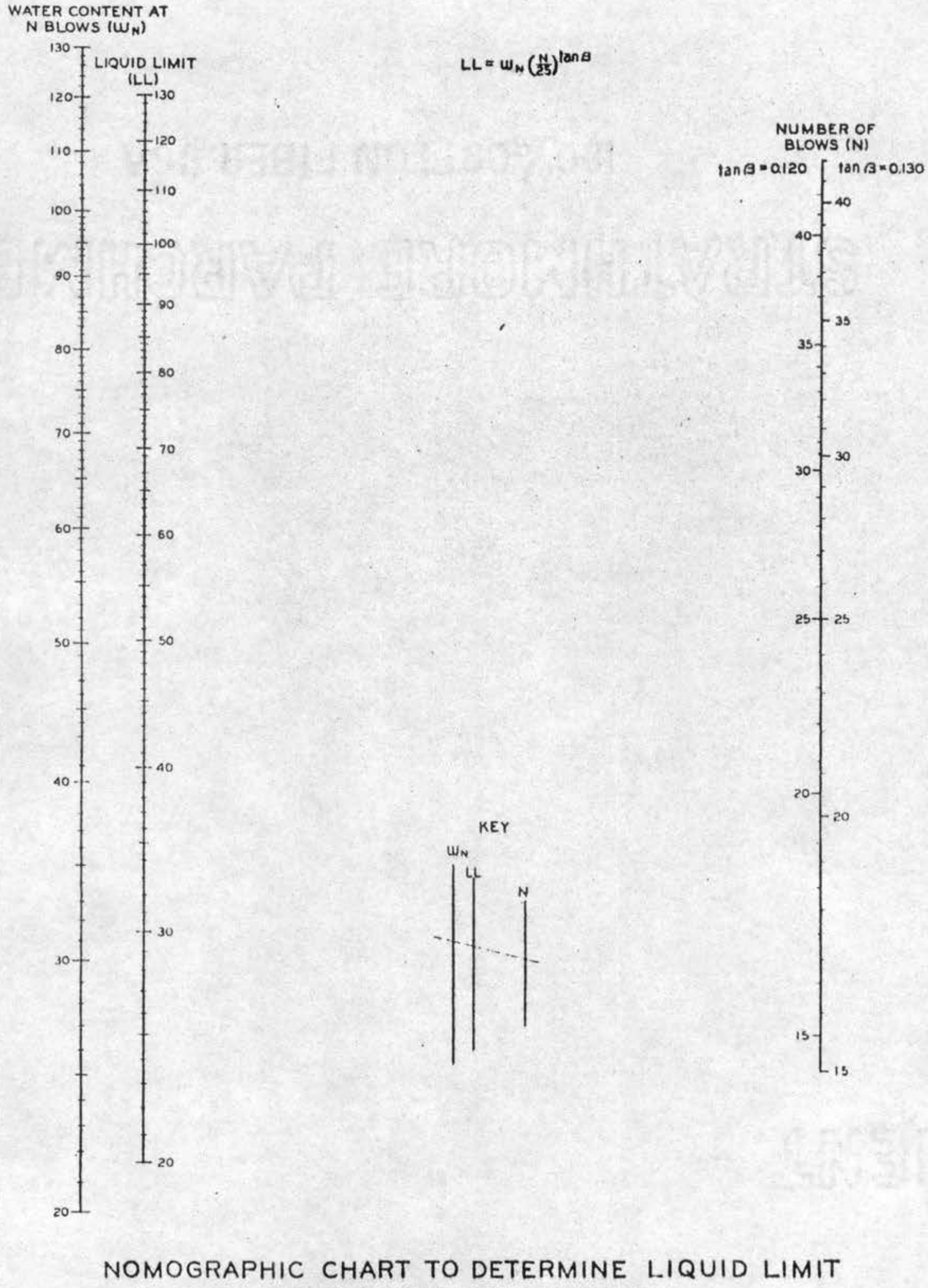
$$LL = W_N \left(\frac{N}{25}\right)^{0.123}$$

where W_N is the water content at N blows. This value can also be determined by use of the nomographic chart (Fig. 24).



NOMOGRAPHIC CHART TO DETERMINE LIQUID LIMIT
USING MEAN SLOPE METHOD
TANβ = 0.123

Figure 24



NOMOGRAPHIC CHART TO DETERMINE LIQUID LIMIT USING MEAN SLOPE METHOD

Figure 25

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