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BY

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USE OF A ONE-POINT LIQUID LIMIT PROCEDURE

By W. J. Eden[1]

Synopsis

The Soil Mechanics Laboratory of the Division of Building Research has used a 1-point liquid limit procedure for most routine tests since 1955. The decision to use the shortened method was based on a statistical study of 390 previous tests made by the 3-point method. This paper reviews the analysis of the test records available to the author along with the results of three other independent investigations on 1-point methods. After considering the variability which can be expected in the liquid limit test, the conclusion is reached that no additional significant errors are introduced through a 1-point method. A detailed 1-point test procedure is appended to the paper.

The 1-point liquid limit test depends upon the assumption that the flow line for the number of blows, N, *versus* water content is considered straight on a logarithmic plot over a limited range of N. Knowing the slope of the flow line, the water content at 25 blows may be extrapolated from the water content determined at N blows, through use of an appropriate correction factor.

The 1-point liquid limit test has been the subject of a number of investigations since 1949. The U. S. Waterways Experiment Station at Vicksburg published (1)[2] the results of the analysis of 767 tests on soils in the Mississippi Valley. This investigation was started in view of Casagrande's comment to the effect that soils of a common geological origin might have flow lines of a constant slope when both the water content and the number of blows were plotted on logarithmic scales. When the results of the 767 tests were assembled, it was concluded that all soils, regardless of geological origin, might be treated as having a flow line of constant slope. The Vicksburg Laboratory (1) proposed the following equation for determining the liquid limit:

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

where:

LL = liquid limit of the soil, per cent,
w = water content at N blows per cent,
N = number of blows, and
$\tan\beta$ = slope of the flow line on a log water content log N plot.

For the 767 test results, it was found that the average value of $\tan\beta$ was 0.121 and that the standard deviation of $\tan\beta$ was ± 0.032. It was concluded that for classification purposes, the 1-point method could be used if the number of blows was kept within the range of 15 to 41. If the test results were to be used for quantitative correlation purposes, the number of blows should be kept within the range from 20 to 31 blows.

[1] Research Officer, Division of Building Research, National Research Council of Canada, Ottawa, Ont., Canada.

[2] The boldface numbers in parenthesis refer to the list of references appended to this paper.

In 1954, Olmstead and Johnston (2) presented analyses of the results of 759 tests on soils from various points in the USA. Their treatment was slightly different than that of Vicksburg and expressed the flow equation as:

$$LL = \frac{w}{1.419 - 0.3 \log N}$$

which could be reduced to:

$$LL = w\left(\frac{N}{25}\right)^{0.135}$$

previously (2,4) and has arrived at the equation

$$LL = w\left(\frac{N}{25}\right)^{0.108}$$

Thus more than 2500 liquid limit tests have been studied, with a view to determining the slope of the flow line, for use with a 1-point liquid limit test.

TREATMENT OF RECORDS

In this paper, the procedure for determining the flow line was the same as

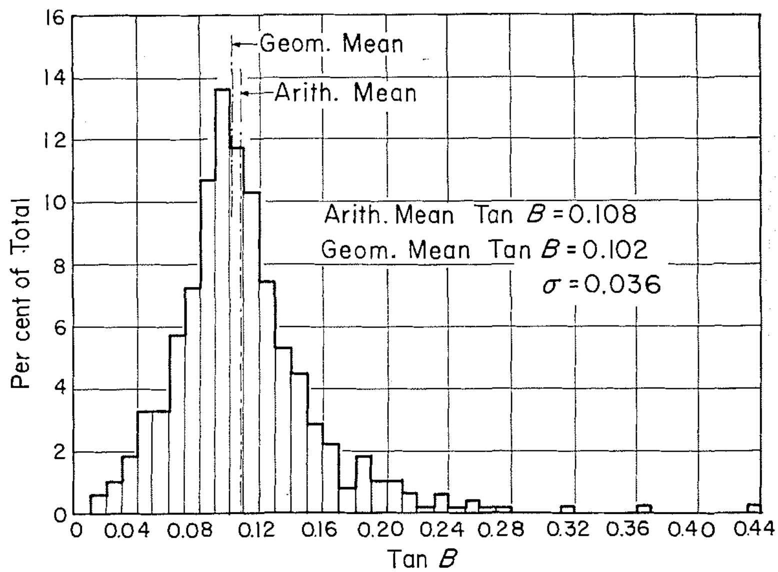

FIG. 1.—Histogram Showing Distribution of Values of tan β About Mean, 484 Observations.

The latest extensive investigation has been made by Norman (3) of the Road Research Laboratory in England. Five hundred and four tests on soils from Great Britain and overseas were treated and the following equation was obtained:

$$LL = w\left(\frac{N}{25}\right)^{0.092}$$

In the present paper, the author has analyzed the results for 484 tests on Canadian soils including those published

that used by Vicksburg (1). Test results were assembled from which the liquid limit had been determined from three or more points indicating the water content at a certain number of blows. From each test, the flow line was extended until the water content corresponding to 10 blows and 30 blows could be obtained. Tan β for the test was calculated by:

$$\tan \beta_1 = \frac{\log w_{10} - \log w_{30}}{\log 30 - \log 10}$$

The arithmetic mean for the value of tan β_1 from the 484 observations was found to be 0.108. The results of the 484 determinations of tan β are presented graphically on the histogram in Fig. 1. It will be noted that the histogram is skewed. By graphical analysis following Inman's method (5), it was found that the geometric mean value of tan β was 0.102 and that the standard deviation was ±0.036.

In order to assess the errors inherent in the 1-point method, the 484 observations were treated in the following manner. First the liquid limits as determined by the multi-point method were tabulated. Then the test record sheets were screened, taking a water content corresponding to the number of blows in the range from 15 to 20 or from 30 to 35. This water content was used in conjunction with the coefficients given in the procedure appended to this paper to calculate the liquid limit. In each case, the multi-point liquid limit was assumed to be correct and the 1-point liquid limit in error. The differences obtained for 444 of the 484 tests are presented in the form of a histogram in Fig. 2. Geometric mean difference was found to be −0.35 per cent of the liquid limit with a standard deviation of ±1.6 per cent. The same procedure was again repeated, this time keeping the number of blows in the range from 20 to 30. Figure 3 presents the histogram from the analysis of 453 tests. Here the geometric mean difference was observed to be −0.20 per cent of the liquid limit with a standard deviation of ±0.60 per cent.

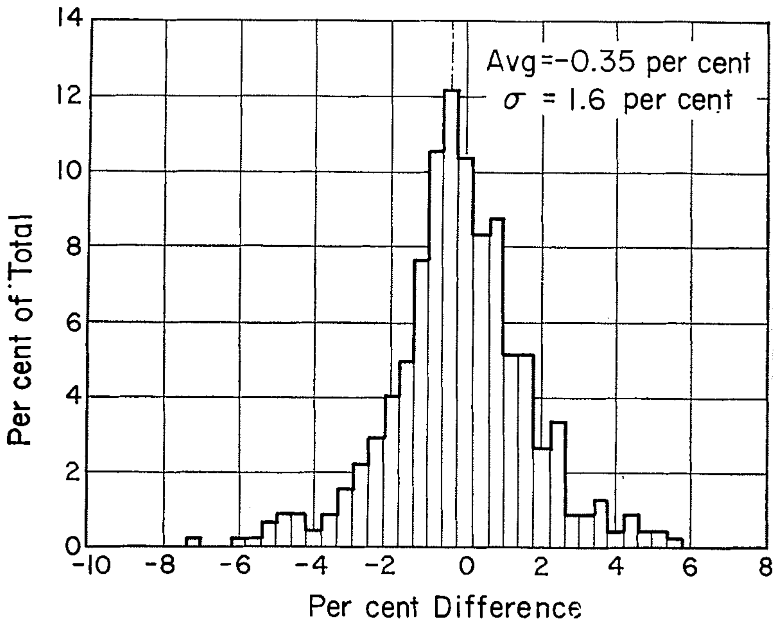

FIG. 2.—Distribution of Differences Between *LL.* Determined by 3 Points and by 1 Point when *N* was Between 15 and 20 and 30 and 35, 444 Observations.

The values of tan β from four sources are tabulated in Table I. It can be seen that the average value of tan β of the 2514 observations is within the range of tan β ± the standard deviation from the various sources.

FACTORS INFLUENCING LIQUID LIMIT

Before attempting to assess the 1-point liquid limit procedure, it may be helpful to review the factors that might influence the liquid limit determination. The liquid limit value for a single test may be influenced by (*a*) the salt or ion concentration of the sample, (*b*) the drying history of the sample, and (*c*) the effect of different operators and apparatus.

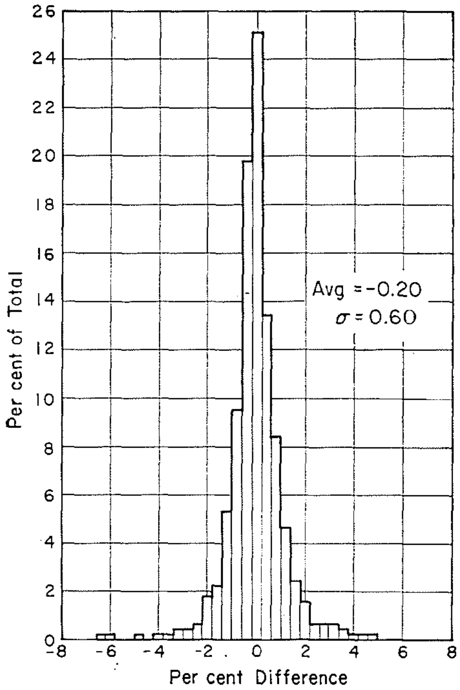

FIG. 3.—Distribution of Differences Between *LL* Determined by 3 Points and by 1 Point when *N* was Between 20 and 30, 453 Observations.

Salt or ion concentration of the soil has a considerable effect on the liquid limit. Reference may first be made to the work of Ahlberg (6) in Sweden. Ahlberg determined the plasticity index for two English clays which were treated with various ions. Table II has been taken from Ahlberg's paper.

Other evidence on the effect of ion concentration may be obtained from recent work in Norway by Bjerrum and Rosenqvist (7). During experiments to measure the effect of leaching of salt from the Norwegian clays, it was found that the liquid limit of a leached clay was 28 per cent. When sufficient salt was added to the same sample to bring the pore water salt concentration to about 35 g per liter, the liquid limit increased to 41.5 per cent.

TABLE I.—COMPARISON OF THE VALUES OF TAN β.

Source	Number of Observations	tan β	tan β × Number of Observations	Standard Deviation
Vicksburg (**1**)...	767	0.121	92.807	±0.032
Olmstead (**2**)....	759	0.135	102.465	not available
Norman (**3**).....	504	0.092	46.368	±0.032
Building Research........	484	0.108	52.272	±0.036
Total........	2514	0.117	293.912	...

TABLE II.—ILLUSTRATING EFFECT OF VARIOUS IONS ON PLASTICITY OF TWO CLAYS.

Ions	Plasticity Index, English Clay No. 1	Plasticity Index, English Clay No. 18
Untreated...........	123	75
Hydrogen...........	98	60
Lithium.............	34	20
Sodium.............	23	21
Potassium...........	41	16
Calcium.............	85	39
Magnesium..........	81	46

Recently some experiments were tried on samples from a profile of extremely sensitive Leda clay near Ottawa. At this site, the clay had a brown oxidized weathered surface crust lying over a stiff fissured clay which presumably resulted from another weathering process similar to that described by Moum and Rosenqvist (8). Below this the clay was soft and unfissured with a sensitivity greater than 100. The pore-water salt concentration throughout the profile was found to be less than 1 g per liter. Liquid limits were conducted on samples dried from their natural water content to a value near their liquid limit. Then the salt concentration was adjusted on the sample to a value slightly in excess of 30 g per liter and the liquid limit test repeated after the salted clay had been thoroughly mixed and allowed to soak for approximately 24 hr. The results are presented in Table III.

TABLE III.—EFFECT OF SALT CONCENTRATION ON LIQUID LIMIT.

Sample	Depth, ft	Natural Water Content	*LL*, Natural Sample	*LL*, Salted Sample
No. 87-9........	15	50.5	45.9	47.2
No. 87-10.......	18	56.0	44.5	49.5
No. 87-11.......	21	61.0	48.2	49.6
No. 87-12.......	24	61.0	39.3	52.5
No. 87-13.......	27	65.0	51.0	56.3
No. 87-14.......	30	69.1	36.0	...
No. 87-15.......	32.5	70.4	47.8	55.8
No. 87-16.......	35.5	69.2	43.1	57.0
No. 87-17.......	38.5	59.5	44.0	50.2
No. 87-18.......	41.5	60.2	50.1	54.0

It will be noted that samples from below the 24-ft depth reacted strongly to the additions of salt, while those above 24-ft depth did not. This difference might be attributed to the entire clay profile at this location being leached from its original salt concentration. In addition to the leaching, the upper portion of the clay profile has been weathered and hence the ion complex had again been altered. Thus when salt was added, the liquid limit of the leached clay was increased while in the leached and weathered clay this effect was offset by the weathering process.

Moum and Rosenqvist (8) have demonstrated the effect of weathering in the presence of oxygen on the liquid limits of clays. The liquid limit of a natural clay was 62.5 per cent. The same clay stored for 14 days at 60 C in space from which air had been evacuated gave a liquid limit of 61.0 per cent. Another portion of the same sample was stored for 14 days at 20 C in the presence of air and gave a liquid limit of 73.3 per cent.

It follows from the previous paragraphs that the drying history of the sample previous to the liquid limit determination can influence the value of the liquid limit. On a number of occasions, the Division of Building Research has conducted liquid limits on samples near their natural state and in the air-dried and oven-dried state. Table IV presents some of the results along with two results on Bearpaw shale from Saskatchewan given here with the permission of R. Peterson, Prairie Farm Rehabilitation Administration, Saskatoon, Sask.

TABLE IV.—EFFECT OF DRYING HISTORY ON LIQUID LIMIT.

Soil Type	*LL* of Undried Soil	*LL* of Air Dried Soil	*LL* of Oven Dry Soil
Bearpaw shale, 47 ft depth..............	124.7	149.7	95.1
Bearpaw shale, 48.5 ft depth..............	132.1	163.2	99.5
Dark band, varved clay[a].	120 to 125	85 to 90	55 to 74
Light band, varved clay[a].	39	37	35
Silt (Aklavik, N.W.T.)..	36.8	36.7	33.8
Silty clay.............	45.0	43.5	40.2
Organic silt...........	124	...	62

[a] (Cooling (**9**))

It is realized that the ASTM Method D 423 – 54 T calls for the test to be conducted on samples which had been previously air dried, so that all tests are conducted on specimens with a common drying history. It will be noted, however, from Table IV and from the previous discussion, that all soils do not react similarly to drying. Therefore, the question arises as to whether it is advisable to specify air-dried materials for the liquid limit test.

Errors due to the apparatus have recently been discussed by Casagrande (10) as follows:

1. Variations in size and resiliency of the base of the apparatus,
2. Influence of position of device on bench or table,
3. Variation in dimensions of the grooving tool,
4. Errors in adjustment of height of blow, and
5. Surface of inside of cup.

Different operators have been found to give slightly different results. Olmstead (2) states that based on many cooperative check tests using experienced operators, liquid limits cannot be expected to agree any closer than within ±2 per cent of the liquid limit value.

DISCUSSION OF THE ONE-POINT TEST

Olmstead's statement suggests that, if the errors due to the 1-point method fall within the same range (±2 per cent) the 1-point test should be an acceptable procedure. It can be seen from the four investigations that tan β varies over a range of values from about 0.01 to 0.4. The arithmetical average value of tan β for the 2514 tests reported is 0.117. Because in the process of averaging the large values of tan β will outweigh the small values, the geometric mean value of tan β will probably be somewhat less than 0.117. Inspection of the histograms presented by Vicksburg (1), Norman (3), and in Fig. 1 indicate that the frequency diagrams are skewed towards the smaller values of tan β. This consideration has led the author (4) to adopt tan $\beta = 0.1$ for calculating correction factors given in the Appendix. The histograms showing the distribution of errors were calculated by using tan $\beta = 0.1$.

It should be pointed out that variations in the value of tan β have a comparatively minor effect on the determination of the liquid limit. According to the analysis of errors given by Vicksburg (1), if the number of blows are kept within the range from 20 to 30, tan β can vary within the limits of ±0.05 with errors of only 1 per cent or less. When the actual test records were used for assessing errors in the 1-point method, it was found that when the blows are kept within the range from 20 to 30, 98 per cent of all the observations have an error limited to the ±1.8 per cent error range. The only criterion for selecting the records used in this analysis was that the flow line was determined by three or more points. Figures 2 and 3 are therefore considered to be a fair assessment of the 1-point method.

Major errors in the 1-point method can be prevented by repeating the mixing, grooving, and determination of blows until three successive determinations of N show a logical agreement. The 1-point method has been used in the Soil Mechanics Laboratory of the Division of Building Research since 1955, for almost all routine testing. The only exceptions are for organic soils and in tests when there is difficulty in obtaining a logical sequence in the number of blows. On a number of occasions, the 1-point method has been checked by a 3-point method test and in no case has a serious discrepancy been found.

OTHER POSSIBILITIES FOR SHORTENED LIQUID LIMIT DETERMINATION

Since the liquid limit test is really a dynamic shear test of the soil at a certain water content, Casagrande (10) suggests that a more accurate determination might be made through use of a simple shear test. He suggests that a simple direct shear test, static penetration test, or "squeeze" test might eliminate some of the difficulties. Recently, two authorities have published articles on the use of a cone penetrometer for determining the liquid limit. Uppal and Aggarwal (11) in India have found that a cone with a half angle of 15 deg 30 min, weighing 148 g, will give the liquid limit when the cone penetrates 1 in. Curves have been derived from which the liquid limit may be calculated and the penetration reading is within the range from 0.8 to 1.1 in. Feda and Škopek (12) report that the Vasiljev test (a 30 deg static cone weighing 76 g) is in use in the Czechoslovakian Academy of Science and in the USSR. These writers claim that the variability of test results with the Vasiljev test is only half that of the Casagrande device.

At the Soil Mechanics Laboratory, Division of Building Research, an attempt is being made to correlate penetration of a 60-deg cone weighing 60 g with the number of blows in the liquid limit determination. Sufficient results have not been obtained as yet to make any significant correlations, but if the correlation is good, as apparently other workers have found, the cone test will offer considerable savings in time over even the 1-point liquid limit test.

CONCLUSIONS

The liquid limit test is really a dynamic shear test for finding the water content of a remolded soil when its shear strength is in the order of 0.2 psi. Norman (13) shows a range from 0.11 psi to 0.32 psi. Hence all the factors influencing shear strength of the soil also affect the value of its liquid limit. In spite of the limitations of the test, the liquid limit of a soil, considered together with its plastic limit, has proved to be one of the most useful correlative values in the practice of soil mechanics. There are, for example, the plasticity chart developed by Casagrande (14), the activity chart proposed by Skempton (15), and the relation between sensitivity and liquidity index shown by Bjerrum (16).

Because of the wide range of tolerance, which is apparently acceptable in the liquid-limit determination, the author submits that the errors introduced through the use of a 1-point method will not alter the general usefulness of the test, provided major errors are guarded against. If the number of blows is kept between 20 and 30, the error will be less than ±2 per cent of the liquid limit value for 99 per cent of the tests.

It is suggested that the cone method offers considerable potential savings in time over even the 1-point method. Before the cone method can be generally accepted, it should define accurately the liquid limit as determined by the Atterberg method in order to make use of the great collection of useful correlations that has been derived through use of the Atterberg tests.

Acknowledgments:

This paper is presented as a contribution from the Division of Building Research, National Research Council of Canada with the approval of the Director of the Division. The author wishes to acknowledge the assistance given him by his colleagues in the Soil Mechanics Laboratory, particularly the research technicians who assembled and summarized the many test records.

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APPENDIX

SUGGESTED PROCEDURE FOR ONE-POINT LIQUID LIMIT DETERMINATION

The liquid limit denotes that moisture content at which a sample of soil just passes from a liquid to a plastic state. It is arbitrarily chosen as the moisture content at which two sections of a pat of soil begin to flow together when subjected in a cup to the impact of 25 sharp blows from below. To eliminate the personal element, which usually has an important influence in this test, a standardized mechanical device is used.

Equipment

(*a*) *Mortar and Rubber-Covered Pestle.*

(*b*) *Sieve*, No. 40.

(*c*) *Dish*, evaporating medium size.

(*d*) *Spatula.*

(*e*) *Wash Bottle* with distilled water.

(*f*) *Liquid Limit Device* (as defined in ASTM Method D 423 – 54 T.[3]

(*g*) *Casagrande Grooving Tools*, 3 or 4.

(*h*) *Metal Weighing Tins*, 1 or 2.

(*i*) *Balance* sensitive to ±0.01 g.

(*j*) *Oven*, constant temperature, 105 to 110C.

(*k*) *Desiccator.*

Procedure

The test is often performed on a soil sample in its natural state. If the sample has begun to dry out, however, it should be thoroughly air-dried and tested from the air-dried state. A sample which has previously been oven-dried, or a sample whose "drying history" is unknown, should not be used. Note the original conditions of the sample on the data sheet for "Atterberg limits" which is used.

(*a*) Choose a representative 150 to 200 g sample of soil. If this sample is in the natural moist state, remove all particles larger than $\frac{1}{16}$ in. with the fingers. If the sample has been

[3] Tentative Method of Test for Liquid Limit of Soils (D 423-54 T), 1958 Book of ASTM Standards, Part 4, p. 1132.

air-dried, grind it in a mortar, using a rubber-covered pestle, and pass it through a No. 40 sieve to remove the coarse particles.

(*b*) Mix the sample in an evaporating dish to the consistency of a very thick paste, using distilled water.

(*c*) Cover the dish and allow the soil to soak, preferably overnight. Record the time of soaking on the data sheet.

(*d*) Using the handle of the grooving tool as a gage, check the liquid limit device to insure that the height of fall of the cup is exactly 1 cm, and adjust if necessary. This should be the vertical distance from the center of the worn spot on the cup to the solid base, when the crank is just about to drop the cup. Set the device in a predetermined spot on a table of sturdy construction, where it will remain throughout the test. (See "Soil Testing for Engineers," Lambe, p. 152, for an illustration of the adjustment of the device.)

(*e*) Place some of the soil sample in the cup of the liquid limit device to a depth of $\frac{3}{8}$ in., being careful not to entrap any air bubbles, and smooth the surface with a spatula so that it is horizontal when the cup is at rest in the device.

(*f*) Take the cup in the palm of one hand. Holding the grooving tool perpendicular to the surface of the cup, and starting at the back, cut a groove in one continuous motion along the diameter through the center line of the cam follower. In silty and sandy soils it may sometimes be necessary to cut the groove with a spatula or special tool, using the grooving tool to check dimensions.

(*g*) Place the cup gently in the liquid-limit device. Turn the handle at approximately 2 turns per second until the bottom of the groove is closed for a distance of $\frac{1}{2}$ in., and record the number of blows. To insure that the handle is rotated smoothly, the operator should stand facing the handle of the device. The number of blows must lie between 20 and 30 before proceeding with the test. More blows than 30 require the addition of distilled water and remixing while less than 20 blows requires air drying.

(*h*) Repeat the operation of mixing in the cup, grooving and testing until 3 successive determinations show logical agreement with a difference of not more than 1 or 2 blows. Record the number of blows for these last 3 determinations.

(*i*) Immediately transfer a minimum of 10 g of the soil from the vicinity of the closed groove to a weighing tin and cover the tin.

(*j*) Weigh the tin containing the sample to the nearest 0.01 g and record.

(*k*) Dry the open tin in the oven overnight.

(*l*) After drying, replace cover and place in the desiccator to cool and then weigh to 0.01 g.

TABLE V.—LIQUID LIMIT CORRECTION FACTORS.

Number of Blows, N	Correction Factor, C_n	Number of Blows, N	Correction Factor, C_n
15	0.950	26	1.004
16	0.955	27	1.008
17	0.962	28	1.012
18	0.968	29	1.015
19	0.973	30	1.019
20	0.977	31	1.022
21	0.983	32	1.025
22	0.987	33	1.028
23	0.992	34	1.031
24	0.996	35	1.034

(*m*) Compute the water content based on the dry weight of the soil. The liquid limit is then computed by multiplying the water content at N blows by the correction factor corresponding to N blows, in Table V.

NOTE.—The determination of the liquid limit by the method outlined above assumes that the slope of the "flow line" is constant (0.100) for all soils. This assumption is not strictly correct, but the error introduced may be neglected in all cases except (1) where special accuracy is required of the test; (2) for highly organic soils.

If there is difficulty in obtaining a consistent number of blows for the one determination, a second determination at a different number of blows, preferably close to 25, should be made. In all cases, the nearer to 25 blows that the determination is made, the more accurate the test is likely to be.

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DISCUSSION

MR. EDWARD A. ABDUN-NUR[1] (*by letter*).—In analyzing 2514 pairs of test results on the 1-point and the standard methods of liquid limit test, the author has given the profession a very fine summary of the extensive work done to date in comparing the two methods, and presents a very convincing case for the use of the 1-point test method.

The standard deviations for the various values of tan β appear a little high for good reliability. It is, of course, true as the author points out, that small changes in tan β do not affect the final test result appreciably, and because of this, the relatively large standard deviations and the author's recommendation to use a value of 0.1 for tan β, would probably provide entirely adequate results.

It would be of interest, however, to know what the coefficient of correlation and its probable error for this extensive set of data might be. With over 2500 pairs of observations, the reliability of such a correlation would be high and would add confidence to the use of the 1-point test.

[1] Consulting Engineer, Denver, Colo.

MR. W. J. EDEN (*author*).—Mr. Abdun-Nur has asked for the coefficient of correlation for the measurements of tan β given in the paper. This could be done for only the 484 tests conducted at the Division of Building Research. Because the final liquid limit result is rather insensitive to variations of tan β, the author hesitates to undertake the considerable volume of calculations necessary to do so.

By way of supplementing the information on tan β given in the paper, reference is made to D. Mohan and R. K. Goel who report the analyses undertaken in India.[2]

[2] D. Mohan and R. K. Goel, "Letter to Editor," *Geotechnique*, Vol. 9, No. 3, p. 144 (1959).

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