

Rapid Determination of Liquid Limit of Soils by Flow Index Method

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This paper presents a new approach to liquid limit determinations by a one-point procedure. Necessary equations, charts and tables, developed on the AASHO Road Test and easily usable by technicians, are presented.

● THE ROUTINE testing of large numbers of soil samples in highway construction and maintenance requires the use of rapid methods for determining standard characteristics. The liquid limit determination for soils is one of the most important of these tests.

The standard method for determining the liquid limit of soils (1) requires that at least three random trials be made, each at a different moisture content. The moisture contents are plotted as the ordinates on an arithmetical scale and the number of blows as abscissae on a logarithmic scale. A flow curve is then drawn and the liquid limit is taken as the moisture content corresponding to the point where the 25 blow line intersects the flow curve.

The more rapid one-point procedure for determining the liquid limit has been given considerable attention in recent years, and the American Association of State Highway Officials has adopted it as an alternate test procedure. It was initiated by the Corps of Engineers (2) and later extended by the Washington State Highway Department (3) and the Bureau of Public Roads (4).

According to the Corps of Engineers method, it was assumed that the flow curve plotted on the logarithmic paper was a straight line and could be expressed by

$$LL = W_n \left(\frac{N}{25} \right)^{\tan B}$$

in which LL = liquid limit;

N = number of blows;

W_n = moisture content at N blows; and

$\tan B$ = slope of the flow curve when plotted on logarithmic paper.

The Washington State Highway Department method was based upon relationships between the different slopes of flow curves obtained for soils with different liquid limit test values. This was called the "Washington Chart Method."

The Bureau of Public Roads method was derived from a family of typical flow curves (from the Washington State Highway Department), and made use of the assumption that the convergence of the flow curves with the zero moisture content axis was a constant. This assumption made it possible to derive the following equation for such a family of curves:

$$\frac{LL}{W_n} = \frac{\log N_a - \log 25}{\log N_a - \log N}$$

N_a is the point of convergence of a family of flow curves intersecting on the zero moisture content axis. The problem was further simplified by arbitrarily moving the point of convergence to the zero moisture content axis. This point was so far from the 25 blow line that the consequent changes in the slopes of the flow curves were negligible within the 17 to 36 blow range used.

This paper presents another approach based on work done on the AASHO Road Test, and making use of published data from the Washington State Highway Department.

In Figure 1, the flow index is defined as the slope of the flow curve. It can be expressed by the formula:

$$\text{Flow Index } (I_f) = \frac{LL - W_n}{\log N - \log 25}$$

From this relationship the liquid limit may be determined by the following equation:

$$LL = W_n + I_f \log \frac{N}{25}$$

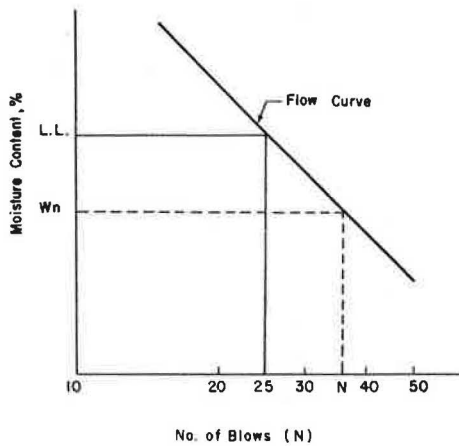


Figure 1. Flow curve on semi-logarithmic plots.

pressed in differential form as:

$$\Delta LL = \log \frac{N}{25} \Delta I_f$$

in which ΔLL is the percent of moisture change in the value of liquid limit for changes in ΔI_f . Calculations of ΔLL for various N and ΔI_f are shown in Figure 3.

Indications from Figure 3 are that the maximum error in liquid limit associated with an error 2.5 in flow index would be 0.4 percentage points, if the number of blows in the one-point test was between 17 and 36.

Figure 4 shows the flow index—liquid limit relationship plotted from data obtained from the Washington State Highway

The term $I_f \log \frac{N}{25}$ is called the moisture correction factor. If N is less than 25, the value of this term will give a negative sign. Table 1 shows the moisture correction factor computed for various flow indexes, and Figure 2 shows the moisture correction factor versus number of blows for various flow indexes.

Effect of variations in the flow index on the value of the liquid limit can be measured by the method of differentials. The equation immediately above can be ex-

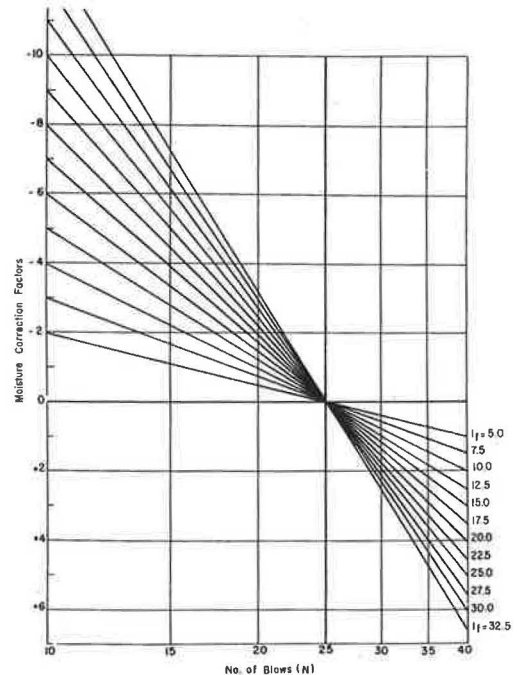


Figure 2. Moisture correction factors vs. No. of blows for various flow indexes.

TABLE 1
MOISTURE CORRECTION FACTOR FOR VARIOUS FLOW INDEXES

* Moisture Correction Factor = $I_f \log \frac{N}{25}$												
$N \backslash I_f$	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5
17	0.84	1.25	1.67	2.09	2.50	2.92	3.34	3.76	4.18	4.59	5.01	5.43
18	0.72	1.07	1.43	1.79	2.14	2.50	2.86	3.22	3.58	3.93	4.29	4.65
19	0.60	0.89	1.19	1.49	1.78	2.08	2.38	2.68	2.98	3.27	3.57	3.87
20	0.48	0.73	0.97	1.21	1.46	1.70	1.94	2.18	2.42	2.67	2.91	3.15
21	0.38	0.57	0.76	0.95	1.14	1.33	1.52	1.71	1.90	2.09	2.28	2.47
22	0.28	0.41	0.55	0.69	0.82	0.96	1.10	1.24	1.38	1.51	1.65	1.79
23	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.81	0.90	0.99	1.08	1.17
24	0.09	0.14	0.18	0.22	0.27	0.32	0.36	0.40	0.45	0.50	0.54	0.58
26	0.08	0.13	0.17	0.21	0.26	0.30	0.34	0.38	0.42	0.47	0.51	0.55
27	0.16	0.25	0.33	0.41	0.50	0.58	0.66	0.74	0.82	0.91	0.99	1.07
28	0.24	0.37	0.49	0.61	0.74	0.86	0.98	1.10	1.22	1.35	1.47	1.59
29	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76	1.92	2.08
30	0.40	0.59	0.79	0.99	1.18	1.38	1.58	1.78	1.98	2.17	2.37	2.57
31	0.47	0.70	0.93	1.16	1.40	1.63	1.86	2.09	2.33	2.56	2.79	3.02
32	0.54	0.80	1.07	1.34	1.61	1.87	2.14	2.41	2.68	2.94	3.21	3.48
33	0.61	0.91	1.21	1.51	1.82	2.12	2.42	2.72	3.03	3.33	3.63	3.93
34	0.67	1.01	1.34	1.68	2.01	2.35	2.68	3.02	3.35	3.69	4.02	4.36
35	0.72	1.08	1.44	1.80	2.16	2.52	2.88	3.24	3.60	3.96	4.32	4.68
36	0.79	1.19	1.58	1.98	2.37	2.77	3.16	3.56	3.95	4.35	4.74	5.14

* The moisture correction factors for number of blows (N) less than 25 should be preceded by a minus (-) sign.
If the number of blows is above 25, the moisture correction factors should be plus (+).

Department (3) and the AASHTO Road Test. From this relationship, it is indicated that the flow index increases uniformly with the liquid limit. (Organic soils are not included.)

Table 2 has been prepared from the data shown in Figure 4 for flow index intervals of 2.5, and may be used with Table 1 to compute liquid limit values.

Using the procedures outlined in this paper, laboratory personnel may easily and accurately estimate liquid limit values from one-point test data. Proper flow index values corresponding to the moisture content (W_n) coincident to the number of blows used in the one-point test are selected from Table 2, provided the number of blows is not less than 17 nor greater than 36. The liquid limit value is determined by applying the proper correction factor from Table 1 to the moisture content obtained in the one-point test.

It is believed that this procedure is an improvement over previously used methods in that it is derived directly from the flow curve and the observed relationship between the slope of the flow curve and the liquid limit for various soils. These relationships are simple and allow use of the procedure by the laboratory technician through the

TABLE 2
SELECTION OF FLOW INDEX

One pt. moisture cont. (range of no. of blow between 17 to 36) (W_n)	Flow Index (I_f)
20.0 — 25.0	5.0
25.0 — 30.0	7.5
30.0 — 37.5	10.0
37.5 — 45.0	12.5
45.0 — 52.5	15.0
52.5 — 60.0	17.5
60.0 — 67.5	20.0
67.5 — 75.0	22.5
75.0 — 82.5	25.0
82.5 — 90.0	27.5
90.0 — 97.5	30.0
97.5 — 105.0	32.5

Equation : $L.L. = W_n + I_f \log \frac{N}{25}$

Example :

Given: a soil with a moisture content (W_n) = 50 % and number of blows (N) = 20.

From table 2, the selection of flow index (I_f) = 15

From table 1, the moisture correction factor = - 1.46

Therefore, the liquid limit (L.L.) = $50 - 1.46 = 48.54$.

application of simple correction factors presented in tabular form.

ACKNOWLEDGMENTS

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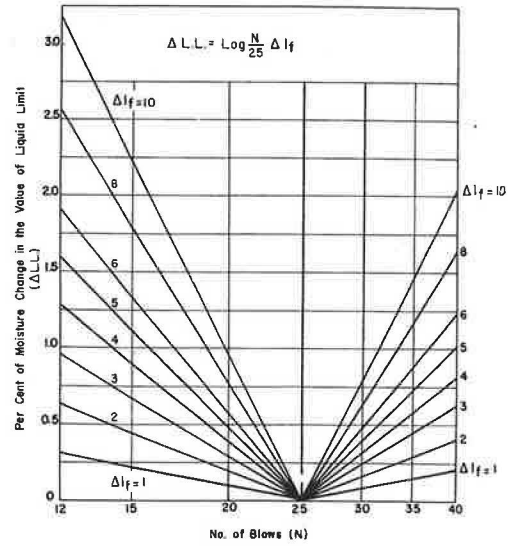


Figure 3. Percent of moisture change in the value of liquid limit vs. No. of blows for change in flow index.

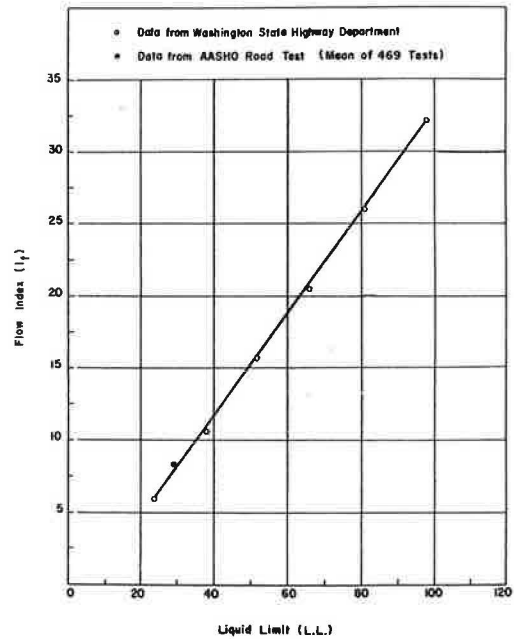


Figure 4. Flow index vs. liquid limit.

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2. "Simplification of the Liquid Limit Test Procedure." Correlation of Soil Properties with Geological Information, Rept. No. 1, Tech. Memo. No. 3-286, Waterways Experiment Station, Corps of Engineers, U.S. Army, Vicksburg, Mississippi (June 1949).
3. Cooper, J. H. and Johnson, K. A., "A Rapid Method of Determining the Liquid Limit of Soils." Rept. No. 83, Washington State Highway Department (March 1950).
4. Olmstead, F. R. and Johnston, C. M., "Rapid Methods for Determining Liquid Limits of Soils." HRB Bul. 95, Washington, D. C. (1955).

Discussion

C. M. JOHNSTON, Soils Research Engineer, Bureau of Public Roads (Retired)—
Mr. Fang's paper is well written. His procedure is well thought out and technically correct. He has added to the knowledge of the soil testing profession by giving us a tabular method for calculating the liquid limit, to add to the three methods listed in the American Association of State Highway Officials Alternate Standard Method for Liquid Limit of Soils, that is, the nomographic chart, the multicurve chart and the slide rule with special "blows" scale. His method appears to qualify for the AASHO Alternate Method, since the last clause in the section regarding calculations reads, "or by any other method which produces equally accurate liquid limit values." The author includes proof that the maximum variation to be expected by his procedure is 0.4 percentage unit, which is as accurate as any of the three accepted methods.

It may be that his method was an "improvement over previously used methods" for the soils and personnel on the AASHO Test Road, but for general use the writer prefers the slide-rule method and would use the tabular one only for personnel who found the slide rule difficult.

For the record, the Washington State Highway Department engineers did not know of the existence of the Corps of Engineers' method when they were developing their method. Neither did the Soils Research Laboratory of the Bureau of Public Roads, as the writer was in charge of the investigation of the Washington State method and the report of the slide-rule method. The Arlington Research Station of the Bureau of Public Roads first learned of the Corps of Engineers' method in August 1956, when the Denver Division office forwarded a copy of the nomograph with a reference to its source. At that time the Research Laboratory had been using the slide-rule method for five years.

CLOSURE, H. Y. Fang—The comments and review of the literatures contributed by Mr. Johnston are much appreciated.

The selection of the flow index using Table 2 gives a maximum possible deviation of 2.5 in the flow index and a deviation of about 0.4 points in the value of liquid limit. This may be somewhat too large an error in the liquid limit determination. To reduce the error, an expansion of Table 2 for selection of the flow index is needed. Since Table 2 has been prepared from the data shown in Figure 4, it is possible to use the following relations for determining the proper flow index with more precision:

$$I_f = 0.36 Wn - 3$$

When the above relationship is used, the deviation of flow index will be reduced from 2.5 to 1.

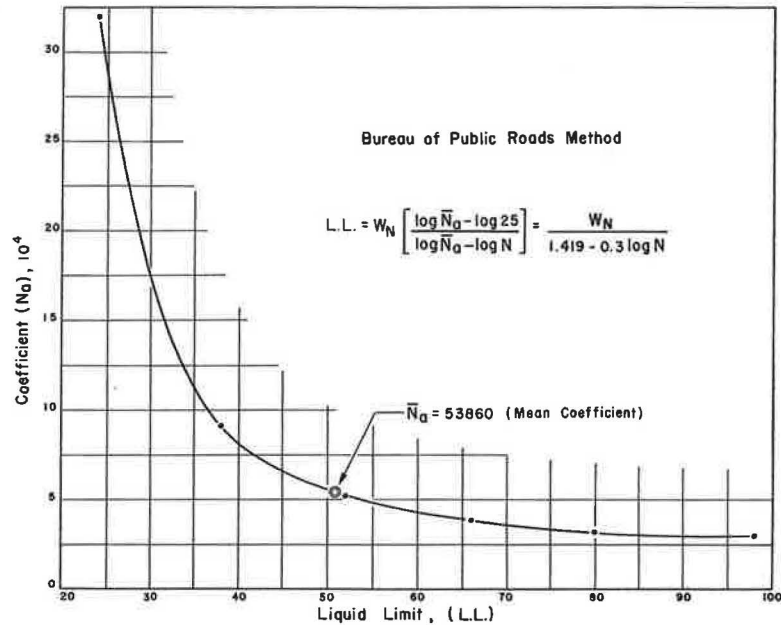


Figure 5. Coefficient (N_a) vs. liquid limit.

Using the published data from the Washington State Highway Department (3) for the evaluation of the Bureau of Public Roads Method, a relationship between coefficient (N_a) and liquid limit was found (shown in Figure 5). It is indicated that the coefficient (N_a) is very sensitive when the liquid limit is small (say lower than 35 or 40). On the other hand, when the liquid limit is larger than 40, the coefficient (N_a) has little effect. Therefore, the use of coefficient (N_a) as a measurement for the liquid limit is limited.

Since the mean coefficient (shown in Figure 5 $\bar{N}_a = 53860$) is used in the Bureau of Public Roads method, the deviation from mean to the true coefficient will be markedly increased when the liquid limit is below 40. Many of the embankment soils used in highway construction and maintenance are classified as A-4 and A-6, with a maximum liquid limit of 40. For these reasons, from a practical point of view, the writer believed that the AASHO Road Test method is an improvement over previously used methods.