THE INFLUENCE OF CUP FRICTION AND GRADING ON THE LIQUID LIMITS OF SOME GHANAIAN SOILS

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ABRIDGMENT

•THE history of the development of soil consistency limit tests from the pioneering work of the Swedish soil scientist, Atterberg, in 1911 to the present stage has been well documented (1, 15). Starting in the late 1920s, extensive research in America on the consistency limits (4, 5, 7) culminated in the standardization of the method of determining the liquid limit and the evolution of soil identification and classification systems based on these limits and particle size distribution of the soil.

The basic condition for the validity of these classification systems is that both the particle size distribution test and the Atterberg limit tests should yield reproducible results using standard testing procedures. Most temperate-zone soils and some laterites meet this condition and can therefore be reliably classified using existing standard procedures. These procedures, however, appear to break down when they are applied to the identification and classification of the so-called troublesome soils that do not yield reproducible results of particle size distribution and Atterberg limits. This group of soils includes micaceous soils (14, 23) and silty or sandy soils of low plasticity (24). The main difficulty with the Atterberg limit tests appears to be the tendency of these soils to either slip in the liquid limit cup or liquefy with shock during the test, thus giving inconsistent results. The difficulties experienced in attempting to classify these "troublesome" soils using standard testing procedures call for a reexamination of the validity of these standard testing procedures when applied to these soils.

ENGINEERING SIGNIFICANCE OF THE ATTERBERG LIMITS

Notwithstanding their essentially empirical and arbitrary origin, the Atterberg limits rapidly assumed increasing importance with the establishment of useful empirical and semi-empirical correlations between them and other more fundamental soil properties. Some of these correlations are between the Atterberg limits and such soil properties as the consolidation characteristics of remolded clays (20), percentage of clay content (17, 19), cone penetration resistance (24), soil moisture tension (16), California bearing ratio (2), swell potential of expansive soils (25), and shear strength.

The considerable research effort directed toward a study of the soil consistency limits has highlighted some serious shortcomings of the present method of determining the liquid limit and has led to attempts to replace the use of the Casagrande liquid limit device with more "reliable" techniques. Some of the methods proposed in the literature are the use of cone penetrometers (9, 24), laboratory vane tests (6), and the measurement of soil moisture tension (16). In spite of the fact that most of these methods have been claimed to be superior to the conventional Casagrande device, none, with perhaps the exception of the cone penetrometer test, has found universal acceptance to date. It is reasonable to suppose, therefore, that the conventional Casagrande device will continue to be used for a long time to come. This paper proposes a possible modification to the conventional device to overcome one of its main drawbacks, namely the inability of the present device to give reproducible results in micaceous and silty soils of low plasticity.

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LIMITATIONS OF THE CONVENTIONAL LIQUID LIMIT TEST

Various investigators have discussed in detail the main limitations of the conventional liquid limit device in relation to the design of the apparatus and its accessories (5, 8, 13), operator errors (11, 18), and soil type, particularly the difficulty of obtaining reproducible results of the liquid limits of micaceous soils and silty and sandy soils of low plasticity (24). For example, Tubey and Bulman (23) reported that consistency limit tests on a sample of a Ghanaian micaceous soil yielded liquid limits ranging from 54 to 65 percent and plastic limits varying from 43 to 36 percent, resulting in a range of plasticity indices from 11 to 29 percent. Ruddock (14), who also experienced considerable difficulty in obtaining meaningful consistency limit values on similar soils, appeared to have reached the same conclusion as Tubey and Bulman (23) and Newill (12) that linear shrinkage probably provided a more reliable basis for the classification of these soils.

In order to obtain consistent liquid limit results on these "troublesome" soils it has been suggested that the roughness of the inside of the cup also be standardized (5, 22). However, as far as the authors are aware, no attempt has been made to evaluate the influence of the roughness of the inside of the cup on liquid limit values. The present study investigates this influence.

THE SHEAR STRENGTH OF A SOIL AT THE LIQUID LIMIT

Probably because of the realization that the mechanized liquid limit test is essentially a dynamic shear test (5) and because of the desire, therefore, to substitute more reliable shear tests for the determination of the liquid limit, the shear strength aspects of the Atterberg limits have received considerable attention from researchers (5, 6, 9, 13, 21, 24).

The value of the undrained shear strength of a soil at the liquid limit reported in the literature varies between 0.1 psi (0.68 kPa) and 0.52 psi (3.58 kPa). Various factors may account for this relatively wide range of variation in shear strength, but perhaps the main factor is the difficulty associated with the measurement of low values of shear strength. Most laboratories use the miniature laboratory vane apparatus for this purpose, but it has been established that the value of the undrained shear strength obtained is influenced by the size of sample and the size of vane (6), the accuracy with which the failure torque can be measured, and the assumptions made regarding the distribution of shear stresses across the ends of the vane.

It is therefore fair to conclude that, while the shear strength of a soil at the liquid limit may fall within a small but measurable range of values, such a range would have to be established for a given situation. The first part of this study therefore concerned the establishment of such a range of shear strength values for some typical plastic Ghanaian clays.

SOIL TYPES INVESTIGATED

Two groups of soils were tested. The first group was composed of plastic clays of sedimentary or residual origin. These soils do not slip in the liquid limit cup and therefore give fairly reproducible results. The second group of soils included the residual soils derived from the chemical decomposition of local rocks, particularly granites. Most of these residual soils, which are micaceous, sandy, or silty clays of low plasticity, occur extensively in Ghana. Typical particle size distribution curves for both groups of soils are shown in Figure 1.

LIQUIDITY INDEX-UNDRAINED SHEAR STRENGTH RELATIONSHIP FOR SOME GHANAIAN CLAYS

The soils selected for this study were plastic clays of the type that would not normally slip in the liquid limit cup. The investigation involved the measurement of the undrained shear strength of these soils over a wide range of consistencies, using a motorized laboratory vane apparatus with a $\frac{1}{2}$-in. diameter vane.

The Atterberg limits of these soils were also determined according to methods stipulated in the relevant British Standards (3), thus enabling graphs of undrained shear strength to be plotted against liquidity index for these soils (Fig. 2). It can be seen from this figure that the undrained shear strengths corresponding to a liquidity index of unity (i.e., the liquid limit) ranged from 0.15 lb/in.^{2} to 0.25 lb/in.^{2} (1.03 to 1.72 kPa). This range of undrained shear strength values has therefore been accepted as defining the "true" liquid limit for local soils.

THE REPRODUCIBILITY OF THE ATTERBERG LIMITS

In a comparative study of this nature, likely to involve the performance of numerous Atterberg limit tests by various operators extending over a long period, it was considered essential that the inherent range of variability in the Atterberg limits be established for the set of operators used. Liquid and plastic limit determinations were made on two soil types by a set of fairly experienced operators. Based on a statistical analysis of the results using the method of variance, it was concluded that, while there were significant differences between operators even at the 5 percent level, for a given operator there were no significant differences between trials even at the 1 percent level. It was further concluded that for a confidence limit of 95 percent the set of operators used in this study could reproduce both the liquid and plastic limits to an accuracy of ±2 percent. Similar conclusions have been reached by other research workers on the basis of more detailed studies (11, 18). As a result of these findings, steps were taken to ensure that during the study the same operator performed all the tests on a particular sample and that the same liquid limit device was used in performing a set of tests.

INFLUENCE OF ROUGHNESS OF THE INSIDE OF THE CUP ON THE LIQUID LIMIT

In order to study the influence of the roughness of the inside of the cup on the liquid limits of soils, the insides of various liquid limit cups were roughened with portions of washed beach sand retained on B.S. sieve Nos. 14, 18, 36, 60, 100, 150, 200, and 240. The roughening was done by applying a thin film of araldite to the inside of the cup prior to sprinkling the sand lightly to cover the whole of the inside of the cup with the exception of the central part, which was kept clear to facilitate easier cutting of the groove. This was achieved by pasting a ⅛-in. wide strip of paper along the center of the cup before sprinkling the sand. The cups were then cured in the oven for 24 hours at a temperature of 105 C. The roughening produced by this technique was effective enough to be used for a long time without the sand particles mixing with the soil being tested. It was only necessary to wash the inside of the cup under running water and mop it dry after each blow-count.

The liquid limits of six soils were determined using the eight roughened cups in addition to the standard smooth cup. The soils tested included three plastic clays and three micaceous soils. The liquid limit values were plotted against the nominal size of roughening taken as the aperture of the sieve on which the roughening sand was retained (Fig. 3). It may be seen from this figure that, while the liquid limits of the plastic clays appeared to be unaffected by the size of roughening, those of the micaceous soils generally increased with increasing size of roughening up to a nominal size of roughening of 0.015 in. (0.38 mm), after which they remained essentially constant.

It would appear, therefore, that the minimum size of roughening that would eliminate the tendency of these micaceous soils to slip in the liquid limit cup is of the order of 0.015 in. (0.38 mm), which is close to the aperture of the No. 36 B.S. sieve, 0.0166 in. (0.4216 mm). The cup roughened with sand retained on the No. 36 B.S. sieve was therefore adopted as the standard rough cup in the subsequent study.

THE "TRUE" LIQUID LIMIT OF A SILTY OR MICACEOUS SOIL

Liquid limits of selected plastic clays and silty and micaceous soils were determined using both the conventional liquid limit cup and the roughened cup. Plastic limits were also determined for these soils as well as their undrained shear strengths, which

Figure 1. Typical particle size distribution of (a) plastic clays and (b) micaceous and silty soils.

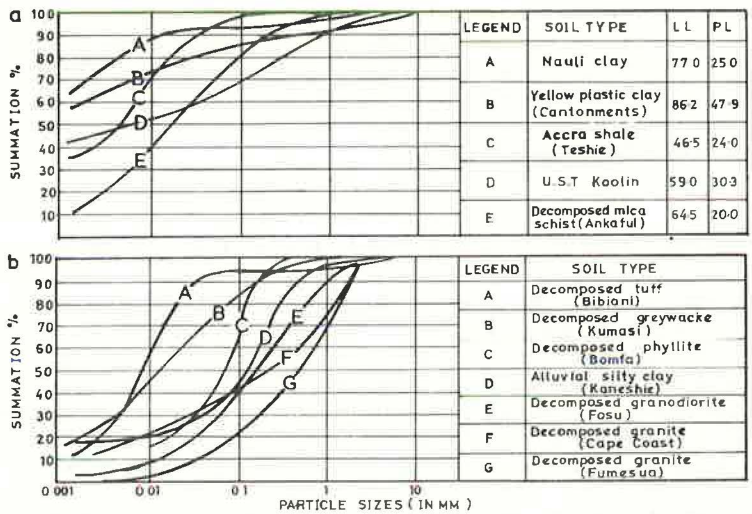


Figure 2. Liquidity in index-undrained shear strength relationship for some plastic Ghanaian clays.

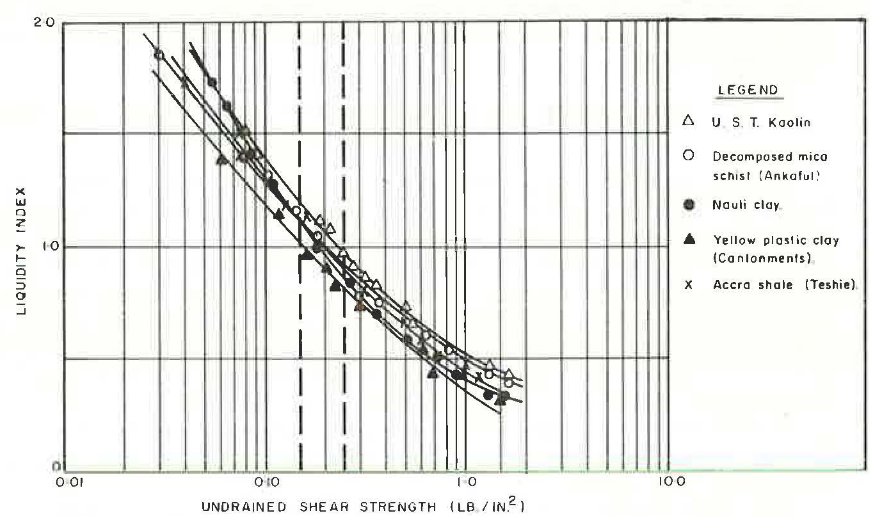
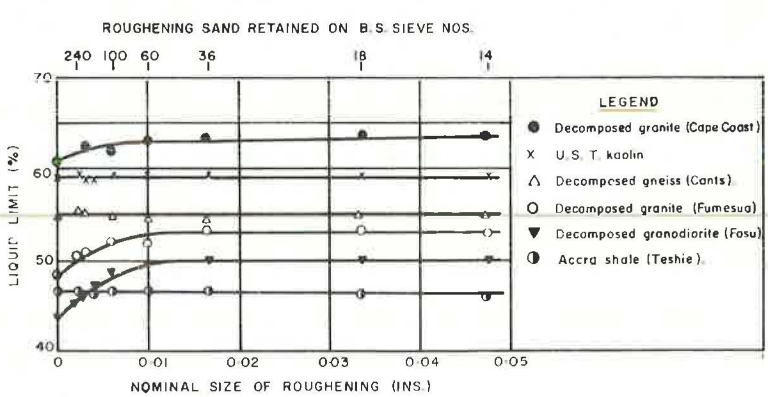


Figure 3. Effect of the nominal size of roughening of cup on the liquid limit.



were measured at various consistencies. Typical curves of liquidity index versus undrained shear strength for six of the "troublesome" soils and two plastic clays are given in Figure 4. It is clear from Figures 4a to 4f that for the silty and micaceous soils the liquidity index-undrained shear strength relationships based on the roughened cup liquid limits gave values of undrained shear strength within the range 0.15 psi to 0.25 psi (1.03 to 1.72 kPa) at the liquid index of unity and that the curves based on standard cup liquid limits gave shear strength values outside this range.

For the plastic clays (Figs. 4g and 4h) both curves lie within the established range of shear strength at the liquidity index of unity. In general, the liquid limits obtained using the roughened cup were higher than those obtained from the conventional cup, the percentage increases in liquid limit varying between 3.7 and 80 percent for the 12 micaceous and silty clays tested.

This tends to indicate that the use of the roughened cup instead of the standard cup would only alter the liquid limits of soils that give "erroneous" results with the standard cup and would not substantially affect the liquid limits of soils that do not slip in the standard cup. Unpublished results of tests currently in progress show that, for the silty and micaceous soils, liquid limits determined using cone penetrometers also correlate fairly well with those determined using the roughened cup.

INFLUENCE OF MAXIMUM PARTICLE SIZE ON THE LIQUID AND PLASTIC LIMITS

Current standards stipulate that the Atterberg limits be determined on the portion of the soil finer than No. 40 sieve in American practice and No. 36 sieve in British practice. The reasoning behind the choice of these sieve sizes as the upper limit of particle sizes for the consistency limit tests is not clear. Lambe (10), for example, questioned the choice and suggested that it would appear more logical to run the Atterberg limit tests on portions of the soil finer than No. 140 or No. 200 U.S. standard sieves.

In order to investigate the possibility that the use of the portion of soil with a smaller maximum particle size may eliminate flaky mica particles and reduce the possibility of these micaceous soils slipping in the conventional cup, it was decided to study the influence of maximum particle size on the liquid and plastic limits of soils. The liquid and plastic limits of soils passing B.S. sieve numbers 14, 18, 25, 36, 60, 100, 150, and 200 were determined using the conventional liquid limit device. The soils investigated included both plastic clays and micaceous and silty soils.

It was found that there were only slight increases in the liquid and plastic limits of the portions of the soils passing B.S. sieve No. 14 and retained on B.S. sieve No. 60. The liquid and plastic limits of the portions finer than the No. 60 B.S. sieve, however, increased sharply with decreasing maximum particle size. Figure 5 shows that the relationship between the plasticity indices (PI) and the maximum particle size is of a similar form.

While it is recognized that the difference between the plasticity indices of the portions of soil passing the No. 36 and No. 60 B.S. sieves may be negligible, it is suggested that the No. 60 B.S. sieve, which appears to represent the maximum particle size beyond which there is a rapid increase in plasticity, be adopted as the lower limit of particle size for the determination of the liquid and plastic limits.

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Figure 4. Effect of roughening of cup on the liquidity index-undrained shear strength relationship.

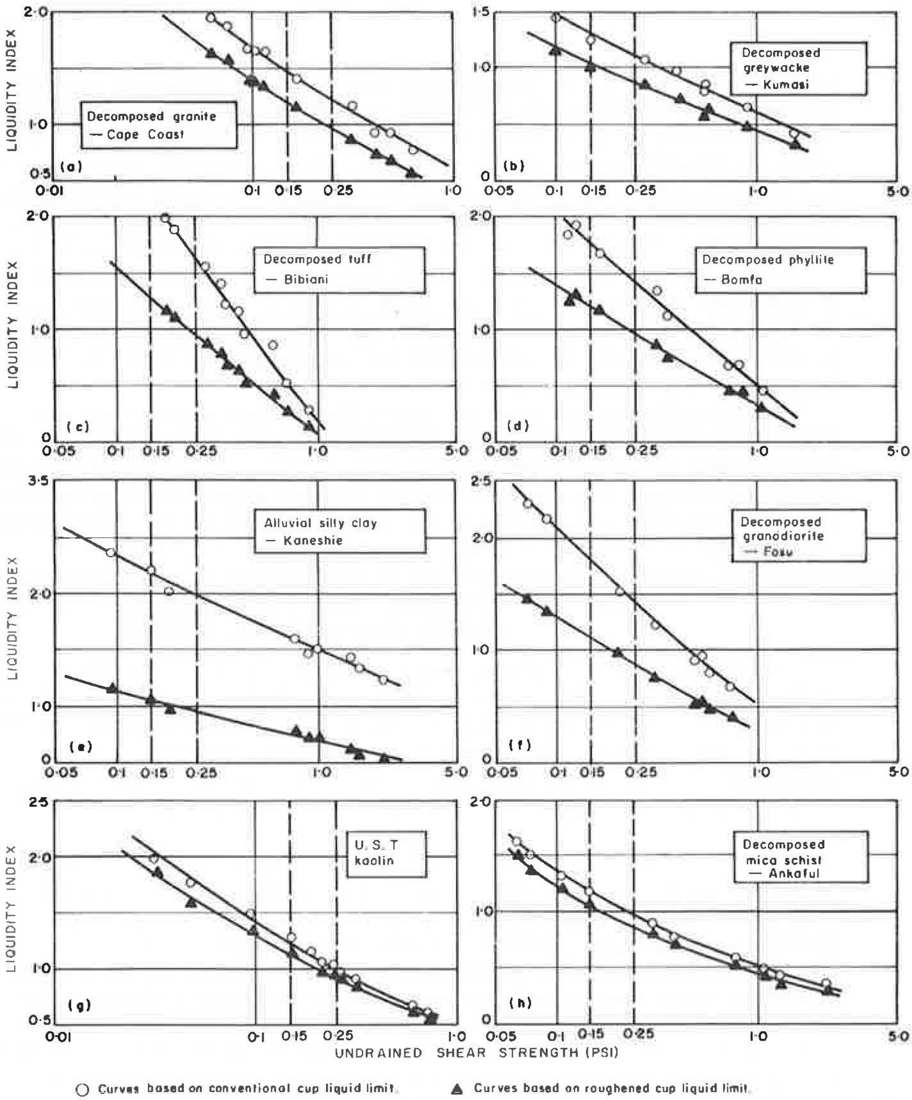
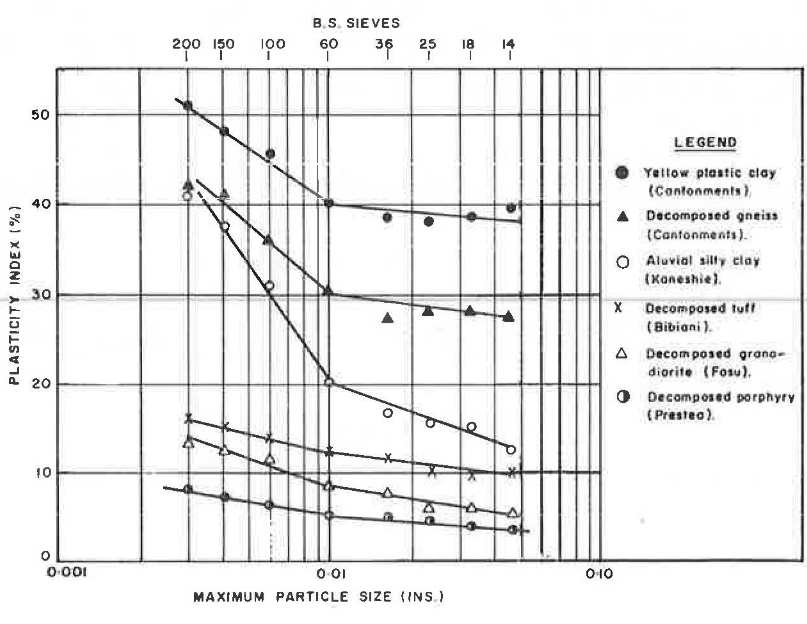


Figure 5. Influence of maximum particle size on the plasticity index.



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