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Determination of Liquid Limit by the Static Cone Penetration Test

Mesure de la limite de liquidité par pénétration statique d'un cone

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Summary

Owing to the fact that the conventional liquid limit device is based on a dynamic shear test, and the difficulty of standardizing this device, which is essential in order to obtain accurate results, Professor Casagrande has suggested the use of an indirect shear test for determining liquid limit.

The author gives the results of such an attempt. The device used in this investigation is a static 90 degree cone penetration apparatus, which measures the equilibrium pressures of a soil at various moisture contents. The liquid limit is derived from this relationship.

The author describes the basic concepts of this method, the apparatus and the test procedure, commenting on the results and comparing this method with the conventional one.

Introduction

Atterberg limits define those moisture contents which designate the transition between the fluid and plastic stage and between the plastic and semi-solid stage respectively. The main objective governing the design of any arbitrarily selected device for measuring these limits is to eliminate human influence and to guarantee accurate duplication of results when tests are repeated.

The conventional liquid limit device is essentially a dynamic shear testing equipment. In the conclusion to his article Professor A. CASAGRANDE (1958) calls this a "disadvantage because it does not provide a uniform basis of comparison for fine grained soils which differ in their reaction when subjected to a shaking (dilatancy) test", and mentions among other possibilities the static penetration test as one way to eliminate some difficulties of the present liquid limit device.

This investigation is an attempt to overcome this problem. The 90° cone penetration device used is essentially that used in the Soil Mechanics Laboratory of the Swiss Federal Institute of Technology, Zurich (HAEFELI, 1951). Similar devices are being used in Sweden and Norway. In these countries they are employed to determine the sensitivity of clay, that is — as the apparatus measures shear strength — the ratio of the strength after remoulding the sample to the undisturbed strength. In Switzerland it has also been used for (consolidation) stress analyses (HAEFELI, 1957).

In Russia and some other satellite countries, a different type of cone device is commonly used for liquid limit determination (LITVINOV, 1954). In a number of details however, their system differs from the procedure used by the author.

An improved device, also for liquid limit determination, is referred to by STEFANOFF (1957) in a paper to the last Soil Mechanics Conference.

Sommaire

Du fait que l'appareil à limite de liquidité conventionnel, est basé sur un test dynamique de cisaillement et à cause des difficultés que pose une standardisation suffisante de l'appareil, ce qui est essentiel pour la comparaison des résultats, le Professeur Arthur Casagrande mentionne dans son article (1958) la possibilité d'un essai indirect de cisaillement pour la détermination de la limite de liquidité.

Cette étude présente les résultats d'un tel essai. L'appareil utilisé qui est un appareil de pénétration statique muni d'un cone dont l'angle est de 90°, mesure les pressions d'équilibre d'un sol à teneur en eau variable. On en déduit la limite de liquidité.

L'étude comprend la description des principes de cette méthode, l'appareil et la manière de réaliser l'essai ; elle commente les résultats et compare cette méthode avec la méthode conventionnelle.

Basic concepts of the method

The device (Figs. 1 and 2) consists of a cone with an angle of exactly 90°, which is gradually loaded from zero to one kilogram in one minute. The final load remains constant at this value. As the cone penetrates a smooth surface, its movement is measured by a dial gauge.

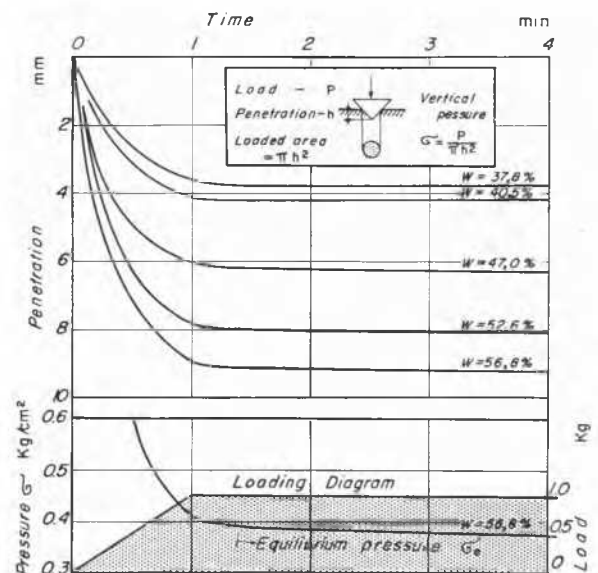


Fig. 1 Cone penetration, loading diagram and cone pressure as a function of time.

Pénétration au cone, diagramme de charge et pression du cone en fonction du temps.

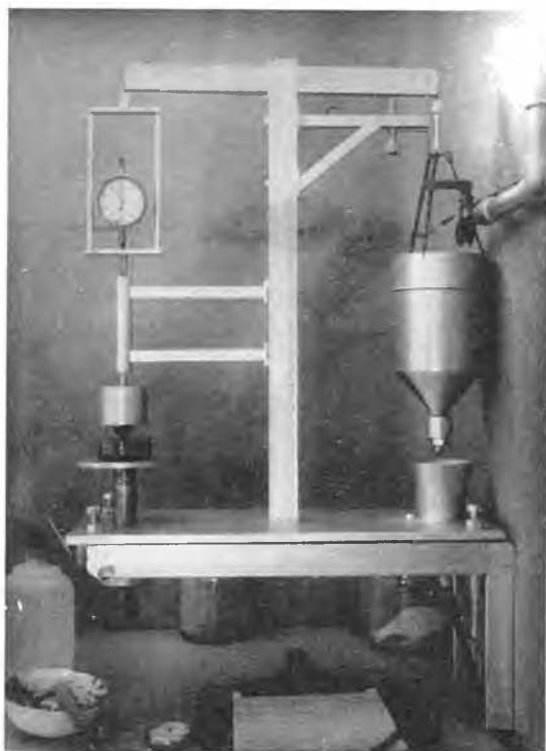


Fig. 2 Cone penetration device used by the author.
Appareil de pénétration à cône utilisé par l'auteur.

The deeper the cone penetrates into the soil, the larger becomes the loaded area and the lower the specific pressure (see Fig. 1). This specific pressure decreases until the soil is capable of supporting the load so that an equilibrium pressure is reached.

Unlike other types of penetration tests, it does not measure the resistance to plastic flow of the soil, but the equilibrium pressure, which is directly proportional to the shear strength of the material. The final stress conditions around the cone might be compared to those beneath a circular footing on clay, where the bearing capacity is a linear function of the cohesion.

As the shear strength of a saturated clay depends directly on the water content, so does the equilibrium pressure. Fig. 1 shows the penetration at various moisture contents of the same remoulded material. For convenience, the relationship between equilibrium pressure and moisture content is plotted on a semi-logarithmic paper, showing a well defined straight line for every material (see Fig. 3). The moisture content corresponding to a definite equilibrium pressure may be regarded as the liquid limit.

Symbols:

- σ_e denotes equilibrium pressure of a remoulded fine-grained material at any moisture content.
 σ_{ew} — equilibrium pressure of a remoulded sample at its natural moisture content.
 σ'_{ew} — equilibrium pressure of an undisturbed sample.
 $\frac{\sigma_{ew}}{\sigma'_{ew}} = \lambda$ — sensitivity of clay, ratio of shear strength after and before remoulding.
 L_c — liquid limit by the cone device
 P_c — plastic limit —
 P_{Ic} — plasticity index —
 I_c — cone-index, difference of moisture contents

corresponding to $\sigma_e = 1$ and 10 kg/cm^2 respectively.
 equilibrium pressure of a consolidated sample, initially remoulded and placed at the liquid limit.

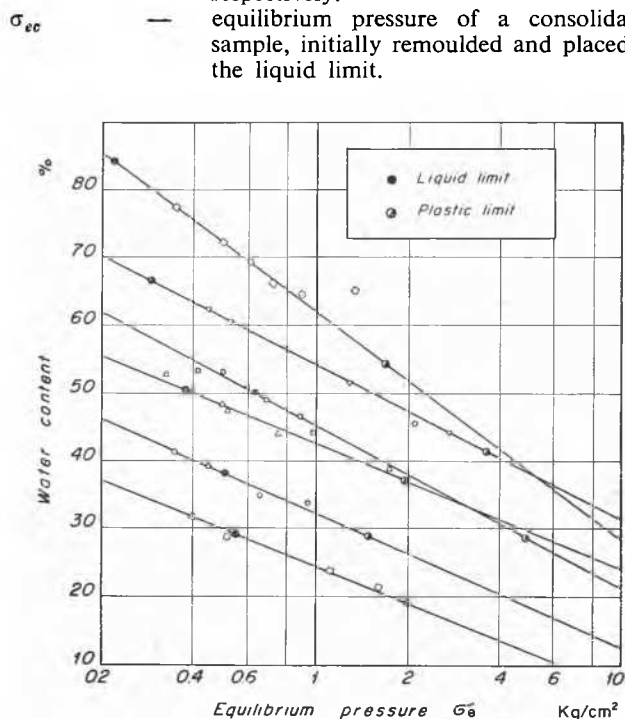


Fig. 3 Relationship between moisture content and equilibrium pressure (final cone pressure).

Relation entre teneur en eau et pression d'équilibre (pression finale du cône).

Apparatus and test procedure

The apparatus consists basically of a balance (see Fig. 2). The cone and pressure dial are perfectly balanced against a container. For the test, a weight of 1 kg is placed on the cone, which is initially counterbalanced by water (ca. 1.07 kg) in the container. Micrometer screws, one raising the right hand lever arm, the other one raising the sample-disc (lower left, Fig. 2), permit perfect setting of the dial to zero and the sample surface to the tip of the cone.

A rubber stopper, raised by a string, releases the water to drain in one minute (after the first 70 gr). Only the 2-minute penetration reading is normally noted. It is an advantage to repeat the same test two or three times on the same surface. The average penetration is calculated and unsuitable values eliminated. The moisture content of the sample is determined.

This set-up guarantees a completely jerk — and impulse — free application of the load. The procedure is almost independent of human influence, involving only the setting of the tip of the cone to the sample surface. The system has to be friction free (knife edge bearing for upper bar, container and core-rod suspended on thin tape developing a circle with knife-edge as centre, cone rod perfectly plumbed to reduce friction on its guide etc.).

Results and commentary

Fig. 3 shows the relationship between moisture content and equilibrium pressure for six different materials. The moisture content corresponding to the liquid limit by the conventional device is indicated by a solid point on the lines. So is the plastic limit by a black and white circle.

Observing the physical stage of the materials for instance, any "liquid limit line" could be established, which — inter-

sected with the material lines — would give the cone liquid limit. However, in order to adhere as closely as possible to the accustomed limits, the limit line has been calibrated according to the conventional device. Fig. 4 shows this cali-

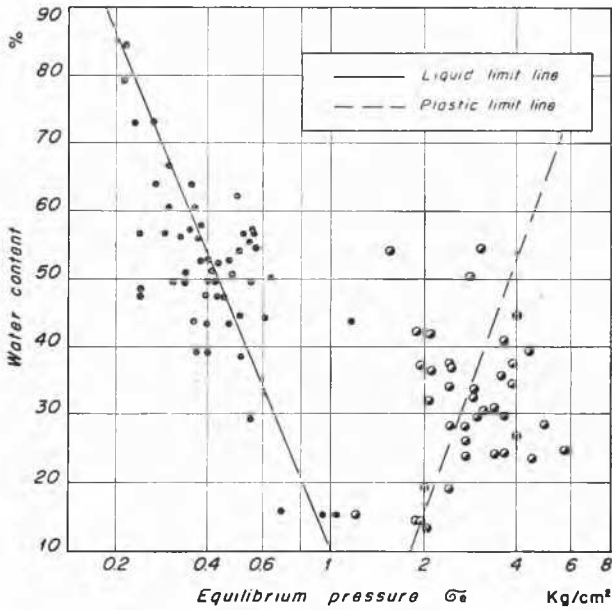


Fig. 4 Determination of the liquid and plastic limit lines according to conventional procedure.
 Determination des lignes de limites de liquidité et de plasticité correspondant à la méthode conventionnelle.

bration, that is all the points corresponding to the conventional liquid limit and plastic limit respectively.

In order to determine the liquid limit by cone, it is necessary to prepare a remoulded sample with at least four different moisture contents. The equilibrium pressures should preferably be less than 1 kg per sq. cm for limits above 50 per cent and less than 2 kg per sq. cm for limits below 50 per cent. The plot of these equilibrium pressures against moisture content on a semi-logarithmic paper should give a straight line. This line, intersected by the liquid and plastic limit line, gives the limits determined by cone penetration.

In 50 per cent of the tested samples, the liquid limit by cone was within 1.8 per cent (w/c) of the conventional liquid limit and in 10 per cent of the tests the difference was more than 6 per cent (w/c). These variations are probably explained by the different principles of the test, that is dynamic versus static shear test. Most of the tested soils are decomposed rocks.

The calibration of a "plastic limit line" seems at first more questionable. However, in 50 per cent of the tests the plastic limit by cone was within 2.1 per cent (w/c) of the conventional method. One disadvantage of the cone for the determination of the plastic limit is, that it operates at a consistency range quite different from the plastic limit. The necessary extrapolation implies sources of inaccuracy.

Fig. 5 shows some repetitions of tests. Some of the samples had been air-dried. The coincidence of the material-lines are satisfactory. The same Fig. also shows two examples where the tests had been carried out with a load of 1/2 kg as well. Although it should theoretically have no bearing on the relation of equilibrium pressure and moisture content, one material reveals quite a different line. Therefore it is preferably to fix the load at 1 kg.

The time required for preparation of a sample and for its testing is about the same as for the conventional device.

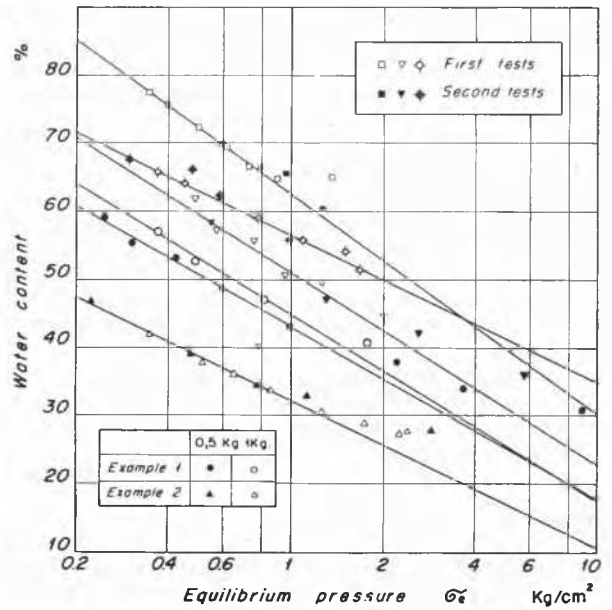


Fig. 5 Some examples of test repetitions and of using half the cone load.
 Quelques exemples de répétition des essais et de l'application de la moitié de la charge sur le cône.

Should it be acceptable to deduce the plastic limit from the same test, there should be some saving of time.

The costs of the two devices are about equal. However, construction specifications are far simpler for the cone-apparatus. Difficulties in reproducing the correct hardness of the base, the correct dimensions and weight of the cup are eliminated. On the other hand, the cone apparatus requires a more complicated installation, particularly for the water. The cone device is also considered to be less dependent on human influence. The most important feature however is that it represents an indirect static shear test.

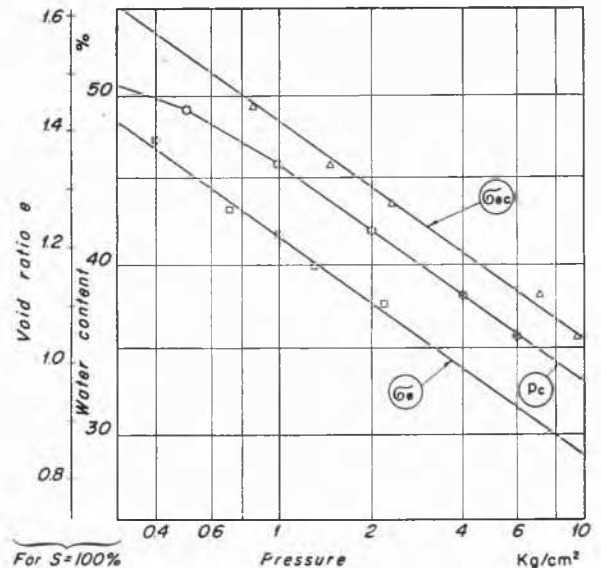


Fig. 6 Consolidation curve, equilibrium pressure curves after consolidation and after remoulding of sample and their relationship.
 Courbes de consolidation, de pression d'équilibre après la consolidation et après le remaniement de l'échantillon et relation entre elles.

The cone apparatus furnishes other valuable information. The inclination of the material line, a characteristic similar to the flow index, can be expressed as difference of moisture content at equilibrium pressures corresponding to one logarithmic cycle, and can be called the "cone index" (I_c).

Fig. 6 illustrates the consolidation curve (p_c) of a remoulded clay. After consolidation, the cone penetration tests reveal equilibrium pressures (σ_{ec}) proportionally larger, the factor being 1.55. Other materials so far tested showed factors ranging from 1 to 2. After remoulding the clay, the equilibrium pressure decreases to the standard σ_e -curve. In some cases, the inclination of the σ_e -line is steeper than the σ_{ec} -line. Thus, the "cone index" can give some indications on the compressibility of a clay.

The cone penetration test can give some indications on shear strength of a fine grained soil, and = as mentioned in the introduction — is used for measuring the sensitivity of clay and for stress analyses.

Conclusion

The first results of this investigation on determination of liquid limit by a static cone penetration test are promising. Some differences between this limit and the conventional

one are to be expected. It remains to be seen how far these liquid limit tests with the cone apparatus are correlated with other soil properties.

Acknowledgement

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