Torsional Field Shear Tests

Essais de chantier de cisaillement en torsion

K. V. HELENELUND, *Professor, Institute of Technology, Helsinki, Finland*

SUMMARY

A description is given of simple field equipment intended for *in-situ* determination of the shear strength of frictional soils. In principle, the tests involved are concerned with torsional shear, and are carried out at the proposed foundation level in an excavated pit, or at different levels in a sheeted bore hole. The normal stress on the horizontal or spherical surface of rupture is applied by means of weights, or by air pressure, and the shear stress is determined by measurement of the torsional moment in the same manner as is employed in a vane test (Fig. 1). If a number of tests are made with different normal stresses in the same soil layer, it is possible to arrive at the cohesion and angle of friction of the soil. The employment of permeable filters enables performance of the test as a uu- or cu-test.

The results of a series of torsional field shear tests are reported. A comparison drawn between the field shear-strength values and the corresponding values found in ordinary laboratory shear box tests shows that the field strength of glacial till is generally greater than the strength determined by means of laboratory tests (Fig. 3). In conclusion, some shear vane modifications are described; these facilitate the performance of *in-situ* shear tests at greater depths (Figs. 5 and 6).

SOMMAIRE

On décrit un simple équipement destiné à la détermination *in situ* de la résistance au cisaillement des sols à friction. Les essais sont en principe des essais de cisaillement en torsion executés au niveau de la fondation projetée dans un puits creusé ou à différentes profondeurs dans un trou perforé chemisé. L'effort normal est appliqué sur la surface horizontale ou sphérique de rupture à l'aide de poids ou à l'aide d'air comprimé et la résistance au cisaillement est déterminée en mesurant le moment de torsion de même façon que dans les essais effectués avec l'appareil à palettes (fig. 1). En exécutant une série d'essais avec des charges normales différentes dans la même couche de sol, on peut déterminer la cohésion et l'angle de friction de ce sol. L'essai peut être fait comme un essai "uu" ou "cu" en utilisant un filtre perméable.

On expose les résultats d'une série d'essais de cisaillement en torsion sur le terrain. Une comparaison des valeurs de la résistance au cisaillement en place avec les valeurs correspondantes des essais ordinaires de laboratoire avec la boîte de cisaillement montre que la résistance *in situ* des moraines glaciares en général est supérieure à celle determinée à l'aide des essais de laboratoire (fig. 3). Finalement, on décrit quelques modifications apportées à l'appareil à palettes, pour faciliter l'exécution des essais *in situ* à de plus grandes profondeurs (figs. 5 et 6).

IN AN INVESTIGATION of the bearing capacity of glacial till deposits, it became necessary to determine the shearing strength of the soil *in situ*, as extreme difficulty was associated with obtaining undisturbed samples for laboratory studies. The simplest solution seemed to be that of constructing a ring shear device, by means of which the shear strength could be determined in a small test pit or borehole, using ordinary sounding weights and rods (Fig. 1). The soundings were made by application of the Swedish weight-sounding method.) A number of types of sounding boxes were constructed (Fig. 2); these were pressed down into the soil, a part of the soil mass outside the shear box was removed, the soil given an even surface and loaded with weights, and then subjected to a shearing stress and sheared by a torsional moment of which the maximum value was measured. In this way, it was possible by making three tests or more with different loads to determine the shearing resistance of the soil as a function of the normal stress on the surface of rupture under the shear box. Apart from the peak value, it is also feasible to measure the shear strength after remoulding, and thus arrive at an expression for the sensitivity of the soil to disturbance. Observation of the shear stress at different angles of rotation enables the construction of the whole stress-strain curve, and the calculation of the modulus of shear deformation of the soil.

Field shear box tests have been reported by a number of authors (Hutchinson and Rolfsen, 1962). One especial advantage of such a test is the possibility of determining real strength values in highly sensitive soils, along with the carrying out of large-scale shear box tests: for example, 1.8 × 1.8 sq. m. has been mentioned (Sowers and Gore, 1961). The principles of the ring shear apparatus introduced by Hvorslev (1936) have been applied by Söhne and Sonnen (1961) in a highly mechanized field shear test; in this instance, the apparatus was mounted on a tractor. For rapid shear tests, and for minor stresses, manual rotation can be employed as in an ordinary vane test. In this way, a simple torsional field shear apparatus is acquired; this can be employed for a shear test at different depths in a test pit or borehole. In a larger pit, or foundation excavation, a number of shear rings can be loaded with different weights at the same time, thus facilitating the performance of a series of consolidated-undrained tests (cu-tests) with a minimum of delay.

TEST RESULTS

Fig. 3 illustrates the results of some torsional field shear tests made on silty glacial till (grain size $D_{50} = 0.04$ mm, uniformity coefficient $D_{60}/D_{10} = 27$, natural water content $w = 8.4$ per cent, dry density $\gamma_d = 2.06$ kg/cu.dm.). The tests were carried out in an excavation 5 m deep, made for a new motor road west of Helsinki. T 1 denotes tests with a shear ring of the type indicated in Fig. 2a, with an external diameter of 12.4 cm, T 2 tests with a similar but larger shear ring (diameter 14.9 cm). T 3 refers to tests with three square shear boxes of the type shown in Fig. 2b, but with a shorter distance to the axis of rotation. The results of the field shear tests have been compared with ordinary shear box tests carried out on undisturbed soil samples in the laboratory. The laboratory tests were made as cu-tests, with soil samples 6 × 6 × 4 cm (the volume of the field shear boxes in Fig. 2b is 6 × 6 × 2.5 cm), and with controlled strain. Fig. 3 shows that there is an appreciable scattering between the results of the different tests. However, as a rule, the field tests provide slightly greater shear-strength values than do the laboratory tests. Probably, this is attributable to the great difficulty experienced in getting really undisturbed samples from a hard till deposit, and accordingly the laboratory shear box samples may be somewhat disturbed—even though the samples, as in this case, may be taken with the greatest possible care. For the same reason, triaxial tests on small samples resulted in such excessive scattering that the findings are unreliable.

Similar tests have been made with sandy till, sandy silt, and overconsolidated clay (Anttikoski, 1964). Field shear tests with the T 1 shear ring furnish values which are in general of the same order, or a little higher, than those arrived at in the laboratory shear box test. The T 3 shear

FIG. 1. Torsional field shear test, and detail of shear ring.

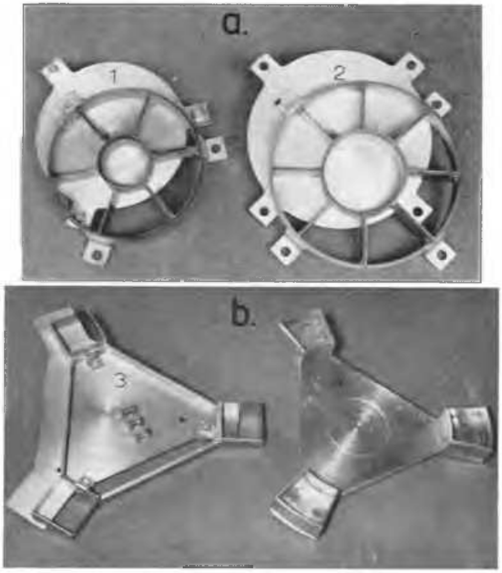

FIG. 2. Shear rings and shear boxes of different types.

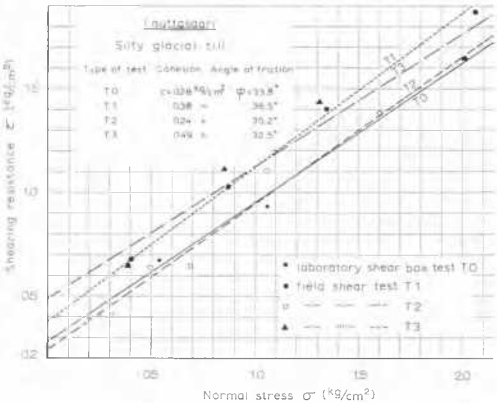

FIG. 3. Test results from field and laboratory shear tests on glacial till.

device frequently gives greater shear strength and greater scattering than do the ring shear tests.

Fig. 4 illustrates some typical stress-strain curves obtained in field and laboratory shear tests on sandy silt (grain size D_{50} = 0.05 mm, uniformity coefficient D_{60}/D_{10} = 3.1, natural water content w = 14 per cent, dry density γ_d = 1.70 kg/cu.dm.) at a normal stress of 1.0 kg/sq.cm. For torsional shear, the strain has been determined as movement of the centre of gravity of each separate shear box, or shear ring section. As can be seen from the figure, the peak values arrived at from different stress-strain curves are quite close one to the other, whereas the ultimate shearing resistance is

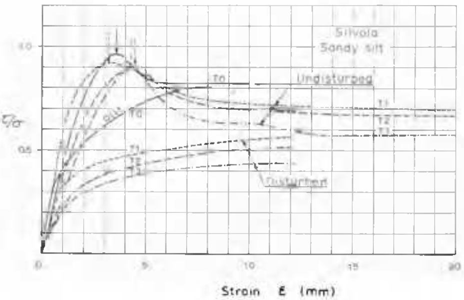

FIG. 4. Stress-strain curves obtained from torsional field shear tests (T 1, T 2, and T 3) and laboratory shear box tests (T 0) on sandy silt.

less for the field tests than for the laboratory tests. One advantage of the torsional shear test is that the shearing resistance can be determined with respect to very large strains.

The contact pressure against a rigid plate is not evenly distributed, but is generally concentrated at the edges of the plate. To ensure a more uniform pressure distribution, a rubber diaphragm is introduced between the circular loading plate and the soil surface. When cu-tests are being made, a flexible permeable filter is placed between rubber and soil.

The maximum load imposed on the shear rings has been 200 kg, corresponding to a normal stress of 2 kg/sq.cm. on the horizontal failure plane of the smaller shear ring, and 1.5 kg/sq.cm. on the larger one. In cases where a greater normal stress has been required, two or more symmetrically situated ring sections have been completely emptied of soil, with the result that the pressure on the remaining sections has been increased.

SUGGESTED IMPROVEMENTS

The torsional shear tests indicate that shear rings with a horizontal rupture surface furnish reliable results, provided the tests can be effected at the ground surface, or in an excavation or test pit where the mass of soil surrounding—and inside—the ring can be carefully removed. However, shear rings are not so practical for use if the tests have to be made in a narrow borehole deep in the ground. In this event, shear vanes of the types illustrated in Figs. 5 (b, c, d) and 6 may be employed.

In Fig. 5b, the load is acting on a horizontal surface at the bottom of a (sheeted) borehole. The bottom surface is levelled by means of a special spade auger, and the shear vane depressed until its upper edge is just below the bottom surface. The circular loading plate is loaded by weights which correspond to the desired normal stress on the curved surface of rupture, and the soil is allowed to consolidate (cu-test). With a view to speeding up the process of consolidation, the vane can be covered by a permeable material. (Tests with vanes covered with filter bronze have been carried out at the Geotechnical Laboratory of the State Institute for Technical Research in Helsinki.)

The surface of rupture should lie in the undisturbed soil beneath the borehole, and consequently the height of the vane should not be too small. The surface of rupture depends on the shape of the shear vane, of which the lower edge can be given a curve which corresponds to a certain stress isobar.

In Fig. 5c (cf. Fig. 6b) the shear vane comprises four half-rings connected to a rotating pipe. The shear vane is pressed down under the bottom of a sheeted borehole, in

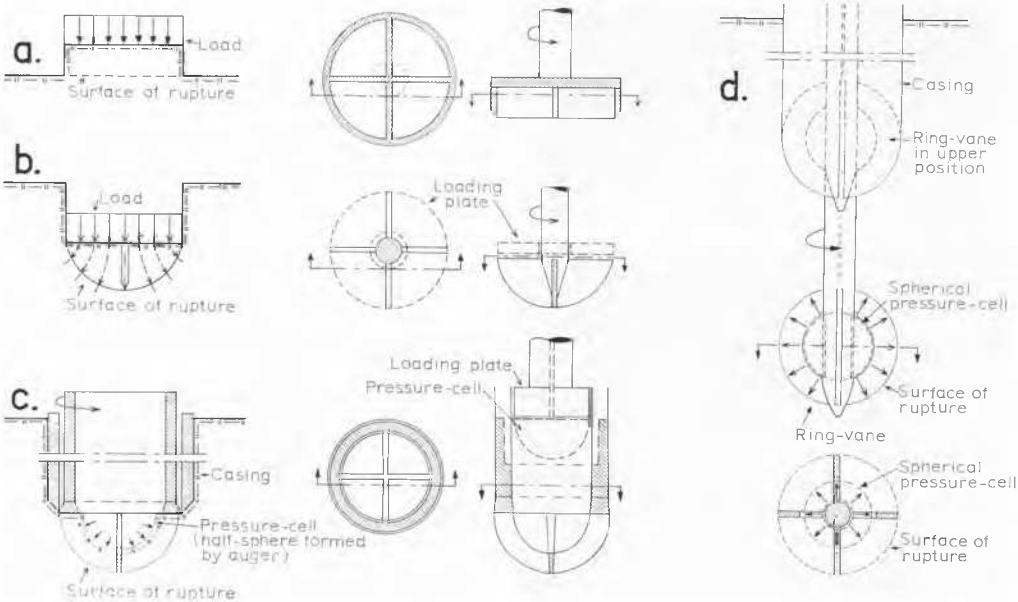

FIG. 5. Different types of torsional field shear test equipment.

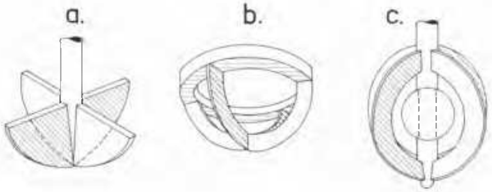

FIG. 6. Shear vanes corresponding to Figs. 5b, c, and d.

which the bottom surface is made of spherical shape by the employment of a special auger. A spherical pressure cell mounted on a loading plate is then inserted in the pipe, and the pressure exerted on the surface of rupture (half-sphere) is increased by the desired amount. When cu-tests are being carried out, the pressure cell should be covered with a permeable filter or a thin layer of sand introduced between the pressure cell and the surrounding soil. After consolidation is complete, the shear vane is exposed to a torsional moment, from which can be calculated the maximum value of the shearing resistance in the surface of rupture.

Vane tests made *in situ* provide reliable values for the undrained shear strength of cohesive soils (Cadling and Odenstad, 1950). Reliable determination of the cohesion and internal friction of undisturbed soil layers could be effected were the normal stress on the surface of rupture determinable and variable. With this aim, a ring-shaped vane of the type indicated in Fig. 5d could be employed. Here, the normal stress on the spherical surface of rupture is raised by increasing the air pressure in a central pressure cell. To accelerate the consolidation process, the vane (or the pressure cell) can be covered with a permeable filter material. Consolidated-undrained tests with pore-water-pressure measurements are also possible, even if this entails making the equipment more complicated in nature. Furthermore, the pressure cell might be employed for determination of the modulus of deformation of the soil, in the same way as in the pressuremeter test introduced by Ménard (1957).

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REFERENCES

ANTTIKOSKI, U. (1964). Shear box auger for measuring the shear strength of undisturbed frictional soils. M.Sc. thesis in Finnish, not published.

CADLING, L., and S. ODENSTAD (1950). The vane borer. Royal Swedish Geotechnical Institute, *Proc.*, No. 2.

HUTCHINSON, J. N., and E. N. ROLFSEN (1962). Large scale field shear box tests on quick clay. *Geologie und Bauwesen*, Vol. 28, No. 2.

HVORSLEV, M. J. (1936). A ring shear apparatus for the determination of the shearing resistance and plastic flow of soils. *Proc. First International Conference on Soil Mechanics and Foundation Engineering*, Vol. 2, p. 125.

MÉNARD, L. (1957). Mesures in situ des propriétés physiques des sols. *Annales des Ponts et Chaussées*, mai-juin.

SOWERS, G. F., and C. E. GORE (1961). Large scale preconstruction tests of embankment materials for an earth-rockfill dam. *Proc. Fifth International Conference on Soil Mechanics and Foundation Engineering*, Vol. 2, p. 717.

SÖHNE, W., and F. J. SONNEN (1961). Messungen von Rollwiderstand und Zugkraft von luftbereiften Ackersleppern sowie mechanischen Bodenkenngrössen und Versuch einer Zuordnung. *Proc. First International Conference on Mechanics of Soil-Vehicle Systems*, p. 512.