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Vane-Triaxial Apparatus

Moulinet triaxial

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SUMMARY

A description is given of a laboratory research apparatus, called the vane-triaxial apparatus, with which it is possible to perform vane tests in soil samples mounted in a triaxial compression cell. The apparatus consists of a standard triaxial compression cell which is modified to allow a vane to be pushed up from the cell base into the soil sample. The vane is rotated, and the torque required to turn the vane is measured, by means of an instrument fastened below the triaxial cell. With this apparatus it is possible to perform vane tests with different sizes and shapes of vane and at various rates of rotation on soil samples which have been consolidated and/or stressed to any set of conditions obtainable with the standard triaxial equipment. Space limitations prevent the inclusion of test results, but a brief discussion is given of the type of laboratory vane research work that is presently being done.

SOMMAIRE

L'article décrit un appareil de laboratoire nommé moulinet triaxial. Il est possible avec cet appareil de faire des essais au moulinet dans des échantillons de sol montés dans une cellule triaxiale. Cette cellule est modifiée pour permettre d'introduire un moulinet par la base dans l'échantillon. La force nécessaire pour tourner le moulinet se mesure avec l'instrument monté sous la base de la cellule. Il est possible de faire des essais avec des vitesses, des grandeurs et des formes différentes des moulinets dans des échantillons consolidés ou soumis à des contraintes. La place manque pour inclure les résultats, mais on discute les recherches récentes sur les moulinets.

AT THE TIME THE VANE was developed for measuring the shear strength of soils, and later when it first began to be widely used in practice, it was assumed that saturated soils behaved as purely cohesive materials. Today we commonly believe that shear strength is not a cohesive property but rather is primarily dependent on the magnitude of effective stress, mode of strain, and rate of strain. Unfortunately, in the case of the vane test, very little is known about these factors or their influence on the test results. For this reason the vane gives only an empirical measure of shear strength, one that is frequently used for engineering design but which, as yet, defies fundamental interpretation. However, the vane test is now firmly established as a valuable practical tool, and the problem we are faced with today is the investigation of the possibilities and limitations of its use. The case of the vane test in soil mechanics is thus similar to many aspects of engineering where theory and evaluation follow practice.

As part of an integrated programme of research at the Norwegian Geotechnical Institute into the general subject of the undrained shear strength of soils, a laboratory investigation of the vane test was initiated in 1960. A necessary condition for all vane tests is to have controlled external stresses on the soil samples, and for this reason the triaxial apparatus was chosen and modified to include a vane-test device. This paper will describe in detail the resulting vane-triaxial apparatus and give a brief discussion of the type of work which is presently being done with it.

GENERAL DESCRIPTION

A photograph and a drawing of the apparatus is given in Figs. 1 and 2 respectively. The apparatus consists of a triaxial cell which is supported on three legs and can stand either on a table or on the platform of a loading press. The vane (item 1 in Fig. 2) in its retracted position is housed in the pedestal of the triaxial cell, and it can be inserted into the soil specimen by pushing up the lower vane shaft (9). The power unit for turning the vane (18 and 19) and the case containing the torque-measuring instrument (13) are mounted on a cylindrical bracket (10) which is fastened to the base of the cell. This vane apparatus is capable of applying and measuring shear stresses greater than 8 tons/sq.m., and by using small changeable electric motors the range of vane speeds can be extended indefinitely.

FIG. 1. Photograph of vane-triaxial apparatus and calibration device.

Vane

The vane blades are made from 0.33 mm-thick spring bronze and are fixed to a 2.0 mm-diameter silver steel shaft. To eliminate friction between the shaft and the soil, the

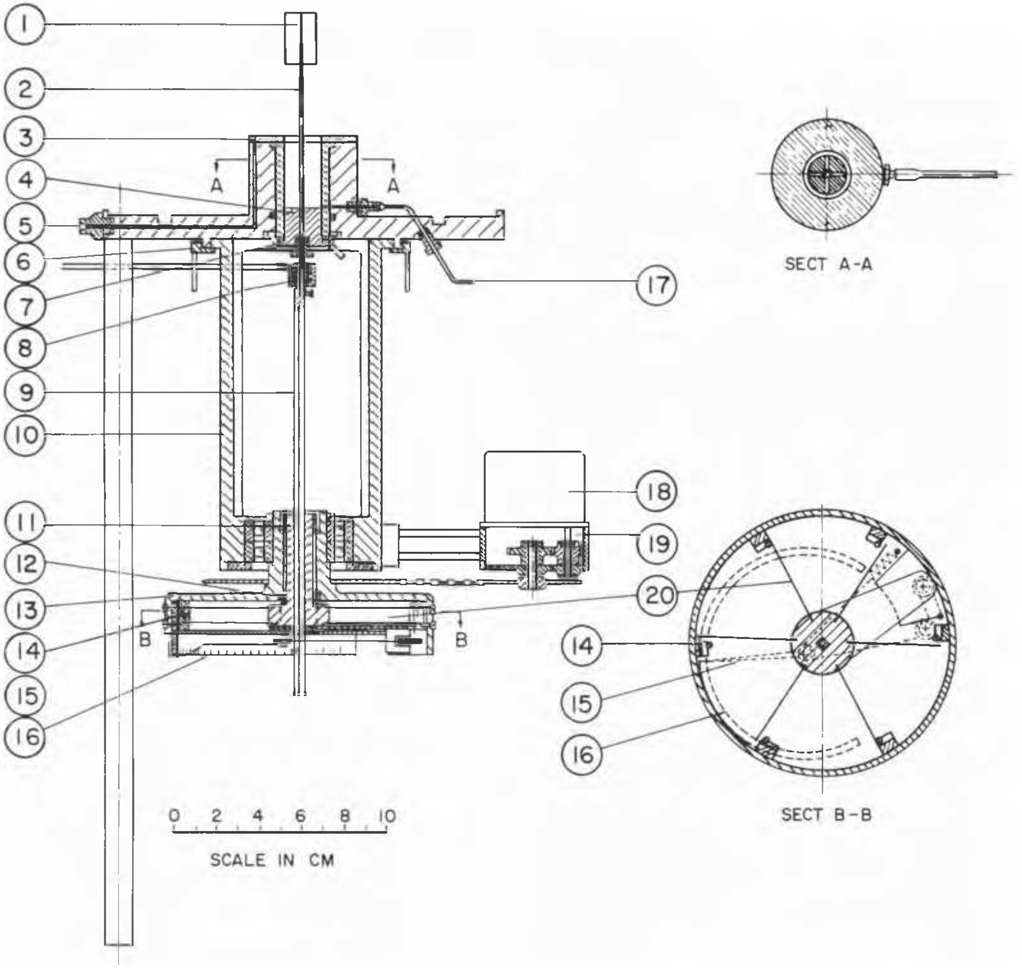

FIG. 2. Details of vane-triaxial apparatus.

shaft is enclosed in an oil-filled stainless steel tube 2.1 mm inside diameter (2) which passes through the pedestal of the cell. This tube can be fixed in position by the rubber packing (7), which when tightened also prevents water drainage from the soil along the outside of the tube. To prevent water drainage from occurring between the tube and the vane shaft, an oil packing (8), through which the vane shaft passes, is fitted to the end of the tube. When the vane is not being rotated, this packing is tightly fastened, and when the vane is in use the packing is loosened to reduce friction on the shaft. If pore pressures exist in the soil sample, as in an undrained compression test, water drainage is prevented during the vane test by delivering oil to the packing at a back pressure equal to the pore pressure in the soil; by allowing some of this oil to slowly leak between the packing and the vane shaft, friction at this point is eliminated.

The maximum torque which can be applied to a vane is governed by the torque capacity of the vane shaft at the point where it is fastened to the vane blades. For this apparatus, the torque capacity has been measured to be approximately 3000 gm cm. Vanes of several shapes and sizes are presently in use, and their dimensions (height and width) range from 8 × 16 mm to 32 × 16 cm. For these two sizes and for torques equalling 3000 gm cm, shear stresses of 4 and 8 tons/sq.m., respectively, can be applied to soil samples. For the more common vane shape of $h = 2w$, a vane having height-width dimensions of 16 × 8 mm can be used to apply shear stresses up to 14 tons/sq.m.

Triaxial Cell Base

Standard Geonor triaxial cells, having a pedestal area of 20 sq.cm., have been used to construct the vane-triaxial apparatus. The central upper part of the pedestal is slotted to house the vane. Into the central lower part of the pedestal fits a removable metal plug (4). The vane can be inserted into the pedestal either from above before the sample is placed on the pedestal or from below the cell base by temporarily removing the metal plug. In the case of undrained tests, when the vane is pushed up from the pedestal it is necessary that water be delivered to the slotted portion of the pedestal to compensate for the volume of the vane, and this can be provided by the water line (17).

The pedestal is equipped with two channels (5), communicating to the slotted filter plate (3) below the soil specimen, which can be used for purposes of soil consolidation and pore-pressure measurement.

Torque-measuring Instrument

The instrument for applying and measuring torque (13) to the vane shaft is fastened to the bottom of the cylindrical bracket (10) by means of a double ball bearing. Within the neck of the instrument is fitted a guide (11) mounted to the neck by small radial-thrust bearings (12). This guide contains a square central hole through which the square vane shaft (9) passes. To the base of the guide are fastened three pairs of blade springs (20). Torque from the power unit (18 and 19) is transmitted to the blade springs and thence to the vane shaft by jewel bearing rollers (14) mounted to the inside periphery of the instrument case. The torque, which is proportional to the deformation of the blade springs, is determined by measuring, by means of the magnification mechanism shown in Section BB of Fig. 2, the difference of rotation between the guide (11) which holds the lower vane shaft (9) and the instrument case (13); this rotation is indicated by the movement of a pointer (15) along a scale (16). The total frictional torque in the apparatus amounts to 10 gm cm, which is 0.2 per cent of the 3000 gm cm torque capacity of the vane shafts. Repeated calibration tests, performed before and after each test, indicate that the calibration characteristics of the torque-measuring instrument are reproduceable with an accuracy of ±1 per cent over the full torque range.

To make the apparatus more practical for laboratory use, the cylindrical bracket (10), on which the torque-measuring device and the power unit are mounted, is fastened to the base of the cell by means of a slip-ring connection (6); this makes it convenient to transfer this portion of the apparatus from one triaxial cell to another.

Power Unit

The power unit consists of a small changeable electric synchronous motor (18) coupled to a three-speed gear box (19) which is connected to the torque-measuring instrument by a chain-and-sprocket drive. The gear box contains two removable gear wheels with which speed ratios of 2:1, 1:1, and 1:2 can be obtained. By using different motors (commercially manufactured at small cost), the range of speeds can be easily extended to cover whatever range is required. The apparatus being used at the present time (1964) has four different motors, and by using these motors and the gear box, rotational speeds in a geometric series of 2 can be obtained from approximately 0.12 to 360 deg./min.

USE OF APPARATUS

To indicate what type of research work is being done at the Norwegian Geotechnical Institute with the vane-triaxial apparatus, it is perhaps best to first consider the relationship between the maximum shear stresses developed in the soil around the periphery of the vane and the measured torque on the vane.

$$\text{Torque} = \tfrac{1}{2}\pi h d^2 \tau_v + \tfrac{1}{2}\pi d^3 \alpha \tau_h \tag{1}$$

where h and d are the effective height and diameter of the assumed cylindrical zone around the vane in which strain occurs, τ_v and τ_h are the maximum shear stresses developed on vertical and horizontal surfaces respectively, and α is a factor dependent on the shear-stress distribution across the ends of the vane. The maximum shear stress developed in the soil on a failure surface is dependent on the effective-stress shear-strength parameters of the soil c' and ϕ' and the difference in magnitude between the total stress σ_n and the pore pressure u acting across the shear zone; that is

$$\tau = (\sigma_n - u) f[c'\phi'] \tag{2}$$

Upon examination of Eqs (1) and (2), there appear to be at least three different classes of unknowns concerning the vane test: (i) failure surface, (ii) shear stress distribution, and (iii) rate of strain. Each of these topics is the subject of research work presently being carried out at the Norwegian Geotechnical Institute, and they will be discussed briefly in the following paragraphs.

Failure Surface

In Eq (1) it is assumed that failure occurs along a circular cylindrical failure surface having height h and diameter d. Field and laboratory observations have indicated that, at large rotational strains, failure occurs on such a surface that is tangential to the vane blades (Gibbs, 1960; Karlsson, 1962). However, it has been stated that the failure surface need not necessarily be tangential to the vane blades but might be located some distance from them (Skempton, 1948); in this case h and d would be larger than the height and width of the vane. Also, there are unanswered questions concerning the shape of the failure surface at small strains and the width of the strain zone. All these questions are of a nature that can, at least partially, be studied by observation and measurement. The technique being used at NGI is to take X-ray photographs of soil slices removed at various stages of vane tests. In these photographs it is possible to observe the zones of shear, and because the photographs are to natural scale, measurements can be made directly and accurately.

Shear-Stress Distribution

This topic concerns the shear-stress distribution on the failure surfaces at the top and bottom of the vane, and in terms of Eq (1) it involves the determination of α. This factor is of minor importance for vanes which are long in comparison to their width, but it is of much greater importance for vanes which are wide in comparison to their height. To determine the magnitude of α for different soils, tests are made in identical samples of isotropic soil at the same rate of rotation with vanes having the same width but different lengths, and α is found by means of Eq (1) by making the assumption that for isotropic soil $\tau_v = \tau_h$.

Rate of Strain

The third topic of research work is the effect of rate of strain on the magnitude of shear stress which can be developed in soils with a vane; published test data (Evans and Sherratt, 1948; Karlsson, 1961) indicate that soil resistance against vane shear is very sensitive to rate of strain. It can be seen from Eq (2) that rate of strain can alter the magnitude of shear resistance of soil by affecting the effective-stress shear-strength parameters of the soil and by affecting the magnitude of effective stress acting across the shear zone. Changes of effective stress can result in two ways. The first is by changes of pore pressure u in the shear zone due to pore water movement. The second is by changes of the total stress σ_n acting across the shear zone, resulting from radial volumetric strains (compression and swelling caused by pore water movement) which cause arching of the soil surrounding the vane.

With the existing vane apparatus it is not possible to measure total stresses and pore pressures acting across the shear zone, and for this reason an indirect test method is now being used to investigate the effects of rate of strain. It involves doing tests on identical soil samples with identical vanes but at different rates of vane rotation (Fig. 3). The difference between the maximum torques for any two tests (points A and B) is a measure of the sum of the effects of rate of strain on $c'\phi'$ and on effective stress σ'_n. All tests are continued beyond the maximum torque stage of the test for time periods long enough to obtain constant or residual torque values (X and Y). It is assumed that at these conditions the excess pore pressures in all tests are zero (independent of the rate of strain) and that in all tests the effective stresses across the shear zones are approximately equal, and therefore that the difference in torque between X and Y is a measure of the effect of rate of strain on only $c'\phi'$. By doing tests in this manner, it is possible to study the effect of rate of strain on the shear resistance of soil in vane tests and to separate the gross effect into a $c'\phi'$ component and an effective stress component.

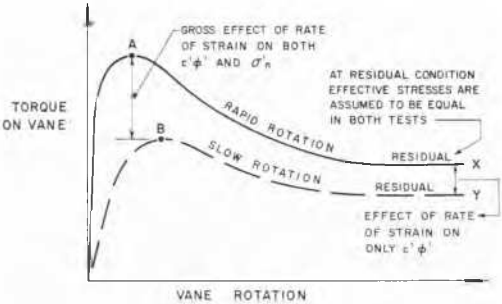

FIG. 3. Study of effects of rate of strain.

ACKNOWLEDGMENT

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