Evaluation of Three-Dimensional Shear Testing

Evaluation des Tests Tri-Dimensionels pour Mésurer la Résistance au Cisaillement

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SYNOPSIS Various three-dimensional testing apparatuses-"true triaxial" devices- which can test cuboidal soil samples in the generalized stress field are briefly reviewed. The results obtained in these and in the tests in this study are examined and compared. Cohesionless soils are in question, and drained strength characteristics rather than stress-strain behaviour are emphasized. Testing procedure and design of apparatus are found to be affecting the results especially at the high intermediate stress states. A reasonable estimate of the shear strength behaviour of cohesionless soils in field at generalized stress states is given.

INTRODUCTION

A number of three-dimensional shear testing apparatuses were designed in the recent years to test samples in the generalized stress field. It is regarded essential to survey these devices and the results associated with them before using the data for the development of soil models. Emphasis will be on the high intermediate stress states, since conflicting results are reported in those states at present.

THREE-DIMENSIONAL TESTING APPARATUSES

Different Designs

The apparatuses employed in generalized testing programs on granular soils are numerous and it is not possible to give a detailed description of each apparatus here, but the basic features of an apparatus are the type of loading platens and the design of loading system in three orthogonal directions. The equipment in the literature may be put in few categories. Reference is given to the equipment and studies in which generalized tests were possible to carry out at high intermediate stress states (i.e. $b = (\sigma_2' - \sigma_3')/(\sigma_1' - \sigma_3') > 0.5$).

(a) The apparatuses that use cubical samples and all six faces of samples are loaded by-rubber bag-flexible platens. Ko and Scott (1968), Lomize et. al. (1969, 1973), Al-Ani (1975).

(b) The apparatus that tests cubical samples and all six faces of samples are loaded by rigid platens. Gudehus (1973). This design uses Hambly's (1969) design concept of "nested platens".

(c) The apparatuses that make use of a mixture of rigid and flexible platens. The most common type of design incorporates a large triaxial cell. Usually there is some sort of a frame around the sample to apply stress through rigid or flexible platens in one of the lateral directions. Water pressure in the triaxial cell provides the principal stress in the remaining lateral direction. Cuboidal-prism shaped-samples are tested. Bishop and Green (1969), Green (1971), Reades (1972), Proctor and Barden (1969), Lade and Duncan (1973) Sutherland and Mesdary (1969). Ramamurty and Rawat (1973) use a classical triaxial loading frame in the axial direction with rigid platens and four flexible platens stress the cubical sample.

Testing Procedures

Partly depending on the design of an apparatus there are a couple of ways during stressing samples to failure. Axial and lateral pairs of rigid and/or flexible loading platens may be moved inwards to apply major and intermediate principal stresses while the remaining pair of lateral platens moves outwards with variable or constant minor principal stress. If design makes use of water pressure in the triaxial cell as the minor principal stress, sample deforms outwards against cell pressure. Different driving speeds of axial and lateral platens determine the intermediate stress state in strain-controlled tests. This procedure will be called the first mode. Mean stress level usually increases in the tests in this mode unless it is specially controlled.

Another procedure followed at intermediate stress states higher than plane strain state is to consolidate samples usually to a higher isotropic stress than that in the first mode, then to decrease axial stress withdrawing top platen similar to a coventional triaxial extension test. Different intermediate stress states are created increasing lateral stresses in one of the two lateral directions to a higher level with respect to the other before withdrawing top platen. Failing samples in this way will be referred as the second mode.

PRESENT STUDY

Equipment

The generalized testing device used in this study is mainly the apparatus designed by Green (1969, 1971). It is an apparatus grouped under (c) above. A pair of flexible platens have been designed to be attached to the frame which originally carries rigid platens. Flexible lateral platens are composed of supporting brass nests and reinforced rubber bags mounted on them. Reinforced rubber bags were manufactured employing the technique by Arthur (1973). No water is allowed to go into or out of the bags during the tests, and the hydraulic jack on the lateral frame provides the deformation in the lateral direction. Details are given in Ergun (1976).

Materials and Test Program

Ham River sand is a uniform medium sand composed of subrounded particles. (C_u = 1.45, γ_s = 2.68 kN/m^3, d_{50} = 0.24 mm). Volcanic sand is a uniform fine sand having particles of angular and needle-like shape. (C_u = 1.64, γ_s = 2.79 kN/m^3, d_{50} = 0.1 mm).

All samples were consolidated isotropically and subsequently sheared drained. Test series on Ham River sand consisted of : (1) Tests in the first mode on dense and loose samples emloying flexible platens in the lateral (intermediate) direction with constant consolidation pressure of 207 kPa. (2) Triaxial extension tests were on short and long (50 mm vs. 85 mm height) and loose and dense samples (3) Special series I were on loose samples, and rigid axial and lateral loading platens were used. Only difference in the test procedure from the conventional first first mode was stress controlled lateral platens which were kept at constant initial consolidation pressure (840 kPA), and while axial platen was driven downwards (major stress) cell pressure was decreased to failure. Special series II were generalized tests in the second mode on loose samples and at high b values. There were mean stress level decreasing (conventional type, similar to triaxial extension test) and increasing type of tests.

Tests on volcanic sand consist of triaxial compression, extension and generalized tests at all stress states and on loose and dense samples. They were in the first mode, and rigid platens were used.

Test Results

The angles of shearing resistance on Ham River sand based on the Mohr-Coulomb failure criterion are given in Fig.1 at different intermediate stress states. The results of the tests on Ham River sand performed by Green (1969) and Reades (1972) are also plotted in the figure. Results of tests on volcanic sand are presented together with the other researchers' in Fig.3. The complete data are given in Ergun (1976).

GENERAL DISCUSSION OF THE RESULTS

It is generally agreed that peak strength values increase markedly from the axisymmetric compression state to plane strain state, and dense samples show greater increase, Fig.1 and Fig.3. An interesting observation in Fig.1 is the difference in behaviour of the loose Ham River sand samples tested in the first and second modes at high intermediate stress states. Stress strain and volume change response are different

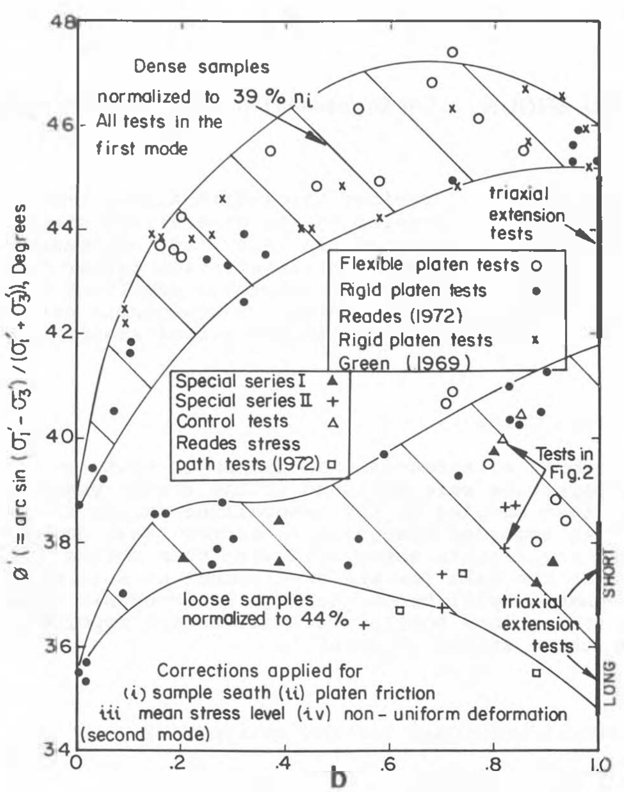

Fig.1 Results of Generalized Tests on Ham River Sand

right from the start of the tests, Fig.2.

This significant difference seems to be the main cause of confusion in the past at high intermediate stress states. The reason for the difference may be explained by the way of application of loads to sample and the degree of freedom of the sample until failure in different modes. Internal shearing mechanism in samples in the first mode leads to more dilation with increasing b values. Effect of interference between rigid loading platens at high b values is a contributing factor to measured ϕ' values. It is interesting to observe the ϕ' values at high b values on loose Ham River sand samples obtained in rigid and flexible platen tests in the first mode and in special series I. A discussion on the point is in Ergun (1977). Lower angles of friction are associated with lower rates of volume changes with respect to major principal strains in the second mode compared to those in the first mode at the same b values. Samples tested in the second mode tend to form necks like in triaxial extension tests.

If Fig. 3 is examined it is seen that the researchers who use the second mode after plane strain find significant ϕ' decreases, curves 2, 3, 7. Except curves 1 and 4 angles of shearing resistance increase above plane strain in the first mode. There is no mean stress level correction in 1 and 4 like in most other studies therefore they will also increase after correction. (a) type of apparatuses show significant increases in friction angles up to b = 0.6-0.8, have a peak and then tend to show decreases towards b = 1, curves 6.8. In (c) type of apparatuses with rigid lateral platens this tendency to decrease is recognized, curves 4,5, 9,10 and dense Ham River sand samples Fig.1. Flexible platen tests in Fig.1 clearly disclose this behaviour. Formation of the failure planes disaappear around the peak till b = 1.

Clearly, given the same sand to the researchers

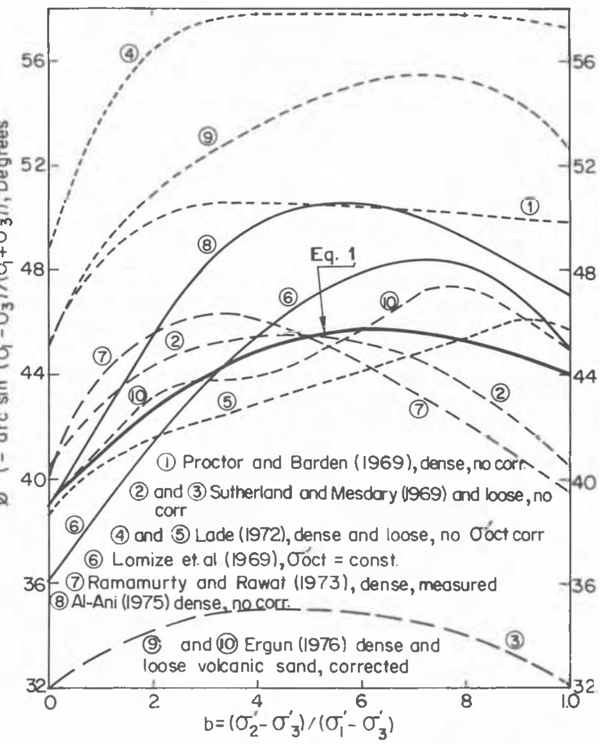

Fig.3 Variation of ϕ' with Change of Intermediate Stress Determined by Various Researchers

referenced above, differences in friction angles and strains will appear throughout the intermediate stress space, and they must be accepted as the effects due to varying experimental techniques. "Field element" is represented by sample in testing apparatus. There are some fundamental questions here; Is the element represented correctly in the testing apparatus as far as the stress-strain boundary conditions in the soil mass are concerned? What is the relevance of the behaviour observed in various experimental programs to the "true" behaviour? It seems to the Writer that neither the tests in the first mode nor in the second mode represent the "true" behavior after plane strain. The "true" variation is expected to be of the form such that the friction angle rapidly increases to plane strain around b = 0.25-0.35, further increases are marginal and occur in denser materials, in loose materials practically no increase should be assumed. After about b = 0.65-0.75 it tends to decrease, and looser materials give larger drops. At the extension state (b = 1) ϕ' values are expected at most a few degrees higher than those at the triaxial compression state in loose materials whereas they are almost at the level of ϕ' values in plane strain for dense materials. It is noticed that soils having high ϕ' values in triaxial compression have also large variations in ϕ'.

A potentially useful, semi-empirical relationship has been found to represent the peak strength behaviour of cohesionless soils after an examination of deviatoric stress components;

$$(\sigma_1' - \sigma_3')^2 + (\sigma_2' - \sigma_3')^2 = \beta^2 \sigma_{oct}'^2 \qquad (1)$$

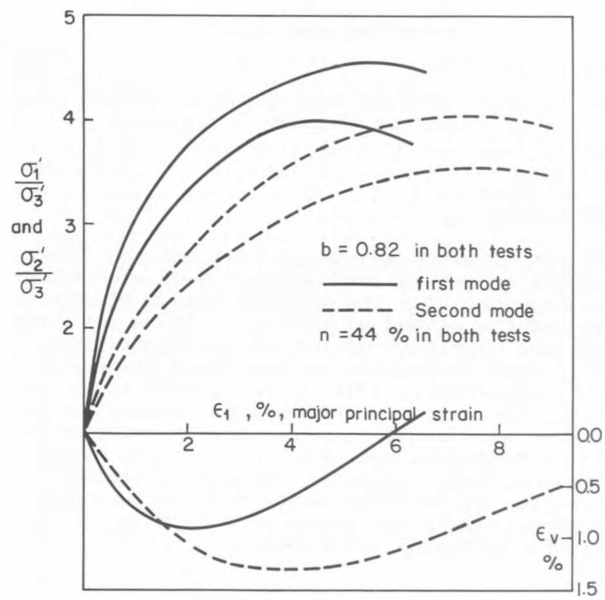

Fig. 2 Comparison of the Two Tests Carried out in Two Different Modes

where $\sigma_1' \geq \sigma_2' \geq \sigma_3'$. The shape of the failure surface defined by Eq.1 is shown on an octahedral plane together with other criteria in Fig.4. Experimental data obtained in this study are also presented. Eq.1 is plotted for $\phi'=39^o$ in triaxial compression in Figs.3 and 4. Analytical study of Eq.1 can be seen in Ergun (1976). Actual β values measured in this and other studies were examined and found to be practically constant for all states. Therefore β values obtained in triaxial compression tests may be used to predict the change in ϕ', and this is a convenience because most, laboratories do not have generalized testing equipment.

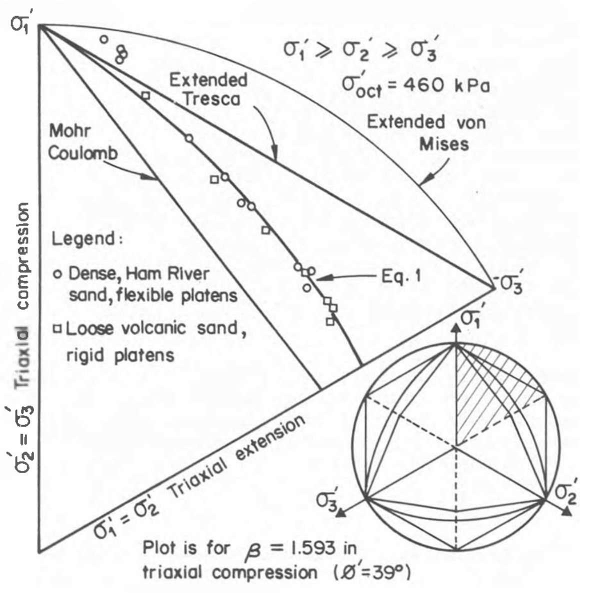

Fig.4 Failure Loci Shown on a 60°-Sector of an Octahedral Plane

CONCLUSION

Results obtained in the present and the other studies in generalized testing have been examined together with the type of design of apparatus and the method of testing. It is concluded that the diversity of the change of friction angle with increasing intermediate principal stress especially after plane strain state is partly due to different ways of imposition of strains and/or stresses to samples and partly due to different designs. Strains are also affected significantly. The most probable variation of friction angle with increasing intermediate stress is decided upon and a failure criterion is proposed.

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