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## Review on Developments in Shear Testing Of Soil

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**ABSTRACT:** Shear strength is an inherent property of soil mass. Various engineering approaches are available for shear strength testing of soil. Present study incorporates various methodologies involved in shear strength testing of soil strata such as direct shear, triaxial shear, torsional shear and vane shear. Developments in shear testing are studied and presented in concise manner. New approaches should be adopted with advanced instrumentation for shear strength testing of soil. The evaluation suggests that direct shear and simple shear devices are best utilized by designers who have gained experience applying the results from such tests to structures that have behaved satisfactorily.

**KEYWORDS:** Shear strength, Direct shear test, Triaxial compression test

### I. INTRODUCTION

Geotechnical testing basically includes laboratory and field determination of various parameters of soil. State of art and state of practice in soil testing includes standardized methodologies adopted worldwide such as those adopted by ASTM, BS, IS codes. Geotechnical engineering, although great strides have been made in recent years, is still less a precise science than structural engineering. It remains, to an important extent, an art based on experience and judgement. Selection of particular type of test depends on various parameters such as In-Situ requirements, required soil properties, degree of accuracy required etc. Sound knowledge of geotechnical investigation will lead to accurate measurements in laboratory testing. Laboratory and field testing in geotechnical engineering forms base for investigation for the purpose of designing and constructing the foundation for structure.

As per George F sowers (1964), two factors are found to be responsible for the lack of standard strength tests for soils. First is the complexity of polyphase soils compared to the simple single phase solids. Second factor is that the physical nature of the deformation and strength properties of most soils is still not clearly understood. In short it can be stated that soil is not a textbook material. As per Sadda A.S. and Townsend F.C. (1981 STP 740 ASTM) Object of laboratory testing of soil is to study the behaviour of a given soil under conditions similar to those encountered in field & to obtain parameters which describe this behaviour in a set of constitutive equations. In laboratory test specimen is intended and generally assumed to represent single point in field. The validity of this assumption depends on the uniformity of stress and strain distributions within the soil samples. Sometimes separate measurements are often made for soil phase, water phase and air phase to relate its contribution to total strength

### II. LITERATURE REVIEW

It was not until the early eighteenth century that there was any mention in the literature of soil testing. The work of these early engineers, particularly Belidor, was concentrated on military fortifications, and their interest in soil strength was limited to speculation (or limited observations) on the angle of the shear surface behind a retaining wall. Even Coulomb (3), who in his paper of 1776 introduced the concept of soil cohesion, apparently based the equation for soil strength, which bears his name, on his observations of other materials such as mortar rather than on the tests of soil.

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What appears to have been the first real soil shear test was described by Collin in 1846 (4). As shown in Fig.1, a long specimen of clay, 4 cm square in cross section, was loaded transversely at its centre until it failed in double direct shear.

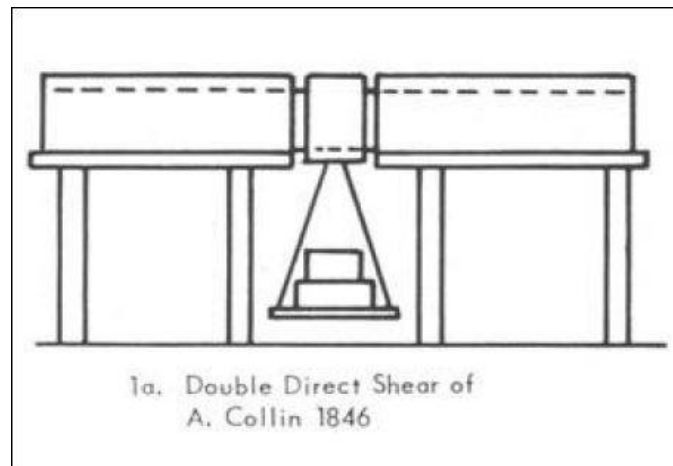


Fig 1 –Direct shear test by Collin

Above fig 1 shows a double direct shear test, which appears to be first soil shear test as described by Collin 1846. Leygue in 1885, describes a single direct shear test for cohesionless soils in which a shear box, similar to the modern device, was tilted until the top slid across the bottom. The first triaxial tests were described by Adams and Nicholson in which cylinders of rocks were confined by metal jackets and then loaded axially. The metal jackets with their indeterminate confining stresses were replaced by fluid pressure in tests reported by v. Karman in 1911. Triaxial testing of soils, however, apparently evolved simultaneously in Germany, in the Netherlands with the work of Buisman, and in the United States with Hveem, Housel, and Casagrande during the early 1930's. Penetration tests have been used to measure soil consistency since the pioneer work of Vicat in France in 1833. The Swedish State Railway began using a static penetration test to measure the relative strength of soils in place in 1917. Cone penetration tests were used by the Swedish Geologic Inst. in its laboratory as early as 1914. The vane test of shear was first used in Sweden in 1928 by Olsson, but not fully developed for use until 1947, as reported by Cadling and Odenstad. Innumerable variations and combinations of these basic forms have been devised, such as the annular torsion direct shear, the torsional triaxial, and the cylindrical-triaxial, but these basic tests remain the mainstay of strength testing.

### III. BASIC REQUIREMENTS IN SHEAR TESTING

There are two objectives in strength testing in which the deformation and rupture under load are measured: First, to gain a fundamental understanding of the mechanics of soils or particular materials; and second, to analyse or predict the behaviour of a mass of soil under field-loading conditions. The first objective is essentially research; it is concerned with soils in general. The second is utilitarian; it is concerned with a specific engineering problem involving a particular soil. The two objectives are not necessarily compatible; however, information gained for one objective can aid the other. In order to meet either objective fully, all the components of stress and strain at any point within the specimen must be determinable. Practically, this requires a reasonably uniform distribution of stress and strain within the specimen, and the control or measurement of stress and strain on the specimen surface. Separate control or measurement of a stress should be provided for each phase of the soil--solid, liquid, and gaseous--in order to isolate their physical contribution to the strength of the mass. While the use of shear data in many engineering problems may not require a knowledge of all the components of stress and strain in all three soil phases, it is necessary to maintain control over all the components so that the effect of neglecting certain ones will be known. The range of stress and strain imposed, as well as other test conditions, such as seepage, temperature, past stress, and physico-chemical

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alterations, depend on the objective. For research on the mechanics of soil strength, the only limitation is the imagination of the investigator. For engineering applications, it is necessary only that the test results can be used to evaluate the strength under the conditions to which the soil will be subjected in the field a much more restricted range.

### A) Parameters considered for shear testing

Mode of shear, In-Situ conditions, Stress controlled or strain controlled test, Measurements of stresses and strains, Type of test according to drainage condition.

### B) Methods of strength testing

There are four principal methods of shear strength testing, direct shear, triaxial compression, torsional and vane or cylindrical shear. In addition to above mentioned properties shear parameters are also computed from penetration testing.

### C) Direct shear test

The direct shear test employs a cylindrical or rectangular specimen which is encased in a split box, as shown in Fig 2. A normal force,  $P$ , is applied to the top of the box after which a shear force,  $S$ , forces the top of the box across the bottom, causing the soil to shear along the plane defined by the split between the box top and bottom.

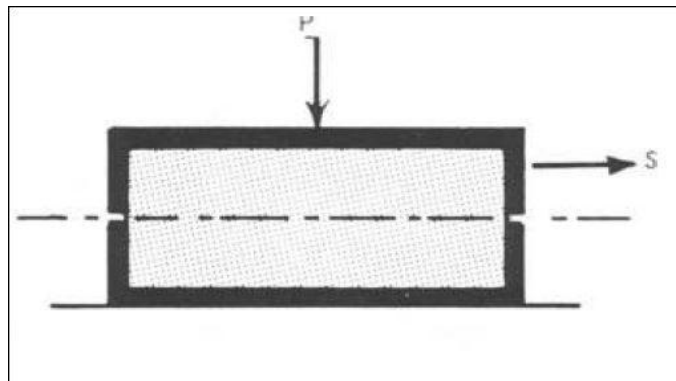


Fig 2- Direct shear test

Above fig 2 shows a simple direct shear test with direct and shearloading. Ordinarily the normal load is applied by a rigid plate that is free to move vertically as the soil deforms. The bottom of the box and the sides are likewise rigid so that no lateral deformation is permitted. The top and bottom of the box are frequently made of a porous material to permit drainage of any pore fluid expelled during loading. Drawback In case of direct shear test is when shear load is applied major and minor principal stresses rotates.

### D) Variations in direct shear test

There are many variations in direct shear loading. The double direct shear, apparently the earliest true shear test for soils, is still in use today in its original form. The load and deformation conditions in double shear are no different from those in single shear, and the stresses and strains within the soil should be similar. Modified loadings have been employed to try to develop more uniform strain conditions within the soils.

### E) Triaxial compression

The triaxial test involves the application of normal forces to all the sides of a cylindrical or prismatic specimen of soil. Fig. 3 shows the most common form of the test, the long axis of the soil specimen is loaded by rigid, parallel end plates, one of which may be free to tilt slightly if non uniform deformation occurs. The end plates usually are of porous material to permit fluid flow in or out of the soil during loading. The soil is loaded laterally by fluid pressure, applied to an impervious flexible membrane that encases the remaining surfaces of the specimen, and which is sealed to the end

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plates. Ordinarily, the lateral pressure is developed by placing the encased, capped specimen in a closed chamber or cell in which air or liquid pressure can be regulated. Failure develops on an oblique surface or system of surfaces, largely unrestrained by the test apparatus. The axial deformation of the specimen is measured directly by the movement of the end plates. The lateral deformation, however, is irregular because of the flexible membrane, and is difficult to measure because of the confining chamber.

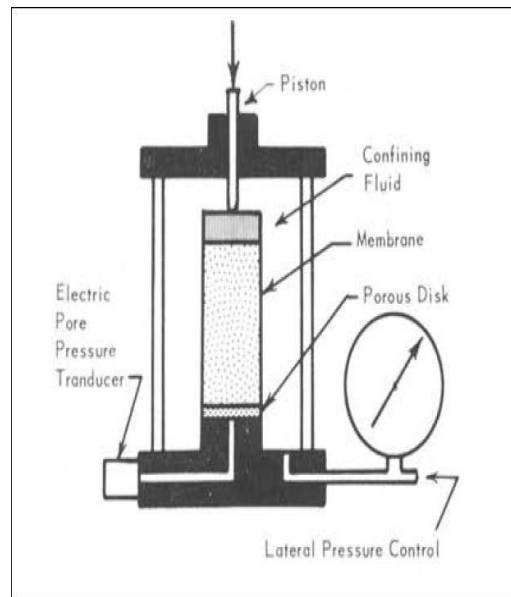


Fig 3- Triaxial shear test

### F) Torsion tests

In the torsion test a cylindrical or annular specimen of soil is subjected first to a normal stress and then a torsional loading which produces failure. In torsional direct shear, Fig.4, as developed by Hvorslev a ring shaped specimen is confined in an annular box, the cross section of which resembles that of the direct shear box. A normal force is applied to the plane surface of the box, which induces normal forces on the inside and outside faces of the ring-shaped specimen. Torsion is applied to the top of the box causing the specimen to shear on a continuous ring-shaped surface parallel to the plane surfaces of the specimen. The test is a continuous direct shear test which permits unlimited shear displacements. In addition to the undefined stresses and non-uniform strains of the specimen direct shear, the shear strains in torsion vary with the distance from the centre of rotation. This test has been primarily utilized in research into large strain effects.

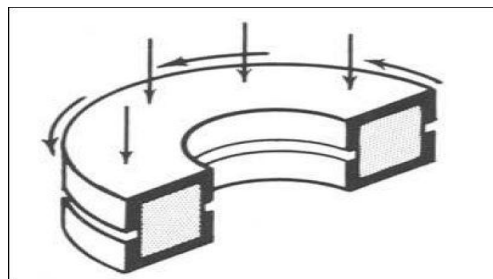


Fig 4- Torsional Shear test

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### G) Vane shear test

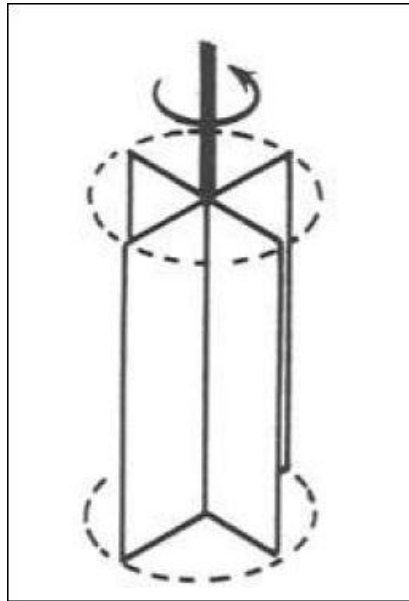


Fig 5- Vane shear test

The vane shear device, Fig. 5, consists of four thin blades welded to a small diameter rod. The vane is forced into the soil and then torque applied to the rod until the soil fails on a cylindrical surface defined by the vane. The torque required to cause failure is a measure of the shear strength. The only stress that is defined in this test is the shear stress on the failure surface, and that is probably not uniform. The other stresses are defined by the state of stress already existing in the soil and are in most cases unknown. Although the angular deformation of the vane can be measured, this can be translated into strain only by assuming some limit to the strained zone; few reliable strain data are yet available from vanes. The test is well adapted to determining the in-place strength of a soil mass with a minimum of disturbance. It has also been used in the laboratory to measure the strengths of small specimens including soils still in the sampling tubes.

### H) Indirect strength test

Penetration tests have long been used to evaluate soil consistency. The primitive builder probably sounded the ground with a pointed stick or his heel, as can be seen in some tribal villages today. The skilled workman forced the point of a pick or drove a rod into the ground with a mallet of known weight. Today there are innumerable penetrometers of standardized design, but all based on the same principle; the penetration of an object into the soil forces the soil aside as shown in Fig.6, developing a shear displacement. The relation between soil strength and penetration resistance is a function of the shear pattern. Various shapes of penetrometers are in use, including flat-tipped rods, cones of different sizes and shapes, augers with cone-shaped tips, and cutting edges of thick-walled samplers. Although there are few comparative data on the effect of shape, there is some feeling that the cones yield more consistent results than the others. Two types of loading are used: static and dynamic. The static loading simulates the shear developed in laboratory testing and can be easily adapted to continuous penetration and automatic recording. The dynamic loading is adapted to a very wide range of soil strengths but introduces the variable effect of dynamic shear and shock or vibration. Both static and dynamic penetration are extensively used in field exploration.

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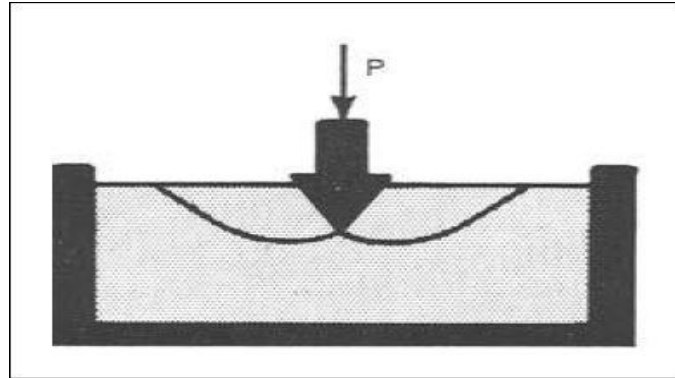


FIG 6 – PENETRATION IN SOIL

## IV. ADVANCEMENT IN TESTING OF SOIL MASS

Following are advance facilities available for soil test:

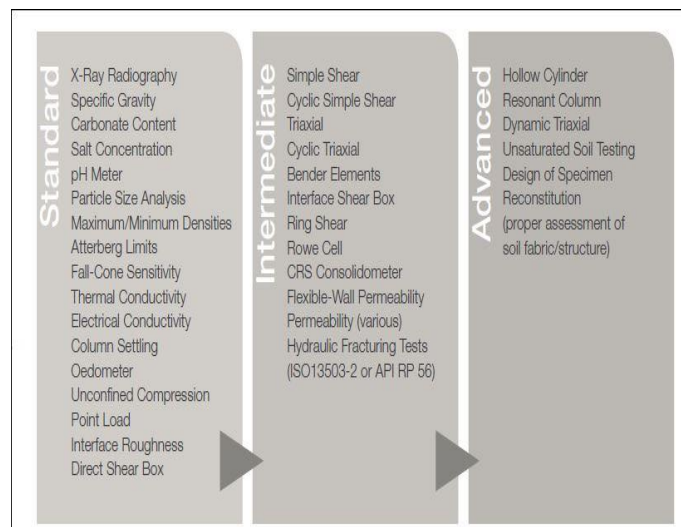


Fig 7- List of advance tests

- Triaxial compression and extension tests
- Mid-height small strain
- Isotropic or Anisotropic conditions
- Mid-height pore pressure
- Two plane bender elements
- Direct simple shear
- Cyclic, Static, Constant volume (quasi undrained)
- Resonant column

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- Isotropic consolidation
- Shear modulus
- Confining pressures up to 2000kPa
- Constant rate of strain consolidation
- Testing for thermal properties of soils and rocks.
- Triaxial Compression and Extension Tests
- Mid-height pore pressure and suction
- Local (small) strain using Hall Effect sensors mounted axially and/or radially
- Shear wave velocity ( $G_{max}$ ) using bender elements
- Isotropically or anisotropically consolidated drained or undrained triaxial Compression or extension
- Anisotropic consolidation
- $K_0$  determination
- Compressive shear modulus from bender elements.
- Resonant Column
- To predict and simulate ground behaviour under vibration, resonant column test
- To ASTM D4015 models the following characteristics of soil:
- Isotropic consolidation
- Determination of shear modulus
- Damping ratio in torsion or flexure

## V. CONCLUSIONS

During last 50 years, shear testing of soil has undergone many advancements in terms of instrumentation, type of loading etc. Present work gives overview of overall progress in shear testing of soils during last 50 years. Endeavour has been made to collect data related to shear strength testing of soils and present that in formal manner

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