Large size-large displacement residual direct shear test device development

Développement d'un dispositif de test de cisaillement direct résiduel de grande taille-déplacement grande

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ABSTRACT: Large size direct shear test devices are capable of handling soil particles as large as 40 mm diameter. The typical problems related to conventional direct shear devices such as; contact area change during shear, limited horizontal displacement and formation of moment couple during application of normal load at larger horizontal displacements are eliminated by the developed device. The top box with300x300x200 mm size, travels on a 900 mm long, 300 mm wide bottom box with adjustable depth between 200 and 400 mm. The normal load is applied over the top box using up to six pneumatic muscle actuators capable of applying 4500 N normal force each. The normality and the magnitude of the vertical force are sustained by continuous movement of the loading mechanism together with the upper box, on low friction rails at two sides of the bottom box. This way the upper box has a horizontal travel stroke up to two times its size. A step motor driven linear actuator with 15 kN capacity is used to pull and push the above box. At a target horizontal displacement, a second horizontal antagonistic system with pneumatic muscle actuators is manufactured to apply stress controlled cyclic load application at the interface.

RÉSUMÉ : Les dispositifs d'essai de cisaillement direct de grande taille sont capables de traiter des particules de sol d'un diamètre aussi grand que 40 mm. Les problèmes typiques liés aux dispositifs de cisaillement direct classiques tels que: le changement de la zone de contact pendant le cisaillement, le déplacement horizontal limité et la formation de couple de moment pendant l'application de la charge normale aux déplacements horizontaux plus grands sont éliminés par le dispositif développé. La boîte supérieure de 300x300x200 mm, se déplace sur une boîte inférieure de 900 mm de long, 300 mm de large avec une profondeur réglable entre 200 et 400 mm. La charge normale est appliquée sur la boîte supérieure en utilisant jusqu'à six actionneurs pneumatiques qui sont capables d'appliquer 4500 N de force normale chacun. La normalité et l'amplitude de la force verticale sont soutenues par un mouvement continu du mécanisme de chargement avec la boîte supérieure, sur des rails à coefficient faible de frottement aux deux côtés de la caisse inférieure. De cette façon, la boîte supérieure a une course de déplacement horizontale jusqu'à deux fois sa taille. Un actionneur linéaire de 15 kN actionné par un moteur pas à pas est utilisé pour tirer et pousser la boîte ci-dessus. Lors d'un déplacement horizontal cible, on fabrique un deuxième système horizontal antagoniste avec des actionneurs de muscle pneumatique pour appliquer une application de charge cyclique commandée par une contrainte à l'interface.

KEYWORDS: Residual shear tests, large size direct shear test device, interface shear strength properties

1 INTRODUCTION

The development of large size direct shear test devices has been an important research task at Bogazici University since 1990. Industrial powder wastes are pelletized by cold bonding process and the shear and interface shear behavior of the manufactured pellets with sizes up to 30 mm diameter have been measured by the specially developed direct shear test devices. Another stream of research is in the area of interface and residual shear testing between soil, manufactured pellets and concrete or geosynthetics. The developed equipments are listed in Table 1.

1 .1 *Large size direct shear device*

The first designed large size direct shear testing device is capable of conducting shear tests, interface tests and pullout tests with changing one wall of the lower box (Baykal and Doven 2000), (Doven 1996). The dimensions of the box are 0.30 m by 0.30 m. The normal load is applied by using an airbag placed on top of the upper box. The horizontal displacement is applied via an electric motor, reduction gear and electronic speed control and the bottom box is pulled and a load cell is attached to the drive shaft. The large size direct shear test device is shown in Figure 1. The equipment is capable of conduction pullout tests also (Baykal and Dadaşbilge, 2008; Dadaşbilge 1999)

Table 1. Large size interface test equipments developed at Bogazici University.

Interface Equipment	Dimensions (meters)
Large size direct shear and pullout device	0.30 x 0.30 x 0.30 m
Cylindrical interface device	Cylindrical sample with diameter range of 0.1 to 0.3 m with 0.50 m height
Pneumatic muscle interface device	0.30 x 0.30 x 0.20 m upper box sliding over 0.90 x 0.3 x 0.2-0.4 m

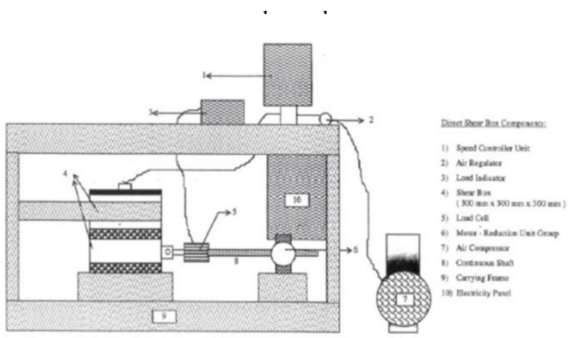

Figure 1. Large size (300 mm x 300 mm) direct shear and pull out testing device (Baykal and Doven, 2000).

The maximum horizontal displacement used for this equipment is 60 mm corresponding to 20 per cent of the length of the sample. Residual tests may be conducted only by moving the box back and forth till the residual interface shear values are reached. The test system has been successfully used for several commercial projects as well as research. Typical results obtained by this equipment are summarized by Baykal (2016).

1 .2 *Cylindrical interface test device*

A cylindrical interface testing device is developed for geosynthetics interface testing (GICT) (Baykal, 1997; Akkol, 1997; Akkol and Baykal, 2001) The geosynthetic to be tested is wrapped over a kestamide cylinder with three boundary conditions; free, one end fixed and two ends fixed. The typical testing set up is given in Figure 2. The cylinder which is wrapped with geosynthetic is placed in the special container and the soil is filled around it at the target relative density. The normal force on the cylinder is applied by a special rubber balloon wrapping the sand at the periphery. By applying air pressure to the peripheral balloon the required normal load is applied to the geosynthetic. The cylinder is turned by an electric motor with a reduction gear. A torque transducer is placed between the kestamide block holding the goesynthetic and the drive shaft of the motor. This way it is possible to measure the torque applied on the interface of geosynthetic and the sand at specified relative density. Using the measured torque value, the shear stress is calculated. The mechanism of the testing system is different than that of the ring shear test device. Here, the interface around the cylinder is measured where in ring shear device the interface at the top of the sample is measured. This test has many advantages over conventional tests. The displacement that can be applied to at the interface is infinite. The cylinder can be turned as many times as required to reach residual values. There is no need to shear the sample back and forth as it is done in conventional tests.

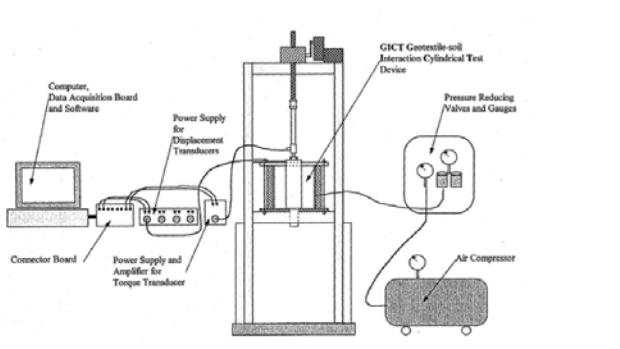

Figure 2. Geosysntehics interface cylindrical test device (Akkol and Baykal, 2001.

As a representative test result, the interface efficiency values are presented for loose and dense Ottawa sand against spun bonded nonwoven geotextile (A), needle punched nonwoven geotextile (C) and woven geotextile (D) in Figure 3.

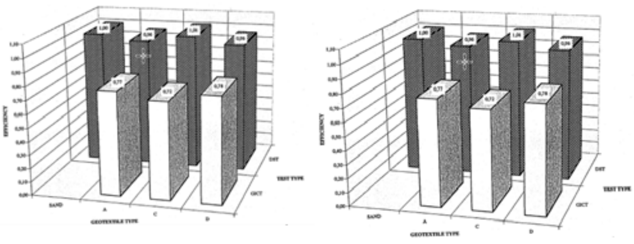

Figure 3. Comparison of interface efficiency for direct shear interface test (dark color) and geosynthetic cylindrical interface test for loose (left) and dense Ottawa sand (Akkol and Baykal, 2001).

1 .3 *Tilting table test device*

Tilting table tests are typically used to determine the friction angle between soils and structures. A major advantage of the tilting table is the large specimen size that can be easily tested with a minimum of complexity and cost (USBR- 6258-09). Very low confining pressures can be applied with this type of equipment which is a major drawback. With this test only peak friction angle is measured. No shear stress/displacement information is obtained. No information is obtained about the residual friction angle.

1 .4 *Ring shear test device*

True residual shear strength values can be measured due to the unlimited displacement. Full stress range can be accommodated. Major disadvantage of this testing device is the direction of shearing is not comparable to that of the field condition. The measured peak shear strengths are not reliable. Granular materials cannot be tested and large geosynthetics samples cannot be accommodated in the testing system.

2 LARGE DISPLACEMENT CONSTANT CONTACT AREA SHEAR DEVICE

With the experience gained from previous equipment developments a complete new and versatile large size, large displacement interface testing system is designed and manufactured (Baykal 2015, Baykal 2016). Pneumatic muscles are used for the application of the normal load, a step motor with reduction gear driven linear actuator is used to apply the horizontal load (strain controlled). An antagonistic loading mechanism is also developed by using pneumatic muscles (stress controlled)(Figure 4).The upper box is 0.30 m by by 0.30 m moving on the lower box with 0.90 m length and 0.30 m width. The height of top box is 0.20 m and the depth of the bottom box can be adjusted between 0.20 m and 0.40 m. The normal load is applied with pneumatic muscle actuators. These actuators contract upon application of air pressure and apply forces up to 6.5 KN for a 40 mm diameter muscle. The pneumatic actuators can contract up to 20 per cent of their lengths. The rubber muscles are attached to a rail near the lower box and can travel together with the upper box (Figure 4). The muscles are connected to a beam in twin order on the top box, exerting compression to the soil in the upper box. The normal stress can be applied by the help of up to six pneumatic artificial muscles, which have a diameter of 40 mm, a nominal length of 250 mm and radial air inlet valves at both end fittings.The bottom part of the muscles, which are connected to rod eyes, are fastened to a linear guide. The top parts, which are connected to rod clevises are fastened to an aluminum beam in order to transmit the tensile load of the muscles to the loading platen. The muscles can operate efficiently up to 25% contraction and the generated force output decreases with increasing contraction ratio. Keeping the contraction at a minimum level, is prefererred to obtain large force output. Typical force magnitudes produced corresponding to varying contraction levels are presented in Figure 5 (Yıldız, 2010). . For six bar of air pressure the load capacity of one muscle actuator is 4500 N at 5 per cent contraction. At 20 per cent contraction, the load capacity of the muscle actuator decreases to 1500 N. For practical testing conditions the contraction of the muscle actuators are small, so high capacities are easily achieved. Up to three beams with six rubber muscles can be attached providing a theoretical total of 39000 N normal force. Considering the fact that a ten story high building exerts 100 kPa to the underlying soil, for a 0.09 m2 contact area, the force generated by artificial muscles will be adequate. This can be achieved even using two 40 mm pneumatic artificial muscles.

As shown in Figure 4, the small size upper box is pulled or pushed over the fixed larger bottom box. A stepper motor with reduction gear is used to move the linear activator as located at the right side of the box. The step motor is controlled by PLC software by the control box shown towards the right end of the equipment. The capacity of the linear actuator is 15 KN capable of applying up to 167 kPa shear force for the 0.09 m^2 upper box. The PLC software is capable of applying monotonic and cyclic horizontal loads with strain control. The software allows control of the direction, displacement rate and frequency of the horizontal load application. The control unit at the left part of the shear box uses PLC software to control the antagonistic loading system.

Figure 4. Large displacement large size direct shear testing device (Baykal 2016).

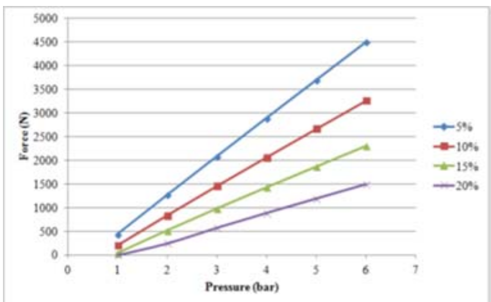

Figure 5. The load capacity of 40 mm muscle at various air pressure and changing contraction

The antagonistic system is composed of two opposing artificial muscle actuators pulling and pushing against each other to apply cyclic load to the upper box. This provides a stress controlled interface test execution. The maximum horizontal cyclic stress that can be applied by using one set of artificial muscle actuator is 50 kPa.

Overall the designed testing system is simple and versatile. Three sections can be easily separated. The left section can operate independently to apply cyclic loads with precise stress control. The middle section can be used as an independent unit even for tilting table test. The sliding normal load mechanism on the shear box will provide the required confining stress for the tilting table which eliminates the major drawback of very low confining pressures of tilting tables. The third independent section of the testing system is the linear actuator side which can be separated from the system easily. This linear actuator also can be used for other static or cyclic strain controlled load applications. Another versatile use of the testing system is for model pile testing. The depth of the lower box is adjustable up to 400 mm. The upper box is 200 mm high. This way model pile groups can be tested up to sixteen piles with 600 mm length subjected to vertical and horizontal loads. Horizontal cyclic loads can be applied either with stress control or strain control. A stress mapping system is used to determine the stresses acting on the interface and on the walls of the device.

The load cells are used in three places to measure the applied load (with a capacity of 10000 N); under the loading arm and over the soil in the upper box; at the connection point of linear actuator and the top box; at the connection point of the antagonistic cyclic loading system and the top box.

Displacement transducers are used to determine the horizontal displacement of the top box in each direction. Contraction and dilation of the soil in the upper box is measured by another displacement transducer. For cyclic load application accelerometers are used in the upper and lower boxes.

3 LARGE DISPLACEMENT INTERFACE TEST ON ROUGH AND SMOOTH GEOMEMBRANE OVER CRUSHED ROCK

To demonstrate the capability of the developed direct shear interface test device a smooth and a textured geomembrane's interface behavior with crushed stone is investigated at large horizontal displacement. The model represents typical drainage material underlain by geomembrane on a slope. A small normal stress of 7.5 kPa is used. The crushed stone diameter is between 16 mm and 23 mm range. Two mm geomembrane thickness is selected for smooth and textured geomembrane samples. The asperity height of the textured geomembrane is 0.25mm. The yield strength of the smooth and textured geomembranes is 35 and 33 kN/m respectively. The geomembrane samples are cut to a size of 0.29 m by 0.89 m to fit in the lower box with dimensions 0.30 m and 0.90 m. Wood square beams with 100 mm cross section are placed side by side and on top of each other to fill the lower shear box. After the geomembrane is tightly placed in the lower box, the crushed stone is placed on top of it at a relative density of fifty per cent. On top of the crushed stone steel weights are placed to apply a normal stress of 7.5 kPa at the interface.

The shear stress versus horizontal displacement relationship of the crushed stone and smooth or textured geomembrane are given in Figure 6. The two geomembranes are from the same company. Both of them are 2 mm thick with close physical properties except the 0.25 mm asperity size of the textured geomembrane. The position of the upper shear box at the end of the test is shown in Figure 7. The normality of the vertical load is sustained perfectly even at a very large horizontal displacement. The interface shear strength of the smooth geomembrane is mobilized immediately and it is sustained even at large horizontal displacement. The low magnitude of the interface shear stress is due to the application of low vertical stress of 7.5 kPa to model the upper cover layer of a typical waste disposal site. The interface shear strength mobilization is different for the textured geomembrane. The full mobilization is achieved at 30 mm; the peak value is reached at 50 mm horizontal displacement. A decrease is observed in the interface shear strength after the first peak. A second peak is reached at 60 mm horizontal displacement. A sharp loss of interface shear strength is observed after 70 mm horizontal displacement.

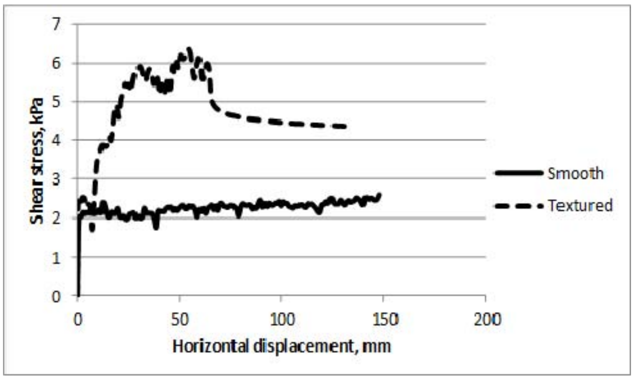

Figure 6. Shear stress vs horizontal displacement of smooth and textured geomembrane and crushed stone.

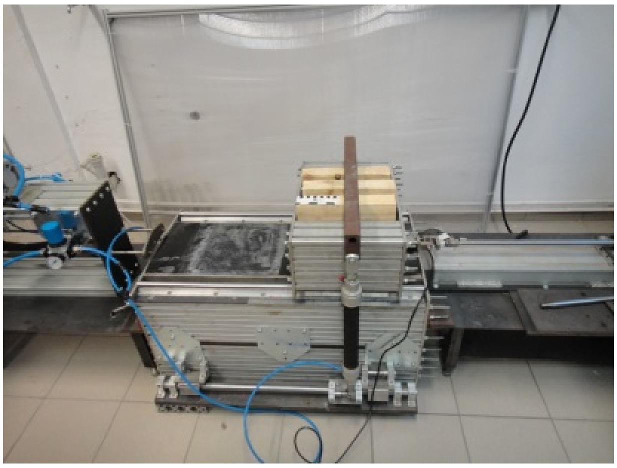

Figure 7. The position of the upper shear box at the end of the test.

Typically in large size direct shear testing device a 20 per cent sample size corresponds to 60 mm horizontal displacement. If a conventional large size direct shear device was used, the interface shear parameter would have been given as a peak value. The residual value of the interface shear strength is 30 percent lower than the peak value.

4 CONCLUSION

The developed equipment is simple, practical and versatile to handle several geotechnical problems. Displacements as large as 600 mm can be applied which is a big advantage for the determination of residual shear strength parameters for soils and crushed rock. The contact area is kept constant even at large displacements. The sliding normal load application mechanism eliminates formation of moment couple even at large displacements. Modular construction of the equipment allows the use of different loading mechanisms for high precision and simple control. The loading module with step motor driven linear actuator allows strain control testing with precise position control. The antagonistic artificial muscle actuator cyclic loading module allows precise stress control. The central module having the shear box and the normal load mechanism with pneumatic artifical muscle actuators allow precise control of normal stress applied. The sliding normal load mechanism sustains the normality of the vertical load even high horizontal displacements as large as 600 mm. The center module can be used as a tilt table interface test device with high confining stress capability. The physical dimensions and adjustable depth of the bottom box upto 400 mm, makes the testing system suitable for model pile testing subjected to vertical and horizontal static and cyclic loading. Model piles upto 600 mm length and pile arrangements up to 16 pile groups can be tested.

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