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TECHNICAL NOTE

Pullout Tests Using Modified Direct Shear Test Setup for Measuring Soil–Geosynthetic Interaction Parameters

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Abstract Soil–geosynthetic interaction parameters and their determination play a vital role in the design of reinforced soil structures. Direct shear test and/or pullout test are commonly used to determine the interaction parameters. Often, it is economically viable to obtain these parameters through existing test setups that are conventionally used in geotechnical engineering. However, the existing test setups need certain modifications, to facilitate the requirement for the specialized tests. This paper introduces modifications to the large size (300 mm × 300 mm) direct shear test setup for evaluating the soil–geosynthetic interaction parameters under pullout. The shear box in the existing test setup is replaced by a rectangular box having internal dimensions of 400 mm × 400 mm wide and 230 mm height, with a slot in the front face. Additional amendments for achieving smooth stress transfer, over entire displacement range, are explained. Typical pullout test results using the modified direct shear test set up are presented. Pullout friction coefficient values are observed to be within the range 0.55–1.69. In general, it is observed that the pullout behavior is sensitive to the normal stress and the type of geosynthetics in terms of its surface roughness.

Keywords Geosynthetics · Soil · Interface · Pullout · Direct shear · Modification

Introduction

Geosynthetics are being widely used as reinforcement in various soil structures such as; retaining walls, foundations, embankments etc. The design of such structures is governed by the soil–geosynthetic interaction characteristics. Primarily, two interaction mechanisms: sliding and pullout are to be considered in the design for reinforcement applications [1–3]. Sliding mechanism represents soil–geosynthetic interaction under shearing, in terms of sliding coefficient, along one of geosynthetic surface in contact with soil. Pullout mechanism represents pullout capacity of the embedded portion of geosynthetic material into the soil. Here the soil–geosynthetic interaction along both the surfaces of the geosynthetic material in contact with soil is considered, in terms of pullout coefficient. In both the cases the coefficients are defined as $\tan\delta/\tan\phi$, where δ is the soil–geosynthetic interface friction angle and ϕ is the soil friction angle. Many researchers have reported the evaluation of soil–geosynthetics interfacial frictional properties through shear tests and pull-out tests [1, 4–9].

Over the years different test setups have been evolved, across the globe for conducting the pullout tests. Bergado et al. [10] developed a pullout test setup made of reinforced concrete which was kept open, both at the top and front. Swan [11] has modified the direct shear test setup for

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evaluating the pullout response of high strength woven geotextiles. Ju et al. [12] developed an apparatus that can perform both the pullout and direct shear tests. Abdel-Rahman et al. [13] carried out laboratory studies using a large-scale universal testing apparatus that could perform pullout tests of geogrids. Subaida et al. [14] have studied, using a pullout box apparatus, the pullout behavior of woven coir geotextiles. In order to investigate the pullout performance of geogrid in sand, Baykal and Dadasbilge [3] have modified the large scale direct shear device. The general procedures followed in all these tests are mostly in accordance with ASTM 6706-01 [15]. However, there is a difference in the sizes of the pullout box used, a summary of which is presented in Table 1.

Many often, direct shear test setup is modified for obtaining the interface shear characteristics of geosynthetics under sliding. It would be economical and convenient if the same test setup can be amended to conduct the pullout tests, in the absence of specialised test setups, for finding the pullout resistance of the geosynthetic materials. This manuscript describes the simple amendments to the available large direct shear setup for conducting the pullout tests. Using the modified direct shear test setup, pullout tests were performed to evaluate the soil–geosynthetic interaction parameters under different test conditions. Thus, the objective of the paper is to explain the modification to the normal direct shear test set up for conducting pullout test and test results in terms of interaction parameters.

Modification of Direct Shear Test Setup into Pullout Test Setup

Conventional Direct Shear Test Setup

Figure 1 depicts the conventional direct shear test setup used for determination of shear parameters of coarse-grained soils. In this device, the upper and lower boxes are of 300 mm × 300 mm in plan and 115 mm deep. During shear, the lower box can move up to 35 mm of total displacement. The normal load is applied through a loading yoke connected to a loading lever counter-balanced by a dead weight. The whole loading system works on lever-arm mechanism that provides mechanical advantage, in terms of higher load transfer through second-class lever principle. The shearing of the test specimen is done by a screw-advanced drive system, powered by a motor and gear system, maintaining a controlled constant rate of shear displacement. There is provision of applying both forward and reverse shear movements. With the onset of motor, the lead screw pushes the shear box along with the lower half box, while the load cell connected to the upper half of the box via the U-arm measures the shear resistance. Horizontal displacement is recorded by placing an LVDT onto the front face of the shear box as shown in Fig. 1. Under the present research work this setup has been modified for determination of geosynthetic–soil interface response under pullout.

Table 1 Different sizes of pullout box used by different researchers

Reference	Box dimensions (mm)
Bergado et al. [10]	800 × 1000 × 900
Bonczkiewicz et al. [25]	1325 × 675 × 150
Ochiai et al. [26]	600 × 400 × 400
Yasuda et al. [27]	500 × 300 × 100
Razaqpur et al. [28]	1040 × 230 × 380
Min et al. [29]	600 × 200 × 300
Bolt and Duszynska [30]	1600 × 600 × 360
Ju et al. [12]	600 × 400 × 190
Subaida et al. [14]	450 × 450 × 600
Nayeri and Fakharian [31]	1200 × 600 × 600

Modification of Test Setup

Figure 2 depicts the pullout test device 'A' obtained through modification of the direct shear test setup. The shear box (water jacket) of the direct shear setup is replaced by a pullout box with inner dimensions of 400 mm long, 400 mm wide and 230 mm height (Fig. 3). A 12 mm wide horizontal slot, as shown in Fig. 3, is provided on the front face through which the geosynthetics is projected out for being connected to the reaction frame (i.e., abutment) through the load cell. Figure 3 also presents the placement of clapped geosynthetic through the slot provided on the front face of the shear box. Dimensions of pullout box were arrived to accommodate a geosynthetic specimen of 150 mm wide and 300 mm long, in contact with soil in the box. To minimize the boundary effects, Juran et al. [16] suggested 'specimen width to box width' ratio to be chosen so as to minimize the effect of friction by side-walls and recommended maximum and minimum width of specimens as 60 and 30 cm respectively for 90 cm width of box. Corresponding maximum and minimum ratios (specimen width/box width) are 0.66 and 0.33, respectively. The ratio for the box and specimen sizes adopted here is 0.375. Further, inner walls of the box are lubricated with grease to minimize the friction development between contact of soil and inside walls. The pullout box is being clamped to lead screw advanced drive system powered by a motor and gear system as shown in Fig. 4. The load cell one end is connected to the geosynthetics, through the clamp, and the other end is fitted to the holding screw that passes

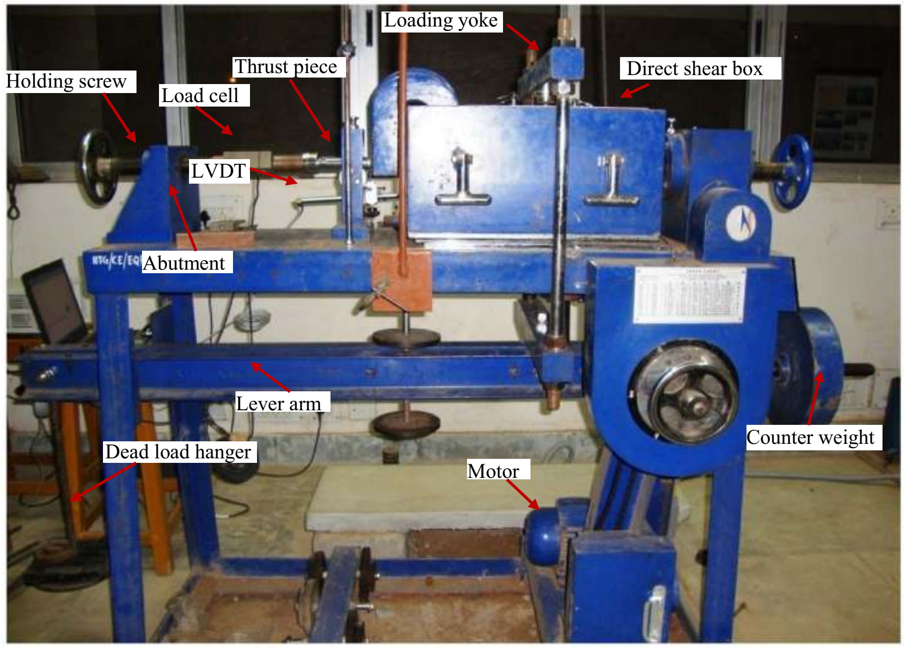


Fig. 1 Large size direct shear box

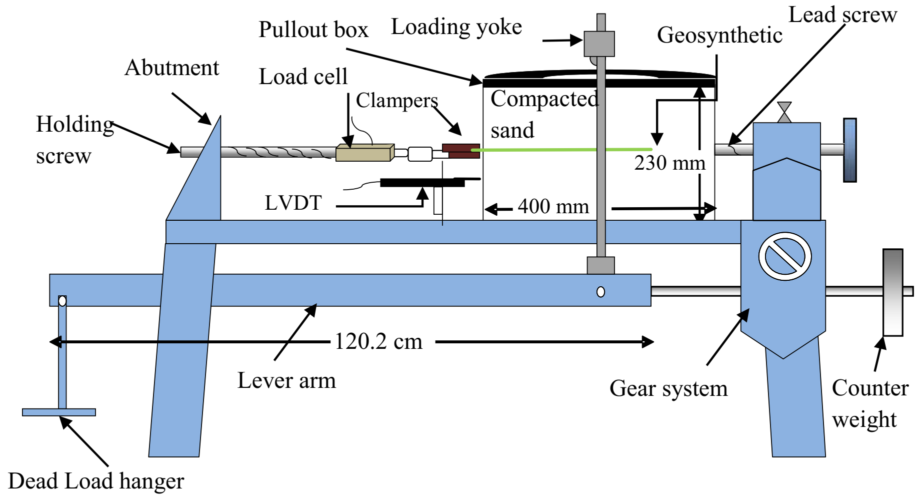


Fig. 2 Schematic diagram of the pullout test setup 'A'

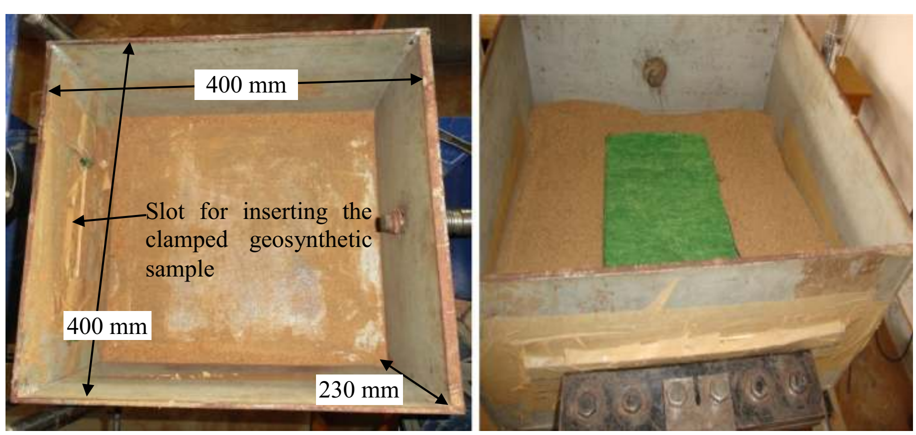


Fig. 3 Pullout box

through the abutment. Normal stress is applied onto the rigid plate resting over the test specimens by means of lever arm system as is done in the conventional direct shear test setup. Subsequently pull is applied to the pullout box, at selected constant rate. The displacement is measured by an LVDT attached to the front face of pullout box as shown in Fig. 4. Resistance offered by the geosynthetics is measured using the load cell and data acquisition system. In this modification, the geosynthetic specimen is held in fixed position, while the neighboring soil along with the box is pulled away. In the process, the loading yoke that is supported over the pullout box keeps rotating as depicted in Fig. 4. As a result of which the normal stress on the specimen keeps changing. As displacement of the pullout box increases the titling of loading pattern increases thereby lever-arm mechanism affects the change in normal stress.

In order to measure the variation of the normal stress (σ_n), a load cell was placed right under the boss of the loading yoke. The recorded normal stress (σ_{vn}) at different horizontal displacements is normalized with respect to the initial normal stress (σ_{in}). Figure 5 depicts the variation of the normalized stress value ($\sigma_{\mathrm{vn}}/\sigma_{\mathrm{in}}$) with displacement (advancement of the pullout box). It could be seen that the induced normal pressure ($\sigma_{\mathrm{vn}}/\sigma_{\mathrm{in}}$) on the test specimen has decreased with increase in the displacement. This is because, the rotation of the loading yoke, due to advancement of pullout box, affects the lever arm action and thereby the load transferred to the soil–geosynthetic system. This effect is more prominently observed at increased level of normal stress, applied onto the sample (Fig. 5). Similar problem due to tilting of the loading platen and the associated non-uniform stress distribution was discussed by Ingold [22]. To minimize such variation of normal stress the loading yoke needs to be held in fixed

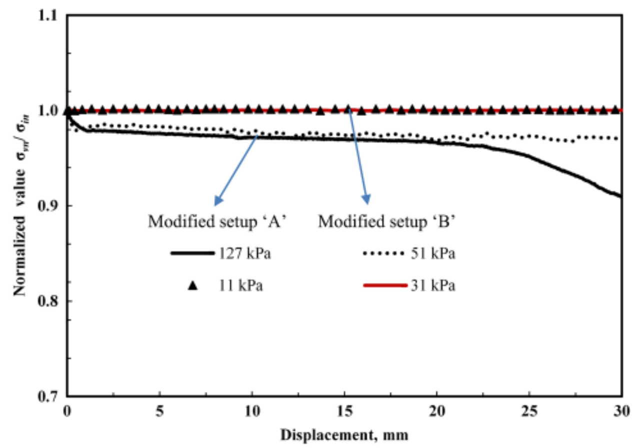


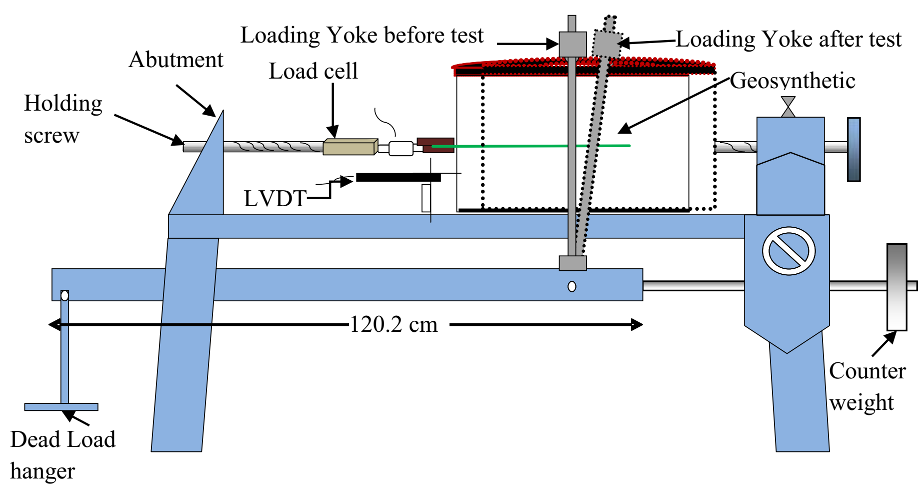
Fig. 5 Variation of normal stress with displacement of box

position, which has been achieved through an additional modification as is explained below.

In order to arrest the movement of loading yoke during testing process, it is required to keep the pullout box stationary. This can be achieved by pulling the geosynthetic specimen rather than the box itself. However, in the conventional direct shear test setup there being less space for displacement, the pullout of the geosynthetics is found to be inadequate. To overcome this limitation, the pullout box was shifted from lead screw side to abutment side and the geosynthetic-load cell assembly was shifted from the abutment side to the lead screw side as shown in the modified pullout test setup 'B' (Fig. 6).

Shifting of the pullout box from lead screw side to abutment side necessitated to change the lever arm pin position on the lever arm beam. To achieve this, a new hole was provided (i.e., about 420 mm away from the old position) corresponding to the new position of the pullout

Fig. 4 Schematic diagram showing the position of loading yoke before and after the test



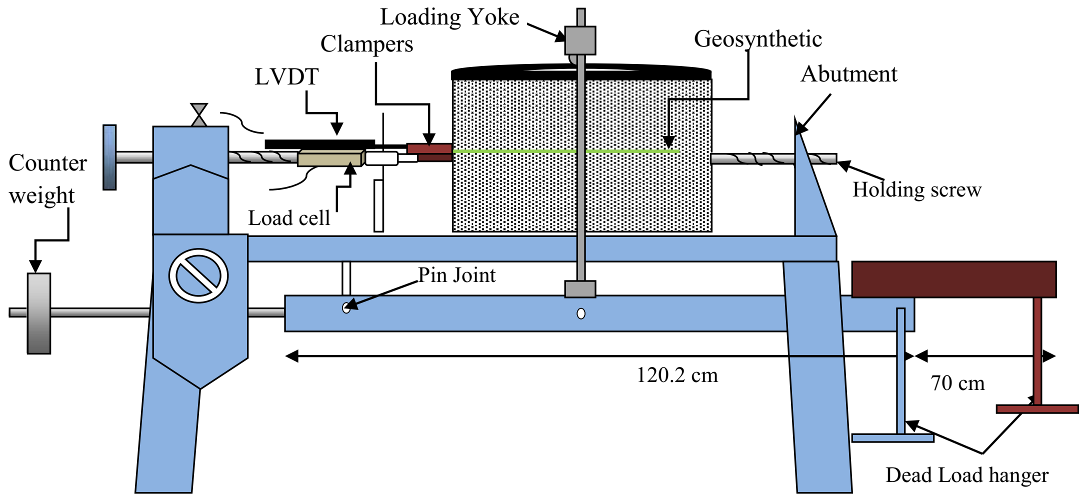


Fig. 6 Schematic diagram of modified pullout test setup ‘B’

box. This new position of loading yoke (lever pin) effectively reduced the lever arm distance from the dead load hanger, which affected the stress levels achieved on the pullout box using the dead weights. To mitigate this effect the length of the lever arm has been extended as shown in the Fig. 6. A lever arm beam of about 700 mm length was attached with the help of screws and bolts to the old lever arm beam. This facilitated adding the dead weights to both the dead load hangers. With the increased length of lever arm and change in the loading yoke position, the counter weight position needed to be changed. For this, the length of the counter weight holding screw was increased, by attaching an additional screw system, to counter balance the moment caused due to increased length of lever arm.

The clamper and load cell arrangement is fitted to lead screw as shown in Fig. 7. As has been explained earlier, to ensure a constant normal load on the specimen throughout the test in the modified pullout setup ‘B’, the box is kept stationary by fixing it to the holding screw (Fig. 7). The pull is applied to the clamped geosynthetic specimen by means of lead screw drive system powered by the motor gear system. The displacement of geosynthetic specimen is measured by placing LVDT on the front side of the clamper. The normalized variation of normal stress (σ_{vn}/σ_{in}), with the advancement of clamed geosynthetic specimen in the present pullout setup (i.e., B) is shown in Fig. 5. It can be observed that, with increase in displacement of the clamped geosynthetic, there is no variation of normal stress value. This is true both the normal stress levels (i.e., 11 and 31 kPa). Therefore, it can be said that the pullout test setup (B) has achieved a constant normal stress on the sample, during the testing process.

Pullout Tests

Materials Used

Sand

Backfill material used is locally available dry sand having an effective size (D_{10}) of 0.16 mm and C_u, C_c of 2.81 and 0.67 respectively. Particle size distribution of the sand is shown in Fig. 8. As per ASTM D2487 [17], the sand is classified as poorly graded sand (SP). Its maximum and minimum unit weights are determined as 16.58 and 14.02 kN/m^3, respectively. To achieve uniform unit weight, in the test specimen, the sand was placed in the pullout box using pluviation (raining) technique. The pluviation technique has been implemented by a setup consisting of an elevated hopper, with a steel pipe (36 cm) fitted with an inverted cone of 60° apex angle. The sand is allowed to fall from hopper through the steel pipe and then dispersing from the inverted cone. The height of fall of sand from the cone was obtained, after several trials, to achieve the desired unit weight (relative density) of the sand sample. The average placement unit weight of the sand adopted in the test setup was in the range of 15.67–15.76 kN/m^3 that corresponds to 70–73 % of relative density. Direct shear tests were performed on samples prepared by sand pulviation technique at 70 % relative densities (RD) and the average friction angle value obtained was 45°.

Geosynthetics

Four different types of geosynthetics (Fig. 9.) were used in the study, viz. composite geotextile (A) (one side woven and

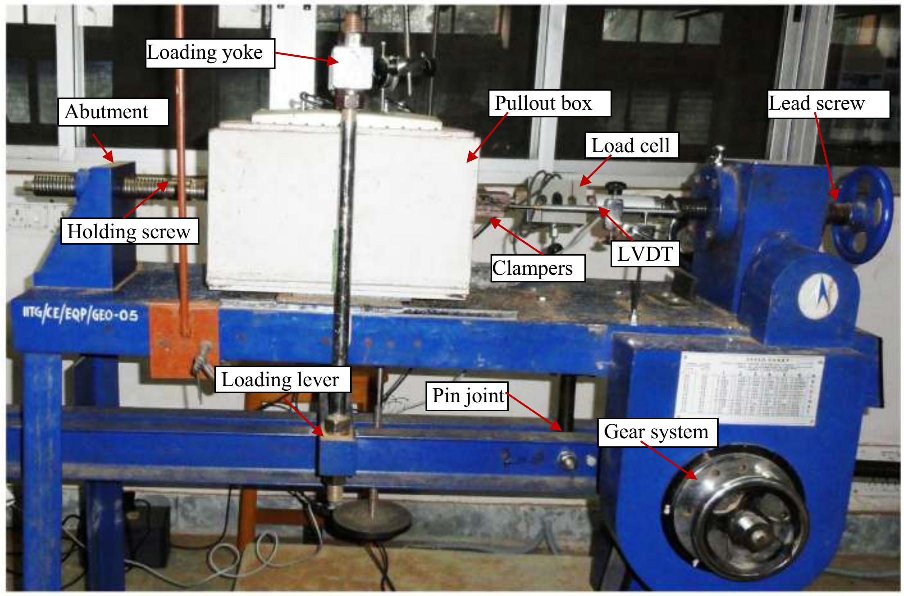


Fig. 7 Modified pullout test setup with associated instrumentation

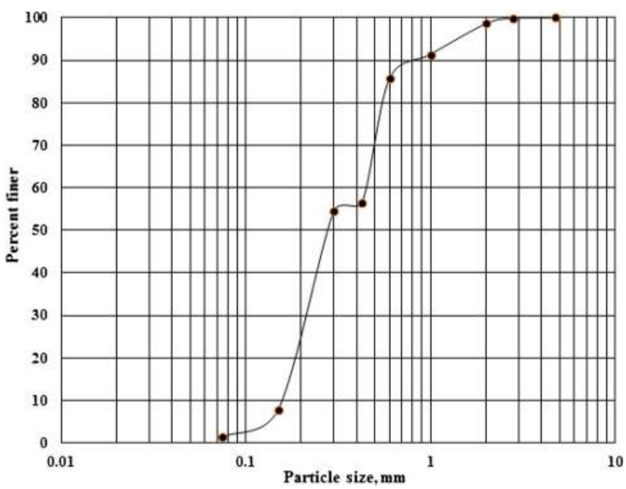


Fig. 8 Particle size distribution of test sand

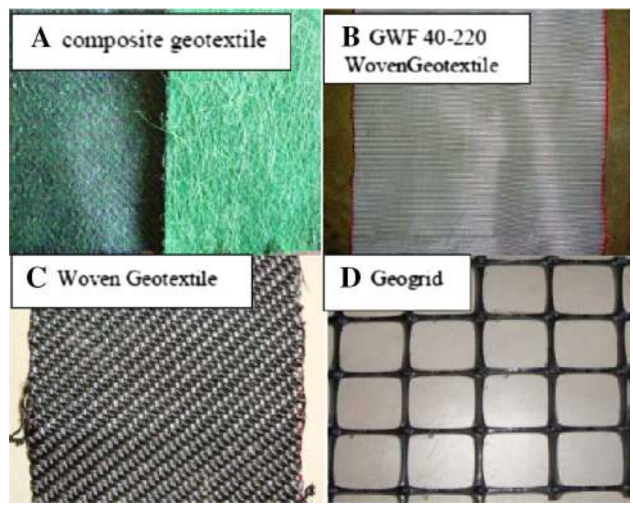


Fig. 9 Geosynthetic materials used

other side nonwoven), two types of woven geotextiles (B and C) with different tensile strength, and a geogrid (D). Tensile properties and mass per unit area of geosynthetic specimens were determined according to ASTM D4595 [18] and ASTM D5261 [19], respectively. Tensile load response curves of the geosynthetic materials (Fig. 10) were obtained for test specimens of 100 mm gauge length and 200 mm wide tested at 10 % strain rate using typical universal testing machine. The properties obtained for different geosynthetic materials are presented in Table 2. From the table it is seen that four materials adopted are of having different elongation levels at tensile rupture of the specimens ranging within 22 and 45 %. Though the tensile strengths of geosynthetics A and B are close to 38 kPa, their unit mass and elongation strains are very different indicating different material type and manufacturing process (woven and non-woven). The pullout tests were conducted using geosynthetic specimens of size 150 mm × 300 mm.

Test Details

The objectives of the testing program are: assessment of interaction properties of different geosynthetic materials and sensitivity of results with normal stress. Table 3 presents the details of the testing program adopted.

Pullout tests were performed in accordance with ASTM D 6706 [15]. The sand was placed into the pull-out box using pluviation method. The sand was filled up to the desired level before inserting the clamped testing specimen

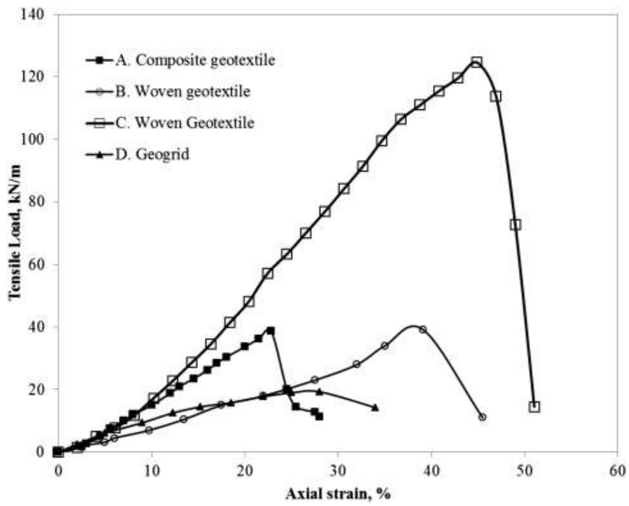


Fig. 10 Tensile load response curves of geosynthetic materials

through the slot and then further pluviation of sand is continued till the top of box. All samples were prepared at relative density 70 % which is equivalent to an average unit weight of 15.7 kN/m^3. A LVDT is fixed to the geosynthetic clamper (as shown in Fig. 7) to measure the horizontal displacement of the geosynthetic during the test. The load cell is connected to clamper (Fig. 7) to measure the load during the test and the same is connected to a screw-advanced drive system powered by a motor and gear system, which pulls the lead screw at constant displacement rate. After having arranged all, the normal stress was applied by adding dead loads on the mechanical lever arm. The clamped geosynthetic was pulled at a displacement rate of 4.57 mm/min. It is to be noted that displacement/shearing rate affects the test results as discussed by Farrag et al. [20] and Lopes and Ladeira [21]. Farrag et al. [20] recommended displacement rates between 2 and 6 mm/min for standard pull-out testing of geotextiles in sands. However, the results presented in the paper shall be referred with reference to the adopted displacement rate of about 4.6 mm/min.

Results

The axial pullout-displacement behavior of composite geotextile (A) at different normal stresses ($\sigma_n = 20$, 33 and 67 kPa) is shown in Fig. 11. The figure also presents the results of repeated tests to ensure the repeatability. It shows that there is significant variation of peak axial pullout resistance with change in normal stress (σ_n) but not in a proportion. An increase in the normal stress (σ_n) from 20 to 33 kPa results in an increase of 64 and 27.8 % in the peak pullout resistance and peak displacement respectively. For a normal stress of 33 kPa the pull-out resistance is equal to 20 kN/m whereas for approximately twice as much normal stress (67 kPa) the pull-out resistance is equal to 30 kN/m.

The effect of normal stress on pullout resistance of the geogrid with sand also investigated, shown in Fig. 12. Three different normal stresses ($\sigma_n = 15$, 28, and 36 kPa) were applied; an increase in confining stress from 15 to 28 kPa caused 67 % increase of peak pullout load. Further increase of normal stress (36 kPa) the specimen has reached its maximum tensile strength and failed.

To evaluate the effect of type of geosynthetic on axial pullout response, three different types of geosynthetics (A, B, and C) were tested at normal stress (σ_n) of 33 kPa. The pullout responses obtained are shown in Fig. 13. From the

Table 2 Properties of geosynthetics used in study

Properties	Composite geotextile (A)	Woven geotextile (B)	Woven geotextile (C)	Geogrid (D)
Mass per unit area (g/m^2)	697	244	1073	332
Tensile strength (kN/m)	38.8	38.17	125	19.3
Elongation at break (%)	22.8	38.5	45	28

Table 3 Testing program of pullout tests

Sl. no.	Purpose	Geosynthetic	Normal stress (σ_n) kPa
1	Effect of normal stress	Composite Geotextile (A)	67
			33
			20
2	Effect of normal stress	Geogrid (D)	28
			15
			36
3	Effect of type of reinforcement	Composite geotextile (A)	33

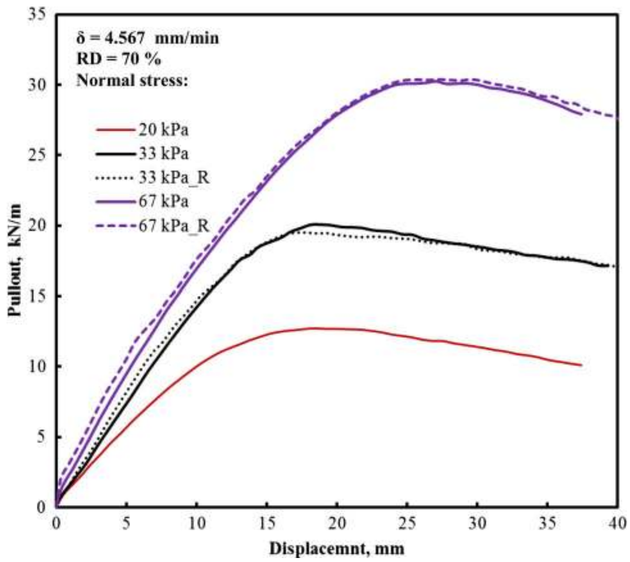


Fig. 11 Interfacial shear response of composite geotextile with sand at different normal stress

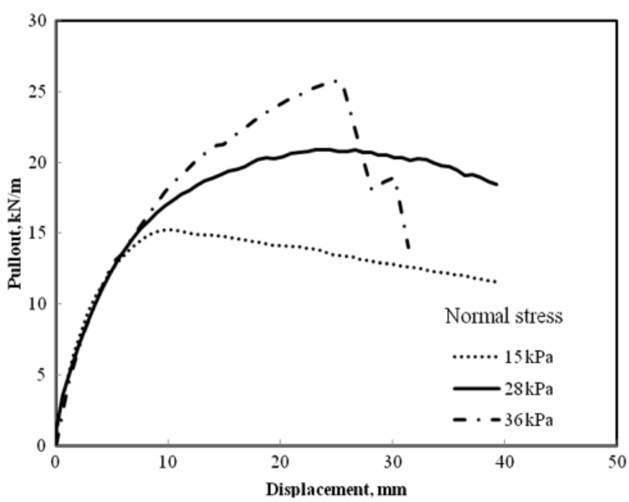


Fig. 12 Pullout-displacement response of geogrid with sand

figure it is noted that different geosynthetic materials exhibited different peak pullout resistance and the corresponding displacements. It is very interesting to observe the similar peak pullout responses of about 20 kN/m for geotextiles (A) and (C), in spite of huge variation in their tensile strength values (39 and 125 kN/m). On the other way, Geotextile specimen (B) showed different (lower) peak pullout response of about 11 kN/m from that of identical tensile strength Geotextile (A). These behaviors are related to the roughness (surface texture as in Fig. 9) properties of geosynthetics materials rather than their tensile strengths. In case of geotextile, the interfacial, resistance is mostly developed due to skin friction and impinging of soil particles with the fibers of the geotextile.

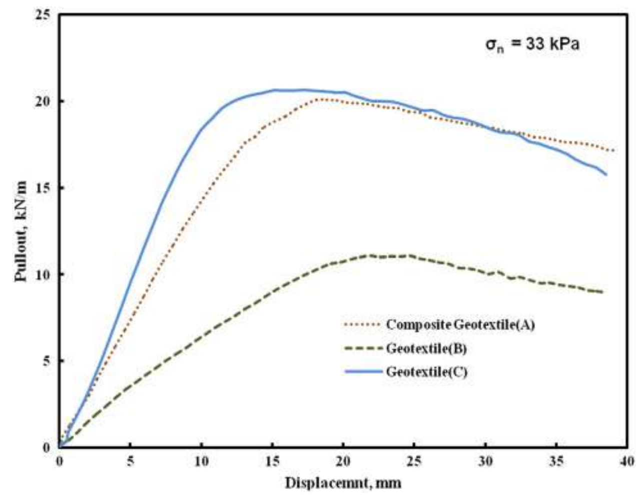


Fig. 13 Pullout-displacement response of different geosynthetics with sand

Thus geosynthetics having high roughness character results in higher soil–geosynthetic interaction values. Similar, roughness dependence of soil–geosynthetic interaction behavior was reported in literature [23, 24, 32].

Results of the pullout tests are generally represented in terms of efficiency factor ($\tan\delta/\tan\phi$), which was defined by Koerner [2]. Where 'δ' is the soil–reinforcement interface friction angle and 'ϕ' is the soil friction angle. However, few authors [4, 8, 33] have also presented the results of pullout in terms of friction coefficient (f^{*}), which is evaluated using Eq. 1. This can also be defined as ratio of maximum shear stress upon applied normal stress (Eq. 2).

$$f^{*} = \tan\delta = \frac{P_{\max}}{2 \times b \times l \times \sigma_n} \tag{1}$$

$$f^{*} = \frac{\tau_{\max}}{\sigma_n} \tag{2}$$

where $\sigma_n =$ normal stress; b and l are width and length of the geosynthetic specimen in contact with soil (150 and 300 mm, respectively); and $P_{\max}$ is the peak pullout load obtained from the test. In general, efficiency factors of a soil-geotextile were found to have in a range from 0.6 to 1.0 and values larger than one for soil-geogrid [2, 16].

Table 4 presents maximum peak pullout force, interfacial shear resistance ($\tau_{\max}$), and friction coefficient (f^{*}), obtained for all the interfaces tested in the new modified pullout test setup.

From the table it is clearly seen that the peak pullout loads and the associated pullout friction coefficient values are sensitive to normal stress and roughness parameter of the geosynthetics material. Pullout friction coefficient values are observed to be within the range 0.55–1.69. The lowest coefficient is observed for geotextile (B) at 33 kPa

Table 4 Pullout friction coefficient values

Type of material	Normal stress (σ_n) (kPa)	Peak pullout force (P) (kN/m)	τ_{max} kPa	Friction coefficient (f^*)
Composite geotextile (A)	20	12.27	20.44	1.02
	33	19.47	32.44	0.97
	67	30.4	50.11	0.75
Woven geotextile (B)	33	11.07	18.44	0.55
Woven geotextile (C)	33	20.67	34.44	1.03
Geogrid (D)	15	15.2	25.33	1.69
	28	20.87	34.78	1.24

normal stress which is primarily attributed to its relatively smoother (less roughness) nature. For geogrid, the coefficient of friction values are higher than one for both the normal stress (15 and 28 kPa). Table 4 results indicate that pullout load and shear stress are increased with increase in the normal (confining) stress. However, the friction coefficients were reduced with increase in normal stress. This behavior could be justified with the nonlinear behavior of pullout response with increase in confining stress. In general it can be stated that the pullout behavior is sensitive to the normal stress and the type of geosynthetics in terms of its surface roughness (texture).

Concluding Remarks

This paper has presented the modifications to the direct shear test setup for evaluating the soil–geosynthetic interaction parameters under pullout and the test results obtained. The shear box in the conventional direct shear test setup has been replaced by a pullout box having a slot in its front face, through which the geosynthetic sample is projected out for pullout. In this modification, the geosynthetic specimen is held in position, while the neighboring soil along with the box is pulled away. It is advantageous to pull the geosynthetic, rather than the box, because the movement of loading yoke during testing process can be effectively arrested. This was achieved by changing the positions of the pullout box and loading yoke, extended lever arm and distance of the counter weight.

The suitability of the modified set-up for conducting pull-out test is demonstrated through sample tests. Pullout tests were presented and discussed. Effect of normal stress and type of geosynthetics on the soil–geosynthetic interaction parameters are brought out. It is confirmed that the interaction parameters are highly sensitive to the normal stress and the surface roughness nature of the geosynthetic materials. The pullout friction coefficient values determined from various tests fall within the range of 0.55–1.69 for the materials used in the study. The pullout resistance and friction coefficient are affected more by the surface texture of the geosynthetics rather its ultimate tensile strength. As the geosynthetics used in the study are extensible, the extensibility measurements of geosynthetic specimens would have been beneficial in evaluating the accurate soil–geosynthetic interaction behavior.

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