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# Dilatancy behavior of soil-structure interfaces for farm roads and embankments

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**Abstract**

The dilatancy behavior is one of the major factors that control the performance of agricultural earth structures during the pullout of geosynthetic and geogrid subject to reinforced slopes, earth embankments or dams. In this article, a new apparatus according to the JIS standard for pullout test is built to evaluate the dilatancy behavior of two types of soils reinforced with geosynthetic/geogrid. A series of pullout tests are carried out to study the effect of type of reinforcements and soils on dilatancy behavior at soil-reinforcement interfaces. Two types of geosynthetic and geogrid, such as, stabilanka and fortrac those are widely used in Japan and globally, are demonstrated. All the pullout tests are performed under six normal stress conditions in order to obtain more precise results of the dilatancy behavior. The parameters of dilatancy behavior of pullout tests are quantified in terms of vertical displacements. The analyses of the data and information reveal that fortrac has higher dilatancy in clayey soil whereas stabilanka has higher dilatancy in sandy soil. Among the four cases investigated in this article, the highest dilatancy is occurred for fortrac in clayey soil. It is concluded that the fluctuating nature of dilatancy which is usually observed in the soil-soil interface without any reinforcement is significantly improved due to the use of reinforcement in soil and almost constant dilatancy is obtained at soil-structure interfaces even until the end of horizontal displacement.

**Keywords:** Agricultural earth structures, dilatancy behavior, stabilanka (geosynthetic), fortrac (geogrid), pullout, soil-structure interface.

**Abbreviation:** $\phi$ : Angle of internal friction, $c$ : Cohesion, $\gamma_d$ : Dry density, $W_{opt}$ : Optimum water content, $\rho_s$ : Specific gravity, JGS: Japanese Geotechnical Society, JIS: Japanese Industrial Standards, kN/m: Kilo Newton per meter, kPa: Kilo Pascal, Max: Maximum, mm: Millimeters.

## Introduction

Dilatancy behavior of soil-structure interfaces, a phenomenon of volume change or shape of earth structures, plays a significant role on the overall performance of agricultural earth structures during construction and on service (Williams et al, 1987). Reinforced earth structures normally endure dilatancy behavior when its reinforcement subjected to pulled out from soil (Mahmood, et al. 2000). Practically, pullout of reinforcement occurs when a soil mass tend to move or slip over a failure surface. An example of pullout of reinforcement of a reinforced slope is shown in Fig.1 indicating the pullout phenomena and soil-reinforcement interfaces. The dilatancy behavior of soil-structure interfaces is usually performed in the laboratory by pulling out the reinforcement embedded in soil. Application of various types of reinforcements in the construction of reinforced soil structures can be found in the technical literatures of which stabilanka and fortrac are most commonly used and are well known (Zanzinger et al. 2001, Kuwano et al. 1999 and Izawa et al. 2001, Hossain 2010). In the present investigation, two types of reinforcements such as stabilanka (geosynthetic), fortrac (geogrid), those are not only widely used and easily available in the local market but also applied all over the world for soil reinforcement applications, are demonstrated. It should be pointed out here that the study on pullout and shear strength of soil-structure interfaces has been carried out rather extensively in the past (Madhab et al. 1998 and Ghionna, et al. 2001). However, the dilatancy behavior of reinforced soil which is an important parameter for understanding the deformation characteristics has not been given considerable attention yet. It is, therefore, utmost crucial to investigate the dilatancy behavior of various soils reinforced by different types of reinforcements for safe design of reinforced soil structures. Unfortunately, there is no code or guideline available on the pullout effect of reinforcements treated in this research article such as stabilanka (geosynthetic), fortrac (geogrid); on dilatancy behavior of soil-reinforcement interface although it presents a considerable versatility in the development of reinforced soil structures. Moreover, to the knowledge of the authors, no attempt has so far been made to investigate the comparative study of reinforced soils treated in this paper such as sandy and clayey soils. In view of the above objectives and necessities, the present investigation is undertaken for comparing the overall response of dilatancy behavior due to pullout of geosynthetics and geogrids embedded in two types of soils. Dilatancy performances of soil-structure interfaces with two types of geosynthetics and geogrids namely stabilanka (geosynthetic) and fortrac (geogrid) are carried out using sandy and clayey soils of Mie prefecture, Japan. All the tests are performed under six normal stresses such as 6, 12, 18, 24, 30 and 36 kPa in order to find out the effect of types of soils and geosynthetics on dilatancy behavior. For clear understanding, the dilatancy behavior is quantified in terms of vertical displacement versus horizontal displacement relationships. The paper also reported an analysis to find out the maximum dilatancy at soil-structure interfaces and soil-soil interface for effective design of reinforced soil structures.

**Properties of materials**

***Properties of soils***

The particle size distribution curve of sandy soil (Fig.2) reveals that nearly 9% of the soil is coarse clay, 7% is fine silt, 6% is coarse silt, 14% is fine sand, 44% is medium sand and more than 20% is coarse sand which means that more than 90 percent of the soil is in the silt and sand fraction. The particle size distribution curve of clayey soil plotted in Fig.2 indicates that nearly 33% of the soil is clay, 24% is fine silt, 5% is medium silt, 4% is coarse silt, 12% is fine sand, 14% is medium sand and 6% is coarse sand which means that more than 66% percent of the soil is in the clay and silt fraction. The other properties of sandy and clayey soils used in these tests are depicted in Table 1.

***Properties of stabilanka (geosynthetic) and fortrac (geogrid)***

The stabilanka (geosynthetic) is made of polyester yarns by interweaving each other in such a way that there is no gap among the filaments (Fig.3a). Thus, the stabilanka looks like a sheet in nature. The junctions are not sheathed nor connected with a protective sheathing. The sheet is 2.0 mm in thickness and commercially nomenclature as Type 800/100, which means that it has a tensile strength of 800 kN/m in the longitudinal direction and 100 kN/m in the transverse direction. The filament is 2.0 mm in diameter with c/c openings of 4.0 mm in the longitudinal direction and 1.0 mm in diameter with 2.0 mm c/c openings in the transverse direction. The physical appearance of fortrac (geogrid) obtained commercially is manufactured from polyester yarns (Fig.3b). The junctions of this geogrid are directly connected and greatly improved by interweaving the yarns and then it is coated with a protective sheathing. The strength of the junctions is adequate to transmit the envisaged loadings. The cross-section of geogrid strand is $2 \times 6$ mm in longitudinal direction and 1.0 mm filament diameter in transverse direction with center to center (c/c) openings of 24.0 mm in longitudinal direction and 20.0 mm in transverse direction. This geogrid is commercially nomenclature as Type 150/30 which has a tensile strength of 150 kN/m in the longitudinal direction and 30 kN/m in the transverse direction.

**Table 1.** Properties of soils

| Parameters | Sandy soil | Clayey soil |
|---|---|---|
| Dry density ( $\gamma_d$ ) | 1.83 t/m$^3$ | 1.53 t/m$^3$ |
| Optimum water content ( $W_{opt}$ ) | 15.3% | 25.0% |
| Specific gravity ( $\rho_s$ ) | 2.64 | 2.7 |
| Cohesion ( $c$ ) | 5.01 kN/m$^2$ | 64.3 kN/m$^2$ |
| Angle of internal friction ( $\phi$ ) | 32.19$^o$ | 16.01$^o$ |
| Sand, >75 $\mu m$ | 78% | 34% |
| Silt, 5-75 $\mu m$ | 13% | 33% |
| Clay, <5 $\mu m$ | 9% | 33% |
| Liquid limit | - | 29.3% |
| Plastic limit | - | 56.2% |
| Plasticity index | - | 26.9 |

**Equipment and methodology**

***Description of the testing equipment***

The apparatus used in this study is capable of performing both pullout and direct shear tes**ts** (Fig.4). Some important features incorporated in the testing equipment are the monitoring of soil dilatancy and the testing arrangement wherein the clamping system [5] for pullout test is located outside the compacted soil to ease of clamping the reinforcement. The pullout box is a rectangular shape of size 150 mm in length, 100 mm in width and 100 mm in height. The box is divided into two parts namely upper [7] and lower [9] boxes, both are 50 mm in depth. The apparatus is designed in such a way that the mobility of soil parallel to the pullout surface is restricted completely by the four side walls along with its girder [8] during the test. The friction between the upper box and the geosynthetics is eliminated with the help of the vertical screws that have been set at both sides of the upper box. The normal stress at the bottom surface of the lower box applied through the lower jack [12] in the upward direction is balanced by the opposite stresses of the upper box [6]. The stresses into the soil are uniformly distributed by adjusting the screw at the top surface of the upper box. The lower and upper boxes are set in such a way that there is no friction between the box wall and the geosynthetics. For the pullout test, the upper part is set to the lower part with the clamping screw. It can be freed while performing the direct shear test. The pullout/direct shear force can be measured by means of an electrical loading cell [4], which is set to a display panel [2]. Front displacements, vertical displacements and the displacements along the reinforcement are measured using dial gages [3 & 11].

***Method of testing***

The geosynthetic was cut to obtain rectangular pieces of 250 mm by 100 mm in size. The specified lengths of the pieces were selected in order to clamping facilitate with the pullout apparatus. As can be seen from Fig.4, the geosynthetic [10] was clamped into the box in such a way that the embedded length of the geosynthetic was 150 mm in the loading direction and 100 mm in the transverse direction during the pullout tests. Water was added gradually to the soil and mixed up to obtain the desired water content uniformly throughout the soil and then it was poured into the bottom box. After embedding the geosynthetics on the soil of the bottom box, the upper box was fastened to the lower box and then additional soil was filled in the upper box. The tests were carried out by pulling out the geosynthetic from the soil with a constant speed of 1.0 mm/min by means of a screw jack under electrically operated constant pressure [1]. The pullout force was measured using a tension load cell with a least count of 5.0 N. The load cell [4] was set between the geosynthetic and the clamping jack to facilitate direct load measurement on the cell avoiding any frictional discrepancy on the machine components. The displacements were measured at the front of the geosynthetics by means of a dial gage [3] with a least count of 0.001mm. The dilatancies were measured at the lower side of vertical load jack by means of a dial gage [11] with a least count of 0.001mm. The soil was compacted in three layers for all the tests and thus obtained the same density of the soil for all the pullout tests. The tests were carried out with 14.63% water content of sandy soil and 26.54% water content of clayey soil whereas the optimum water contents were calculated as 15.3% and 27.0% for sandy and clayey soils, respectively. After performing the experiment, a close inspection of the tested reinforcements by visible observation was made. This indicates that no extension of geosynthetics was observed during the

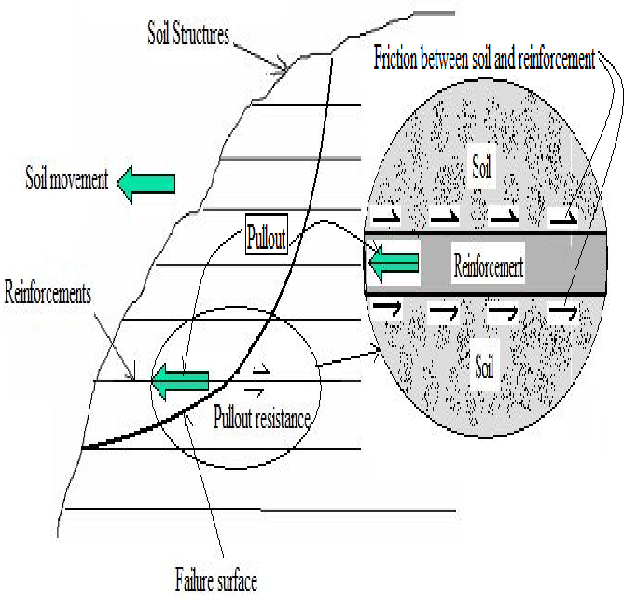


**Fig1.** Pullout phenomena and soil structure interface

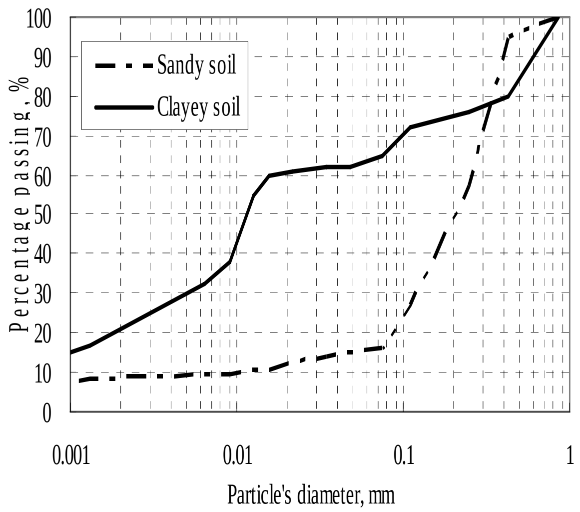


**Fig2** . Particle size distribution curve of sandy and clayey soil

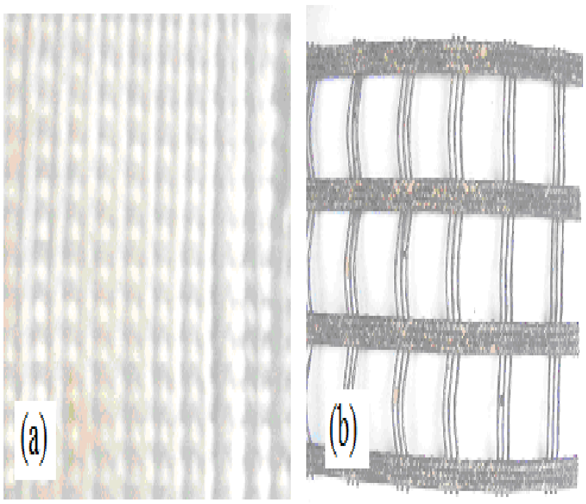


**Fig 3.** (a) Stabilanka (geosynthetic), (b) Fortrac (geogrid)

pullout test. This was also confirmed by the fact that the maximum pullout stress needed for this test was much lower than the tensile strength of geosynthetics/geogrids. Therefore, the pullout displacement was measured at a point in front of the geosynthetics/geogrids. It should be pointed out here that the testing equipment is designed by following the standard of JIS and the Japanese Geotechnical Society (JGS: T941-199X). The equipment can take a maximum normal stress of 2 kg/cm$^2$ which is the same as of the standard of JGS: T941-199X. The inner walls of the pullout box were smooth enough as they were coated by galvanized steel to reduce frictional resistances between the side walls and the soils as well as between the side walls and the geosynthetics.

## Results and discussion

### *Dilatancy behavior of stabilanka in sandy soil*

The dilatancy behavior in the form of vertical displacement and horizontal displacement of pullout test for stabilanka in sandy soil with water content 14.36% is plotted in Fig .5. It is interesting to note that there was not any negative vertical displacement for any normal stress. There is very small amount of vertical displacement for normal stress of 12 kPa. On the other hand, the vertical displacement for normal stress of 30 and 36 kPa increases stiffly with the increase in horizontal displacement, especially, at the initial loading stage. The vertical displacement becomes doubled when the normal stress changes from 24 to 30 kPa and further resumes its doubling trend when normal stresses are increased from 30 to 36 kPa. At normal stress of 36 kPa, the vertical displacement maintains its upswing trend even until the horizontal displacement of 45 mm. The maximum vertical displacements are calculated as 0.00, 0.02, 0.11, 0.14, 0.34 and 0. 78 mm for the normal stresses of 6, 12, 18, 24, 30 and 36 kPa, respectively.

### *Dilatancy behavior of stabilanka in clayey soil*

Figure 6 depicts the relationships between vertical displacements and horizontal displacements of the pullout tests for stabilanka in clayey soil. Negative vertical displacement that was not observed in the case of sandy soil becomes apparent in the case of clayey soil especially for normal stress of 6 kPa. There is very small amount of positive vertical displacement for normal stress of 12 kPa. Even after the peak values, the vertical displacements for higher normal stresses increase more or less similar trend with the increase in horizontal displacement. Upswing trend continues until the end of horizontal displacement for all the four normal stresses such as 18, 24, 30 and 36 kPa. All the four curves follow the same pattern and these characteristics have not been attributed in the previous case such as stabilanka in sandy soil. For this case, the maximum vertical displacements are calculated as -0.08, 0.015, 0.17, 0.24, 0.34, and 0.49 corresponding to normal stresses of 6, 12, 18, 24, 30 and 36 kPa, respectively.

### *Dilatancy behavior of fortrac in sandy soil*

In Fig.7, the relationships between the horizontal displacement and vertical displacement of pullout test for fortrac subject to normal stresses of 6, 12, 18, 24, 30 and 36 kPa in sandy soil are depicted. At lower normal stresses such as 6 and 12 kPa, the increase of vertical displacement is insignificant for any amount of horizontal displacement. However, at higher normal stresses, such as at 18 to 36 kPa, the amount of vertical displacement is increased with the increase in horizontal displacement, especially,

**Fig4.** Pullout and shear testing apparatus

1-Mechanical jack for pullout
2-Display for pullout stress
3-Horizontal displacement measuring dial gage
4-Load cell
5-Clamping jack
6-Balancing normal stress
7- Upper/top pullout box
8- Clearance providing device
9- Lower/bottom pullout box
10-Reinforcement
11-Dilatancy measuring device
12-Normal stress measuring dial gage

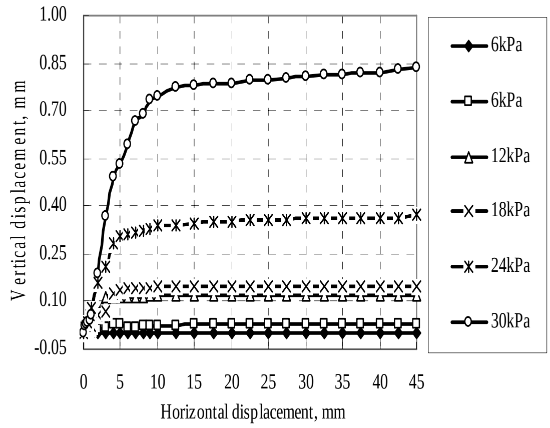


**Fig 5.** Vertical vs. horizontal displacement relationships for stabilanka in sandy soil

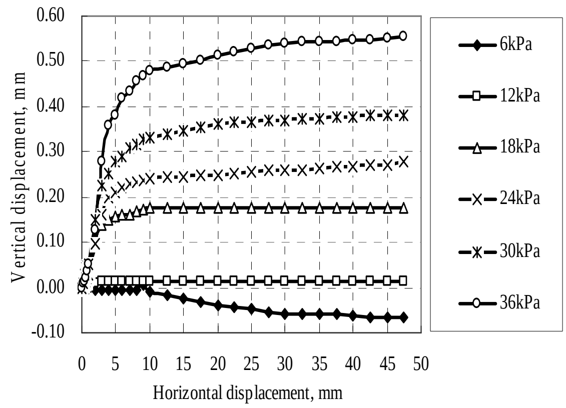


**Fig 6.** Vertical vs. horizontal displacement relationships for stabilanka in clayey soil

up to 10 mm of horizontal displacement. Here, slightly negative vertical displacement can be observed for the case of 6 kPa normal stress only. At about 7 to 10 mm of horizontal displacement, the maximum values of vertical displacements can be noted for all the cases. After that, the vertical displacements are almost constant and all the curves become parallel to x-axis for any value of horizontal displacement. As expected, the vertical displacement is more for higher normal stresses. The maximum vertical displacement are recorded as -0.001, 0.01, 0.12, 0.10, 0.21 and 0.635 mm corresponding to the normal stresses 5, 12, 18, 24, 30 and 36 kPa, respectively.

***Dilatancy behavior of fortrac in clayey soil***

The vertical displacement versus horizontal displacement relationships for fortrac in clayey soil are given in Fig.8. It is evident that the vertical displacements are almost zero for normal stress of 6 kPa and gently increase for normal stresses of 12 and 18 kPa. At higher normal stresses such as 24 to 36 kPa, the increase in vertical displacement is remarkable at initial loading stage. Dissimilar to the sandy soil, the vertical displacement shows its gradual increase with the increase in horizontal displacements at higher normal stresses. However, at lower normal stresses, the trend that was observed in the case of sandy soil remains similar in the case of clayey soil except normal stresses of 18 and 24 kPa. The rate of increase of the vertical displacement is higher at higher normal stress (36 kPa) in the case of clayed soil. The maximum vertical displacements can be noted as -0.009, 0.013, 0.039, 0.63, 0.54 and 0.84 mm for the six normal stresses of 6, 12, 18, 24, 30 and 36 kPa, respectively.

***Maximum dilatancy***

In order to obtain a clear perception and comparison among the dilatancy phenomena under pullout tests, maximum vertical displacements corresponding to normal stresses for different cases are shown in Fig.9. Scatters in the dilatancy phenomena depending on the type of soils and geosynthetics/geogrids can be noted but is not so rigorous. The negative value of vertical displacement indicates an increase in volume whereas the positive values are for a decrease in volume. Very few cases have negative vertical displacements which mean that an increase in volume occurred for few cases, especially, in the lower normal stress such as 6 kPa, only. The increase in volume under lower normal stress mainly depends on the disturbance of soil particles at the soil-structure interfaces during pullout. It is known that at the lower normal stress, the soils are in the situation of over consolidation region facilitating more disturbances of the soil particles at the soil-structure interface during pullout of reinforcement. On the other hand, most of the test results have positive vertical displacement as well as decrease in volume of soil during the pullout test under higher normal stresses. This is thought to be due to the fact that as the normal stress increases, the additional pressure is applied to the soil-structure interfaces and thereby, the soil particles near to the surface of structure are reconsolidated and lead to the situation of normally consolidated condition.

***Dilatancy behavior of soil-soil interface (without reinforcement)***

For more clarification of dilatancy behavior of reinforced soil with respect to the bench mark dilatancy behavior of soil-soil interface without reinforcement, direct shear test of both the soils are performed without any reinforcement and the results are given in Fig.10. The fact discussed in the previous section can

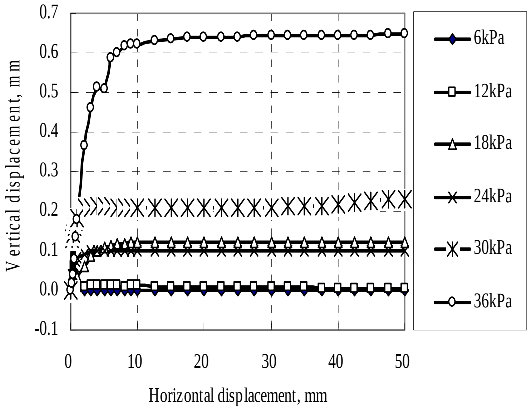


**Fig 7.** Vertical vs. horizontal displacement relationships for fortrac in sandy soil

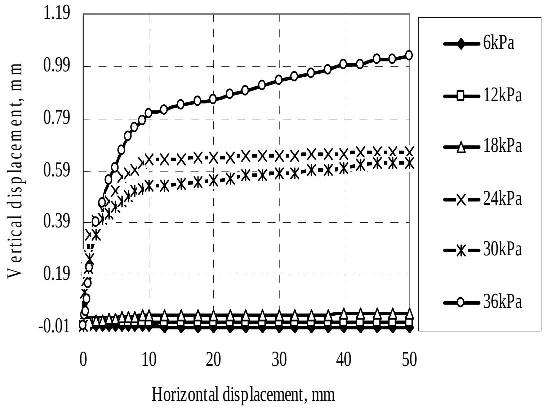


**Fig 8.** Vertical vs. horizontal displacement relationships for fortrac in clayey soil

be discerned from this figure which depicts that the dilatancies of clayey soils are higher than that of the sandy soils under any normal stresses indicating more consolidation of the clayey soils than the sandy soils. As expected, the dilatancy behavior of both soils used in pullout tests follows the usual pattern that are generally obtain under direct shear tests. In spite of several tests and results of soil-structure interaction under pullout test as depicted above, it is apparent that the fluctuating nature of dilatancy that is usually found in the soil-soil interface without any reinforcement (Fig.10), is conspicuously absent in the case of reinforced soil at soil-structure interfaces (Figs.5-8).

**Discussion**

The dilatancy (vertical displacement) increases with the increase in pullout displacement for both reinforcements in sandy and clayey soils. This type of behavior can be observed in both soils for rigid and flexible reinforcements (Hossain and Sakai 2008). Scatters in the dilatancy phenomena for various types of reinforcements in different soils are common features of pullout behavior. These characteristics can be found in the technical literatures for composite reinforcements (Hossain 2010). Dilatancy behavior of soil-soil interface obtained by the shear and pullout testing apparatus agrees well with the results obtained by the traditional apparatuses (JGS, 2000).

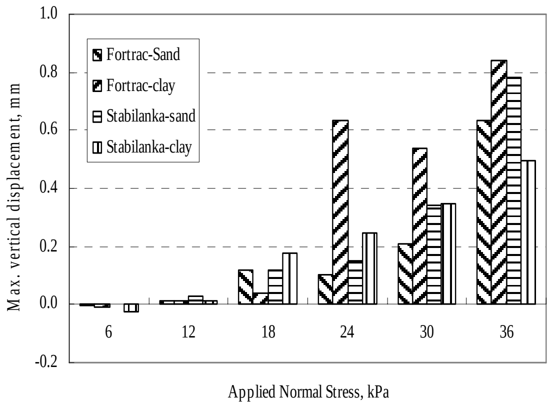


**Fig 9.** Maximum dilatancy at soil-structure interface

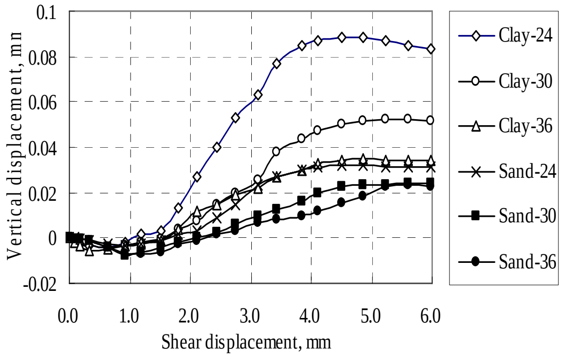


**Fig 10.** Dilatancy behavior of soil without reinforcement

**Conclusions**

It is observed that the fundamental pullout tests are useful in characterization of dilatancy behavior at soil-reinforcement interfaces. The common feature is that there is an increase in vertical displacement with the increase in horizontal displacement for all the cases studied in this article. In case of sandy soil, the vertical displacement increases initially with the increase in horizontal displacement and then shows its constant value even until the end of horizontal displacement irrespective of type of reinforcements. On the other hand, in case of clayey soil, the vertical displacement after reaching its peak value shows its continuous change (increase for higher normal stresses and decrease for lower normal stresses) irrespective of type of reinforcements. There are some scatters in the maximum dilatancy values. Nonetheless, most of the cases show positive dilatancies at higher normal stress for any type of soils and reinforcements. Fortrac has higher dilatancy in clayey soil whereas stabilanka has higher dilatancy in sandy soil. Among the four cases investigated in this article, the highest dilatancy is occurred for fortrac in clayey soil. These things should be taken into account in the design of reinforced soil structures with geosynthetics/geogrids. The fluctuating nature of dilatancy which is usually observed in the soil-soil interface without any reinforcement is significantly improved due to the use of reinforcement in soil and almost constant dilatancy is obtained in the case of reinforced soil at soil-structure interfaces.

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