砂質土におけるジオシンセティクスの引き抜き挙動について
On the Pullout Behavior of Geosynthetics in Sandy Soil

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Introduction: Effect of types of geosynthetics on pullout behavior is one of the major contentious issues in designing all sorts of reinforced earth structures. A study on the pullout behavior of two types of geosynthetics such as fortrac and stabilanka in sandy soil is made to find out their effects on soil-reinforcement interactions. A series of pullout tests with six normal stresses have been carried out in the laboratory in order to obtain pullout behavior of the geosynthetics. In this paper, the parameters of pullout behavior such as cohesion and frictional resistances for both the geosynthetics with sandy soil are presented and compared. Pullout behaviors in terms of stress-displacement relationships and ultimate strengths are depicted in various charts and diagrams as a ready reference to aid in practical design and constructions. It is observed from the results of the pullout tests performed that the stabilanka geosynthetic has less frictional resistance and more cohesion in sandy soil than that of the fortrac geosynthetic.

Materials: The particle size distribution curve of sandy soil 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 mean that more than 90 percent of the soil being in the silt and sand fraction. The average specific gravity of the soil is calculated as 2.644. The other properties of the soil used in these tests are given in Table 1. The fortrac geosynthetic is manufactured from polyester yarns. The junctions of this mesh are directly connected and greatly improved by interweaving the yarns and then it is coated with protective sheathing. The strength of the junctions is adequate to transmit the envisaged loadings. The cross-section of geogrid strands is 2mmX6mm in longitudinal direction and filament diameter of 1.0mm in transverse direction with center to center openings of 24mm in longitudinal direction and 20mm in transverse direction. This mesh is commercially nomenclatured as Type 150/30-20 which has tensile strengths 150 kN/m in longitudinal direction and 30 kN/m in transverse direction. The stabilanka geosynthetic is also manufactured from polyester yarns by interweaving each other in such a way that there is no gap among the filaments. Thus, the stabilanka geosynthetic looks like a sheet in nature. The junctions are not sheathed nor connected with protective sheathing. This sheet is commercially nomenclatured as Type 800/100, which means that it has tensile strengths 800 kN/m in longitudinal direction and 100 kN/m in transverse direction. The thickness of the sheet is 2 mm.

Table 1 Properties of sandy soil

Dry density (γ_d)	1.83 t/m^3
Optimum water content (W_{opt})	15.3%
Specific gravity (ρ_s)	2.64
Cohesion (c)	5.01 kN/m^2
Angle of internal friction (ϕ)	32.19^o
Sand, >75μm	78%
Silt, 5-75μm	13%
Clay, <5μm	9%

Methodology: The geosynthetic was cut to obtain rectangular pieces of 200 mm by 100 mm in size. The specified lengths of the pieces were selected in order to facilitate ease of clamping with the pullout apparatus. The geosynthetic was clamped into the box in such a way that the embedded length of the geosynthetic is 150 mm in the loading direction and 100 mm in the transverse direction. Water was added gradually to the soil and mixed up to obtain desired water content uniformly throughout the soil and then it was poured into the bottom box. After embedding the geosynthetics on the soil poured in the lower part of the box, the upper part was fastened to the lower part and then additional soil was filled in the upper box. The tests were carried out in the way of pulling out the geosynthetic from the soil with constant speed of 1 mm/min by means of screw jack under electrically operated constant pressure. The pullout force was measured using a tension load cell with a least count of 5 N. The load cell 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 geosynthetic by means of a dial gage with a least count of 0.001mm. After each testing, the geosynthetic piece was removed and replaced with another one to account for the damages in the geosynthetic's texture that might have occurred as a result of previous test. The dilatancies were measured at the lower side of vertical load jack by means of a dial gage with a least count of 0.001mm.

Results and discussion: Pullout stress-displacement relationships of fortrac geosynthetic as depicted in Fig.1. show that the pullout stress is increasing linearly with the increase in displacement of about 12mm. After that, it increases nonlinearly with the increase in displacement of about 16mm. The pullout stress fluctuates with displacement exceeding 16mm and continues in the same fashion of up to 50mm. This may be due to the variation of stress distribution along the reinforcement in the loading direction. Because of the rectangular cross section and larger grid size of the fortrac reinforcement, some soils might be accumulated some

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soils in the front side of the transverse filament which gives an increase in soil pressure and after accumulation of certain amount of soil i.e. while the accumulation exceeds the limit to cause failure, the pullout stress becomes decrease by slippage of the soil particles. As expected, for all the test results, the pullout resistance is more for higher normal stresses. The ultimate pullout strengths for fortrac geosynthetic in sandy soil are calculated as 14.4 kN/m^2, 12.4 kN/m^2, 26.6 kN/m^2, 30.8 kN/m^2, 36.6 kN/m^2 and 58.4 kN/m^2 for normal stresses 6 kN/m^2, 12 kN/m^2, 18 kN/m^2, 24 kN/m^2, 30 kN/m^2 and 36 kN/m^2, respectively.

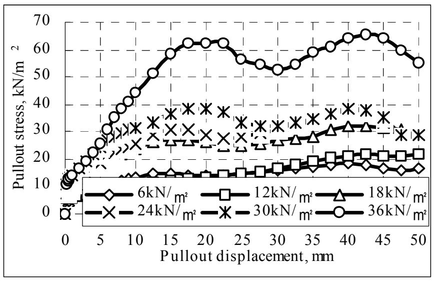

Fig.1. Stress-displacement curves for fortrac

All the six graphs of stress-displacement relationships for stabilanka geosynthetic as plotted in Fig.2. belong to the same characteristic at the initial stage and can be taken in a group with the linear portion restricted to the displacement of about 3.0 mm. Then, all the curves become nonlinear with the pullout displacement of 4.0 mm to 10.0 mm. A greater part of linearity can be taken from 10.0 mm to 45.0 mm displacement for higher normal stresses such as 18 kN/m^2, 24 kN/m^2, 30 kN/m^2 and 36 kN/m^2. The fluctuating trend of the pullout stresses with the increase in pullout displacement for lower normal stresses such as 6 kN/m^2 and 12 kN/m^2 is clearly evident from this figure. This phenomenon mainly depends on the surface roughness of stabilanka. Unlike to the fortrac geosynthetic, pullout stresses are almost smooth at higher normal stresses and fluctuates rapidly at lower normal stresses owing to more smoothing surface of stabilanka than that of the fortrac geosynthetic. The ultimate strengths vary apparently; they have values of 13.66 kN/m^2, 20.73 kN/m^2, 21.2 kN/m^2, 26.33 kN/m^2, 26.66 kN/m^2 and 29.53 kN/m^2 for the six applied normal stresses.

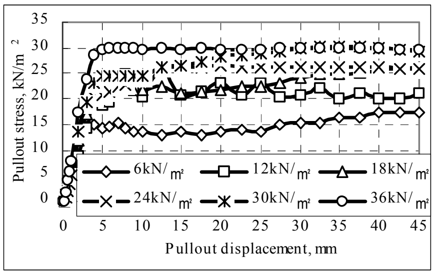

Fig.2. Stress-displacement curves for stabilanka

For the sake of clear perception of the bearing capacity under pullout test, the ultimate pullout strengths corresponding to the different normal stresses are plotted as bar diagram in Fig.3. It is evident that the ultimate pullout strengths are increasing with the increase in normal stresses for any type of geosynthetics. The ultimate pullout strengths of fortrac geosynthetics are higher than the stabilanka geosynthetic under all the normal stresses except 12 kN/m^2. In order to calculate the cohesion and internal friction, the linearized curves are given in Fig.4. Fortrac geosynthetic shows more frictional resistance whereas stabilanka geosynthetic has higher cohesion. This may be the effect of surface roughness as well as grid size and shape of the geosynthetic. The larger grid size of fortrac geosynthetic causes more frictional resistance and large surface area of stabilanka geosynthetic provides more cohesion intercept. The following equations are obtained from the straight lines as plotted in Fig.4. for fortrac (*f*) and stabilanka (*s*) geosynthetics, respectively

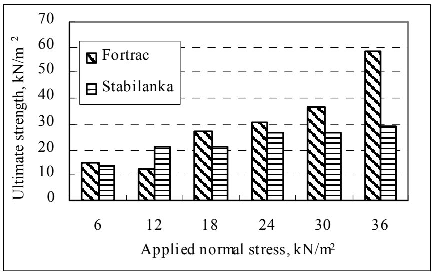

Fig.3. Comparison of ultimate strengths

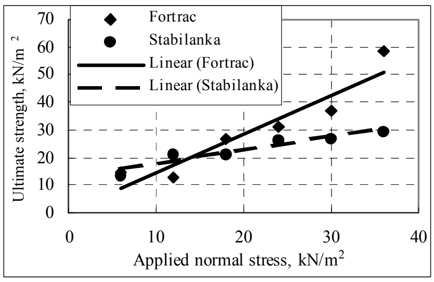

Fig.4. Linearized curves of ultimate strengths

$$\tau_f = 1.4067\,\sigma_f + 0.4489 \quad ---- \quad (1)$$

$$\tau_s = 0.4870\,\sigma_s + 12.796 \quad ---- \quad (2)$$

where, τ is the pullout resistance on both surfaces of reinforcement in kN/m^2 and σ is the applied normal stress on reinforcement in kN/m^2. Therefore, the values of cohesion are obtained as 0.4489 kN/m^2 and 12.79 kN/m^2 kN/m^2, and the angles of internal friction are calculated as 54.52 and 25.96 degrees for fortrac and stabilanka geosynthetics, respectively.

Conclusions: There is an increase in pullout stress with the increase in displacement as well as with the increase in normal stress for any type of geosynthetic. The fortrac geosynthetic has more frictional resistance and less cohesion than that of the stabilanka geosynthetic in sandy soil. Equations for strength parameters of the individual categories presented in this paper may be useful to aid in design of reinforced soil structures.

References: 1) 座狩屋保世院 and 井上宗治 (2002) : Studies on Square Wire Mesh/Soil Interface Shear Strength, 平成 14 年度農業土木学会京都支部研究発表会講演要旨集、pp.126-127.