THREE-DIMENSIONAL EFFECT ON PULLOUT RESISTANCE OF GEOGRID STRIP REINFORCEMENT

Member ○ K. Watanabe Saga University
Member S. Hayashi Saga University
Member M.C. Alfaro Saga University

I INTRODUCTION

This paper describes the investigation on the combined 2-D and 3-D interaction mechanisms of geogrid strip reinforcement embedded in dense granular soil. It also describes the laboratory test program that was undertaken to evaluate the parameters of the corresponding interaction mechanism. The results obtained are presented and discussed.

II CONCEPTUALIZED PULLOUT INTERACTION MECHANISM

When strip type of reinforcement is placed in dense granular soils, it involves a three-dimensional (3-D) interaction mechanism as a consequence of restrained dilatancy effect. As the strip reinforcement is pulled out which produced shear at the interface, the zone of soil surrounding the reinforcement tends to dilate. However, the volume change is restrained by the surrounding non-dilating soil inducing an increase in normal stress on the soil-reinforcement interface. Modern practice of reinforced soil systems which includes the utilization of geosynthetic reinforcements (e.g.,geogrids) commonly adopts wider strip which ranges from 0.20 m to 1 m. In such a case, the soil-reinforcement interaction phenomenon is a combination of the plain strain or 2-D interface friction mechanism at middle section and the 3-D interface friction mechanism at both edges of the strip reinforcement as shown in Fig. 1. The non-dilating zone in the soil surrounding the strip reinforcement functions as a restraint against soil

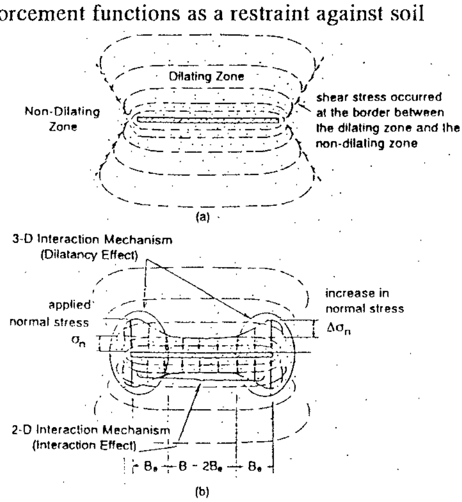

Fig.1 Pullout Interaction Mechanism

dilatancy in the dilating zone.This generates shear stress at the border between the dilating and the non-dilating zones resulting to an increase in applied normal stress at both edges of the strip reinforcement. A 3-D interface friction mechanism will develop at both edges of the strip reinforcement while its middle section has a 2-D interaction behavior. The shear stress, and thus the increase in normal stress, increases as the tendency of dilatancy propagates with shear displacement at the interface.

For the above interaction mechanism, the following relationship is proposed for the mobilized pullout resistance, P_{TE}:

$$P_{TE} = P_{2-D} + P_{3-D} \quad (1)$$

Equation (1) can be expressed as:

$$P_{TE} = 2 \cdot B \cdot L_e \cdot \sigma_n \tan\delta_p + 4 \cdot B_e \cdot L_e \cdot \Delta\sigma_n \tan\delta_p \quad (2)$$

where B=width of reinforcement; L_e=effective reinforcement length; σ_n=applied normal stress; B_e= width along the edge of reinforcement influenced by restrained dilatancy effect; $\Delta\sigma_n$=increase in normal stress at the soil-reinforcement interface on the extent of B_e; and δ_p=angle of interface friction. The equation neglects the interface adhesion and assumes that the angle of interface friction is the same for 2-D and 3-D friction mechanism; thus, only the increase in normal stress is contributing to the additional pullout resistance as represented by P_{3-D}. The value of P_{3-D} can be obtained from pullout tests using reinforcements of different widths under different applied normal stresses. It should be noted that as the width of reinforcement becomes narrow, i.e. $B \leq 2B_e$, the influence of restrained dilatancy results in the development of what is considered a purely 3-D interface friction mechanism.

III TESTING DETAILS &OBSERVATIONS

Details of the testing equipment and the materials used in this investigation can be found in Alfaro et al. (1994). A total of 24 pullout tests were conducted consisting of six different reinforcement specimen widths (B=0.10, 0.15, 0.20, 0.30, 0.45, and 0.58 m) under four different applied normal stresses (σ_n=20, 30, 40, and 50 kPa). The series of tests on specimen width, B=0.58 m, which is slightly smaller than the width of the testing box, correspond to the plain strain or 2-D interaction mechanism. This interaction mechanism was envisaged to be appropriate to this condition because the lubricated side walls would not induce restraining effect which might have been caused with the presence of the non-dilating zones within the backfill soil; thus the classical 2-D interaction behavior throughout the width of the reinforcement is appropriate. On the other hand, the relatively narrower widths of specimen with respect to the box referred to the condition wherein the interaction phenomenon is the combination of 2-D and 3-D interaction mechanisms as discussed earlier.

The pullout resistance is evaluated following the Japanese standard method of determining the soil-geosynthetic frictional behavior (Hayashi et al., 1994). All series of tests used $L_e = L_T$ wherein L_T is the limiting reinforcement length which can be determined from Equation (3):

$$L_T = F_U / 2 \cdot (c + \sigma_n \cdot \tan\phi) \qquad (3)$$

where F_U=ultimate strength of geogrid per unit width (kN/m); c=apparent cohesion of the soil; σ_n=applied normal stress; ϕ=internal friction angle of the soil. Interaction parameters corresponding to plain strain or 2-D condition are as follows: c_p=0 kPa & δ_p=35°. The contribution of 2-D interface friction resistance for narrower specimen widths (B=0.10, 0.15, 0.20, 0.30, and 0.45 m) is determined from test results on specimen width, B = 0.58 m based on specimen width proportion. The difference between the effective pullout force measured for narrower widths and their corresponding 2-D interface friction resistance is considered as the contribution of 3-D interface friction resistance. This difference is quantified by the second term of Equation (2).

IV TEST RESULTS & DISCUSSION

The results from all series of tests are plotted in Fig. 2 which identifies the following trends:

a) The contribution of 3-D interface friction mechanism diminishes with increasing applied normal stress. This further confirms that the 3-D interface friction mechanism is a consequence of restrained dilatancy effect because it is generally established that dilatancy decreases with increasing applied normal stress.

b) Test specimen width has influence on the pullout resistance particularly on the development of 3-D interface friction mechanism. More 3-D interface friction resistance is observed for specimen width of 0.20 & 0.30 m. A test specimen which has a width relatively closer to the width of the pullout testing box (e.g., B=0.45 m) has minimal 3-D interface friction resistance due to the minimal restraining on the dilating soil which have been caused partly by the lubricated membrane in the side walls and partly by a lesser non-dilating zone of soil at both edges of the specimen. Minimal 3-D interface friction resistance is also observed for specimen width smaller than 20 cm. This was seen in this investigation as the case when the extent of B_e at both edges of the specimen overlapped each other which could reduce the magnitude of the 3-D interface friction resistance.

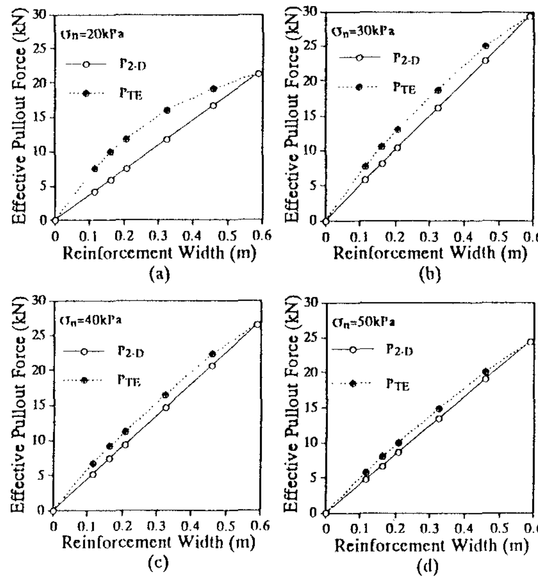

Fig. 2 Summary of Pullout Test Results

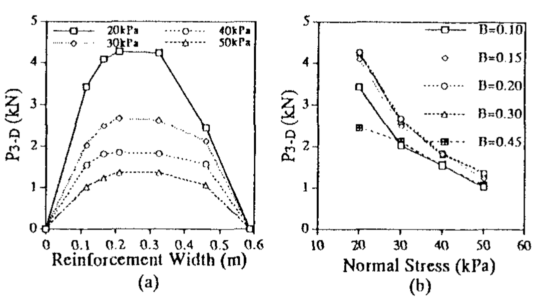

Fig. 3 Restrained Dilatancy Effect

These observations are useful in quantifying the 3-D interface friction resistance as shown in Fig.3. In this figure, it can be seen that the value of $2B_e$, in which 3-D interaction mechanism starts to develop throughout the specimen width, can be taken equal to 0.20 m.

REFERENCES

Alfaro et al., 1994, "Laboratory Testing on Soil-Geogrid Reinforcement Interaction", *Proc. on Geotextiles Standard Testing Methods*, Tokyo, pp. 37-44.

Hayashi et al., 1994, "Testing Methods for Soil-Geosynthetic Frictional Behavior-Japanese Standard", *Proc. 5th Intl. Conference on Geotextiles, Geomembranes and Related Products*, Singapore, pp. 411-414.