SOIL-GEOGRID REINFORCEMENT INTERACTION

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I INTRODUCTION

The interaction between soil and reinforcement is in the form of load transfer along the interface which can be facilitated through frictional resistance, bearing resistance or a combination of the two depending on the type of reinforcement (i.e sheet, strip, or grid) and on the mode of interaction. Jewell (1992) illustrated two interaction modes at failure, namely: pullout and direct shear modes. It was indicated (Bergado et al, 1994) that even at service (working load) condition, these two modes of interaction are developed along the interface for reinforced earth structures constructed on soft foundations. Interaction parameters from tests corresponding to the appropriate mode of interaction must be employed in the design and analysis. Pullout and direct shear tests are the two tests commonly used to measure the interaction parameters closely simulating the two interaction modes. These tests are associated with different loading paths and interaction mechanisms. Consequently, interaction parameters provided by these two tests could vary. This paper presents some results of the pullout and direct shear tests. Measured dilatancy in the soil accompanying shear deformation along the interface is also discussed.

II EXPERIMENTAL DETAILS

A schematic diagram of the testing equipment used both for pullout and direct shear tests is illustrated in Fig. 1. Electronic data acquisition system was used to record the pullout/direct shear force, front displacement, displacements along the reinforcement, and the vertical displacements. A well-graded gravel was used as backfill material with grain size properties as follows: average grain size, D_{50} = 5 mm; uniformity coeff., C_u = 15; and coeff. of gradation C_z = 1.6. The max. and min. dry densities are 18.7 kN/m^3 and 14.3 kN/m^3, respectively. The internal friction angle of the compacted soil determined from UU triaxial tests was found to be 45^o for 95% relative density. Tensar SR-80 geogrid was employed as reinforcement test specimens. Different normal pressures were being applied to the soil-geogrid system. For pullout test, resistance of the clamping plates located inside the compacted soil is determined by conducting pullout on clamping plates alone. Their resistance are subtracted to the measured pullout loads on geogrids. The arrangement wherein clamping plates are located inside the apparatus ensures that the geogrid specimen remains confined throughout the test. Coupling of confined and unconfined properties of the geogrid will be eliminated. Both long and short geogrids were tested. Tests on long geogrid specimens (6-ribbed lengths) are considered as model tests, while tests on short geogrids (2-ribbed lengths) are considered as element tests. Pullout test on long geogrid allows the evaluation of the load transfer mechanism and pullout resistance with the integration of reinforcement extensibility. Pullout test on short geogrid is recommended to establish shear stress-displacement and bearing stress-displacement relationships valuable for numerical modelling. Pullout test on geogrids with their transverse members removed were also conducted to evaluate the contribution of their bearing resistance to the overall pullout load.

III RESULTS AND DISCUSSIONS

Figure 2 shows a typical pullout test result on long geogrid. The non-linearity of displacement distribution and progressive movement along the reinforcement at pullout levels are illustrated. This results in non-uniform mobilization of interface shear stress along the reinforcement, with large portion of it mobilized near the pullout application point. It was found that the increase in normal stress tends to localize the reinforcement strains at the point of load application and consequently, the failure mode can be due to tension failure rather than pullout. Localization of geogrid displacement which provides higher mobilization of interface shear stress near the pullout load application point results in shorter effective adherence length. Method of evaluating pullout resistance with effective adherence length taken into consideration is appropriate and has been introduced by Ochiai et al (1992). A summary of interaction parameters from pullout and direct shear tests is given in Table 1. The interface shear stress determined from pullout model test is considered as an average value because of non-uniform mobilization due to reinforcement elongation. Bearing stress is determined by back-analysis from pullout test on short geogrids with and without transverse members. Measured dilatancy during shear deformation is given in Fig. 3a indicating that the increase in normal stress reduces soil dilatancy. Shear stress-shear displacement relationship (Fig. 3b) is established from nodal displacement measurements and shear stress-displacement relationship from pullout element test which is represented by hyperbolic formulation. All the solid curves assume that the normal stress was maintained constant at indicated initial value throughout the shearing process. This would not have been true if dilatancy is restrained. In field condition, the adjacent soil-reinforcement system could restrained soil dilatancy as the reinforcement is pulled out. When soil dilation is restrained, the normal stress at the vicinity of interface increases and results in an apparent increase in shear stress. The shear stress-displacement relationship when dilatancy is restrained can be determined using the method of Goodman (1980) for rock mass discontinuities. For example, if the soil under a normal stress of 20 kPa with initial compression at Point 1 (Fig. 3a) is sheared to Point 2 without dilatancy, it would acquire normal stress equal to 30 kPa with shear stress appropriate to the point on shear stress–displacement curve corresponding to σ_n = 30 kPa. Thus, as shearing progresses the shear stress will rise according to the dashed locus 1–2–3. Similarly, for soil under a normal stress of 50 kPa with initial compression at Point 4 and then sheared with no further normal displacement, then the shear stress–displacement curve followed will be given by locus 4–5–6. It is interesting to note that additional shear stress is acquired and the behavior becomes more ductile.

IV CONCLUSIONS

The interaction parameters provided by pullout and direct shear tests may vary due to different loading paths and interaction mechanisms. The concept of a uniformly mobilized interface shear stress is not proper for interpreting results of pullout model test on extensible reinforcements such as geogrid. Pullout tests on both long geogrid (model test) and short geogrid (element test) allow the investigation of pullout mode interaction behavior in a more appropriate way. The measured dilatancy in the laboratory provides valuable information to the increase in shear stress when soil dilatancy is restrained under field conditions.

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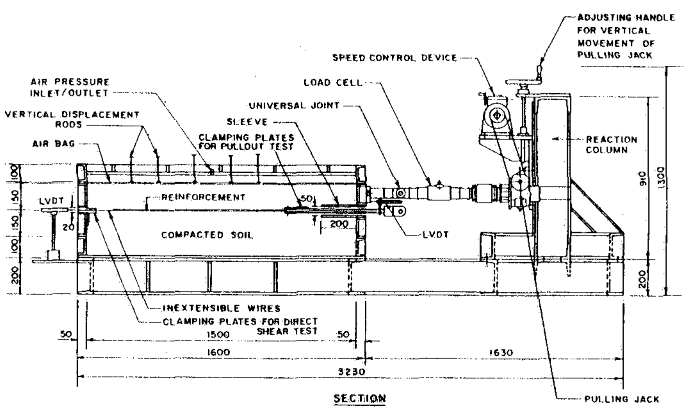

Fig. 1 Pullout/Direct Shear Test Apparatus

Table 1 Interaction Parameters

INTERACTION MODE	NORMALIZED PARAMETER	SYMBOL	VALUE
PULLOUT (Model Test)	Average Shear Stress	τ_{ave} / σ_n	0.96
	Shear Stiffness	k_{sm} / σ_n	102 m^{-1}
PULLOUT (Element Test)	Maximum Shear Stress	τ_{max} / σ_n	1.62
	Shear Stiffness	k_{se} / σ_n	1567 m^{-1}
	Maximum Bearing Stress	σ_b / σ_n	52
	Bearing Stiffness	k_{pe} / σ_n	96 m^{-1}
DIRECT SHEAR (Model Test)	Average Shear Stress	τ_{ave} / σ_n	1.35
	Shear Stiffness	k_{sm} / σ_n	3843 m^{-1}

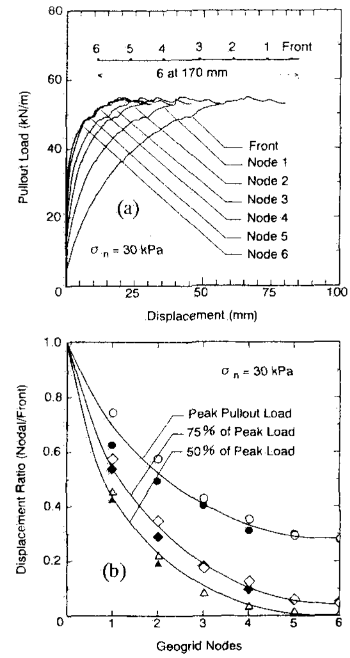

Fig. 2 Pullout Test Results

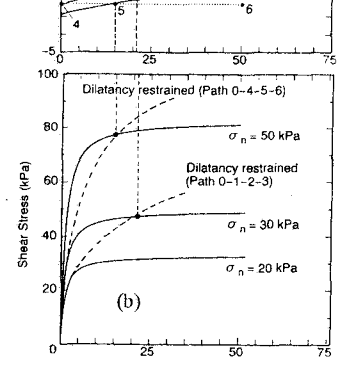

Fig. 3 Restrained Dilatancy Effect on Interface Shear Stress