Effects of wetting on the soil-geogrid interaction

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ABSTRACT: This paper presents an evaluation of the soil-geogrid interaction under the effects of inundation. An experimental program was conducted using a series of laboratory large-scale pullout test for two types of geogrid. Observations and comparisons under different normal stresses were made for pullout behaviors at the interface of soil and geogrid before and after wetting. Test results have shown that the pullout resistance increased with the increases of applied normal stresses for both before and after wetting conditions. However, inundation of a soil-geogrid system presents significant negative effect on the soil-geogrid interaction. The values of pullout resistance sharply decreased more than 50 % after inundations were applied. The types of geogrid and the applied normal pressure showed only minor effect on the pullout resistance. The results obtained in this study appear to be favorable for a better understanding of analysis for RES under severe rainfall condition.

1 INTRODUCTION

The interaction behaviors at the interface of soil and geosynthetic reinforcement are extremely important to ensure an accurate design of reinforced earth structure (RES). Recently, failures of geosynthetic reinforced earth structures initiated by intense rainfall have been often reported (Wu and Tang 2006). The interaction mechanism of the soil-geosynthetics system upon wetting apparently requires strong attentions to avoid further failures of RES. Research has been performed for the failure mechanism due to wetting which involves infiltration into unreinforced slope that contributed to decrease in soil strength (Chen et al. 2004; Collins and Znidarcic 2004, and Crosta 2004). Available researches for RES are very limited to the wetting effect in the stability analysis (Wu and Tang 2008).

This research investigates the effects of inundation on soil samples reinforced with geogrid using a laboratory large pullout test apparatus. Observations and comparisons were made for pullout behaviors at the interface of soil and geogrid before wetting and after inundation. Various conditions such as normal pressures and types of reinforcement were applied to examine the influences of different factors on the interaction mechanism of soil-geogrid system.

2 MATERIALS AND METHODS

2.1 *Materials*

Table 1 presents the properties and geometric dimensions of the two geogrid specimens (Type A and Type B) used for this study. They were woven biaxial and made by high strength polyester (PET) yarns, exterior coated with polyvinyl chloride (PVC).

The non-plastic silty soil sample used in this research was taken from Bastrop, Texas. It has a liquid limit of 18 with a clay size fraction (percent finer than 2 μm) of about 18 %. The specific gravity of the soil solids is 2.66 (ASTM D854). The soil can be classified as silt with sand (ML) according to the Unified Soil Classification System (ASTM D2487). The maximum dry unit weight and optimum moisture content of the soil are 19.3 kN/m^3 and 11.8 %, respectively, according to the Modified Proctor test (ASTM D1557).

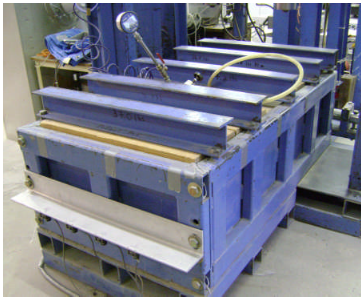
Table 1 Properties of Geogrid Materials for the Study

Type of Geogrid	Aperture Size* (mm)	MD Tensile Strength (ASTM D 6637)			
		Single Rib (kN/m)	Elongation @ Break (%)	Multiple Ribs (kN/m)	Elongation @ Break (%)
Type A	32 × 22	91.8	12.1	83.8	9.4
Type B	34 × 22	175.7	11.5	168.1	9.8

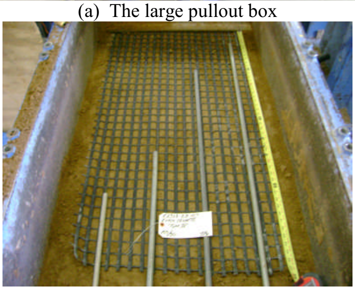
* MD × XMD

2.2 *Laboratory Methods*

As shown in Figure 1a, the pullout box is a custom-made apparatus (1520×760×610 mm) with vertical and horizontal loading systems, and all the required instrumentation. The testing procedures were in general accordance with ASTM D 6706. Soil is placed beneath and above the geosynthetic layer. It was compacted to a density equals to 90 % of the modified proctor density. Four tell-tails were mounted to the geogrid to monitor the movement of the specimen at various points along its length during the test (Figure 1b). A rigid steel platen was used to cover the soil and restrain a large air bladder, which air pressure was applied as normal load for the specimen.



(a) The large pullout box



(b) Typical pullout testing set-up with tell-tails

Figure 1. Large pullout box used in this research and experimental set-up for geogrid pullout testing

The width of the geogrid specimens was 61 mm and the embedment length was 1200 mm. Normal pressures ranging from 13.8 kPa to 68.9 kPa were applied to the specimens during the pullout testing. A horizontal force was then applied and the geogrid specimen was pulled out at a constant rate of 1 mm per minute. Normal load, pullout force, and displacement of specimen at the front of the pullout box and at points along the geogrid from the four tell-tails were collected during the entire testing.

For inundation of the specimen, a total of about 20 liters of water was sprayed over the top of the compacted soil in 3 steps. Half amount of the water was applied as soon as the upper half of the compacted soil was placed. Six hours later, another 25 % of the water was applied and the last 25 % of the water was added after 30 hours. The specimen was then soaked for overnight without any disturbance. In summary, the specimen was inundated for at least 48 hours before pullout was applied. All specimens were prepared in the same manner to ensure consistency for the pullout tests for both with and without inundation.

3 RESULTS AND DISCUSSION

Pullout resistance, P_r, is obtained by dividing the maximum load attained on the geogrid by the specimen width. Table 2 presents a summary of the test results for Type A and B geogrids tested before wetting. The maximum pullout resistance increased with the increase of normal stress. The deformation at the front of pullout box varied from 62 to 96 mm. The pullout interaction coefficient, C_i , was calculated based on the following equation as recommended by Koerner (2005):

$$C_i = \frac{P_{r,Max}}{\left[2 \times L_e \times \left(c' + \sigma'_v \tan\phi'\right)\right]}$$

where

$P_{r,\,Max}$ = maximum pullout resistance per unit width,
L_e = embedment length of geogrid,
σ'_v = effective normal stress on the geogrid,
c', ϕ' = Mohr-Coulomb strength parameters as determined from direct shear test (ASTM D 3080).

The shear strength of the silty soil used in this study was examined using consolidated-drained direct shear test (ASTM D 3080). Normal stresses ranging from 6.9 kPa to 69 kPa were applied for testing. The cohesion intercept observed was 7.2 kPa and the angle of internal friction was 34°. Based on these parameters, the coefficient of interaction (C_i) was calculated. As shown in Table 2, the values of C_i tended to decrease with the increases of normal stresses for all geogrid specimens tested.

In general, the mode of failure for most of the geogrid materials tested was pullout-failure and virtually no physical damages were observed after the pullout tests. However, junctions-failure was found for Type A geogrid under the normal stress of 41.4 kPa. It also demonstrated the lowest value of C_i for this particular case.

Table 3 presents a summary of the findings for Type A and Type B geogrid tested after soaking. The initial degree of saturation was 61 % at initial as-compacted condition and finally increased to 94 % after soaking. The corresponding averaged moisture content increased from about 11.6 % before wetting to 16 % after inundation. To evaluate the effect of wetting on the reduction of maximum pullout resistance, a reduction ratio is defined as below:

$$Reduction\ Ratio = \frac{P_{r,Max,after}\ \text{wetting}}{P_{r,Max,before}\ \text{wetting}}$$

As can be seen in Table 3, the reduction ratios were ranging from 0.43 to 0.62 with an averaged value of 0.50 for both types of geogrids. It clearly indicated that despite of the differences of the geogrid materials tested, the maximum pullout resistance decreased more than 50 % after 48 hours of soaking periods. The reductions of the pullout resistance were found to be affected by the initial moisture content, the compacted soil density, and the soaking periods. The types of reinforcement and the applied normal stress appear to have minor effect on the pullout resistance.

The mode of failure for specimens tested after wetting was found to be pullout-failure and there was no any physical damage observed for all reinforcements. The values of coefficient of interaction after inundation decreased to 0.41~0.52, which again showed a reduction of more than 50 % in the pullout resistance after soaking.

Figure 2 shows a comparison of pullout resistance observed for Type B geogrid before and after wetting. For similar normal stress, the peak pullout values dropped more than 50 % for specimens tested after inundation. Moreover, the effect of wetting also tended to mobilize the pullout resistance with lesser displacement. For example, under a normal pressure of 27.6 kPa, the mobilized deformation decreased from 62 mm before wetting to 24 mm after inundation. Such tendency was more significant for those specimens tested under a lower normal stress.

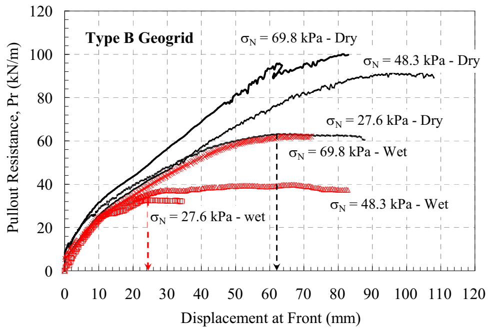


Figure 2. Comparisons of pullout resistance for Type B geogrid before and after wetting

Figure 3 shows the effect of wetting on the maximum pullout resistance plotted as a function of normal stress for all geogrid materials tested. It clearly reveals a linear relationship between the maximum pullout resistance and the applied normal pressure for both testing conditions. In addition, the significant linear reduction/loss of pullout resistance is observed after inundation.

Table 2 Summary of Test Results for Geogrid Tested before Wetting

Geogrid	Normal Stress, σ_N (kPa)	Approx. Soil Depth (m)	Moisture content (%)	Dry Density (kN/m^3)	Degree of Saturation, Sr (%)	Max. Pullout Resistance, $P_{r,Max}$ (kN/m)	Deformation @ $P_{r,Max}$ (mm)	Mode of Failure	Interaction Coefficient, Ci
Type A	13.8	0.7	11.4	17.5	62	39	74	Pullout	0.98
	27.6	1.5	11.6	17.5	63	58	92	Pullout	0.92
	41.4	2.2	11.8	17.4	64	63	74	Junctions Failure	0.73
Type B	27.6	1.5	11.6	17.8	64	63	62	Pullout	1.01
	48.3	2.6	11.6	17.6	62	92	96	Pullout	0.95
	68.9	3.7	11.8	17.9	63	100	81	Pullout	0.76
	68.9	3.7	11.8	17.9	63	100	81	Pullout	0.76

Table 3 Summary of Test Results for Geogrid Tested after Wetting

Geogrid	Normal Stress, σ_N (kPa)	Post testing conditions: Moisture content (%)	Post testing conditions: Degree of Saturation, Sr (%)	Post testing conditions: Soaking Time (hour)	Max. Pull-out Resis-tance, $P_{r,Max}$ (kN/m)	Deformation @ $P_{r,Max}$ (mm)	Mode of Fail-ure	Reduction Ratio	Interaction Coefficient, Ci
Type A	13.8	16.6	91	46.0	18	29	Pullout	0.45	0.44
	27.6	17.1	94	47.0	26	49	Pullout	0.45	0.41
	41.4	16.2	89	45.0	31	53	Pullout	0.50	0.37
Type B	27.6	15.7	86	46.0	33	24	Pullout	0.52	0.52
	48.3	16.0	87	48.0	40	66	Pullout	0.43	0.41
	68.9	14.3	78	49.5	62	67	Pullout	0.62	0.47

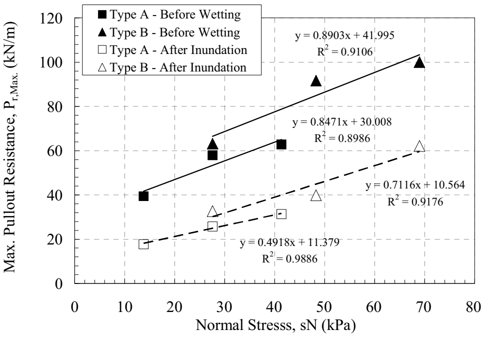


Figure 4. Maximum pullout resistance versus normal stress for geogrid materials tested before and after wetting

4 CONCLUSIONS

Reinforced earth structures (RES) have been used in numerous projects for the past decades. Recently, failures of RES initiated by intense rainfall have become a noticeable issue. The soil-geosynthetics interaction behaviors are significantly important to assure an accurate design of RES. This study investigates the effect of wetting on soil samples reinforced with geogrid using a large-scale pullout test box.

Test results have shown that the pullout resistance increased with the increases of applied normal stresses for both before and after wetting conditions. A critical finding was that the pullout resistance sharply decreased more than 50 % after inundations were applied. The maximum pullout values only can be mobilized at smaller displacements. The reductions of the pullout resistance were found to be affected by the initial moisture content, the compacted soil density, and the soaking periods. The types of geogrid and the applied normal stress appear to have minor effect on the pullout resistance when the soil samples were near saturated. The results obtained in this study provide a rational way to evaluate the potential weakness of pullout resistance in the soil-geosynthetics system, and therefore certainly warrant a better understanding for the analysis of RES under severe rainfall condition.

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