

Interaction between Geogrid Reinforcement and Tire Chip-Sand Mixture

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ABSTRACT

The interaction between reinforcing and backfill materials is a significant factor for analysis and design of reinforced earth structures. It can be simplified as pullout resistance and direct shear resistance, which depend on both reinforcing and backfill materials. This study is aimed at studying the interaction between geogrid and tire chip-sand mixture. Numerous experiments including index tests, compaction tests, pullout tests and large-scale direct shear tests were conducted to meet the mentioned objectives. Saint-Gobain and Polyfelt geogrids were selected as reinforcing materials whereas tire chip-sand mixtures at the mixing ratios of 30:70, 40:60 and 50:50 % by weight were used as fill materials. The mixture at the mixing ratio of 30:70 % was found to be the most suitable fill material. The pullout resistance and the pullout interaction coefficients of Saint-Gobain geogrids were higher than those of Polyfelt geogrids. In contrast, the direct shear resistance, the direct shear interaction coefficients, and the efficiency values of Polyfelt geogrids were higher than those of Saint-Gobain geogrids. The ultimate tensile strength of Polyfelt geogrid was slightly lower than that of Saint-Gobain geogrid. Finally, Polyfelt geogrid and the tire chip-sand mixture at the mixing ratio of 30:70 % by weight were recommended as reinforcing and backfill materials for field applications.

Key words: interaction, geogrid, tire-chip

INTRODUCTION

Soil reinforcing materials such as strips, grids, sheets, etc have been developed for the past decades in order to increase their functional abilities for reinforced structures. They can be generally classified into two types by considering its extensibility—one is inextensible and the other is extensible. For the analysis and design of soil reinforcement, interaction between reinforcing material and soil backfill is significant factor that have to be taken into consideration. Hence, the

interaction between soil and reinforcement can be simplified into two categories—the former is the sliding of soil over the reinforcing material or “direct shear resistance,” and the latter is the pulling of the reinforcing material out from soil or “pullout resistance”. In recent years, the applications of “shredded used tires” or “tire shreds” have been introduced into civil engineering projects. The particle sizes of tire shreds are bigger than those of tire chips. Usually, unit weight of tire shreds or tire chips are up to 6 times lower than that of conventional backfill

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materials such as cohesionless soil. Even though the use of tire shreds alone as backfill can reduce earth pressures, its disadvantages are more considerable; for example, high deformation, compaction problems, and self-heating mechanism. This led to the ways of mixing sand into tire shred backfill to reduce those kinds of such problems. (Bergado and Vootipruex, 2000)

This study comprised several tests-the study began with sieve analyses and specific gravity tests for both Ayutthaya sand and tire chips to determine their specific gravity. Then compaction tests on tire chip-sand mixture were performed to determine maximum dry unit weight and optimum moisture content of the mixtures. Subsequently, in-air tensile, large-scale direct shear, and pullout tests were done to perform so as to study the interaction between reinforcing and fill materials. Only three different mixing tire chip-sand mixers with ratios of 30:70, 40:60, and 50:50 % by weight were tested. Two different types of geogrids, namely: Saint-Gobain geogrid (DJG 120X120-1) and Polyfelt geogrid (GX 100/30) were selected as the reinforcing materials.

METHODOLOGY

The interaction between tire chip-sand mixture and extensible grid reinforcement needs to be investigated thoroughly in this study. Before conducting pullout and large-scale direct shear tests, some basic properties of Ayutthaya sand, tire chips, and tire chip-sand mixtures needs to be investigated by performing index property tests, including specific gravity tests, sieve analyses, and compaction tests. (Prempramote, 2005)

Index property tests

For fill materials, they are the mixtures of tire chips and Ayutthaya sand at three different mixing ratios of 30:70, 40:60, and 50:50 % by weight. The specific gravity test of sand was conducted by following the recommended

procedures in ASTM D854-97, but for tire chips, the procedures in ASTM C127-01 were adopted. The procedures of sieve analyses, which are provided in ASTM D422-63, were adopted to investigate the particle-size distribution curves of both Ayutthaya sand and tire chips. Compaction tests were conducted by complying with the procedures outlined in ASTM D689-91, to obtain the optimum moisture content and maximum dry unit weight of fill materials.

Preparation of materials

Two types of geogrid reinforcements and tire chip-sand mixtures would be employed in both pullout and large-scale direct shear tests. In convenience, the mixing ratios of the tire chip-sand mixtures were based on the dry weight of each material in sample preparation. Each group of fill materials needs to be cured to its respective optimum moisture condition based on the results of standard Proctor compaction test with the modified mold. There are two types of geogrid reinforcements selected in this study. One is Saint-Gobain DJG 120X120-1 (Figure 4a) and the other is Polyfelt geogrid GX 100/30 (Figure 4b).

In-soil pullout tests

Pullout tests conducted in this study were in-soil pullout tests i.e. the clamp was normally installed in the pullout box. This pullout test program was mainly used for investigating the interaction between tire chip-sand mixture and geogrid reinforcements, and the relationship between pullout force and pullout displacement. In the entire tests, there were four normal stresses of 30, 60, 90, and 120 kPa applied on the fill materials. The purpose of applying these four values was to cover the range of possible reinforcement failures (i.e. slippage and breakage). The pullout machine used for evaluating the interaction between tire chip-sand mixture and geogrid reinforcements is shown schematically in Figure 1. The pullout forces were usually

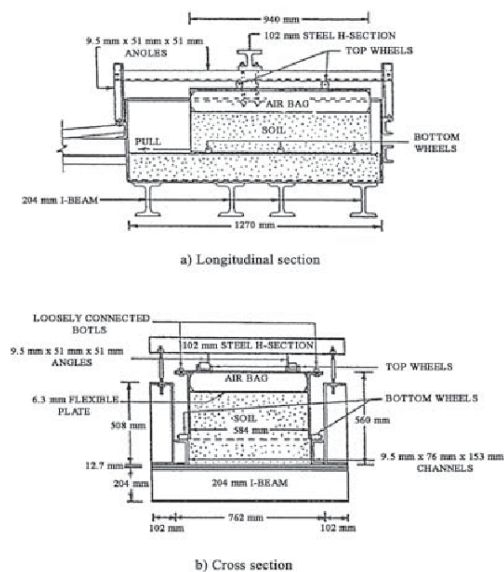


Figure 1 Schematic pullout test apparatus.

generated by a 225 kN capacity electrohydraulic controlled jack through the steel reaction frame. The normal pressures were applied by the inflated air bag installed between the flexible steel plate and the top cover of the pullout box. The load cell used in the pullout resistance measurement was connected to the 21X data logger to automatically record the resistances. The pullout displacements of a geogrids sample were monitored by using a Linear Variable Differential Transducer (LVDT). To determine the displacements increasing along the longitudinal direction of geogrids sample during the pullout tests, four inextensible wires were mounted on the geogrids sample at predetermined positions. The pullout rate of 1 mm/min was adopted throughout the tests. The pullout forces and pullout displacements were measured and recorded by the data logger. The maximum displacement of 100 mm reached, the test would be stopped. (Bergado and Chai, 1994)

Large-scale direct shear tests

The large-scale direct shear apparatus was adapted from the pullout machine. Likewise, the measurement apparatus was set up same as

the in-soil pullout tests. The instrumented geogrids sample with the sizes of 50 cm × 70 cm was laid on the shear plane. The upper shear box was pulled at a constant rate of 1 mm/min throughout the test. The residual strength and the maximum displacement of 100 mm reached, the test would be stopped. The same test procedure was followed to determine the shear strength parameters of each fill material group except the cases of the tests without any geogrid reinforcements placed on the shear plane.

In-air tensile tests

The in-air tensile apparatus was adapted from the pullout machine. The geogrids sample was pulled by the same hydraulic jack used in the pullout machine. Likewise, the measurement apparatus was set up same as the in-soil pullout tests. Each test was conducted on the pullout apparatus without any usage of fill materials.

RESULTS AND DISCUSSION

Index properties of tire chip-sand backfills

The specific gravity of Ayutthaya sand is 2.65, while that of tire chips is 1.12. For Ayutthaya Sand, there was 1.64 % passing through No. 200 sieve. The effective diameter (D_{10}) is 0.22 mm, D_{30} is 0.38 mm, D_{60} is 0.62 mm, the uniformity coefficient (C_u) is 2.82, and the gradation coefficient (C_c) is 1.06. According to the Unified Soil Classification System (USCS), the sand can be classified as poorly graded (SP). For tire chips, most of the particle size range between 12 and 50 mm with irregular shape due to the random cutting process. The particle-size distribution curve show in Figure 2. Compaction test results of the tire chip-sand mixtures are summarized in Table 1 and also shown in Figure 3. The maximum dry unit weight and the optimum moisture content of the tire chip-sand mixtures vary from 9.5 to 13.6 and from 5.7 to 8.8, respectively.

In-soil pullout test results

The in-soil pullout test results revealed that the pullout resistance normally increased while the displacement at the maximum pullout

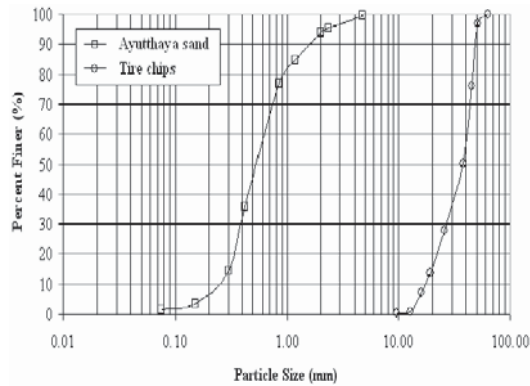


Figure 2 Particle-size distribution curves.

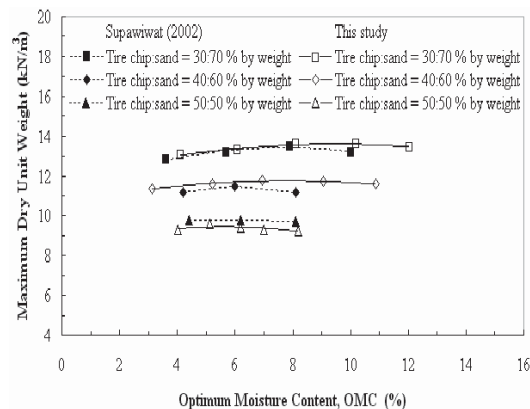


Figure 3 Compaction test results.

force tended to decrease with increasing normal stress. Moreover, the pullout resistance increased with the increasing sand content in the mixture. The mixing ratio of 30:70 % by weight yielded the highest pullout resistance for both Saint-Gobain and Polyfelt geogrids as shown in Figure 4. and Table 2. The sand content in the tire chip-sand mixtures directly affects the pullout resistance because the frictional angle of sand is higher than that of tire chips. Thus, the frictional resistance obtained from sand governs the pullout resistance rather than that obtained from tire chips. Comparing the pullout resistance of Saint-Gobain geogrids to that of Polyfelt geogrids at the same mixing ratio and the same normal stress (see Figure 4.), the former has higher magnitudes than the latter. The displacements at the maximum pullout force were measured along the length of geogrid reinforcements during the in-soil pullout tests. The results of both Saint-Gobain and Polyfelt geogrid reinforcements revealed that the largest displacement occurred at the pullout face, which was connected to the in-soil pullout clamp. The displacement at the maximum pullout force along the entire geogrid reinforcements decreased with the increasing distance from the pullout face. The pullout resistance of geogrid reinforcements depended on the sand content in the tire chip-sand mixtures, not the tire chip content. (Youwai and Bergado, 2003)

Table 1 Compaction test results of tire-chip sand mixtures.

Mixing Ratio of Tire Chip:Sand (% by weight)	Supawiwat (2002)		This Study (2005)	
	Max. Dry Unit Weight (kN/m ³)	Optimum Moisture Content (%)	Max. Dry Unit Weight (kN/m ³)	Optimum Moisture Content (%)
Sand	18.40	11.3	-	-
30:70	13.60	8.0	13.60	8.8
40:60	11.50	6.0	11.90	7.1
50:50	9.80	6.0	9.50	5.7
Tire Chips	5.35	-	-	-

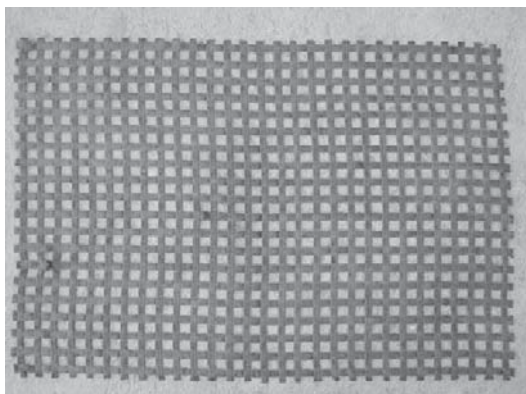


Figure 4a Saint-Gobain geogrid (size 15×15 mm.).

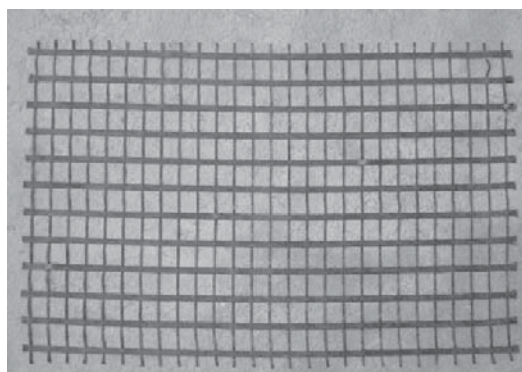


Figure 4b Polyfelt geogrid (size 25×30 mm.).

Table 2 Maximum pullout forces of geogrid reinforcements.

Mixing Ratio (% by weight)	Saint-Gobain Polyfelt		
	Normal Stress (kPa)	Max. Pullout Force (kN/m)	Max. Pullout Force (kN/m)
30:70	30	32.40	27.40
	60	51.80	46.00
	90	72.50	66.50
	120	81.00	74.00
40:60	30	26.40	21.00
	60	47.30	40.99
	90	67.20	61.50
	120	77.00	71.00
50:50	30	26.30	19.00
	60	42.00	36.20
	90	58.00	52.00
	120	63.00	57.00

Large-scale direct shear test results

At the same normal stresses and mixing ratios, the direct shear stresses of the tire chip-sand backfills were higher than those of Saint-Gobain and Polyfelt geogrid reinforcements because there were no any reinforcements blocking the contact area of the backfills at the shear plane. Therefore, the direct shear stresses were able to be mobilized fully at the shear plane. In comparison between the geogrid reinforcements, at the same normal stresses and mixing ratios, the

direct shear stresses of Polyfelt geogrid reinforcements were higher than those of Saint-Gobain geogrid reinforcements because the aperture sizes of Polyfelt geogrid reinforcements were bigger than those of Saint-Gobain geogrid reinforcements. At the same normal stresses and mixing ratios, the adhesion and skin friction angles of Saint-Gobain and Polyfelt geogrid reinforcements were found to be lower than those of the backfills. In comparison between geogrid reinforcements, the adhesion and skin friction

angles of Polyfelt geogrid reinforcements were found to be higher than those of Saint-Gobain geogrid reinforcements. Test results of tire chip-sand mixtures at 30:70 by weight shown in Figure 5.

Efficiency and interaction coefficients of geogrids

It could be observed that all efficiency values of Polyfelt geogrids are higher than those of Saint-Gobain geogrids. This indicates that Polyfelt geogrids has better direct shear resistance. In case of reinforcements in the tire chip-sand mixture at the ratio of 30:70 %, the direct shear stresses obtained from Polyfelt geogrid reinforcements were higher than those obtained from Saint-Gobain geogrid reinforcements if considering at the same normal stresses. The failure modes of geogrid reinforcements were confirmed to be slippage failure at the normal stresses of 30 and 60 kPa and tensile failure at the high normal stresses of 90 and 120 kPa. (Supawiwat, 2002)

In-air tensile test results

In-air tensile test results of Saint-Gobain and Polyfelt geogrids can conclude that the tensile strength of Saint-Gobain geogrids is 120 kN/m

with the strain at break of 12.7 %, while that of Polyfelt geogrids is 100 kN/m with the strain at break of 13.2 %. These values are not so different from those in the specifications.

CONCLUSIONS AND RECOMMENDATIONS

The percentage of sand or sand content mixed in tire chip-sand mixtures was the most significant factor controlling the unit weight of the mixtures. The moisture content was not a significant factor for controlling the unit weight of the tire chip-sand mixtures. The pullout resistance increased with increasing sand content in the mixture. The applied normal stresses were significant factors for pullout resistance which increased with the increasing normal stresses. The higher tensile strength of geogrids in longitudinal direction and the higher strength of the junctions could contribute to the pullout resistance of geogrids. The direct shear resistance of tire chip-sand mixtures and geogrid reinforcements depended on the sand content in the tire chip-sand mixtures which increased with the increasing sand content. It was confirmed that the aperture sizes of geogrids significantly affected the direct shear resistance of geogrids. The bigger the aperture size,

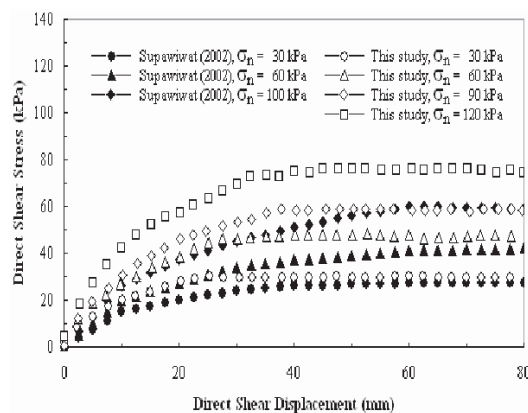


Figure 5 Direct shear test results of tire chip-sand mixture 30:70 % by weight.

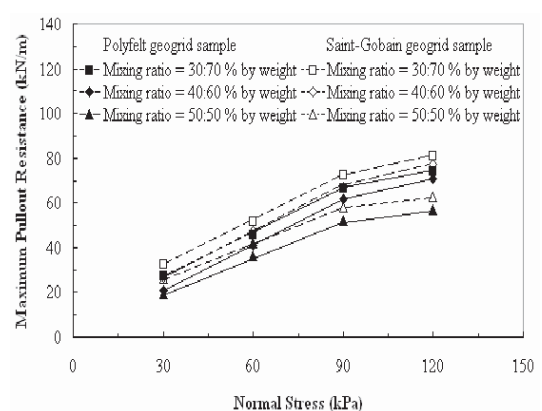


Figure 6 Maximum pullout resistance versus normal stress curves.

the higher the direct shear resistance. The tire chip-sand mixture with the mixing ratio of 30:70 % by weight yielded the higher pullout and direct shear resistances compared to the other mixtures. Therefore, the mixture with the mixing ratio of 30:70 is recommended as lightweight tire chip-sand backfill material. Even though the tensile strength of Saint-Gobain geogrids is higher than that of Polyfelt geogrids, the pullout resistance of Polyfelt geogrid reinforcements in tire chip-sand backfills was only slightly lower than that of Saint-Gobain geogrid reinforcements. Hence, the Polyfelt geogrid was recommended as reinforcing material. A full scale test embankment made of lightweight tire chip-sand backfill with Polyfelt geogrid reinforcements was constructed in the soft Bangkok clay to study the actual behaviors and the benefits.

LITERATURE CITED

- Bergado, D.T. and J.C. Chai. 1994. Pullout Force/Displacement Relationship of Extensible Grid Reinforcements. **Geotextiles and Geomembranes**. 13: 295-316.
- Bergado, D.T. and P. Voottipruex. 2000. Interaction Coefficient between Silty Sand Backfill and Various Types of Reinforcements. **Proceedings of the 2nd Asian Geosynthetics Conference**. 1: 119-151.
- Prempramote, S. 2005. Interaction between geogrid reinforcement and tire chip-sand mixture. M.Eng. Thesis No. GE-04-12 Asian Institute of Technology, Thailand
- Supawiwat, N. 2002. Behavior of Shredded Rubber Tires with and without Sand, its Interaction with Hexagonal Wire Reinforcement and their Numerical Simulation," M.Eng. Thesis No. GE-01-14, Asian Institute of Technology, Thailand
- Youwai, S. and D.T. Bergado. 2003. Strength and Deformation Characteristics of Shredded Rubber Tire-Sand Mixtures. **Canadian Geotechnical Journal**. 40: 254-264.