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Interaction between geogrid reinforcement and tire chips-sands mixture

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ABSTRACT: The aim of this study is to investigate the interaction between two different types of geogrid and tire chip-sand mixture at different mixing ratios in order to design a full-scale test of reinforced tire chip-sand mixture embankment. Different experiments including index tests, compaction tests, pullout tests, and geogrids consisting of Saint-Gobain (Geogrid A) and Polyfelt (Geogrid B) were selected as reinforcing materials. The weight mixing ratios of 30:70, 40:60, and 50:50% were used for the tire chip-sand mixtures. The experimental results indicated that the mixing ratio of 30:70% is the most suitable fill material. The pullout resistance and interaction coefficients of Geogrid A were slightly higher than those of Geogrid B. In contrast, the direct shear resistance, the direct shear interaction coefficients, and the efficiency values of Geogrid B were higher than those of Geogrid A. The ultimate tensile strength of Geogrid A was slightly lower than that of Geogrid B. Finally, it was concluded that Geogrid B and the tire chip-sand mixture at the mixing ratio of 30:70% by weight were recommended for full scale test embankment.

1 INTRODUCTION

Soil reinforcement with strips, grids, and sheets has been developed in the past decades to increase their functional abilities as reinforced structures. The reinforcing material can be generally classified into two types by considering its extensibility, namely: inextensible and extensible. For the analysis and design of soil reinforcement, the interaction between reinforcing material and soil backfill is significant factor that have to be taken into consideration. The interaction between soil and reinforcement can be simplified into two categories, the sliding of soil over the reinforcing material or "direct shear resistance", and the pulling of the reinforcing material out from soil or "pullout resistance". Recently, 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 materials such as cohesionless soil. Although the use of tire shreds alone as backfill can reduce earth pressures, other disadvantages should be 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 problem.

The experimental work of this study consists of four phases. The first phase involves the determination of the physical properties (grain size distribution and specific gravity) for both of Ayutthaya sand and tire chips. In the second phase, the compaction tests on tire chip-sand mixture were performed to determine maximum dry unit weight and optimum moisture content of the different tire chip-sand mixtures (30:70, 40:60, and 50:50% by weight). The third phase concern with the mechanical properties of the utilized geogrid (in-air tensile). In the last phase, large-scale direct shear, and pullout tests were done to investigate the interaction between reinforcing and fill materials. In the following, the experimental program will be presented and the test results will be discussed. Then, the conclusions will be derived.

2 EXPERIMENTAL PROGRAM

This study was directed to investigate the interaction between tire chip-sand mixture and two different type of extensible grid reinforcement, Saint-Gobain geogrids (DJG 120X120-1) denoted as Geogrid A, and Geogrid B referred to Polyfelt geogrids (GX 100/30). Geogrid A is made of the high tenacity polyester yarns knits into mesh coated with modified polymer mixture, high tensile strength, high modulus, good creep resistance. It is generally used for soil reinforcement and stabilization such as steep slopes, retaining walls, bridge abutments etc. Geogrid B consists of high molecular, high strength polyester yarns that are knitted to a stable network and equipped with a polymeric coating protection. This product is suitable for both short-term and long-term soil reinforcement application. Geogrid B are designed for technical applications such as reinforcement in reinforced earth structures.

2.1 *Index property tests*

The fill materials in this study consists of 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 tests of sand and tire chips were conducted according to ASTM D854-97 and ASTM C127-01, respectively. The grain size distributions of sand and tire chips were conducted according to ASTM D422-63. ASTM D689-91 test procedures were adopted to obtain the optimum moisture content and maximum dry unit weight of the mixture fill materials.

2.2 *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.

2.3 *In-soil pullout tests*

This pullout tests 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 different 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 Fig. 1. The pullout forces were usually generated by a 225 kN capacity electro-hydraulic 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.

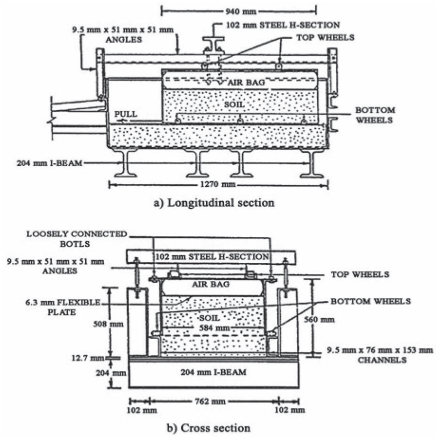

Figure 1. Schematic pullout test apparatus.

2.4 *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 500 mm × 700 mm 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.

2.5 *In-air tensile tests*

In this test, 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.

3 RESULTS AND DISCUSSION

3.1 *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

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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. Compaction test results of the tire chip-sand mixtures are shown in Fig. 2. 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.

3.2 *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 force tended to decrease as the normal stress increased. Moreover, the pullout resistance increased with the increasing of the sand content in the mixture. The mixing ratio of 30:70% by weight yielded the highest pullout resistance for both geogrids as shown in Fig. 3. The frictional resistance affects the pullout resistance rather than bearing resistance. Hence, 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. The comparison between the pullout resistance of two types of geogrids at the same mixing ratio and the same normal stress was illustrated in Fig. 4. 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 geogrid reinforcements indicated 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.

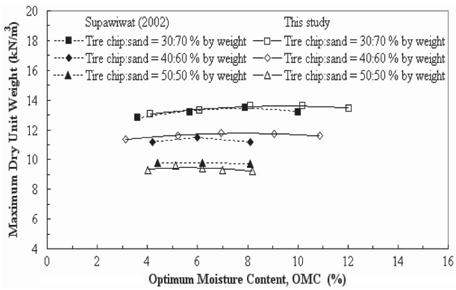

Figure 2. Compaction test results.

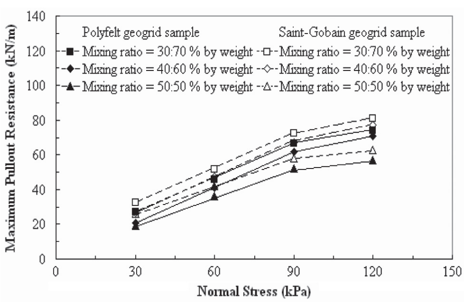

Figure 3. Maximum pullout resistance vs normal stress.

3.3 *Large-scale direct shear test results*

Under the same normal stresses and mixing ratios, the direct shear stresses of the tire chip-sand backfills were higher than those of both 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 Geogrid B were higher than those of Geogrid A because the aperture sizes of Geogrid B were bigger than those of Geogrid A (as shown in Fig. 4). At the same normal stresses and mixing ratios, the adhesion and skin friction angles of Geogrid A and Geogrid B were found to be lower than those of the backfills. In comparison between geogrid reinforcements, the adhesion and skin friction angles of Geogrid B were found to be higher than those of Geogrid A.

3.4 *Efficiency and interaction coefficients of geogrid.*

It could be observed that all efficiency values of Geogrid B are higher than those of Geogrid A. This indicates that Geogrid B 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 Geogrid B were higher than those obtained from Geogrid A if considering at the same normal stresses.

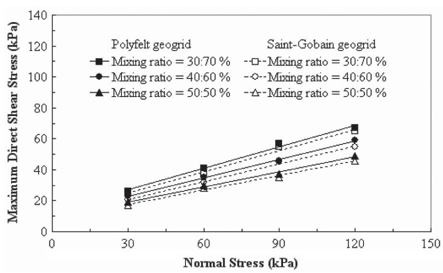

Figure 4. Maximum direct shear stress versus normal stress.

3.5 *In-air tensile test results*

In-air tensile test results can be concluded that, the tensile strength of Geogrid A is 120 kN/m with the strain at break of 12.7%, while that of Geogrid B is 100 kN/m with the strain at break of 13.2%. These values are not so different from those in the specifications.

4 CONCLUSIONS

The percentage of sand 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 of geogrid reinforcements depended on the sand content in the tire chip-sand mixtures, not the tire chip content. The pullout resistance increased with the 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 failure modes of geogrid reinforcements were confirmed to be slippage failure at the normal stresses of 30 and 60 kPa, and breakage failure at the high normal stresses of 90 and 120 kPa. 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, the higher the direct shear resistance. The tire chip-sand mixture with the mixing ratio of 30:70% by weight yields the higher results in the pullout and direct shear resistance rather than 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 Geogrid A was much higher than that of Geogrid B, the pullout resistance of Geogrid B in tire chip-sand backfills was only slightly lower than that of Geogrid A. Hence, Geogrid B was recommended as reinforcing material. A full scale test embankment made of lightweight tire chip-sand backfill with geogrid reinforcements was constructed in the soft Bangkok clay to study the actual behaviour and the benefits.

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