Improvement effects of two and three dimensional geosynthetics used in liquefaction countermeasures

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ABSTRACT

This study focuses on accumulation of basic data on deformation and energy absorbing characteristics of geosynthetics (recycled tire chips and geogrid), which are used as liquefaction prevention materials for shallow foundations. Because tire chips have high compressibility, decrease of bearing capacity and excessive differential settlement of the foundation ground may arise. A new reinforcement method, using gravel mixed tire chips layer and layers of geogrid, was proposed to compensate for the inadequate bearing capacity and suppress differential settlement. In this study, the deformation and energy absorbing characteristics of tire chips and gravel mixed tire chips were made clear by performing direct shear test under dynamic loading using a large scale shearing device. Based on the results, it was found that the vibration-absorbing energy of tire chips decreases as the gravel fraction increases. Considering the pros and cons, we could arrive at the conclusion that the sample with 50% gravel mixture was the most effective. It was also confirmed that the rigidity of gravel mixed tire chips was improved through reinforcement by geogrid.

Keywords: absorbed energy, cyclic shear, deformation characteristics, geogrid, tire chips

1. INTRODUCTION

In the Great East Japan Earthquake, nearly 20,000 houses suffered damage from liquefaction in the Kanto area alone. Although many methods to prevent liquefaction exist, most of them can only be applied to large structures. This is because, many of those existing methods against liquefaction have high construction costs, and are difficult to apply in general residential buildings. Therefore, development of an inexpensive method against liquefaction that can be applied to general residential buildings is necessary.

Hazarika et al. (2009) proposed a liquefaction prevention method that can reduce building damage at low cost by using recycled tire materials (tire chips) under the foundations of residential buildings. A conceptual diagram for the method is shown in Fig. 1. In addition to recycling of waste tires, and thus reducing burden to environment, it is expected that, owing to their elastic deformation, tire chips will absorb earthquake energy and prevent damage to the building during earthquakes. Tire chips are also known to experience no liquefaction because of their effects in suppressing the increase of excess pore water pressure and their excellent damping performance (Hyodo et al., 2008; Konza et al., 2012; Hazarika, 2013). The elastic behaviour and energy absorbing capacity of pure tire chips have been studied before by the authors and their co-workers (Hazarika and Igarashi, 2009; Niiya et al., 2011a; Niiya et al., 2011b; Niiya et al., 2011c). However, tire chips have high compressibility, and thus the method explained in Fig. 1 is expected to have disadvantages, which include the occurrence of differential settlement and insufficient bearing capacity. Therefore, as a countermeasure it is proposed to reinforce the tire chip layer by adopting a dual approach: mixing gravel with tire chips and laying geogrid within the gravel mixed tire chips layer, as shown in Fig. 2. Such a measure can suppress differential settlement and improve the bearing capacity of foundation soils. This type of measure effectively utilizes the functions of two dimensional geosynthetics such as geogrid and three dimensional geosynthetics such as tire chips. The concepts and functions of the two-dimensional and three dimensional geosynthetics have been enunciated by the International Geosynthetics Society (IGS, 2009). Few applications of such geosynthetics can also be found in Emersleben and Groeger (2013) and Hazarika et al. (2010).

Meanwhile, from the cost point of view, it is expected that tire chips with relatively large grain sizes will be used in practice. However, there are insufficient data on tire chip samples with large grain sizes, owing to limitations in the sizes of conventional testing apparatus. The effects of gravel mixture on large grained tire chips or geogrid laying on various factors
such as bearing capacity improvement, deformation and energy absorbing characteristics etc., thus, need to be studied in detail, for firm establishment of the technique described in Fig. 2. The objective of this research, therefore, is to examine the deformation and frictional characteristics of gravel mixed tire chips for both the reinforced and unreinforced cases when subjected to dynamic loading using a large-scale direct shear testing apparatus. Direct shear tests were conducted on various test samples, and based on the test results the energy absorbing capacity and rigidity of the improved foundation soils were made clear.

2. DESCRIPTION OF TEST SERIES

A past study (Niiya and Hazarika, 2011) concluded that the grain sizes of gravel to be mixed with tire chips should be approximately similar to those of tire chips. In this study, we conducted direct shear tests under dynamic loading on samples with varying gravel fractions (percentage of gravel in the mixture). The effects of gravel fraction (called GF hereafter) and reinforcement with geogrid on the improvement of bearing capacity, as well as the damping and strength characteristics of tire chips were studied. In liquefaction countermeasure described above, the effect of water table will come into the picture. However, this study is restricted only to dry state of the material. It is to be noted that the aim of this research is not the verification of liquefaction prevention technique described before, but to make clear the deformation and energy absorbing characteristics of the geosynthetics used in the technique. It is, therefore, assumed that those characteristics will not vary depending on whether the ground is dry or not.

2.1 Test materials used
Tire chips with a relatively large grain size (which are expected to be used in practice owing to their low cost), and gravel of approximately the similar grain size were used in the testing. Fig. 3 shows the samples that were used in tests. Fig. 4 shows the grain size distribution for the samples, and Table 1 lists the basic physical properties of the samples. To examine the effects of GF on the deformation characteristics of tire chips, tests were conducted on a total of five types of samples by adding those with gravel of 30%, 50%, and 70% in volume ratio. The reason for using volume ratio in mixing gravel and tire chips is simply for the ease in preparing the test specimens. It may be more practical to use weight ratio instead of volume ratio.

2.2 Test conditions and procedures
Tests were conducted by using a newly developed large scale shearing/pull out testing apparatus (Igarashi and Hazarika, 2009). The shear box of this testing apparatus has large dimensions of W200 × L400 × D300 mm; thus, it is capable of testing samples with large grain sizes that cannot be tested with conventional testing apparatus.

For all samples, the specimens were prepared by free falling method to compact those inside the shear box, and adjusting it to a relative density of 30%. Although such low relative density may not be very

![Fig. 1 Liquefaction mitigation method using tire recycle material](image1)

![Fig. 2 Improved technique using gravel and geogrid](image2)

![Fig. 3 Materials used in the test](image3)

![Table 1 Physical properties of materials](table)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Particle density (gm/cm³)</th>
<th>Maximum density (gm/cm³)</th>
<th>Minimum density (gm/cm³)</th>
<th>Average particle size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tire chips</td>
<td>1.15</td>
<td>0.60</td>
<td>0.50</td>
<td>11.6</td>
</tr>
<tr>
<td>Gravel</td>
<td>2.70</td>
<td>1.63</td>
<td>1.34</td>
<td>14.2</td>
</tr>
</tbody>
</table>

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realistic in the field, in this testing program this value was used to keep the same relative density for the tire chips and the surrounding soils, as tire chips is difficult to compact within the shear box to achieve a high relative density. The relative density of highly granular materials such as gravel and tire chips was determined based on the standard specified by the Japanese Geotechnical Society (JGS, 2009) and also following the standard described in Farrar (1999).

A conceptual drawing of the test is shown in Fig. 5. In this test, the geogrid was made to move together with the lower shear box. Considering the fact that the shear surface may shift when the geogrid is laid, a dummy specimen was packed into half of the lower shear box as shown in the figure, instead of filling the whole lower half with tire chips or gravel mixed tire chips.

3. DEFORMATION AND ENERGY ABSORBING CHARACTERISTICS OF THE MATERIALS

3.1 Deformation characteristics of tire chips and gravel mixed tire chips without geogrid reinforcement

Fig. 6 shows the temporal changes in vertical displacement. Based on this figure, there was a difference in vertical displacement of approximately 100 mm at maximum between the sample composed only of tire chips and that composed only of gravel, indicating the high compressibility of tire chips. Focusing on gravel fraction (GF), it can also be seen that the vertical displacement reduced more with the increase of GF.

Fig. 7 shows the relationship between the maximum value for vertical displacement and GF. When the samples with 50% GF and that composed only of tire chips are compared, it is evident that the vertical displacement was decreased to nearly half by mixing gravel. Vertical displacement decreased in proportion to the GF, indicating that the mixture of gravel is extremely effective in reducing vertical displacement.

A confining pressure of 150 kN/m² was applied for 10 minutes before the shearing test to consolidate the specimen. Then, cyclic shearing was conducted by applying a sinusoidal wave (frequency = 0.01 Hz) in horizontal direction through stress controlled method (cyclic stress ratio = 0.15) on the lower shear box. A total of 20 cycles of load were applied. Based on these tests, the effects of gravel mixture and geogrid reinforcement on the damping characteristics and rigidity of tire chips were examined.
tests. The figure indicates that the absorbed energy decreases as the GF increases. A comparison between the sample composed only of tire chips and that composed only of gravel reveals the high vibration absorption properties of tire chips: the absorbed energy was approximately 10 times higher in the tire chip sample than in the gravel sample after 50 cycles of loading. In addition, as loading was repeated, ΔW decreased more slowly in samples mixing tire chips and gravel than in the unmixed samples. It is surmised that this occurred as tire chips, which are usually resistant to compacting, underwent compaction under cyclic loads.

Fig. 8 Variation of absorbed energy

Fig. 9 shows the changes in apparent shear modulus, G′, which are obtained from the stress deformation curves of the materials. This shows that the rigidity increases as the GF increases, and that tire chips have a rigidity of about 1/7 that of the sample composed only of gravel. This implies that pure tire chips has insufficient bearing capacity compared with unmixed samples. When we focus on the increase in rigidity in concurrence with cyclic shear, these results also indicate that the rigidity tends to increase dramatically during the initial stages of loading as the GF increases.

Furthermore, the increase in rigidity became more prominent and the effect of gravel more considerable when the GF exceeded 50%. Rigidity continued to increase slowly in samples containing tire chips as loading was repeated. It is surmised that the grain alignment of tire chips gradually became refined and compacted due to repetitive loading.

3.2 Deformation characteristics of tire chips and gravel mixed tire chips with geogrid reinforcement

Fig. 10 shows the absorbed energy for the sample of each test case calculated for each cycle. This indicates that the sample composed only of tire chips has more than 10 times higher absorbed energy than that composed only of gravel, regardless of reinforcement.

When we focused on the decrease in ΔW, we found that this value was smaller in all samples reinforced with geogrid than in samples without reinforcement, except for the sample composed only of gravel. It is surmised that this is because the samples reinforced with geogrid have stable horizontal displacement from the initial stages of loading. Regarding GF, the results indicate that the absorbed energy decreases as the GF increases, regardless of reinforcement. Absorbed energy is slightly smaller in test cases with reinforcement than those without reinforcement for the same GF.

Fig. 11 shows the plots absorbed energy ΔW after 20 cycles as a function of GF. It shows that absorbed energy ΔW decreases in proportion to the GF and that it is dependent on the GF. Although absorbed energy also decreases with geogrid reinforcement, it is surmised that the absorbed energy is maintained, because even the sample with 50% GF has more than five times greater absorbed energy than pure gravel.
Fig. 12 shows the value of apparent shear modulus, $G'$ in each cycle of each test case. Here the dashed lines represent the reinforced cases. Based on the graph, it can be inferred that the rigidity became larger as the GF increased. Rigidity did not increase much upon the completion of 20 cycles for samples with GF 50% or smaller. It is considered that this occurred because of the compressibility of tire chips, with characteristics of gravel conversely becoming more dominant when the GF exceeded 50% and rigidity increasing rapidly during the initial stages of loading. When we compare samples with and without reinforcement, rigidity was larger for samples reinforced with geogrid than those without reinforcement at any GF, indicating the effect of reinforcement with geogrid.

Fig. 13 shows the plots of apparent shear modulus, $G'$ after 20 cycles as a function of GF. This figure indicates that the shear modulus has a tendency to increase exponentially as the GF increases. The shear modulus is smaller when the GF is smaller. It is surmised that the constraining effect of the geogrid was not mobilized sufficiently when displacement was small, because the tire chip sample deformed under shear. Therefore, it can be concluded that a larger GF is better because the reinforcement effect can be mobilized sufficiently, even against minute displacement by small loads.

4. CONCLUSIONS

The following conclusions could be drawn based on this experimental research.

(1) Absorbed energy in tire chips becomes smaller and rigidity larger when the gravel fraction increases.

(2) Absorbed energy in the sample decreases when geogrid is used. However, in a sample with 50% gravel mixture, it is still approximately five times larger than that of pure gravel, indicating that the seismic base isolation characteristics is maintained.

(3) The constraining effect of geogrid is not adequately mobilized with pure tire chips as its particles undergo deformation. However, the frictional and pull out characteristics can be improved by mixing gravel with tire chips.

(4) Gravel mixture and geogrid laying are extremely effective in improving the bearing capacity of tire chips. The reinforcement effect of geogrid is particularly high.

(5) It is expected that tire chips with 50% gravel fraction, in which the constraining effect of geogrid is mobilized effectively and seismic resistant effects are maintained to some extent, will be most effective.

REFERENCES


