Effects of geogrids on compaction of granular materials made from recycled glass bottles in backfilling works

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ABSTRACT: A new technology has been introduced to recycle glass bottles into granular materials to be used as geo-materials. One of these granular materials has diameters in the range of 5 to 10 mm. Since this material has a high permeability, it would not liquefy during earthquakes. Thus, it can be used as a backfill material of underground pipes for preventing them from earthquake-induced uplift. In relevant studies, its applicability has been confirmed based on a series of centrifugal model tests. However, in these tests, settlement of the above material occurred remarkably during shaking. A solution to this issue is compaction, while this material is poorly compactable. Therefore, effects of insertion of geogrids for efficient compaction are investigated in this study. In order to evaluate the effects of geogrids on the compaction of this material, compaction tests were conducted using a large scale mold. In these tests, arrangement of geogrids and thicknesses of compacted layers were changed. Moreover, possible particle crushing due to compaction was measured quantitatively. They revealed that the shorter the distance from geogrid to the loading plane was, the higher the degree of compaction became, provided that a proper amount of overburden pressure was ensured.

1 INTRODUCTION

In Japan, a lot of transparent and brown colored glass bottles are recycled. However, a lot of other colored glass bottles are not recycled. It is difficult to reproduce uniformly-colored homogeneous glass bottles from them because there are various kinds of other colored glass bottles which have different coefficients of thermal expansion. Thus, these glass bottles become wastes after single use. The total amount of the waste of glass bottles in Japan was 470,000 ton/year as of 2007 (GBRPA, 2009). Therefore, granular materials made from recycled glass bottles have been developed for their effective re-use (called simply as “glass material” below).

A previous study conducted by the authors (Mikami et al., 2009) revealed that the glass material having diameters in the range of 5 to 10 mm can be used as a countermeasure against earthquake-induced uplift of underground pipes, since it has high permeability. It also revealed that residual settlements of ground surface can occur due to earthquake. Therefore, not only resistance to earthquake-induced uplift of underground pipes but also resistance to settlements of surfaces should be secured in using the glass material as backfill of underground pipes.

In this study, the authors focus on the compaction as countermeasure against residual settlements of surfaces. However, the glass material having diameters in the range of 5 to 10 mm is a poorly compactable material. When compaction was carried out on the glass material by tamping, particles moved easily from the near part of rammer to the far part. Therefore almost all of compaction energy was consumed for this movement. It was expected that geogrids could restrain the movement of particles and that compaction energy would be consumed more effectively.

In order to evaluate the effects of geogrids in improving material compaction, compaction tests using a large scale mold were conducted. In these tests, arrangement of geogrids and thicknesses of compacted layers were changed. Moreover, possible particle crushing due to compaction was measured quantitatively.

2 TEST CONDITIONS AND METHODS

In a mold with a cross-section of 233 × 233 mm and a height (including the collar) of 538 mm, the glass material having diameters in the range of 5 to 10 mm (ρ_{dmax}=1.526 g/cm^3 evaluated at a compaction energy of 550 kJ/m^3) in air-dried condition (w=0.4

%) of prescribed weight was placed. A metal loading block with a cross section of 70 × 70 mm and a height of 200 mm was placed on the surface of the material. On the loading block, a 12 kg metal mass was free-fallen from a prescribed height for compaction. During compaction, the surface of the material was leveled when the bottom of the loading block penetrated into the material deeply.

Figure 1, Table 1, Figure 2, and Photo 1 show, respectively, particle size distribution of the tested glass material, test conditions, initial thicknesses of layers and the geogrids employed in this study.

It should be noted that, during the preparation of the tested material, particles having diameters smaller than 5 mm were removed by a special sieve. However, this sieving process was not strict. Therefore the glass material having nominal diameters in the range of 5 to 10 mm included some amount of particles having diameters smaller than 5 mm.

In cases 1 to 10, the glass material was used repeatedly. During compaction, particle crushing occurred to some degrees. Therefore, the observed difference in the degrees of compaction might be affected by not only the different test conditions but also the change of particle size due to particle crushing. In order to confirm the repeatability of test results on compaction, the new batches of the glass material were used in cases 11 and 12. Test conditions of cases 11 and 12 were the same as those of cases 10 and 8, respectively.

As mentioned above, almost all of compaction energy was consumed for the movement of particles during compaction without geogrids, and it was inferred that geogrids could restrain the movement. Therefore, in order to estimate the effects of geogrids on restraint of movement of particles and improve compaction, the cross-section of the loading block was adjusted to be smaller than that of the mold as shown in Figure 2.

The target compaction energy was 2600 kJ/m^3. The compaction energy was calculated on the hypothesis that the compaction energy was consumed only in the material having the same cross-section as the loading block. As a result, the total number of falls was 240, and the height of fall was approximately 22.5 cm.

Before and after compaction of each layer, distances from the top of the mold to the surface of the material were measured. These distances after compaction were measured after leveling the surface, because the loading block penetrated into the material. The change in the local density of the compacted layer was calculated on a hypothesis that change of thickness of the layer occurred in the uppermost layer only.

In order to evaluate the degree of particle crushing due to compaction, particles having diameters smaller than 0.85 mm were removed before the tests, and their increment was measured after the tests. The degree of particle crushing was compared in terms of the increment that was normalized by the total amount of particles by weight. This ratio is called as $R_{0.85}$ below.

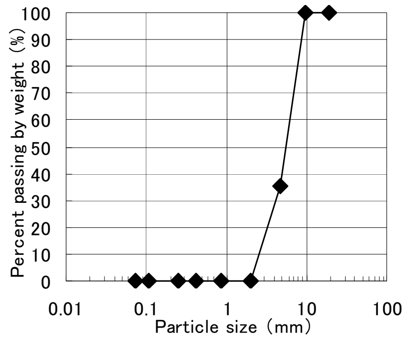


Figure 1. Particle size distribution

Table 1. Test conditions

case	position of geogrids in each layers*					initial thickness of layers**	geogrids***
	1st	2nd	3rd	4th	5th		
1	-	-	-			a	-
2	-	250	125			a	A
3	-	250	125			a	B
4	-	125	125	125	62.5	c	A
5	125	125	125	125		b	A
6	0,125	0	0	0		b	A
7	31.25	31.25	31.25	31.25		b	A
8	-	-	-	-		b	-
9	62.5	62.5	-			a	A
10	31.25	31.25	31.25	31.25		b	B
11	31.25	31.25	31.25	31.25		b	B
12	-	-	-	-		b	-

*distance from compaction plane(mm)
**refer to Figure 1
***refer to Photo 1

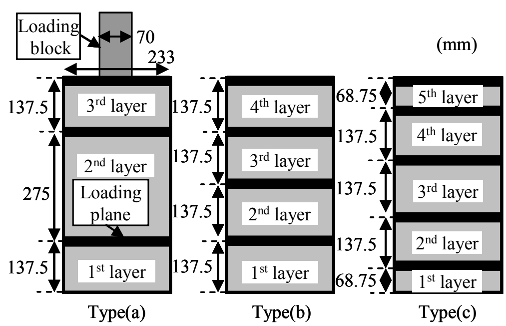
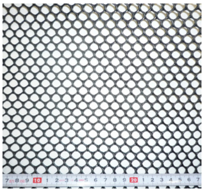


Figure 2. Initial thickness of layers

Type(A)
Opening: 20×25 mm
Nominal tensile load:
1.96×1.96 kN/m



Type(B)
Opening: 8×8 mm
Nominal tensile load:
5.89×4.41 kN/m

Photo 1. geogrids

3 TEST RESULTS

Table 2 summarizes the test results. In order to calculate the degree of compaction, Dc, the average density of the whole specimen after removing the collar and leveling the surface was used. The same definition is herein employed except for Figure 3. In Table 2, “Dc,with / Dc,without” means the Dc value in a case with geogrids divided by the one in the corresponding case without geogrids under the same condition of initial thickness of layers.

Figure 3 shows distribution of the local degree of compaction, Dc, in the vertical direction. The notations of symbols in figures below are the same as those in Figure 3.

The local Dc value of the lowermost layer was the lowest among all the local Dc values in each case shown in Figure 3. As shown in Section 2 of this paper, in order to calculate the local Dc value, the hypothesis that change of thickness of layer occurred in the uppermost layer only was adopted. However, the lower layers should have been compacted to larger degree due to compaction of the overlying layers. Therefore it was inferred that the local Dc values of the lower layers were underestimated. In some cases, the local Dc value of the uppermost layer was smaller than that of the lower layers, for which the reason has not been revealed.

3.1 *Effects of geogrid insertion*

In this section, effects of geogrid insertion will be verified based on the test results on cases 7, 9, 10 and 11 where the distance from loading plane, as will be defined in the next section, is relatively small (i.e. about 30 to 60 mm). All of the values of “Dc,with / Dc,without” for these cases as listed in Table 2 were exceeding 1.0, suggesting positive effects of geogrid insertion. However, the gains in compaction efficiency due to use of geogrid were limited under the test conditions employed in this study. It might be due to the scale effect; the sizes of the mold and the loading block used in these tests might not be enough to simulate the compaction in real construction sites.

The test results of the other cases conducted under different conditions will be analyzed more in detail in the next section in terms of the effects of geogrid location

3.2 *Effects of geogrid location*

Figure 4 shows the relationships between degrees of compaction and distances from loading plane to geogrid, L. In cases 2 and 3, assuming prototype ground having geogrids which were placed at a constant interval, the initial thicknesses of layers were set on the hypothesis that the center of this ground was the center of the mold. In preparing Figure 4, the largest distance from loading plane to geogrid in cases 2 and 3 was used as schematically shown in Figure 5. The distance in case 4 was also assigned based on this hypothesis.

As a result, the shorter the distance from loading plane to geogrid was, the higher the degree of compaction became while the initial thicknesses of layers were not the same.

When the distance from loading plane to geogrid was zero (i.e., in case 6), the Dc value was not high. It is due to the warp of geogrids that occurred during compaction without applying any overburden pressure, suggesting that a proper amount of overburden pressure shall be ensured in improving compaction using the geogrid.

3.3 *Particle crushing*

The difference between the Dc values in cases 11 and 12 using the new batches of the glass material is lower than the difference between those in cases 10 and 8 under a repeated use of the material. Therefore test results in cases 1 to 10 might be affected by not only the different test conditions but also the change of particle size due to particle crushing.

Figure 6 shows the relationship between degree of compaction and the ratio of increase of particles having diameters smaller than 0.85 mm, $R_{0.85}$. The higher the $R_{0.85}$ value became, the higher the degrees of compaction became. Therefore the observed degrees of compaction should have been affected by not only the different test conditions but also the changes of particle sizes due to particle crushing.

Table 2. Test results

case	initial thickness of layers	geogrids	Dc(%)	Dc,with / Dc,without	$R_{0.85}$(%)	L(mm)
1	a	-	94.9	-	0.23	-
2	a	A	94.5	1.00	0.22	250
3	a	B	94.3	0.99	0.23	250
4	c	A	95.8	-	0.27	125
5	b	A	95.9	1.00	0.24	125
6	b	A	95.9	1.00	0.19	0
7	b	A	97.2	1.01	0.33	31.25
8	b	-	96.2	-	0.43	-
9	a	A	96.7	1.02	0.41	62.5
10	b	B	98.8	1.03	0.33	31.25
11	b	B	98.1	1.01	0.52	31.25
12	b	-	97.0	-	0.59	-

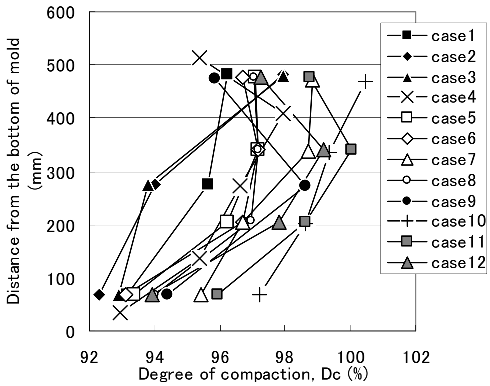


Figure 3. Distribution of degree of compaction in vertical direction

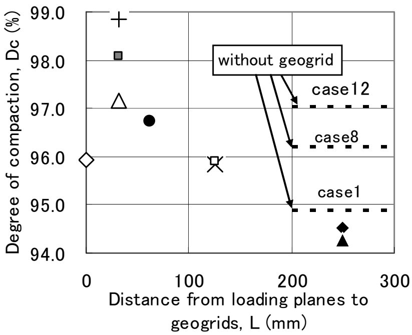


Figure 4. Relationship between degree of compaction and distance from loading plane to geogrid

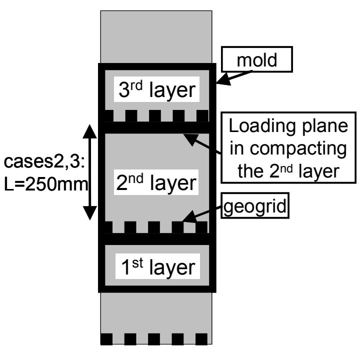


Figure 5. Hypothesis about the distance from the loading plane to geogrid

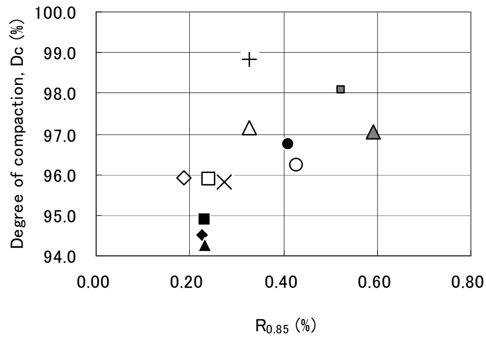


Figure 6. Relationship between degree of compaction and the ratio of increase of particles having diameters smaller than 0.85 mm, $R_{0.85}$

4 CONCLUSIONS

The compaction test results on the granular material made from recycled glass bottles with/without geogrid can be summarized as follows.

Under a proper amount of overburden pressure, geogrid was effective in improving the compaction of the glass material.

Under the test conditions employed in this study, the shorter the distance from the loading plane to the geogrid was, the higher the degree of compaction became. However, when the distance from loading plane to geogrid was zero, the geogrid was warped extensively, suggesting that a proper amount of overburden pressure shall be ensured in improving compaction using the geogrid.

When the degree of compaction became higher, grater particle crushing occurred. Therefore the observed degrees of compaction should have been affected by not only the different test conditions but also the changes of particle sizes due to particle crushing.

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