EXPERIMENTAL STUDY ON MITIGATION OF LIQUEFACTION-INDUCED FLOTATION OF SEWERAGE MANHOLE BY USING PERMEABLE RECYCLED MATERIALS PACKED IN SANDBAGS

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ABSTRACT:
The 2004 Niigata Chuetsu earthquake in Japan caused serious damage to sewerage facilities such as uplift of manholes and settlement of pavement above backfill soil for pipes. This paper deals with shaking table tests in a 1-g gravity field on application of permeable recycled materials for ground improvement to mitigation of liquefaction-induced flotation of manhole during earthquakes. The recycled materials used in tests were tire chips made of waste tires and crushed gravels made of waste reinforced concrete, and they were packed in sandbags. From the test results, it was confirmed that the recycled materials packed in sandbags could be treated as one of the countermeasures to restrain the flotation of manholes and settlement of ground surrounded by sandbags.

KEYWORDS:
Liquefaction, shaking table test, recycled material, sandbag, manhole

1. INTRODUCTION

The 2004 Niigata Chuetsu earthquake in Japan caused serious damage to sewerage facilities such as uplift of manholes and settlement of pavement above backfill soil for pipes. Photo 1 shows the uplift of manhole in Nagaoka city. The uplift of manhole was as much as 1 m and settlement of surrounding pavement was at most 30 cm. These phenomena could be observed at over 1,400 locations in devastated area. These were also observed during 2007 Noto Hanto earthquake and 2007 Niigata Chuetsu-oki earthquake. It was considered that the cause of uplift of sewerage manholes was liquefaction of backfill soil.

Photo 1 Uplift of manhole and settlement of pavement above backfill soil for pipe

It is considered that the damage of sewerage facilities might cause following problems:
1) The life of inhabitant may be inconvenient because toilet cannot be used.
2) Traffic of road may be obstructed because the manhole is uplifted in the road.
3) Public health and water quality may become worse because untreated sewage leak from broken pipe.

Therefore, it is very important to take countermeasure to mitigate the damage of them. On the other hand, since the diffusion rate of population of sewage disposal is about 68 % in Japan, the construction of sewerage facilities will be conducted more in future. Therefore, because it seems that stock of sewerage facilities will increase, we must take countermeasure to mitigate the damage of them immediately.

In order to avoid similar damage in the future, the government recommended employing one of the following countermeasures against liquefaction of backfill soil in the reconstruction work of the damaged sewerage facilities after the 2004 Niigata Chuetsu earthquake (MLIT, 2004):
1) In using sands as the backfill material for sewage pipes, they should be compacted to a value of degree of compaction exceeding 90 %.
2) To maintain high permeability, crashed gravels that have D_{50} not less than 10 mm and D_{10} not less than 1 mm should be used as the backfill material, while compacting them to a value of degree of compaction exceeding 90 %.
3) The backfill material should be solidified by adding cement or other cement-origin hardening additives to have an unconfined compressive strength in the range of 100 to 200 kPa after curing for 28 days in the laboratory. This range corresponds to in-situ strength of 50 to 100 kPa.

Among them, the authors have been studying the second one called as gravel drain system which is installed to increase permeability of ground and thus rapidly dissipate the excess pore water pressure during liquefaction (Miyajima et al., 1999). Moreover the authors were investigating whether some recycled materials could be used instead of natural gravels (Yoshida et al., 2006). The recycled materials were tire chips made of waste tires and crushed gravels made of waste reinforced concrete as shown in Photo 2.

(a) Tire chips

(b) Recycled gravels

Photo 2 Permeable Recycled materials used in this study

The authors proposed a method of packing these materials in a bag made of polyethylene net which was often used as a sandbag as shown in Photo 3 because bearing strength of these granular materials could become strong. Furthermore application of the sandbags to improvement of the backfill soil around the manhole was investigated as shown in Figure 1. In this paper, a series of shaking table tests was conducted in a 1-g gravity field in order to evaluate the performance of the recycled materials packed in sandbags in liquefiable sand layers during an earthquake. From the test results, it was confirmed that the recycled materials packed in sandbags could be treated as one of the countermeasures to restrain the flotation of manholes and settlement of ground surrounded by sandbags.

Photo 3 Sandbag used in this study

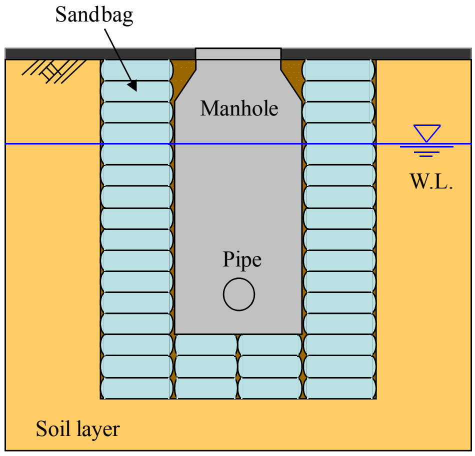


Figure 1 Schematic diagram of countermeasure

2. TEST PROCEDURE

Figure 2 illustrates cross sections of top and front view of a model ground with locations of transducers. The model ground was set up in a rigid acrylic container that measured 1200 mm long, 400 mm wide and 540 mm high. The tests were conducted by using a composite ground which consists of two parts. One was tire chips packed in sandbags were installed, the other was recycled gravels packed in sandbags, and they were separated by a steel partition wall. The sandbags of tire chips were set at left side and the sandbags of recycled gravels were set at right side as shown in Figure 2.

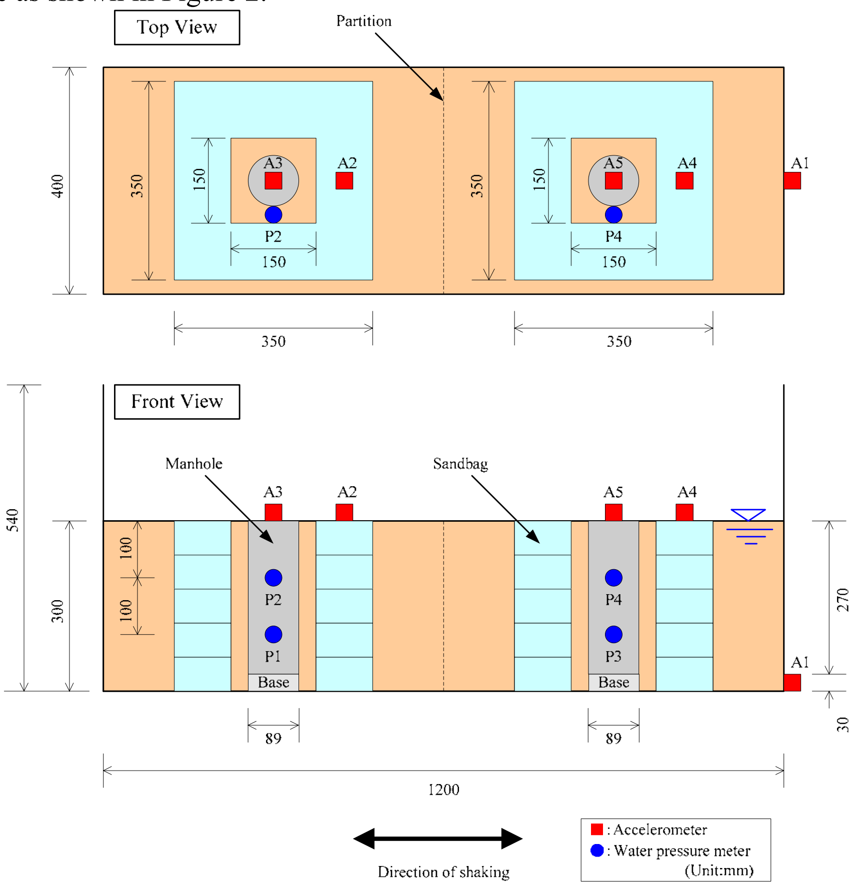


Figure 2 General view of model ground and transducers

The tire chips were made by shredding the whole tires and their particle size were adjusted between 10 mm and 16 mm. The recycled gravels were extracted from crushed waste reinforced concrete and their particle size was adjusted between 2.5 mm and 5 mm. These two materials were packed in the sandbags of polyethylene that measured 250 mm long, 100 mm wide and 50 mm high. The loose liquefiable sand layer was made of silica sand No.7 and the relative density was about 35%. The physical properties of these materials are listed in Table 1. A model of manhole was made by vinyl chloride that measured 89 mm diameter and 270 mm high. The density of manhole was adjusted to 1 g/cm^3 so that it could float certainly due to liquefaction.

Table 1 Physical properties of sand and drain material

	Sand	Drain material	
Material	Silica Sand No.7	Tire Chips	Recycled gravels
Density ρ (g/cm^3)	2.63	1.26	2.56
Average diameter D_{50}(mm)	0.17	8.00	3.25
Coefficient of permeability k (cm/s)	4.79×10^{-3}	1.84×10^{-1}	1.40×10^{-1}
Coefficient of permeability with sandbag k (cm/s)	-	1.68×10^{-1}	1.17×10^{-1}

Four types of drain arrangement were adopted as illustrated in Figure 3. Case 1 had the drain from bottom to surface of soil layer with 5-layer sandbags as shown in Photo 4, Case 2 had the drain of upper soil layer with 3-layer sandbags and Case 3 had the drain of lower soil layer with 3-layer sandbags. Case 4 was an improved version of Case 3 which had the drain to surface of soil layer above the 3-layer sandbags. A test without countermeasure called as Case 0 was also carried out in order to compare with Cases 1 to 4.

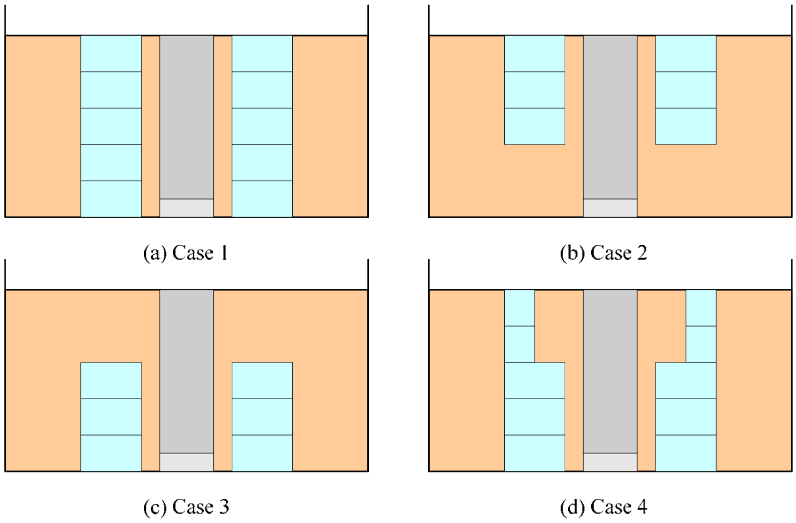

(a) Case 1 (b) Case 2
(c) Case 3 (d) Case 4

Figure 3 Drain arrangement used in shaking table tests

Photo 4 Drain arrangement of Case 1

The shaking table tests were conducted as follows: 1) The recycled materials packed in sandbags and model of manhole were installed in the container. 2) Pore water pressure transducers were installed at the locations as shown in Figure 2. 3) The container was first filled with water to 30 cm high from the bottom. Then a sieve with a 2 mm mesh was moved back and forth below water surface, pouring wet sand through water to form a uniform sand layer with a thickness 30 cm. 4) Excess water above the sand layer was soaked up so that the water surface was level with the surface of the sand layer. 5) Accelerometers were installed at the locations as shown in Figure 2. 6) The model ground was shaken in the horizontal direction with the sinusoidal wave of 80 gal in peak amplitude, 5 Hz in frequency and 5 seconds in duration time as shown in Figure 4. The pore water pressures and the response accelerations were recorded simultaneously on the data recorder. A vertical displacement of manhole was also measured by a laser displacement meter. 7) After the excess pore water pressure had completely dissipated, the vertical displacement of ground surface was measured by a point gauge. 8) The processes of 6) to 7) repeated five times with different amplitude which was from 80 gal to 160 gal at intervals of 20 gal.

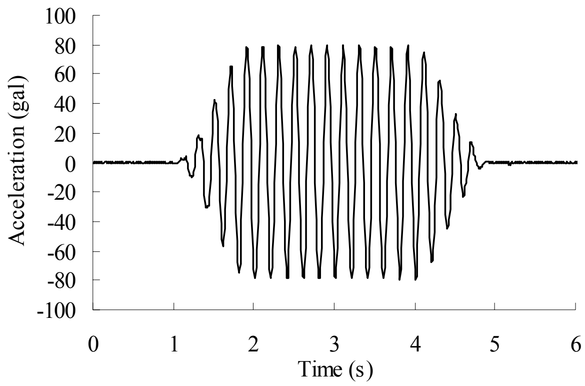
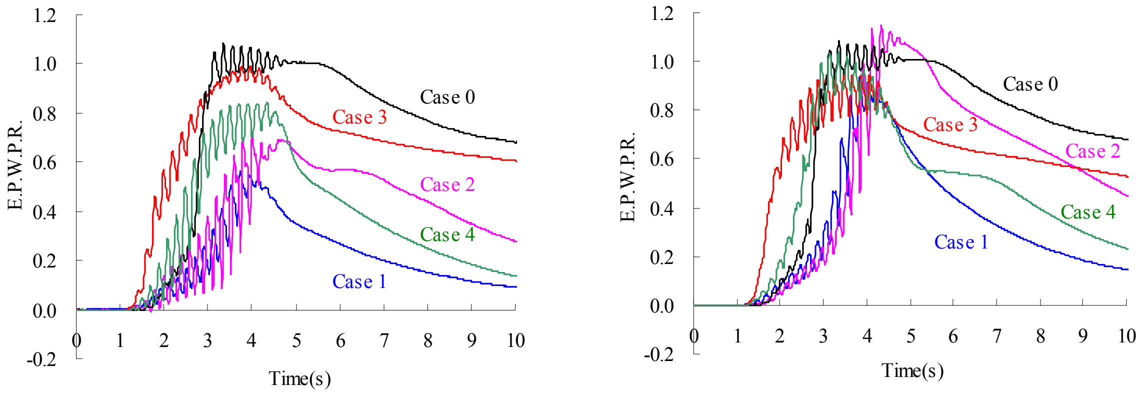


Figure 4 Time history of input acceleration

3. TEST RESULTS AND DISCUSSIONS

Figure 5 shows time histories of excess pore water pressure ratios located at 200 mm in depth from ground surface after undergoing shaking of 100 gal. Figure 5(a) indicates the cases of tire chips and Figure 5(b) indicates the cases of recycled gravels. In case of unimproved ground (Case 0), it took about 40 seconds that the excess pore water pressure completely dissipated, while in case of the ground with sandbags (Cases 1 to 4), the time of dissipation was extremely shortened. It is clear that Case 1 has highest permeability among four cases. Though Case 2 shows about the same effect as Case 1 during accumulation process of excess pore water pressure, its ability of dissipation is relatively low. In Case 3, it was hard to dissipate the excess pore water pressure because the way of drain did not reach to the ground surface. However, in case 4 which has the drain toward the ground surface, the effect of dissipation was improved considerably. Since tire chips have high permeability rather than recycled gravels, the effect of dissipation of tire chips was greater than the recycled gravels. This suggests that the tire chips will be able to use for drain material instead of natural crushed gravels. It is supported that effect of the recycled gravels and natural crushed gravels was almost same because their physical properties were similar.



(a) Tire chips [P1] (b) Recycled gravels [P3]

Figure 5 Time histories of excess pore water pressure ratio

Figure 6 shows settlement ratio of soil layer surrounded by sandbags. The settlement ratio is defined as a vertical displacement of soil layer divided by initial thickness of the ground, and the residual vertical displacement was accumulated after fifth shaking. Though the settlement ratio was about 7 % in case of unimproved ground (Case 0), it could be restrained in case of the ground with sandbags except Case 4. It was confirmed from observation of tests that vibration of sandbags at ground surface promoted the deformation of surrounding ground due to softening of soil. It is considered that the vibration of additional sandbags at the ground surface caused large settlement in Case 4 because the restraint of sandbags might be incomplete as compared with Case1 and Case 2. It is obvious that the settlement ratio in case of tire chips was smaller than that of recycled gravels due to their high permeability.

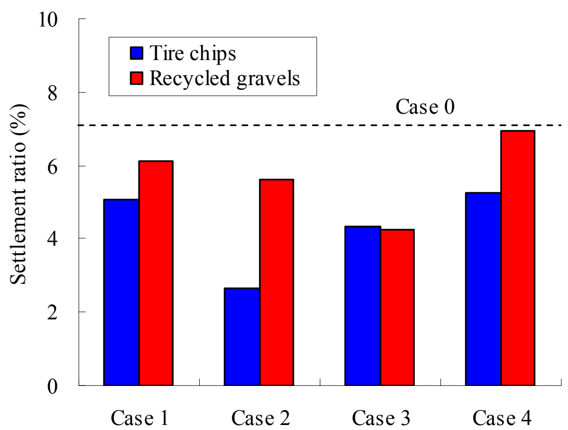


Figure 6 Settlement ratio of soil layer surrounded by sandbags

Accumulated vertical displacement of manhole after fifth shaking is shown in Figure 7. All of the displacement means flotation of manhole. It is clear that the flotation could be restrained in case of improved ground. The order of high performance to restrain the flotation is Case 1, Case 2, Case 4 and Case 3 in case of tire chips. It seems that this order was caused by existence of drain function toward ground surface because they affected the time of dissipation of excess pore water pressure in each case. Meanwhile, though it can be seen that the case of recycled gravels had a same tendency as the case of tire chips, the performance of restraining flotation relatively low due to its low permeability.

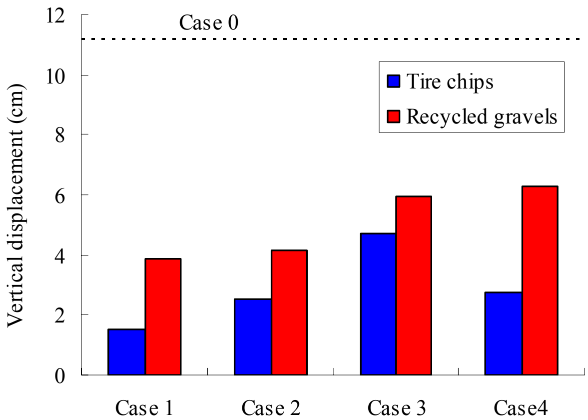


Figure 7 Vertical displacement of manhole

To investigate relation between duration time of shaking and flotation of manhole, shaking table tests were conducted using the model ground of Case 1. Input wave used in the tests was sinusoidal wave with a frequency of 5 Hz and a peak magnitude of 120 gal. The duration time of shaking was 4 s, 8 s and 12 s in this study. Figure 8 shows the relation between vertical displacement of manhole and duration time of shaking. It is obvious that the flotation of manhole increased with increase of shaking time in case of recycled gravels, but the flotation was restrained considerably in case of tire chips. It is considered a decrease of void ratio of tire chips due to shaking was relatively small as compared with recycled gravels because the density of tire chips was very small and it had high elasticity. Therefore the tire chips could maintain high permeability even if the duration time of shaking increased.

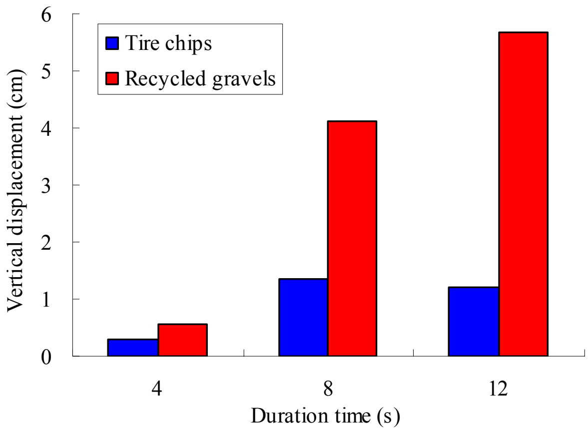


Figure 8 Relation between vertical displacement of manhole and duration time of shaking

4. CONCLUSIONS

A series of shaking table tests was conducted in a 1-g gravity field in order to evaluate the performance of the recycled materials packed in sandbags in liquefiable sand layers during earthquakes. The following conclusions may be made on the basis of the experimental study:

(1) The recycled materials packed in sandbags had high permeability and could dissipate the excess pore water pressure during liquefaction immediately. The improved ground by tire chips especially showed good performance rather than the recycled gravels. Therefore the tire chips will be able to use for drain material instead of natural crushed gravels.

(2) By installing the recycled materials packed in sandbags in liquefiable soil layer, the flotation of manhole and settlement surrounded by sandbags could be restrained due to its permeability.

(3) The tire chips could maintain high permeability even if the duration time of shaking increased because the density of tire chips was very small and it had high elasticity.

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