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EFFECTIVENESS OF CRASHED TILE IN COUNTERMEASURE AGAINST LIQUEFACTION

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ABSTRACT: Liquefaction usually occurs in many sandy grounds during earthquake including Japan. Liquefaction causes damage of structures by making floatation or subsidence of them, and reduces the necessary performance of the structures. For example, stability of retaining wall based on skeleton weight of the structure is reduced due to subsidence and inadequate support which causes the destabilization of the structure. In addition, the light weight underground structure suffers damage such as floating due to the reduction of shear strength of soils during liquefaction. The damage occurs not only to the civil engineering structures (roads, bridges, etc.) but also to the residential buildings which makes the building unusable. On the other hand, Aichi Prefecture (Japan) is a center of the production of tiles where the crushed tile can be used as recycling materials for a measure of soil liquefaction. In this research, we have investigated the material property of the crushed tile and examined the effectiveness of countermeasure against liquefaction by shaking table tests. It is found that liquefaction of the ground can be reduced using crushed tiles because of its high friction and drainage properties. In the research, we found that the anti-liquefaction manhole which was backfilled by clashed tile floated only by 1/3 of the magnitude observed in the case of without countermeasure against liquefaction.

Keywords: Countermeasure against liquefaction, recycling materials, clashed tile, disaster mitigation

1. INTRODUCTION

In Great East Japan Earthquake happened on March 11 2011, huge damage was reported [1] and [2]. Especially, the damage caused by tsunami and liquefaction was the largest scale in the history of observation. Liquefaction has been intensively dealt with for a main shock in huge earthquake. In recent years, however it is found that the bearing capacity of soils may not only decrease in the main shock with relative short time period but also in multiple aftershocks with relative a long time seismic motion. In addition, the multiple aftershocks in short time period enlarge the damaged area by the liquefaction. For this reason, it is necessary to predict the damage and take counter measures against the mixed disasters of huge earthquake that will happen with very high probability within thirty years.

Countermeasures against the earthquake for small structures such as branch lifelines and personal houses are urgently needed because they are vulnerable to not only the main shock but also to the secondary disaster that had become serious problems in the past earthquakes. Therefore, it becomes social concern and more important for the research on feasible and effective countermeasures for the existing small structures against the liquefaction caused by long-time seismic motion and short-time multiple aftershocks.

2. IMPORTANCE OF THE COUNTER-MEASURES AGAINST LIQUEFACTION FOR SMALL STRUCTURES

The countermeasures to protect the small structures from the damage are not so intensively dealt with compared with huge structures in civil engineering [3]. As observed in Great East Japan Earthquake, liquefaction causes the floating of underground structures such as sewage pipe, water pipes and gas pipe. Most of which became unusable for a long period (Fig.1).



Fig. 1 Damage as floating of underground structure due to liquefaction

In this research, we investigated the material properties of a crushed tile and examined the effectiveness of countermeasure against liquefaction for small structures using the crushed tile. Aichi Prefecture, Japan, is a major production source of tiles where useless or crushed tile comes out as garbage. If it can be used as recycling materials for anti-liquefaction, then it will be of great benefit.

3. RECYCLING MATERIAL AS ANTI-LIQUEFACTION MATERIAL

3.1 About Clashed Tile

The useless or crushed tile, called as abolished tiles, are produced in a fixed quantity each year, among which more than 80% of the abolished tiles are reused as raw materials for the production of new tile. The other 20%, however, is left unusable. Besides, the old abolished tile in the process of reroofing of houses is not recycled at all. The crushed tile is crushed to small angular particles in order to make it possible for recycling, as shown in Fig.2. Physically, the tile is stable that has no bed influence on environment because it is burnt at a very high temperature of 1150 ºC.



Fig. 2 Shape of the particle of material (Left: crashed tile, Right: Toyoura sand)

3.2 Physical Properties of Crushed Tile

In this research, some laboratory tests are conducted in order to investigate the applicability of the crashed tile as anti-liquefaction material. A red-brown crashed tile made in Mikawa area, hereafter called as Mikawa crashed tile, is used in the laboratory tests, including 1G shaking table test.

Figures.3-6 show test results of grain size distribution curve, density test of soil particle, and minimum-maximum density test of soil (void ratio and dry unit weight). In addition, the compressive strength of the particle in crushed tile is 78MPa, and its water absorption is 6-7%.

As for crashed tile that we used in the all tests, the maximum grain size is 4.75mm, uniformity coefficient is 6.0, and coefficient of curvature is 0.8 (Fig.3). The grain size distribution of crashed tile is better than Toyoura sand, a clean sand with a maximum grain size is 0.425mm, uniformity coefficient is 1.6, and coefficient of curvature is 0.9.

As to the density of the crashed tile, because it has a lot of small voids inside the particles as shown Fig.4, the density is rather lighter (Gs=2.56) than the general soil (Gs=2.65).

As mentioned before that the grain size distribution of the crashed tile is better than Toyoura sand, the distribution of the minimum-maximum void ratio, however, ranging from e=0.863 to e=1.457, is much bigger than the other materials, e.g., Toyoura sand: e=0.614-0.959 (Fig.5).

As the result, the dry density of the crashed tile, as shown Fig.6, is smaller than other materials because the void ratio of crashed tile is bigger and the density of soil particle is lighter.

From the above test results, it is found that the crashed tile is light soil material that has relatively good grain size distribution but large void.

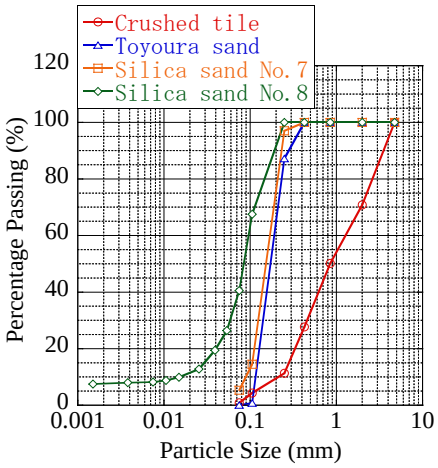


Fig. 3 Grain Size Distribution

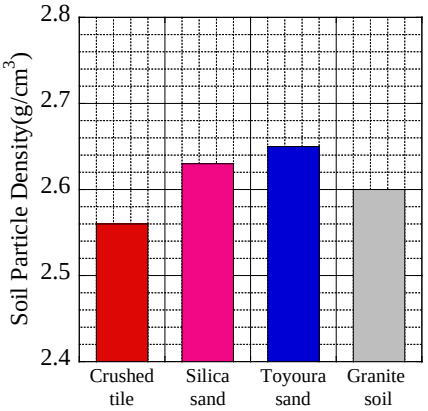


Fig. 4 Density of Soil Particle

3.3 Mechanical properties of Crushed Tile

Figure 7 shows the test results of a repose test, a simplest and easiest way to examine the reposed angle of a particle material under dry condition. The reposed angle of the crashed tile is 41deg that is

higher than general sand (around 30deg) from the result. The reposed angle of aluminum ball whose shape is completely round, is about 23º, which means that a particle material with angler shape will possess a high frictional resistance or, a high internal friction angle.

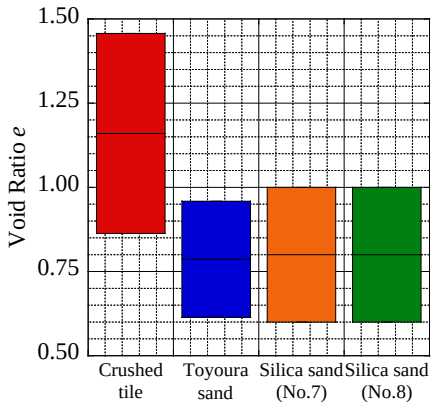


Fig. 5 Range of Void Ratio

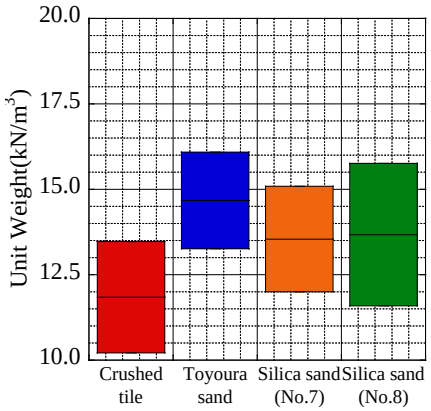


Fig. 6 Range of Dry Unit Weight

Figures 8-10 shows the test results of permeability test, direct shear test and conventional triaxial test. The permeability of the crashed tile is 2.76×10-3m/sec, as shown in Fig.8, a higher value than that of Toyoura sand (5.77×10-4 m/sec) because the maximum grain size and void ratio of the crashed tile is bigger than that of Toyoura sand. The permeability of the crashed tile can be classified as a coarse sand or gravel.

Figure 9 shows the result from the direct shear test. The internal frictional angle ϕ of the clashed tile is 42deg higher than that of Toyoura sand (around 30ddeg). In addition, the test result of triaxial compression test is shown in Fig.10. The internal frictional angle of the crashed tile is 41.5deg. Therefore it is reasonable to conclude that the internal frictional angle of the clashed tile is over 40deg from these mechanical tests.



(a) Clashed Tile (b) Aluminum ball

(c) Toyoura Sand (d) Silica Sand

Fig. 7 Repose angle of different materials

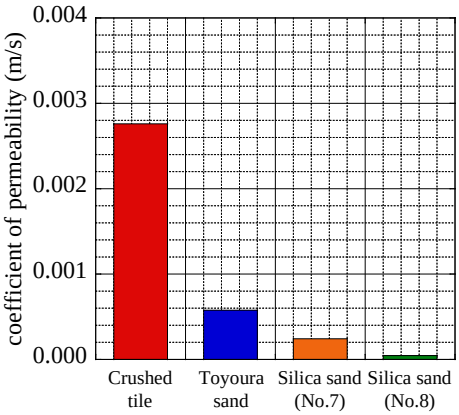


Fig. 8 Permeability Test

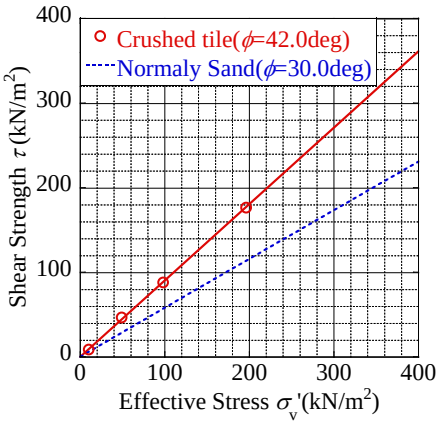


Fig. 9 Direct Shear Test

4. COUNTERMEASURE AGAINST FLOATING OF UNDERGROUND STRUCTURES

4.1 Setup of Experiment

The crashed tile is then regarded as an effective material for anti-liquefaction because its internal frictional angle and permeability is higher than

those of sands. In order to confirm this factor, we conducted a floating test of manhole which is backfilled with the clashed tile on liquefiable sandy ground using 1G shaking table test, as shown in Fig.11.

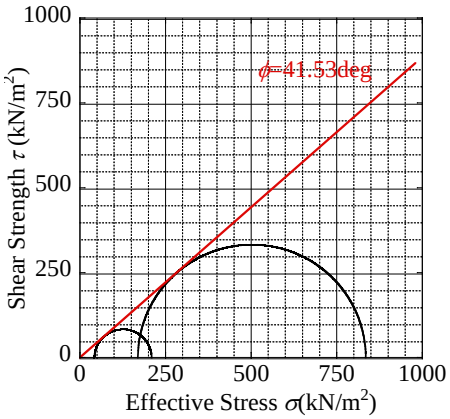


Fig. 10 Triaxial Test

Table 1 Property of Clashed Tile

Maximum density	$\rho_{d\,min}$	g/cm^3	1.042
Minimum density	$\rho_{d\,max}$	g/cm^3	1.374
Maximum void ratio	e_{min}		1.457
Minimum void ratio	e_{max}		0.863
Soil particle density	ρ_s	g/cm^3	2.56
Maximum grain size	D_{max}	mm	4.75
60% diameter on the grain size diagram	D_{60}	mm	1.28
50% diameter on the grain size diagram	D_{50}	mm	0.847
30% diameter on the grain size diagram	D_{30}	mm	0.456
10% diameter on the grain size diagram	D_{10}	mm	0.213
Uniformity coefficient	U_c		6.0
Coefficient of curvature	U_c'		0.8
Coefficient of permeability	k	m/s	2.76*10^{-3}
Angle of Internal friction	ϕə	deg	42.0



Fig. 11 Shaking Table

The shaking table test device uses air-pressure actuator that has an advantage of high performance of maintenance but disadvantage of less accuracy of wave output. The maximum air pressure is 1.0MPa, the maximum stroke is 0.05m, the maximum loading capacity is 18kN, and the maximum vibration acceleration is 9.80m /s2. A laminate shear box is installed on the table whose depth, length and width is 0.8m, 1.2m and 1.0m respectively. The average relative density of Toyoura sand and the crashed tile that used in the shaking table test, is 24.2% and 23.7% respectively.

4.2 Test Conditions

In the shaking table test, we use the crashed tile as a backfill material against the liquefaction and Toyoura sand as the model ground material. In the test, the apparent gravity of the manhole, an underground structure, is 1.2, its diameter is 0.10m, the height is 0.30m, and the manhole is made from acryl hollow cylinder. Figure.12 shows the plan view of the model ground. In the test, one manhole is backfilled by the crashed tile and another one is backfilled with the same sand as the model general. Both the manholes were installed in the same laminate shear box and were excited with the same earthquake motion. As shown in Fig.12, the anti-floating manhole is on the left side and the manhole without countermeasure is on the right side of the shear box. In the test, the height of model ground is 0.50m while the depth of the crashed tile as countermeasure against floating is from GL-0.30m to the top surface, which is the same depth as the manhole length. Of course it is much better to backfill the manhole by the crashed tile from in whole depth, here we only investigate a minimum improvement effect of the backfill.

We installed 12 excessive pore water pressure sensors within the model ground, Point A, where is located inside the backfilling area with the crashed tile, Point B where is near the backfilled area, and Point C where is no-countermeasure area, as shown in Fig.12. In all the measurement points, the sensors ware installed at 4 different depths (GL-0.10m, GL-0.20m, GL-0.30m, GL-0.40m).

4.3 Results of Shaking Table Test

Figure 13 shows the input wave which was measured on the table of the test. Its frequency is 4Hz, shaking time is 10sec, and the maximum acceleration is around 0.2 m/sec^2.

Figures 14-17 show the excessive pore water pressure ratio (EPWPR) at each measurement point. The results shows that the EPWPR may rise over 1.0, which we consider as a measuring error, because the reason why this phenomenon occurred

is due to the small initial value of the confining stress but with relative large up-down movement happened around the sensors near the surface.

From the measuring results at point A (inside of the clashed tile), it is known that the excessive pore water pressure (EPWP) decreased substantially immediately after the excitation at the depth of 30 cm, implying that the crashed tile is a good material to enhance the dissipation of EPWP and hard to be liquefied.

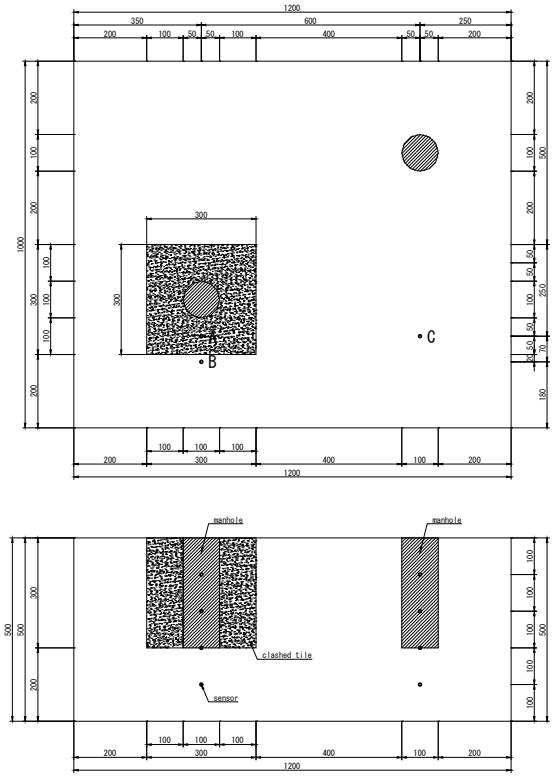


Fig. 12 Plan and x-section of the shaking table test

In addition, the EPWP at Point B (around of the crashed tile) also dissipated immediately after the excitation, the same as Point A, meaning that it is an effective countermeasure against the liquefaction using the crashed tile as backfilling material.

The EPWP at all the points below GL-0.30m, however, the effectiveness of the countermeasure against liquefaction cannot be confirmed, as shown in Fig.17.

Figure 18 shows the situation of the manhole after the excitation. In the first vibration loading, the manhole without countermeasure against liquefaction floated by 95mm, shown in Fig.18 (a), while the manhole backfilled with the crashed tile for anti-liquefaction, floated only by 31mm, shown in Fig.18 (b).

Furthermore, in the second shaking, the manhole without countermeasure floated and then fell down completely, shown in Fig.19 (a), but the damage to the manhole with anti-liquefaction measure is limited, as shown in Fig.19 (b).

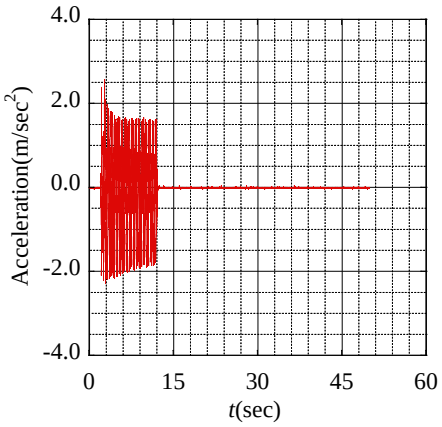


Fig. 13 Input Wave

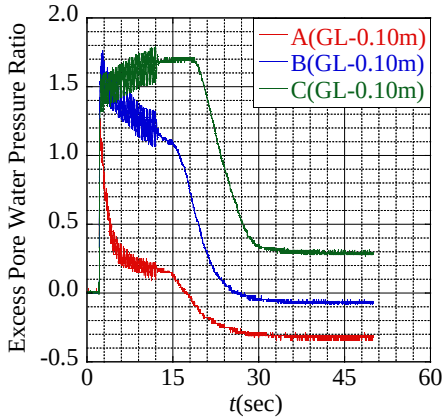


Fig. 14 Excess Pore Water Pressure Ratio (GL-0.10m)

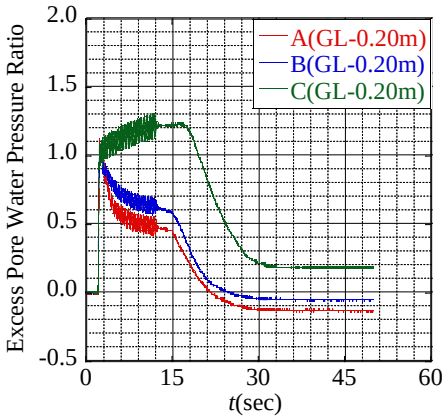


Fig. 15 Excess Pore Water Pressure Ratio (GL-0.20m)

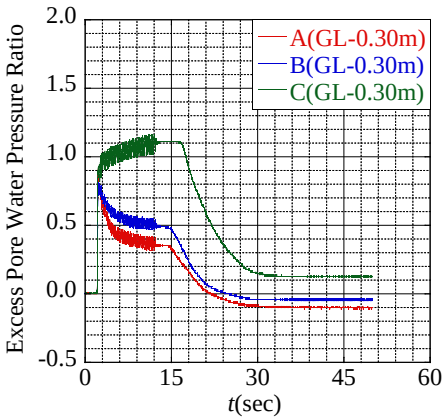


Fig. 16 Excess Pore Water Pressure Ratio (GL-0.30m)

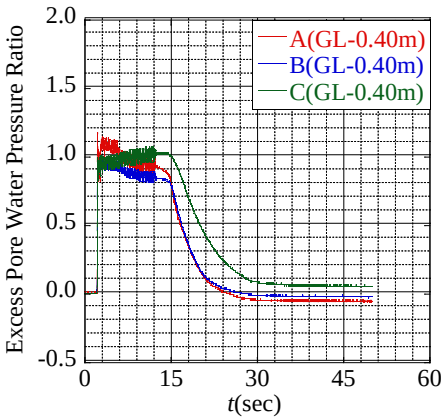
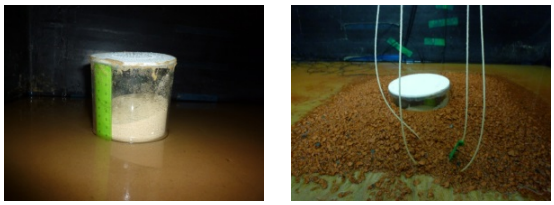


Fig. 17 Excess Pore Water Pressure Ratio (GL-0.40m)



(a) (b)

Fig. 18 Situation of the Manhole (1st earthquake): (a) Manhole Without Countermeasure, (b) Manhole With Countermeasure



(a) (b)

Fig. 19 Situation of the Manhole (2nd earthquake): (a) Manhole Without Countermeasure, (b) Manhole With Countermeasure

Based on the above results, it is clear that the crashed tile is very effective backfilling material the countermeasure against liquefaction. When an underground structure is backfilled by a material with high frictional resistance and high permeability like the crashed tile, it is possible to minimize the damage related to the floatation due to liquefaction.

5. CONCLUSION

5.1 The Performance of Clashed Tile

1) The angle of internal friction is very high.
2) The coefficient of permeability is very high.

5.2 Effectiveness of Countermeasure

1) The anti-liquefaction manhole which was backfilled by clashed tile floated only by 1/3 of the magnitude observed in the case of without countermeasure against liquefaction.
2) EPWP inside and around the clashed tile decreases immediately after excitation, hence clashed tile can be an effective countermeasure against liquefaction.

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