Scale effects on the shear strength of waste in coastal landfill sites

Nguyen Chau Lan\(^i\), Toru Inui\(^ii\) and Takeshi Katsumi\(^iii\)

\(^i\) PhD, Faculty of Civil Engineering, University of Transport and Communications, Hanoi, Vietnam.
\(^ii\) Associate Professor, Graduate School of Global Environmental Studies, Kyoto University, Japan.
\(^iii\) Professor, Graduate School of Global Environmental Studies, Kyoto University, Japan.

ABSTRACT

In Japan, a significant volume of municipal solid waste incinerator ash (MSWIA), slag and soil are disposed in coastal landfill sites located in Tokyo and Osaka bay. Future reclamation of these final disposal sites is an important goal. Thus, it is relevant to understand the shear strength properties of the waste layers in coastal landfill sites to utilize the land after closure. However, the particle size distribution of the waste ranges from fine-grained to coarse-grained (gravel, glass, etc.) affecting the estimation of the shear strength properties of the waste sample in coastal landfill sites. There is no available research on the effects of oversize particle on the shear strength of waste samples in coastal landfill sites. Therefore, this paper presents the results of larger triaxial test (150 mm x 300 mm) for waste samples. In the large triaxial test, the pore water pressure generated is higher compared to the results obtained for small samples. The smaller values of shear strength for large samples are also related to the crushability of large particle size. Thus, the frictional angle of large specimens is slightly smaller than that of small ones. Moreover, to calculate the stability of coastal landfill sites, if the strength parameters results from large triaxial test are used, the safety factor might decrease due to the lower of friction angle of large triaxial test and it would be more precise compared to the value obtained from a small triaxial test.

Keywords: waste, ash, coastal landfill, large triaxial test, mechanical properties

1 INTRODUCTION

In Japan, a significant volume of municipal solid waste incinerator ash (MSWIA), slag and soil are disposed in coastal landfill sites located in Tokyo and Osaka bay. Future reclamation of these final disposal sites is an important goal. Thus, it is relevant to understand the strength properties of the waste mixture layers in coastal landfill sites to utilize the land after closure. However, the particle size distribution of the waste mixture ranges from fine-grained to coarse-grained (gravel, glass, etc.) affecting the estimation of the strength properties of the waste mixture sample in coastal landfill sites. Generally, the strength properties of a sample material is investigated by a triaxial test. When triaxial tests are run, the maximum particle size of the samples must be less than one-sixth of the diameter of the specimen. Therefore the standard triaxial test, with a specimen of 50 mm in diameter, cannot be used if the diameter of the waste mixture sample is larger than 9.5 mm. Numerous research studies have attempted to increase the maximum particle size of the specimens tested by increasing the size of the testing apparatus in order to accurately measured the mechanical behavior of geomaterials (Hennes, 1952; Holtz & J., 1956).

Previous studies have investigated the effect of large particles on shear strength of soil by using large triaxial test and reported that the increase in gravel content decreases the density and shear strength of the material (R. Fragaszy, Su, & Siddiqi, 1990; R. J. Fragaszy, Su, Siddiqi, &Ho, 1992). Kirkpatrick (1965) studied the Leighton Buzzard sand with uniform particle sizes using triaxial tests; the results showed a reduction in friction angle as the mean particle size increased while the porosity was kept constant. However, other researchers concluded that the shear strength of mixture (soil and gravel) increases with gravel content.

However, there is no available research on the effects of large particle on the shear strength of waste mixture samples in coastal landfill sites. Therefore, in this research, large-scale (150 mm x 300 mm) and small-scale (50 mm x 100 mm) triaxial tests were carried out on waste mixture samples to study the effect of specimen size on the shear strength of the samples. This paper deals with the effects of particle size and confining pressure on the shear strength of waste mixture samples.
2 MATERIAL AND METHODS

2.1 Material

The waste samples and the simulated water in coastal landfill site employed in this study were obtained from the coastal landfill site in Osaka Prefecture. The waste samples were collected before being disposed at the coastal landfill site. Approximately 200 kg of wet waste sample include incinerator ash; slag and surplus soil, etc. were collected and then dried in a room with an average temperature of 20°C. For conducting small specimen, large pieces such as glasses or rocks were removed and the sample was sieved with 9.5mm opening sieve and set aside until use. For large specimen, all large pieces were used except pieces larger than19mm. The maximum diameter of waste mixture for small and large triaxial test is 9.5mm and 19 mm, respectively. Figure 1 shows the particle size distribution for small and large samples, determined according to JIS A1204. The specific gravity of the waste sample was 2.67.

2.2 Methods

In this study, small specimens were prepared by compacting 5 layers of waste in to a split cylindrical mold (50 mm diameter and 100 mm in height) 80% of maximum dry density (1.28 g/cm³) with optimum water content of 34.5% according to the value obtained from the Standard Proctor Compaction Test.

For large CU triaxial test, specimens were prepared by compacting 5 layers of waste mixture in to a split cylindrical mold (150 mm diameter and 300 mm in height) with the same maximum dry density and optimum water content as small specimens. In this test, D/dmax= 15/1.9= 7.89 (where D is diameter of specimen in large triaxial test and dmax is the maximum particle size of waste mixture).

Small and large CU triaxial tests were carried out on waste mixture specimens following the same procedure. These specimens were saturated by applying a vacuum procedure (Rad & Clough, 1984) to keep a constant confining pressure of 20 kPa. After reaching the final step (-70 kPa for cell pressure and -90 kPa for sample pressure) de-aired water was circulated into the specimen for 3 hours and then sample pressure and cell pressure were reduced to -20 kPa and 0 kPa respectively. Back pressure was increased step by step until it reached 240 kPa and cell pressure was 220 kPa. After that, pore pressure coefficient (B-value) was checked to have B-values larger than 0.95 and ensure that samples were fully saturated. The samples were consolidated with an effective confining pressure of 50, 100 and 150 kPa and sheared at a constant strain rate of 0.5%/min until 15% of axial strain was reached.

The target of conducting small and large samples in triaxial test is to consider the effect specimen size on shear strength of waste mixture is considered. It is crucial to estimate the shear strength of waste mixture in coastal landfill sites for future land utilization. The initial conditions for large and small triaxial test are shown in Table 1.

| Type of Triaxial test | Confining pressure (kPa) | Dry density after consolidated (g/cm³) | B value | Dmax (mm) |
|-----------------------|--------------------------|----------------------------------------|---------|-----------|
| For small triaxial test | 50                       | 1.02                                   | 0.95    | 9.5       |
|                       | 100                      | 1.02                                   | 0.95    |           |
|                       | 150                      | 1.02                                   | 0.95    |           |
| For large triaxial test | 50                       | 1.02                                   | 0.95    | 19        |
|                       | 100                      | 1.03                                   | 0.95    |           |
|                       | 150                      | 1.06                                   | 0.95    |           |

3 RESULT AND DISCUSSION

3.1 CU test for small triaxial test

Figure 2 shows the stress-strain curves for small samples. Generally, the deviator stress increases dramatically from 0 to 2% of axial strain and reaches a peak after 6% of axial strain. After that the deviator stress reaches a constant value until 15% of axial strain. The stress-strain curves illustrate the strain hardening behavior of waste mixture samples.
Figure 3 shows the pore pressure results versus axial strain. For samples under a confining pressure of 50 kPa, the pore water pressure shows an increase trend at the initial stage until it reached a peak value of about 20 kPa and then it is reduced steadily to nearly zero at 15% of axial strain. Pore water pressure generated in samples that sustained 100 kPa confining pressure, showed a similar trend than samples under 50 kPa but reaching a pore pressure peak value of about 50 kPa and then reducing steadily until reaching about 35 kPa. However, for samples under 150 kPa, pore water pressure increases and reaches a peak at 2% and then keeps a constant value until an axial strain of 15% is reached. The samples under initial conditions in small triaxial test showed a contractive behavior in shearing process due to the positive value of the pore water pressure when the axial strain increased from 0 to 15%.

The deviator stress (q) and the mean effective stress ($p'$) are calculated by following Eqs. (1) and (2):

$$q = \sigma_1' - \sigma_3'$$  \hspace{1cm} (1)

$$p' = (\sigma_1' + 2\sigma_3')/3$$  \hspace{1cm} (2)

where $\sigma_1'$ and $\sigma_3'$ are the effective axial and confining stress. Fig. 4 shows the effective stress paths for samples in small triaxial test were plotted in a $p'$-q plane. In this figure, from the beginning, stress paths showed an increase of pore pressure with the stress path moving to the left until pore pressure reduces and the effective pressure increases moving the stress path into the right direction.

### 3.2 CU test for large triaxial

Figure 5 shows the stress-strain curves for large samples. The deviator stress increases dramatically from origin to reach a peak value at about 2% of axial strain. After that, the deviator stress decreases steadily until 15% of axial strain and the stress-strain curves illustrate the strain softening behavior of waste mixture samples. This behavior significantly change compare with the results for small samples.

Figure 6 shows the pore water pressure versus axial strain. For specimens that sustained 100 and 150 kPa of confining pressure, the pore water pressure increases dramatically from 0% to 2% of axial strain and from 2% to 15% it has a mild but steady increases. In the case of specimen that sustained 50 kPa of confining pressure, pore water pressure has a constant value from 2% to about 15% axial strain.
3.3 Effect of particle size on shear strength of waste mixture sample

In order to compare the peak strength envelopes and the shear strength parameters for large and small samples, the shear strength parameters are determined using a linear interpolation. Figure 8 shows the peak strength of small samples and large samples. The shear strength parameters-cohesion intercept c' and the angle of friction $\phi'$- associated with these peak strength envelopes can be obtained using the following two equations:

$$\phi' = \sin^{-1} \left( \frac{3M}{6 + M} \right)$$  \hspace{1cm} (3)

$$c' = f \left[ \frac{3 - \sin(\phi')}{6 \cos(\phi')} \right]$$  \hspace{1cm} (4)

where M is the slope of peak strength envelope and f is the q-intercept of the peak strength envelopes in p'-q stress space.

The cohesion and angle of friction obtained are 0 kPa, 46.7° for small sample, and 2.8 kPa, 44.78° for large sample, respectively. The direction of peak strength envelope for samples and larger samples is similar. Thus, the strength parameters results are almost no change. The most important reason for the change in shear strength is related to pore water pressure generated. In the large sample, due to large diameter of mixture waste and large specimen the pore water pressure generated are higher compare to those in small samples. The change in pore water pressure contributed to the change in shear strength of large sample compare with small samples. Thus, most important reason for the change in shear strength is related to pore water pressure generated. In the large sample, due its the large diameter, the pore water pressure generated is higher compare to the results obtained for small samples. The change in pore water pressure contributed to the increased in shear strength for large sample compare.
The differences in stress paths for small and large samples could be related to the crushability of the larger samples. The crushability of larger samples were observed, although the initial of dry density for small and large samples are the same but the void ratio were reduced in consolidated step for large samples compared with small samples. These results showed that the volume of large samples was reduced due to crushability. This behavior has been observed in a previous research conducted by Kokusho (2004). The two major factors governing the shear strength of granular materials are interlocking between particles and particle breakage. The interlocking between particles increases the shearing resistance, while the breakage of particles decreases the shear strength. In this test, the larger samples had larger breakage of particle and that lead to lower shear strength compare with results obtained from small samples. The results of this study show that as the size of particles increase, the shear strength of waste mixture decreases. These results are consistent with results presented by Kirkpatrick (1965); Fragaszy et al. (1990) and Kokusho et al. (2004).

4 CONCLUSIONS

Based on the experimental results, the following summarizes about the scale effects of specimens on the mechanical properties of waste mixture in coastal landfills:

1) In coastal landfill sites, the presence of large particles in waste mixture can change the results of triaxial test. It is necessary to estimate the change of shear strength if the waste mixture sample contains large particles. Thus, the comparison between small and large triaxial test is necessary to understand better the shear strength behavior and pore water generated from waste mixture samples. In this research, the particle size of the larger samples for large triaxial test 15cmx30cm is larger than 9.5mm. In the large triaxial test, the pore water pressure generated is higher compared to the results obtained for small samples due to the longer dissipation time of pore water pressure.

2) The value of shear strength obtained from the triaxial tests for large samples are smaller than with the results obtained for small samples due to the dissipation of pore water pressure that affect stress paths and that in turn reduce in the strength of large samples. The smaller of the shear strength for large samples are also related to the crushability of large particle size. Thus, the frictional angle of large specimens is slightly smaller than that of small ones. Therefore, in order to estimate the shear strength in the coastal landfill sites, it is suggested that the large triaxial test should be conducted due to large particle size of sample collected from the sites (23% of particle size larger than 9.5mm for the samples in Osaka coastal landfill sites). Moreover, for calculating the stability of coastal landfill sites, if we use the strength parameters results from large triaxial test, the safety factor will be lower due to the lower of friction angle of large triaxial test and it is more precise compare to the value of the small triaxial test.

REFERENCES

1) Cerato, A. B., and Lutenegger, A. J. (2006): Specimen size and scale effects of direct shear box tests of sands. Geotechnical Testing Journal, 29(6), 507-516.
2) Fragaszy, R., Su, W., and Siddiqi, F. (1990): Effects of oversize particles on the density of clean granular soils. Geotechnical Testing Journal 13(2), 106-114.
3) Fragaszy, R. J., Su, J., Siddiqi, F. H., and Ho, C. L. (1992): Modeling strength of sandy gravel. Journal of Geotechnical Engineering-ASCE, 118(6), 920-935.
4) Hennes, R. G. (1952): The strength of gravel in direct shear. ASTM special technical publication, STP 131, 51-62.
5) Holtz, W. G., and J., G. H. (1956): Triaxial shear tests on pervious gravelly soils. Journal of the Soil Mechanics and Foundation Division, 82, 1-22.
6) Kirkpatrick, W. M. (1965): Effect of grain size and grading on the shearing behavior of granular materials. Paper presented at the Proceedings of the sixth International Conference on Soil Mechanics and Foundation Engineering.
7) Rad, N. S., and Clough, G. W. (1984): New procedure for saturating sand specimens. Journal of Geotechnical Engineering-ASCE, 110(9), 1205-1218.
8) Simoni, A., and Houlsby, G. T. (2006): The direct shear strength and dilatancy of sand-gravel mixtures. Geotechnical and Geological Engineering, 24(3), 523-549.