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Mechanical properties of municipal waste deposits and ground improvement

Propriétés mécaniques des dépôts de déchets municipaux et amélioration des sols

T. Itoh [1], I. Towhata [2] & Y. Kawano[1]
[1]Fudo Construction Co., Ltd., Japan [2]Department of Civil Engineering, University of Tokyo, Japan
M.Kameda & S. Fukui
Former Student, University of Tokyo, Japan
F. Koelsch
Department of Civil Engineering, Technical University of Braunschweig, Germany
Y.Yonai
Former Student, Tokyo Science University, Tokyo

ABSTRACT

The present study carried out laboratory tests on different kinds of municipal waste samples in order to understand their deformation and strength properties as well as creep deformation. It was therein aimed to help develop huge areas of waste deposit island for future urbanization. Firstly, it was found that municipal wastes follow the conventional ideas of soil mechanics such as the optimal moisture content, effects of densification, and influence of effective stress. It was further shown that wastes are of remarkable shear strength, although the low rigidity at small strain and long duration of creep deformation are problems. Studies were conducted further to reveal that these problems are mitigated by such conventional soil improvement technologies as preloading, compaction, and cement mixing.

RÉSUMÉ

La présente étude a consisté à réaliser des tests de laboratoire surdifférents échantillons de déchets municipaux dans le but de comprendre leurs propriétés en terme de déformation et de résistance ainsi que la nature des déformations au fluage. Le but de cette recherche est d'aider à développer de grandes îles de dépôts de déchets pour de futures urbanisations. D'abord, il a été montré que les déchets municipaux suivent les régles conventionnelles de la mécanique des sols telles que la teneur en eau optimale, les effets de la densification, et l'influence de la contrainte effective. De plus, il a été montré que les déchets pre´sentent une résistance remarquable au cisaillement, quoique la faible rigidité à faible pression et la durée importante des déformations de fluage sont problématiques. Cette recherche a finalement montré que ces problémes peuvent être mitigés par des technologies conventionnelles d'amélioration des sols telles que le pré-tassement, la compaction et le mélange avec du ciment.

1 INTRODUCTION

Japan has a large number of municipal waste disposal sites nationwide and some of them are located on artificial island. The large areas of land thus formed are conveniently sited close to city centers with access to international airports etc., and therefore have significant value for use as international cities. Currently, however, most reclaimed lands made by waste disposal are used only for minor facilities such as parks and golf courses. This is because the land remains unstable for long periods, and ground settlement and inadequate bearing capacity create major problems for building of sizable structures. This paper reports on laboratory tests using real samples of municipal waste material, to study the behavior of a former waste disposal site from the viewpoint of geotechnical engineering, and determine how it responds to improvement by compaction and cement mixing.

2 TESTED MATERIALS

The content of municipal waste varies with different disposal procedures. As a test case for this study, samples of real waste were collected from a disposal site located on the seaward side of Tokyo Harbour (Tokyo Waste Deposit). This site was first infilled up to sea level with soil such as construction-displaced waste soil etc., after which incinerated ash and incombustible municipal waste were used as infill in the proportion of 7 to 3. The samples collected for these tests consisted of this incombustible waste and incinerated ash.

2.1 *Incombustible waste*

Fig. 1 shows the incombustible waste collected for the present tests. The material has been completely broken down to fragments smaller than about 3 to 5 cm. As shown in Fig. 2, it consists largely of vinyls and plastics, as well as glass, ceramic, humus, types of fibres etc. Due to the large quantity of plastic and vinyl the samples were found through grain density tests to be extremely light, $\rho s=1.324$ g/cm^3.

Figure 1. Incombustible waste from Tokyo Waste Deposit.

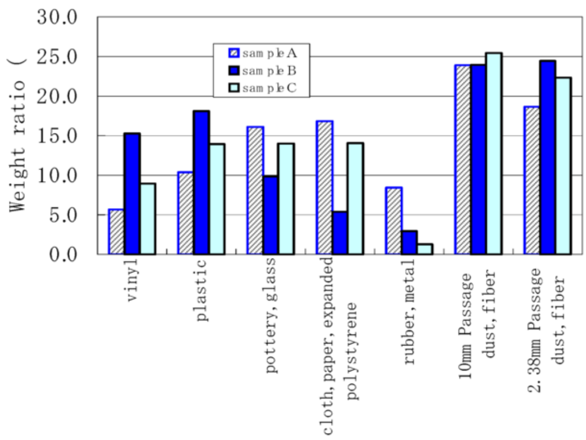
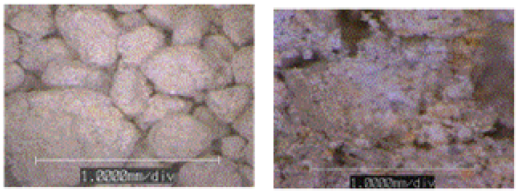


Figure 2. Composition analysis of incombustible waste.

2.2 *Incinerated ash*

Fig. 3 shows the ash sample particles of the incinerated ash can be seen to have fused together to make a soil-like material. Grain density tests of the samples gave a result of ρ s=2.53 g/m^3. Permeability of this ash are tested over a 10-day period. The permeability coefficient at the start was found to be in the order of k=10^{-3} cm/sec, and it fell after 10 days to the order of k=10^{-5} cm/sec. Fig 4. shows how fine particles fused together to hinder permeability. Thus, when incinerated ash contains moisture, it self-hardens, and its material strength is possibly effected by this hardening.

Figure 3. Incinerated ash from Tokyo's Waste Deposit.



before test 10 days later

Figure 4. Permeability testing (incinerated ash).

3 COMPACTION PROPERTIES

Figs. 5 and 6 show the results of compaction tests. The incombustible waste had an optimal moisture content of 10~20% and the max. dry density of ρ_d =0.6~0.8 g/cm^3. For an incinerated ash sample with grain size less than 2 mm, the

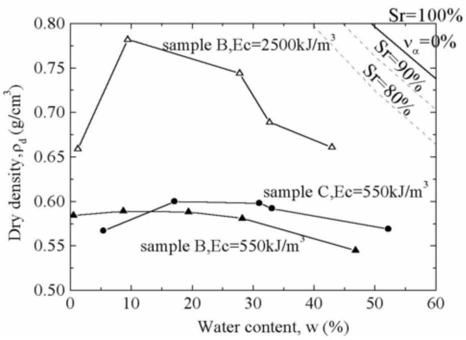


Figure 5. Compaction test results: incombustible waste.

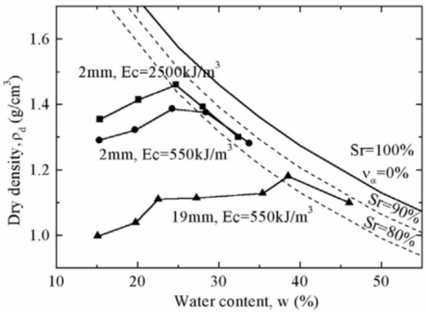


Figure 6. Compaction test results: incinerated ash.

optimal moisture content content was 25%, and the max. dry density ρ_d=1.45 g/cm^3. For a sample with grain size no greater than 19 mm, the optimal moisture content was 40%, and the max. dry density was ρ_d =1.2g/cm^3. This indicates that the finer the ash particles the better they are compacted. Insummary, the results indicate that the waste material can be compacted, and conventional compaction concepts of soil mechanics are applicable.

4 METHOD OF DEFORMATION TESTS

Triaxial tests were conducted on deformation properties of wastes. In particular, the study examined the effectiveness of the increase in density due to compaction and of cement hardening as measures to mitigate the problems of large amounts of settlement and lack of bearing capacity in municipal waste ground. Details of testing methods are described in what follows.

4.1 *Incombustible waste*

4.1.1 *Sample preparation*

Tested samples were prepared over a range of degree of compaction (range of density). Compressibility and strength of the samples were determined from volume creep tests and monotonic drained loading tests using a triaxial testing equipment. For the triaxial tests, large square column specimens, 23 cm x 24 cm x 57.5 cm high, were used in consideration of the material's grain size and variability. The specimens were in a dry condition and were compacted to a density of about 0.6~0.65 g/cm^3, in accordance with the compaction test results above.

4.1.2 *Cement hardening material*

Ordinary Portland cement or the cement used for ground improvement (geo10) was mixed with the samples, and specimens were tested to examine whether or not improvement by cement mixing was possible. Strength and creep deformation of the specimens were measured by triaxial tests (specimen size: 5 cm diameter X 10 cm high).

4.2 *Incinerated ash*

A hollow torsional shear device was used to study the material strength and creep deformation. The size of the specimens were: 10 cm (outer diameter) x 6 cm (inner diameter) x 20 cm high. To prepare specimens, the material was compacted at the optimal moisture content in accordance with the results of the compaction tests above, and kept in a loading weight placed on top to allow atmospheric curing thus, the cylinder in-site condition was reproduced.

5 VOLUMETRIC CREEP TESTS

Volumetric creep tests were carried out using the incombustible waste which is considered the most susceptible to large amounts of settlement. Large-sized triaxial equipment was used, and the results for isotropic consolidation at 20～40 kPa, and isotropic consolidation at 50 kPa subsequently unloaded to 30 kPa, are shown in Fig. 7. Due to the variability of the material used to make up the specimens, test results are variable as well. However, tests No.2 and 3 suggest that denser sample under identical stress level develops less extent of volumetric creep.

For the specimens isotropically consolidated at 50 kPa and unloaded to 30 kPa, settlement after unloading rebounded before becoming steady. This implies that the preloading technology can mitigate the subsidence problem.

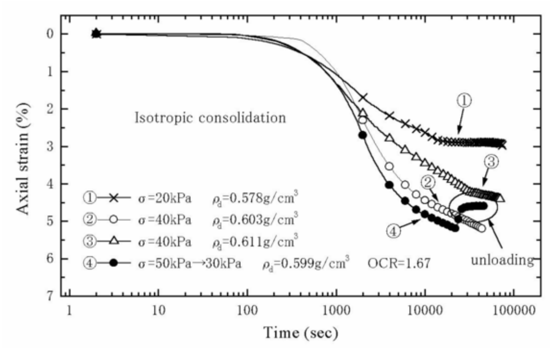


Figure 7. Results of volumetric creep tests.

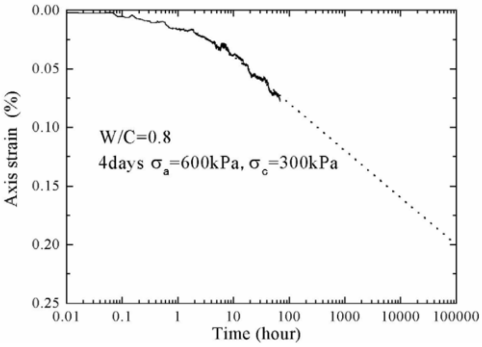


Figure 9. Results of creep loading tests (cement-mixing Incombustible waste).

6 CREEP DEFORMATION UNDER SHEAR STRESS

6.1 *Incombustible waste*

6.1.1 *Compaction*

Specimens consolidated with a confining pressure of 40 kPa were loaded with 50 kPa deviator stress, and creep tests were carried out using large triaxial testing equipment. The results are shown in Fig. 8. Over the creep period, deformation in the axial direction was almost logarithmically linear, it seems possible to assess the amount of settlement during the life period of a superstracture. Assuming the service to begin one month after loading, and the amount of deformation after 15 years of service will be 2%.

Since the incombustible waste layer at the Tokyo Waste Deposit is approximately 30 m thick, about 60 cm of settlement is expected to occur. This level of settlement exceeds allowable levels for building structures, and soil improvement measure is made necessary.

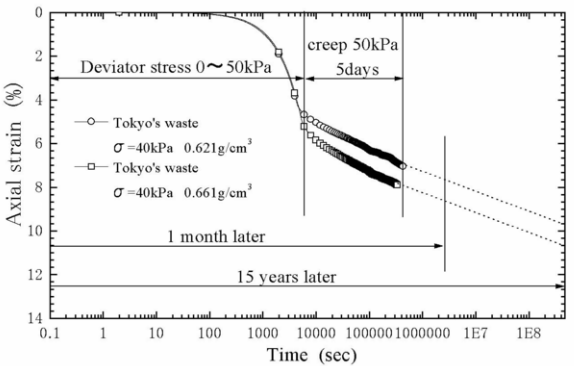


Figure 8. Results of creep loading tests (compacted noncombustible waste).

6.1.2 *Cement mixing*

Fig. 9 shows the results of creep tests on cement-hardened specimens (deviator stress: 300 kPa). Similar to Fig. 8. , the increase in axial strain was almost logarithmically linear. Noteworthy is that the extent of deformation is significantly smaller in Fig. 9 than in Fig. 8. The level of settlement was estimated in the same way. After 100,000 hours (11 years), assuming the thickness of the improved ground to be 30 m, despite a significant deviator stress of 300 kPa, creep displacement will be 60 mm (increase in strain 0.2%). At this level of displacement, even with the occurrence of some differential settlement, countermeasures such as jacking up can be considered viable.

6.2 *Incinerated ash*

After consolidation under 100 kPa of confining pressure, the incinerated ash specimens were left for a creep period of about 12 days with 75 kPa of deviator stress applied. Shear strain increased with time. The rate of creep is lower than the incinerated ash in Frag. 8. In the final stage of creep a slight tendency to convergence was observed. This needs to be confirmed with longer creep tests in the future.

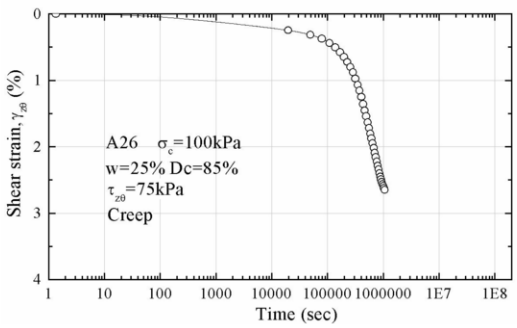


Figure 10. Results of creep shear tests (incinerated ash).

7 TRIAXIAL SHEAR TESTS

Conventional triaxial drained compression tests were conducted to study the stress-strain-strength properties of wastes.

7.1 *Incombustible waste*

7.1.1 *Test results*

The results of triaxial shear tests on incombustible as well as biotreated wastes are shown in Fig.11. It is seen therein that the strength and rigidity increase with the density of sand. More over, the material strength increases with the confining pressure. These findings are consistent with the behavior of soils. As compared with Toyoura sand data, the initial rigidity of waste is smaller, while the strength of waste at large strain is much greater, without yielding. This nonyielding behavior was generated by plastic and other fibrous inclusions, which is evidenced by the fact that the biotreated waste (Towhata et al., 2003) with big fibers removed exhibits yielding at 10% strain. This reinforcing effects of fibers do not occur in rigidity because fibers do not yet undergo sufficient tension. Finally, Mohr stress circles were drawn at 15% axial strain to demonstrate the internal friction angle increases with compaction.

7.1.2 *Cement mixing*

Fig. 12 shows the stress-strain relation are bio-treated waste of cement-mixed incombustible waste to which geo10 has been added. For 60 g of waste material the amount of cement added was 180 g for W/C=0.5 and 105 g for W/C=1.0, thus the void was filled with grout. The strength of the improved sample was found to be higher when W/C of the added cement was smaller. At W/C below 0.8, in most of the improved samples, peak strength occurred and high levels of strength were achieved. For W/C=1.0, strength was still high compared with unimproved specimens, but peak strength did not occur. However, because it is characteristic of unimproved incombustible waste that it tends not to collapse under increased strain, one of the properties of the ground is that it does not collapse. Fig. 13 shows photos of improved samples for W/C=0.5 and 1.0 after testing. Compared with W/C=0.5, the W/C=1.0 sample shows less clear indication of shear failure.

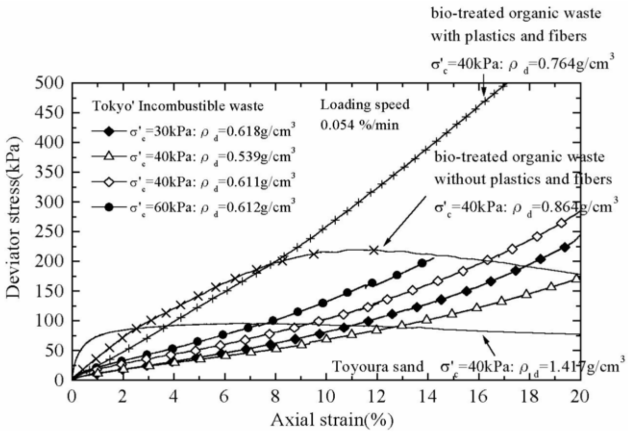


Figure 11. Stress-strain relationship of incombustible waste.

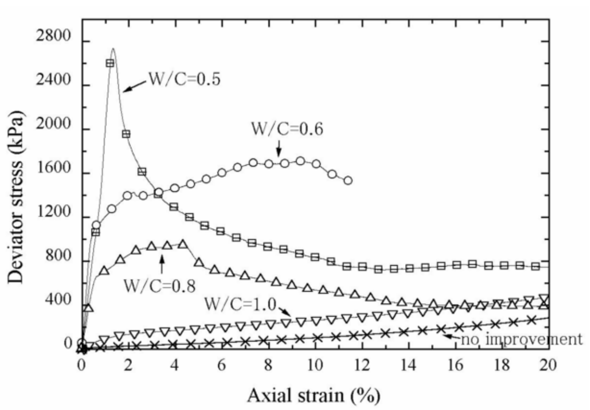


Figure 12. Stress-strain relationship of cement-mixed incombustible waste.

W/C=0.5 W/C=1.0

Figure 13. Cement-mixed Specimens after shear testing.

7.2 *Incinerated ash*

The results of drained hollow torsional shear tests on incinerated ash are shown in Figs. 14 and 15. The figures show that, similar to soils, the strength of incinerated ash increases with the degree of compaction (Dc), and that the self curing property of incinerated ash is dependent on the number of days.

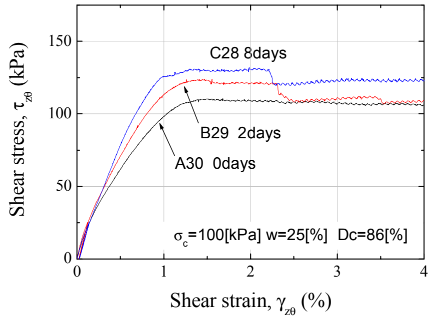


Figure 14. Stress-strain relation (curing period).

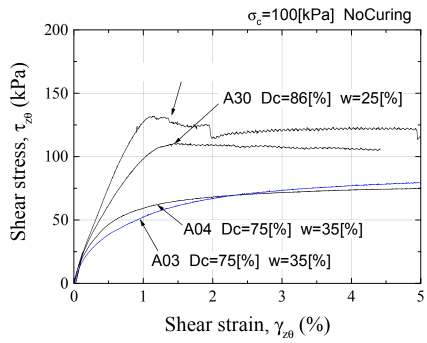


Figure 15. Stress-strain relation (degree of compaction).

8 CONCLUSION

Municipal waste deposit has been considered soft and unstable ground due to the softness and continued subsidence. The present study carried out laboratory tests on deformation and strength behavior of wastes and attempted to show the possibility to improve them. The conclusions drawn by this study are as what follows.

1) The conventional ideas in soil mechanics such as the optimal moisture content as well as effects of density and effective stress are valid in wastes as well.
2) Wastes even without improvement exhibits substantial shear strength due to their fibrous components. The rigidity of waste at small strain, however, is low because fibers are not yet in tension.
3) Creep deformation in waste deposit may be significant. This problem, however, can be mitigated by conventional technologies of soil improvement such as preloading, compaction, and cement mixing.
4) Cement mixing varies the stress-strain behavior of waste substantially; from a brittle behavior under low W/C ratio to a ductile one under high W/C.
5) Consequently, it seems possible to urbanize municipal waste islands with building construction upon them.

REFERENCE

Towhata, I., Y. Kawano, Y. Yonai and F. Koelsch, Laboratory tests on dynamic properties of municipal waste, *Proc. 11th Int. Conf. Soil Dynamics and Earthquake Engineering, and 3rd Int. Conf. Earthquake Geotechnical Engineering, Berkeley*, Vol. 1, pp.688~693, 2004.