Laboratory Tests on Dynamic Properties of Municipal Wastes

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Abstract— Urban development of a huge artificial island which is composed of municipal waste is discussed. Among many topics to be investigated, the present paper concerns with the mechanical properties of such waste with a special attention to its dynamic behavior. Two materials were used which were organic waste undergoing deterioration with time and inflammable waste that included small plastic sheets. Triaxial drained tests firstly revealed that waste material is soft but has significant shear resistance which is generated by plastic sheets and other fibrous components. Cyclic drained tests indicated that the damping ratio of waste is higher than that of soil, which suggests that earthquake shaking is reduced during wave propagation in the waste deposit. Thirdly, shaking model tests on a shaking table facility confirmed these findings.

Keywords— Municipal waste, dynamic properties, triaxial shear, shaking table tests

INTRODUCTION

The treatment of municipal waste to date consists of two types. The first one is what is called recycling. Since important resources are used repeatedly, this measure seems to suit the environmental issues of the future world. There are however significant drawbacks in recycling. For example, procedure of recycling needs labor and energy which may not be accepted automatically by the public. Moreover, it is evident that all the municipal waste cannot be recycled. Therefore, the second kind of waste treatment becomes important; it is landfilling.

The landfilling treatment of municipal waste poses a variety of engineering problems. The most frequently discussed among them is the prevention of environmental pollution in which leakage of polluted water from a waste deposit is the major topic. The present study, however, does not concern this popular topic and rather focuses its attention on the mechanical properties of waste materials.

Photo 1 illustrates the failure of municipal waste deposit in the Philippines which was induced by a heavy rainfall and killed many people upon failure. It is often the case in many developing countries that an unstable waste landfill is constructed close to a residential area. There is a need therefore to understand the failure mechanism and strength parameters of municipal waste in order to achieve safety. Another issue is the limited capacity of a waste filling site. Since it is not an easy task in countries of dense population to find many waste filling sites, it is important to damp as much waste as possible in an existing site. In this line, efforts have been made to incinerate waste and reduce the volume. Therefore, shear strength parameters have to be studied not only of raw waste but also of incinerated ash.

It is important in large cities to make use of former landfilling sites for other purposes because a large damping site offers a large and vacant area for further development of cities. Problems lying in this respect are two folds. Firstly, consolidation settlement due to the own weight of waste lasts long and may affect the function of facilities resting on a waste deposit. An example of this damage is shown in Photo 2. The differential settlement around a stable building causes many engineering problems. The second problem is the bearing capacity of a waste deposit and the extent of subsidence of a building foundation. To cope with this, a detailed knowledge is necessary concerning the stress-strain-strength behavior of wastes.

With these points in mind, the present study made an attempt to run laboratory tests on deformation and strength of waste. One type of waste represents raw waste which is filled in site without incineration. Another kind of waste is an inflammable waste which is composed of plastics with some amount of organic materials.

Photo 1 : Rainfall-induced failure of municipal waste at Payatas, the Philippines (by R.Orense).

Photo 2: Settlement of waste deposit in proximity of pile-supported building.

TESTED MATERIALS

The present study made use of two kinds of waste material. The first one is an organic material. Since it was feared that real organic and raw municipal wastes might cause sanitary problems in handling and testing procedures, an alternative material was imported from Germany. This alternative was produced by biological treatments of equivalent waste-like materials. Although care was still taken of handling this material, risk was much reduced. Photo 3 indicates the appearance of this organic material and Fig.1 shows its composition.

Photo 3: Organic waste-like material imported from Germany.

Fig.1: Composition of organic waste material.

Another tested material is the inflammable waste which was collected at the municipal waste repository in the Tokyo Harbor. This site is operated on an reclaimed island where the flammable waste is incinerated to be ash while the inflammable waste is cut into small pieces and damped directly. Although being called inflammable, most of this waste was a container of food (disposable lunch box) and contains organic materials. Thus, care was taken prior to tests to clean? the deteriorated materials. The site of sampling this material is shown in Photo 4 and the appearance of this material is indicated in Photo 5, respectively.

Photo 4: Sampling site of inflammable waste in Tokyo Harbor repository.

Photo 5: Inflammable waste from Tokyo Harbor repository.

Table 1 Physical properties of tested waste materials.

	Organic waste	Inflammable waste
Specific gravity Gs	2.126	1.917
Gs	2.063*	
Maximum dry density ρ_d	0.75**	-- --
Optimum water content (%)	40**	-- --

*: after removal of plastic sheets.
** : after removal of coarse particles for triaxial tests.

Additional tests on physical properties showed the results as shown in Table 1. Accordingly, the following triaxial tests were done at the degree of compaction of

80 %. This light degree of compaction corresponds to the field light compaction by bulldozers.

METHOD OF TRIAXIAL COMPRESSION TESTS

A series of triaxial tests were carried out on both waste materials. Since the specimen had a limited size of 10cm in diameter and 20cm in height, big grains which did not pass 10mm sieve were removed. Wastes were compacted at 80% degree of compaction and were subjected to triaxial compression tests in a drained manner. At the beginning of testing program, it was feared that drained pore water from the waste might include acidic material and damage the testing machine. Hence, it was decided to keep specimens unsaturated with only 40% moisture content so that no pore water might come out during tests. Accordingly, the volume change of the specimen were not measured by the volume of drained water. As an alternative, the lateral deformation was measured by laser transducers. This measure was made possible by applying confining pressure by means of vacuum pressure in the pore in place of the conventional cell pressure loading. Thus, no pressure chamber was needed. The employed effective confining pressure varied from 10kPa to 50kPa in normally- as well as overconsolidated states.

BEHAVIOR OF WASTE SPECIMENS DURING CONSOLIDATION IN TRIAXIAL DEVICE

Consolidation settlement is an engineering problem which is as important as the shear failure in waste deposit. In this respect, volume change of waste specimens was measured in the triaxial. A conventional oedometer was not used because the specimens size in this device was too small to accommodate large grain sizes of waste materials.

In the first series of consolidation tests, specimens were initially consolidated under the isotropic confining pressure of 10kPa, followed by isotropic loading, creep deformation for 30 minutes under constant stress, unloading to 10kPa, and 30-minute creep again. The employed loading rate was 5kPa/minute throughout testing. In the conventional sense of consolidation test the rate of loading is not important because waste specimens have low degree of saturation and volume change is caused by quick migration of pore air.

Fig.2 demonstrates the e-logP' relationship of the German organic waste. Similar to conventional soil-mechanic knowledge, this waste reveals greater volume change during compression than unloading. Note that creep distortion occurred not only at the maximum pressure of 40kPa but also to some extent after unloading at 10 kPa. The long-lasting creep distortion under the normally consolidated state implies that waste ground in reality will generate substantial problems of secondary compression. It seems that this problem of creep compression is mitigated or solved by preloading by which the waste is brought to the state of overconsolidation.

Another series of tests was carried out in a Ko manner in which the axial stress, σ_a', was increased at a rate of 0.5 kPa/minute while the radial stress, σ_r', was controlled so that the radial displacement at a specimen surface was kept less than 0.05mm. Note that the diameter of a specimen was 10 cm. Fig.3 shows the relationship between the radial and axial stresses. After the initial isotropic stress state of 10 kPa, the axial stress was greater than the radial stress, implying Ko<1. It is also interesting that the radial stress occasionally stopped its change. This is probbaly because the specimen did not deform temporarily due to constraint made by fibrous components. Consequently, the variation of Ko value with increaasing the stress level was obtained as shown in Fig.4. It seems that Ko=0.3 to 0.4 is appropriate beyond 100 kPa stress at which the effects of the initial isotropic consolidation (10kPa) has been erased.

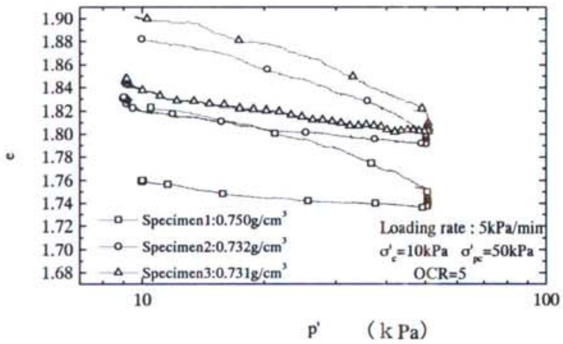


Fig.2: Isotropic compression and unloading of organic waste material.

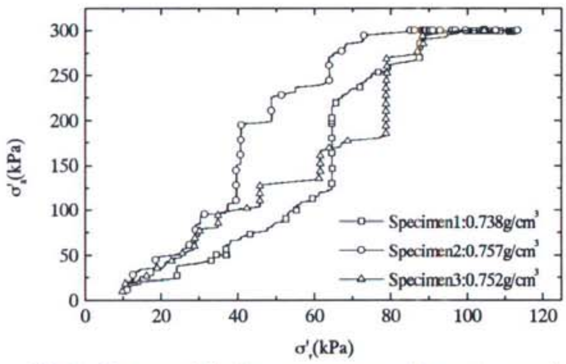


Fig.3: Ko consolidation tests on organic waste material.

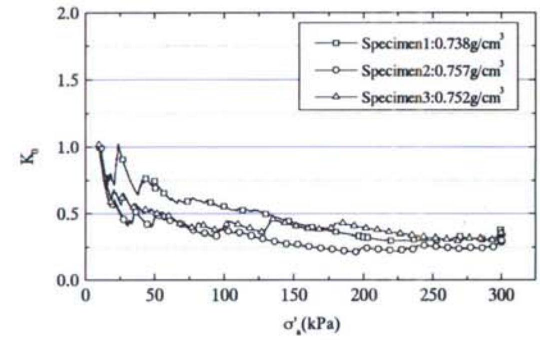


Fig.4: Variation of measured Ko value with increasing stress level.

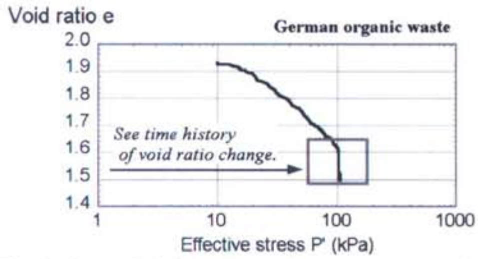


Fig.5: Consolidation test on long-term creep of organic waste.

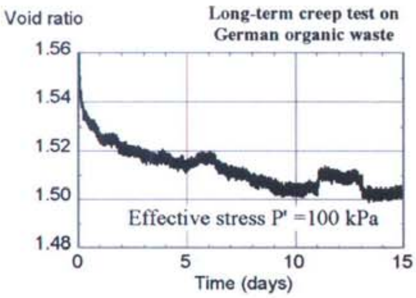


Fig.6: Long-term creep test on organic waste.

The long-term creep was investigated due to the importance of secondary compression in practice. To achieve this goal, the isotropic stress state of the organic waste specimen was held constant for two weeks in a triaxial device. The consolidation data in this test is shown in Fig.5 and the drained creep for two weeks is shown in Fig.5. Note that creep was not terminated in two weeks in spite of the unsaturated state and the easy drainage of pore air.

TRIAXIAL COMPRESSION TESTS ON ORGANIC WASTE

Triaxial compression tests were performed in a drained manner on isotropically consolidated specimens of waste. Fig.7 illustrates the deviator stress- axial strain relationship of the tested materials. It is interesting firstly that the organic waste imported from Germany did not achieve any peak strength within the range of tested deformation; see top three curves in the legend. By comparing these data with the curve of loose Toyoura sand (solid square symbols ■) it is found that the tested waste is much softer than sand in the small strain range. This relationship is reversed later in the larger strain range in which Toyoura sand yields while the organic waste does not, achieving much higher stress level.

The authors suppose that this behavior of the organic waste is substantially affected by the inclusion of plastic sheets. In the small strain range the plastic sheets does not expand horizontally and the overall behavior is governed by the soft waste. In contrast when the strain is large, the plastic sheets are stretched in the radial direction and resist further distortion; thus yielding does not occur. To validate this idea, the fourth test in Fig.7 was conducted on the same organic waste with plastic sheets removed. The obtained data (dashed curve) shows that yielding occurred at the strain of 15% as expected. Note that the greater rigidity of this specimen in the small strain range was generated by the higher dry density of waste. It may be said therefore that inclusion of the plastic sheet changes the soft nonlinear waste to a soft but approximately linear material. Similar quasi-elastic behavior is seen with the inflammable waste from Tokyo as well.

Fig.8 summarizes the measured shear strength. Since yielding hardly occurred, the strength here is defined as the stress level at 15% axial strain. Noteworthy is the range of variation of data which suggests the nonuniformity of waste ground. It is interesting that the highest strength was achieved by the organic waste with plastics (average dry mass density = 0.737 to 0.769 g/cm^3), followed by removal of plastics (0.869 to 0.897 g/cm^3); the lowest strength for the inflammable waste (0.424 to 0.497 g/cm^3). This suggests the importance of the reinforcement effects of plastic inclusions as well as the dry density.

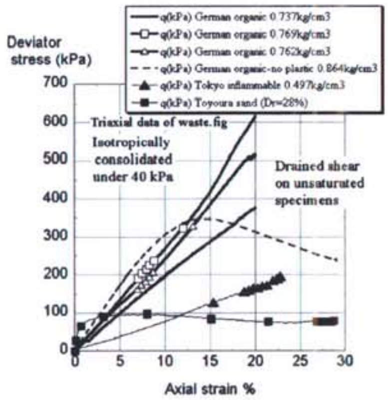


Fig.7: Drained triaxial compression tests on organic waste.

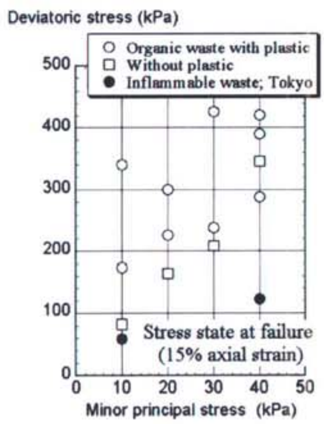


Fig.8: Shear strength of waste materials.

CYCLIC TRIAXIAL TESTS

Cyclic triaxial tests were conducted in order to understand the behavior of waste during earthquake loading. This investigation was carried out by firstly consolidating specimens under isotropic 40kPa pressure and then increasing the axial stress. Cyclic axial loading was conducted in the meantime at a rate of 0.01 to 0.1Hz in a stress-controlled manner. The dry mass density of the tested organic waste was 0.75 to 0.76 g/cm^3.

Fig.9 indicates the variation of secant Young's modulus with the strain amplitude. The modulus decreased with the increase of strain amplitude. Care is necessary of this figure, however, because the higher σ_1' stress increased the rigidity and reduced the strain amplitude. It is important that both kinds of specimens with and without plastic sheets exhibit similar trends, implying that plastic sheets do not affect the deformation characteristics in a small strain range. This point was mentioned before in triaxial compression tests.

Fig.10 shows the damping ratio. Although the number of data is not sufficient, it is suggested therein that damping ratio increases with the increase of strain range. Of particular interest is the relatively high values of damping ratio when plastic sheets were removed. This may imply that nonlinear deformation of soft waste is increased when constraint due to plastics disappears.

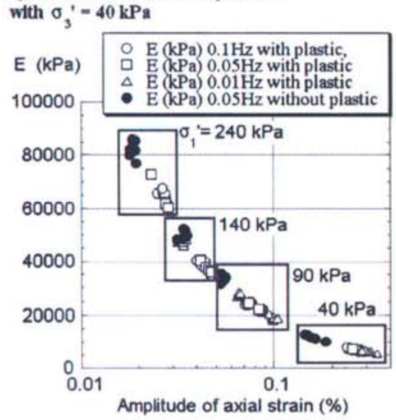


Fig.9: Variation of dynamic Young's modulus with strain amplitude (organic waste).

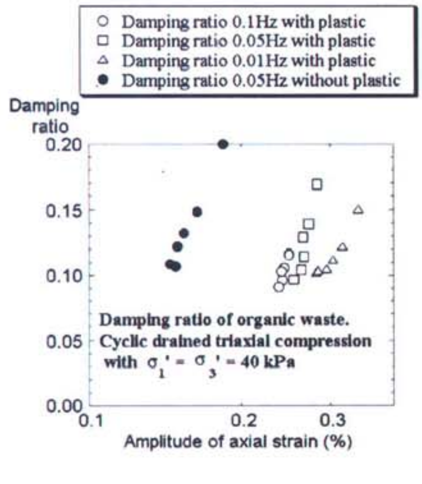


Fig.10: Variation of damping ratio with strain amplitude (organic waste).

SHAKING TABLE TESTS

Shaking table tests in 1-g field were carried out on unsaturated waste specimens in order to measure the dynamic deformation characteristics and the development of residual deformation caused by sustained static loading.

Fig.11 illustrates the laminar box which was mounted on a shaking table and contained the organic waste. This laminar box consists of 11 layers of frames and precise roller bearing are installed between layers so that the frictional resistance may be minimized. The left and right ends of each frame are made of rotational walls that make simple shear condition possible.

Static shear stress was produced in the model by tilting the bottom of the laminar box. The angle of inclination was either 0 or 14 degrees. Since shaking took place in the horizontal direction, the inclined model ground was subjected to both cyclic shear stress in the direction of inclination and the cyclic normal stress. The effects of the latter stress were ignored since the major interest lay in the shear stress-strain relationship. The static normal stress as well as shear stress was further controlled by the weight of the top plate. This weight was adjusted by placing soil bags and increasing the weight. The top plate made a drained boundary by open holes.

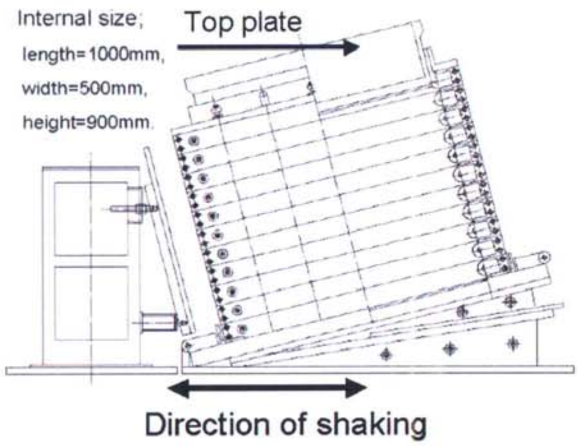
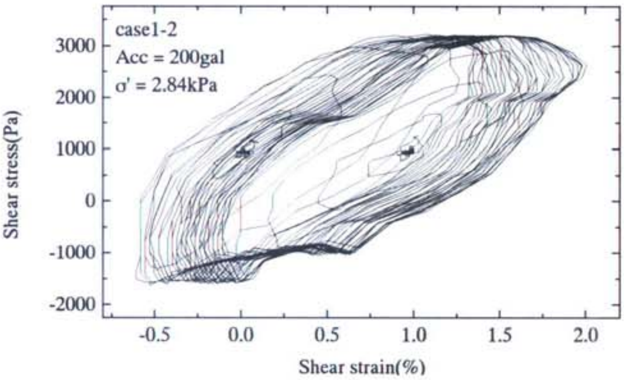


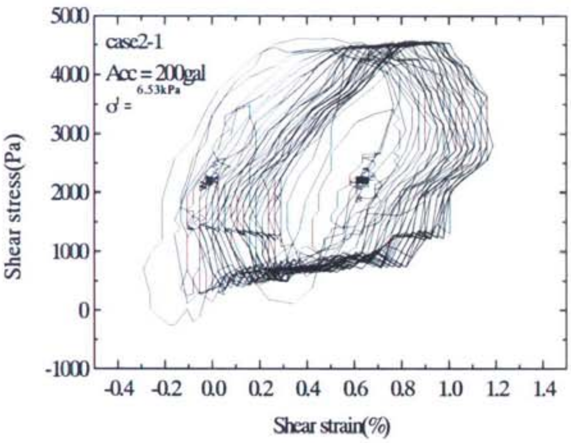
Fig.11: Laminar box employed for shaking table tests.

The organic waste with plastic sheets was placed by layers and each layer was densified by human foot. The moisture content of the waste was adjusted to be 40% which is the optimum water content (Table 1). Being unsaturated, the shaking tests are considered to be drained.

The lateral displacement of each laminar frame was monitored by external laser transducers. By differentiating this, time histories of shear strain were obtained. On the other hand, the cyclic shear stress was obtained by integrating the response acceleration from the top plate downwards. This acceleration was measured by transducers embedded in the model waste ground. Shaking was given in the horizontal direction with constant amplitudes of acceleration. The shaking frequency was set equal to 5Hz that is slightly lower than the natural frequency of 5.1Hz. Note that the natural frequency was determined by sweep tests under week 40-gal shaking with varying frequencies.



(a) Without surcharge



(b) With surcharge

Fig.12: Measured stress-strain behavior of organic waste in shaking table tests.

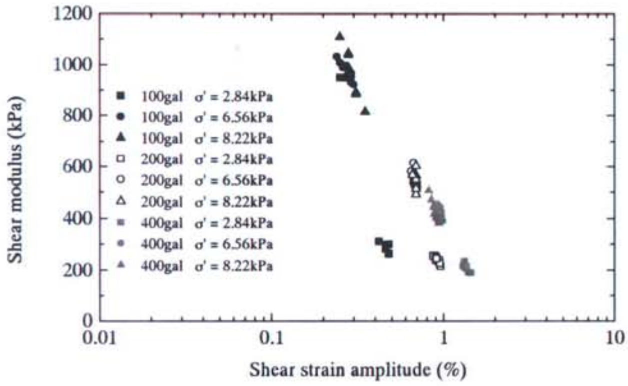


Fig.13: Variation of shear modulus with shear strain amplitude in shaking table tests.

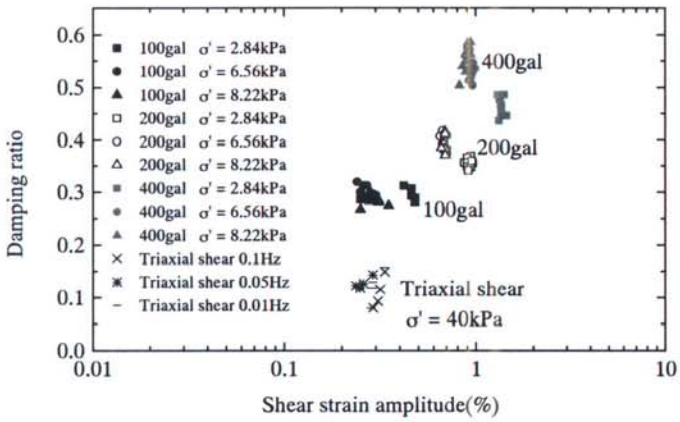


Fig.14: Variation of damping ratio with shear strain amplitude in shaking table tests.

Fig.12 compares the measured hysteresis loops at 13cm below the top under two different overburden pressures. Although the intensity of base shaking was identical, the higher overburden pressure increased the rigidity and reduced the strain amplitude. By interpreting such stress-strain loops under different testing conditions, the variation of shear modulus and the damping ratio with strain amplitude was obtained as shown in Figs 13 and 14. Nonlinearity of shear rigidity is evident, and the variation of damping ratio in shaking tests is consistent with the triaxial test data.

CONCLUSIONS

To help the land development of municipal waste repository, the mechanical properties of wastes were investigated. Organic waste made by bio-treatment as well as inflammable waste was studied by triaxial shear and shaking table tests. Basically waste materials are soft and have nonlinearity. It should be noted that the plastic sheet component affects the properties by means of the reinforcement effects. Creep behavior which leads to secondary long-term consolidation can be mitigated by overconsolidation which can be practiced by preloading method of ground improvement. Nonlinearity in dynamic properties was measured and the high damping ration is noteworthy.

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