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Geotechnical Considerations for End-Use of Old Municipal Solid Waste Landfills

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ABSTRACT: Geotechnical investigations of waste fills are rarely undertaken, and consequently the geotechnical community has little knowledge of their engineering properties. In this study, a geotechnical testing program was conducted to evaluate the engineering properties of old municipal solid waste sampled in Whamyung MSW landfill site, Busan, Korea. The conducted tests included water content, specific gravity, Atterberg limits, grain-size distribution, compaction, small scale and large scale consolidation, triaxial compression (CU), and direct shear tests. The Compression Index, C_c, derived from small scale (70mm in diameter) and large scale (250mm in diameter) one-dimensional consolidation tests was about 0.04 and 0.09, respectively. A secondary compression coefficient, C_α, appeared to be less dependent on stress level and more dependent on the aging level. In triaxial compression and direct shear tests, friction angle and cohesion were evaluated as 36~46^o and 25~60 kN/m^2, respectively. The results reported in this study are comparable to those reported in the literature and obtained from laboratory and field tests.

Key words: Compressibility, Shear strength, Solid waste, Landfill, Consolidation

INTRODUCTION

As well as so-called ‘end of pipe’ alternatives such as burning, there are many ways to deal with waste, including reducing the production, encouraging recycling, and re-using municipal solid waste (MSW). However, large amounts of waste are still disposed in the environment, and the primary option for the safe deposition of MSW continues to be sanitary landfill. As MSW itself is the main construction material used to build these engineering structures, its mechanical behavior is of paramount importance in obtaining a safe and economical design. MSW is known to be a heterogeneous material of varying constituent types and dimensions, containing elements that degrade with time. In order to consider MSW as a geo-material supporting the foundation of structures such as buildings and pavement, an analysis of the bearing capacity of the foundation and further long-term settlement of MSW as well as the basic geotechnical properties should be carried out: 1) Basic geotechnical properties of landfills are known through testing for waste composition, particle size distribution, organic content, water content, liquid limit and plastic limit, specific gravity, and compaction; 2) Compression characteristics of landfills are evaluated through oedometer and large consolidation tests; and 3) additionally, to evaluate the parameters of shear strength for landfills, direct shear tests and tri-axial compression tests have been conducted.

In this study, the authors collected old municipal solid wastes at a site that was considered as apartment construction and analyzed the basic mechanical properties, the characteristics of settlement, and strength of the waste material. The outcomes are compared with other testing results from published data in the literature. This research, therefore, aims to provide insightful information about landfills’ geotechnical properties to engineers regarding the consideration of old MSW as construction material supporting structural foundations.

MATERIALS & METHODS

For this research, laboratory tests were conducted on samples from old municipal solid waste at the

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Whamyung MSW landfill site, Busan, Korea. At the time of collection, the landfill site was older than approximately 15 years. The samples were obtained at two different locations of the landfill, at a depth of 2.5 ~ 3.5 m below the surface. Tests were done with the samples, which were passed through a #4 sieve to mitigate the possibility of irregularity arising from overly large particles in the samples. For compression, direct shear, and tri-axial compression (CU) tests, the samples that had an initial 95 % wet side of maximum dry unit weight, as obtained from compaction tests, were remolded.

For compression tests, remolded specimens were compacted directly into 100mm diameter, 2mm thick circular consolidation rings. This test is generally applied to evaluate the compression characteristics of common clayey soils. However, as there are larger particles in municipal solid wastes than in common soils, it is anticipated that the inclusion of large particles might influence the test results compared to results obtained from larger scale tests. For comparison, large-scaled compression tests (diameter = 250 mm, height = 150 mm) were performed for vertical stresses at 2.5, 5, 10, 20, 45, and 100 kN/m^2 (Fig. 1) and time and settlement were measured for two days for each stress level.

Direct shear specimens were compacted directly into a circular shear box (diameter = 100 mm, thickness = 25 mm). The specimens were prepared in the same manner as described for the consolidation specimens. The tests were conducted under normal stresses at 108, 170, and 264 kN/m^2. The triaxial shear test is one of the most reliable methods available for determining shear strength parameters. For this test, the specimens were compacted in a cylinder (diameter = 100 mm, thickness = 50 mm) and encased by a thin rubber membrane and then subjected to confining stresses at 108, 170, and 264 kN/m^2. The specimens were consolidated at the confining stress and then sheared as axial stress was applied.

RESULTS & DISCUSSION

Generally, soils are composed of various weathered rock particles, and they are classified as gravel, sand, silt, or clay depending on the particle size. From a geotechnical perspective, engineering properties such as compressibility and strength are greatly influenced by soil composition, thus signifying the importance of soil classification.

The composition of the municipal solid waste in this study was determined by hand-segregating and weighing the similar components of the waste samples. The results are shown in Table 1 together with the compositions of other MSWs from other sites from data reported in the literature. Table 1 shows the landfill wastes contained various components, ranging from uncompressible contents such as soil and metal to degradable/ non-degradable compressible contents such as paper, wood, and rubber. For the various compositional characteristics of landfill wastes, a few classification systems have been proposed (Landva and Clark, 1990; Kolsch 1996). For example, Landva and Clark (1990) classified landfill waste into organic and inorganic components. This system provides

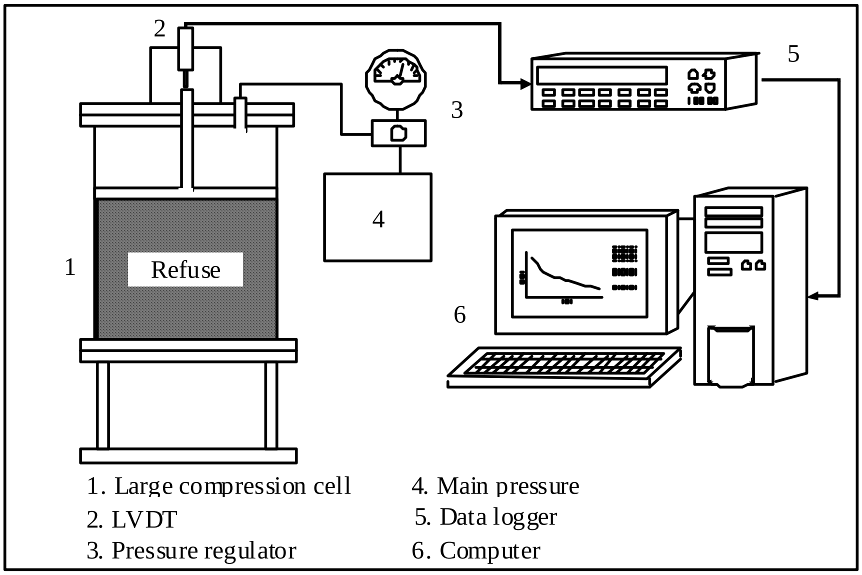


Fig. 1. Large compression cell

Table 1. Compositions of the wastes (% of total weight)

Reference	This study	Gabr & Valero (1995)	KGS (1994)	Rao et al. (1977)	Park (2000)
Aging level / Category	10 years old	15~30 years old	8 year old	Fresh	Fresh
Food & Garden refuse	0	0	0	30	45
Papers	0.05	2	3.3	40	23
Textiles	0.08	23	7.2	2	10
Plastics and Rubbers	0.62	13	16.6	3	7
Woods	0.44	9	5.9	1	2
Metals	0.49	10	2.3	10	4
Glass and Others	5.56	10	21.3	14	9
Soil	93.51	33	42.5	0	0
Sum.	100	100	100	100	100

detailed information on degradation and compressibility potential of components. Kolsch (1996) proposed a classification system including material groups, size, and dimension of components. When the waste in landfills becomes older, most organic materials gradually disappear through decomposition, and therefore inorganic materials comprise the main remaining components. Since most organic materials were decomposed in the waste samples of this research and soil content was above 90 % of the waste samples, a soil classification system is more appropriate than classification of waste.

A grain size test was performed for further classification, and the results are shown in Fig. 2 along with distribution curves of other wastes reported in the literature. It is of note that the fine-grained material amount increased with the age of the waste. Since the large organic components had disintegrated and mostly decomposed, the grain size distribution curve located in the range of small grain size, uniformity coefficient, C_u was in a range of 10~21. is defined as the following ratio: the size at which 60 percent (by weight) of a sample passes through a sieve divided by the size at which 10 percent of the same sample (by weight) passes through a sieve. If is less than 2, the sample can be classified as uniform. Otherwise, if is greater than 6, it can be classified as well-graded. Therefore, the present MSW sample can be classified as well-graded sandy silt with a small amount of organic content. A fresh MSW whose fill age is less than a few years would contain significant amounts of organic components with size larger than gravel. It is thus not appropriate in this case to use soil classification, but rather the classification systems mentioned above should be employed.

Moisture content varied from 34.3 to 35.3% and organic content (volatile solid / total solid) varied from 6.1 to 7.5 %. Fig. 3 shows the relationship between the water content and the organic content of the samples of this research as well as various refuse samples from Canadian landfill sites (Landva and Clark, 1990). In general, water content does appear to increase with increasing organic content. Since the sample of this study contained a very small amount of organic content, it is reasonable that its water content was in the lower range.

The specific gravity of the samples was distributed in a range of 2.44 ~ 2.54. These values were less than the specific gravity of soil (ranging from 2.6~2.9) due to the presence of organic matter such as textiles, rubbers, plastic, and others. It was not possible to conduct liquid limit (LI) and plastic limit (PI) tests.

Increase of soil unit weight enhances its strength, resulting in an increase of its bearing capacity and a decrease of the opportunity for unbalanced settlement. Therefore, it is essential to evaluate the unit weight of the MSW when it is incorporated in the foundation for structures such as roads or buildings. The unit weight of waste landfills varies considerably with the compaction level, aging level, depth, and waste to soil cover ratio (Fasset et al. 1994; NSWMA, 1985; Kavazanjian et al. 1995; Landva and Clark 1986). The unit weights of fresh waste whose fill age is usually a few years range from 3 to 11 kN/m^2 with compaction

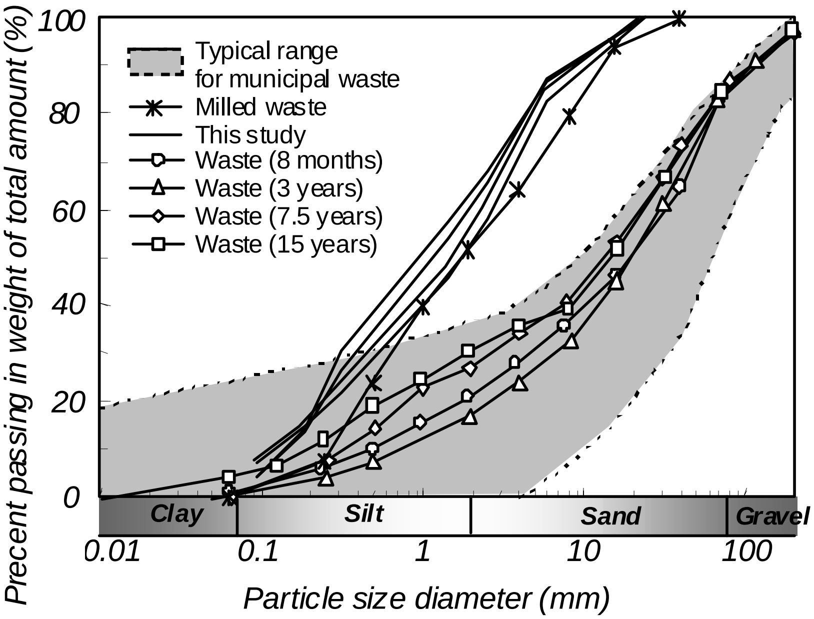


Fig. 2. Grain size distribution (from Jessberger, 1994)

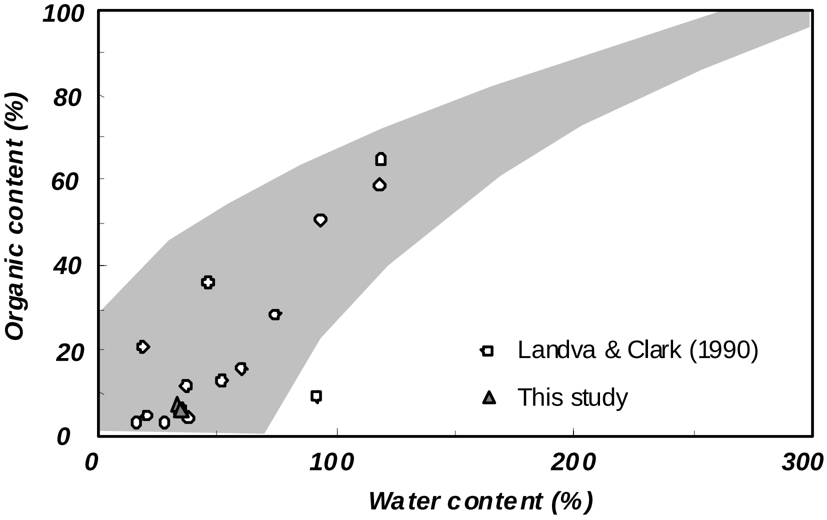


Fig. 3. Organic content and water content of samples

level, as shown in Table 2 (Fasset *et al.*, 1994). It was elsewhere reported that the unit weight of MSW was in a range of 6.9~7.5 kN/m^3 and increased to 7.0~13.2 kN/m^3 with decomposition and settlement of MSW landfills (NSWMA, 1985). Kavazanjian (1995) reported a unit weight of 6 ~ 7 KN/ m^3 for fresh MSW and 14 ~ 20 KN/ m^3 for highly degraded waste with high soil concentration depending on the level of compaction. The compaction results of the sample of this study are presented in Fig. 4. The optimum moisture content ranged between 21% and 24 % and the maximum dry unit weight ranged between 13 and 14 kN/m^2. The values of the unit weight of the specimens fall in the range suggested by Kavazanjian for old MSW, mainly because the samples in this study include a high ratio of soil materials in comparison with other wastes, as illustrated in Table 1.

Table 2. Unit weight data for fresh waste (after Fassett *et al.*, 1994)

Reference	Poor compaction	Moderate compaction	Good compaction
Range	3.0~9.0	5.0~9.0	8.8~10.5
Average	5.3	7.0	9.6
Standard deviation (kN/m^3)	2.5	0.5	0.8

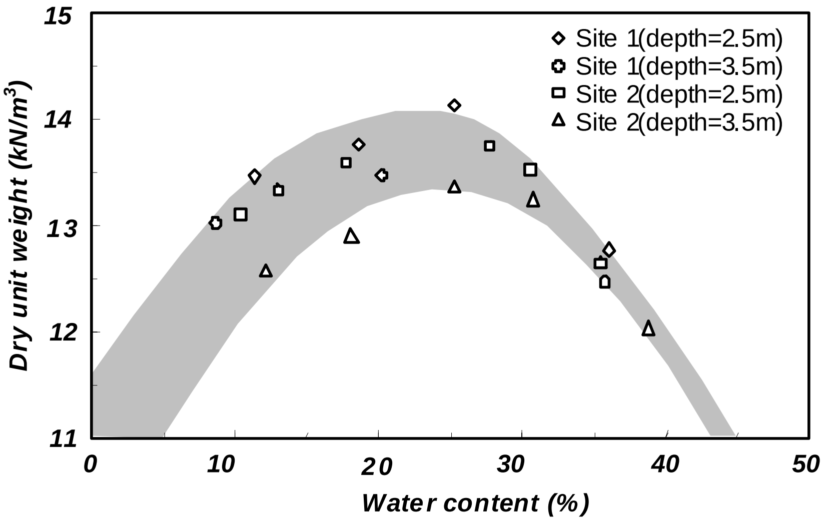


Fig. 4. Relationship with dry unit weight and water content

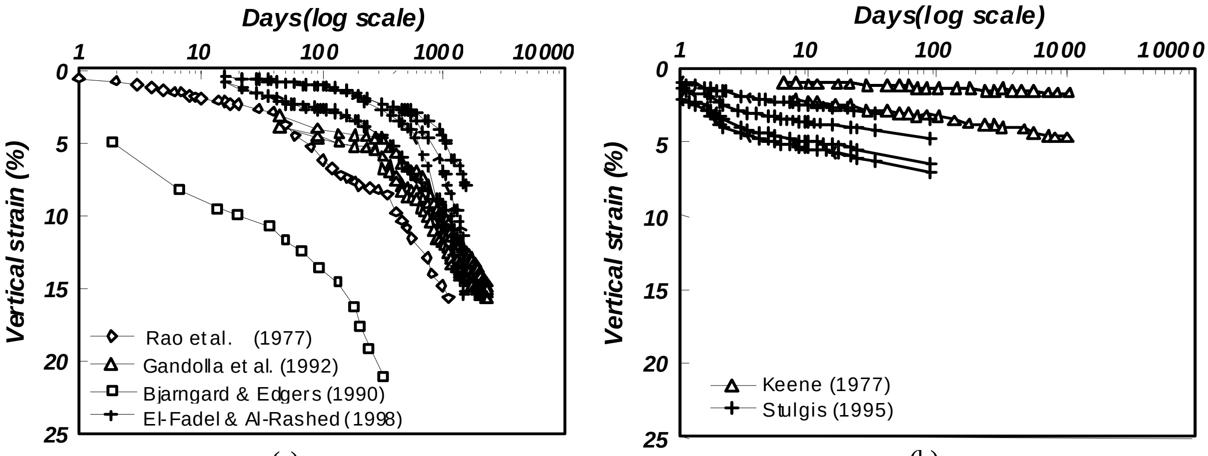
As depicted in Fig. 5, Bjarngard and Edgers (1990) proposed a settlement pattern that is explained through three distinct settlement phases based on an analysis of landfill settlement data collected from 24 case histories. In the initial phase (Phase I), immediate settlement occurs due to compression of waste components under loading conditions. Afterward, due to long-term slippage or reorientation of the particles, mechanical long-term settlement (Phase II) is initiated. Continuous decomposition introduces more settlement, resulting in a steep increase in settlement (Phase III) with respect to a logarithmic time scale. Considering these three phases of settlement development, Bjarngard and Edgers (1990) modeled waste landfill settlement as delineated in equation (7).

$$S / H = CR \log \frac{\overline{P}_o + \Delta p}{\overline{P}_o} + C_{\alpha(1)} \log \frac{t_{(2)}}{t_{(1)}} + C_{\alpha(2)} \log \frac{t_{(3)}}{t_{(2)}} \qquad (1)$$

where S = settlement, H = initial thickness of landfill, $\overline{P}_o$ = initial effective stress, Δp = stress increment, CR = compression index which means the slope of strain verses logarithmic effective stress, $C_{\alpha(1)}$ = coefficient of mechanical secondary coefficient, and $C_{\alpha(2)}$ = coefficient of secondary compression due to additional decomposition.

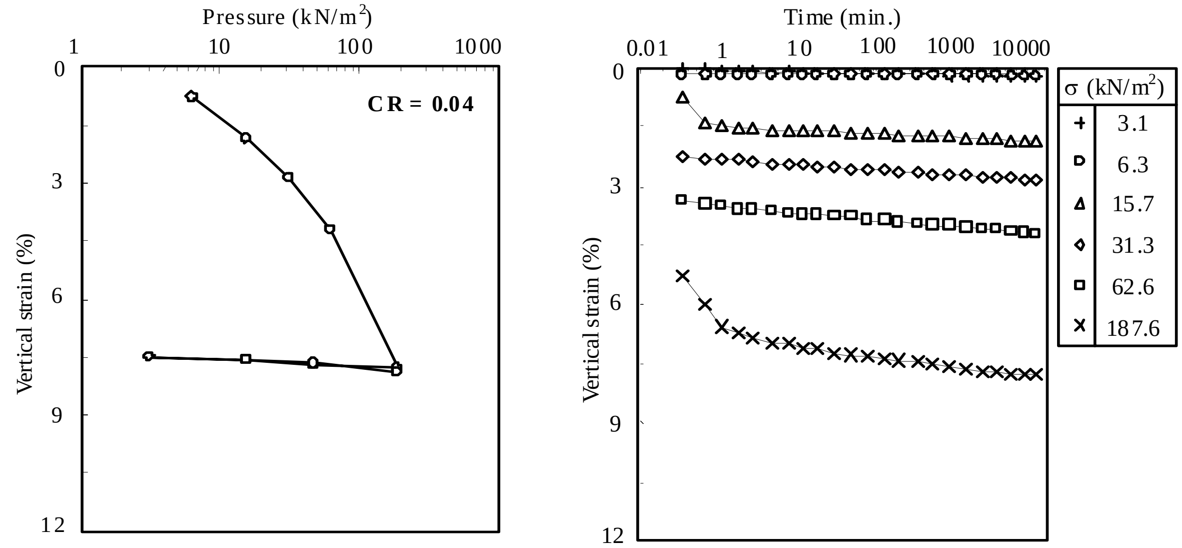
The settlement characteristics of fresh MSW landfills are shown in Fig. 6(a). As shown in Fig. 5, the settlement curve showed a linear relation, with a small slope in the strain vs. log-time graph, and developed a much greater slope approximately 300 days after measurements due to activation of decomposition. The settlement characteristics of MSW landfills whose fill ages were above 20 years are shown in Fig. 6(b). After the initial compression, the settlement curves show only linear relationships with small slopes without steep settlement due to decomposition. This means that the settlement due to decomposition was almost completed, signifying that a small amount of settlement is induced by residual decomposition, reorientation of waste materials, and creep due to the compressible materials such as non-degradable organic solids including rubber.

In this study, a small scaled compression test (diameter = 10cm) known as an oedometer test was conducted to estimate the compression characteristics of old wastes. Moreover, a large scale compression test (diameter = 25cm) was performed to consider the settlement characteristics of larger waste materials than soil particles (Landva and Clark, 1990; Jessberger and Kockel, 1993; Gabr and Valero, 1995). The logarithmic time-strain and the logarithmic stress-strain relationships obtained from different scaled compression tests are presented in Fig. 7. Even though the behaviors obtained from the oedometer tests were similar to the characteristics of compression found from the large scale compression tests, the compression index, CR of the oedometer test is less than it of large scale test, is increased from 0.04 to 0.09 with an increase of the compression test size. In the case of considering the old MSW landfill site as the foundation ground of a structure, the large scale compression test appears to be more appropriate than the oedometer test for estimation of the settlement characteristics of MSW

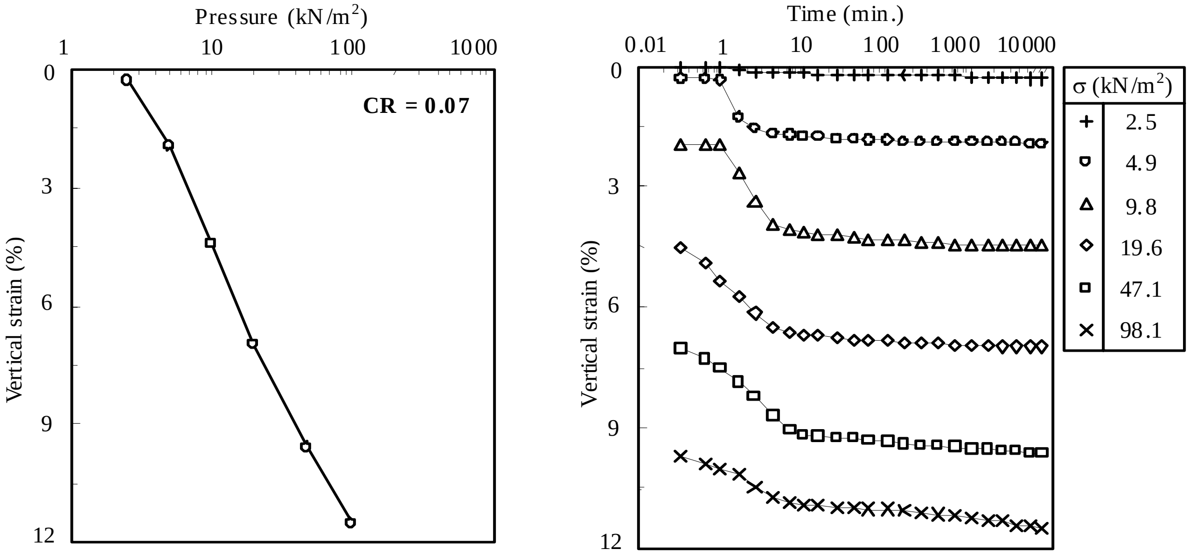


(a) (b)

Fig. 6. Compression characteristics of fresh and old MSW landfills



(a) small-scale compression test results



(b) small-scale compression test results

Fig. 7. Results of compression tests

landfill due to the size effect of MSW components having size greater than that of soil particles. As an additional comparison, the percentage compressive strain versus applied logarithmic stress from both data in the literature and the results of this study are plotted in Fig. 8. Values of estimated CR from all data are also illustrated in Table 3. It is of note that the values were 0.19 and 0.24 for the fresh waste (cases 5 and 6), which are comparatively greater than the results for the old waste (cases 1, 2, and 4), including the samples from this study.

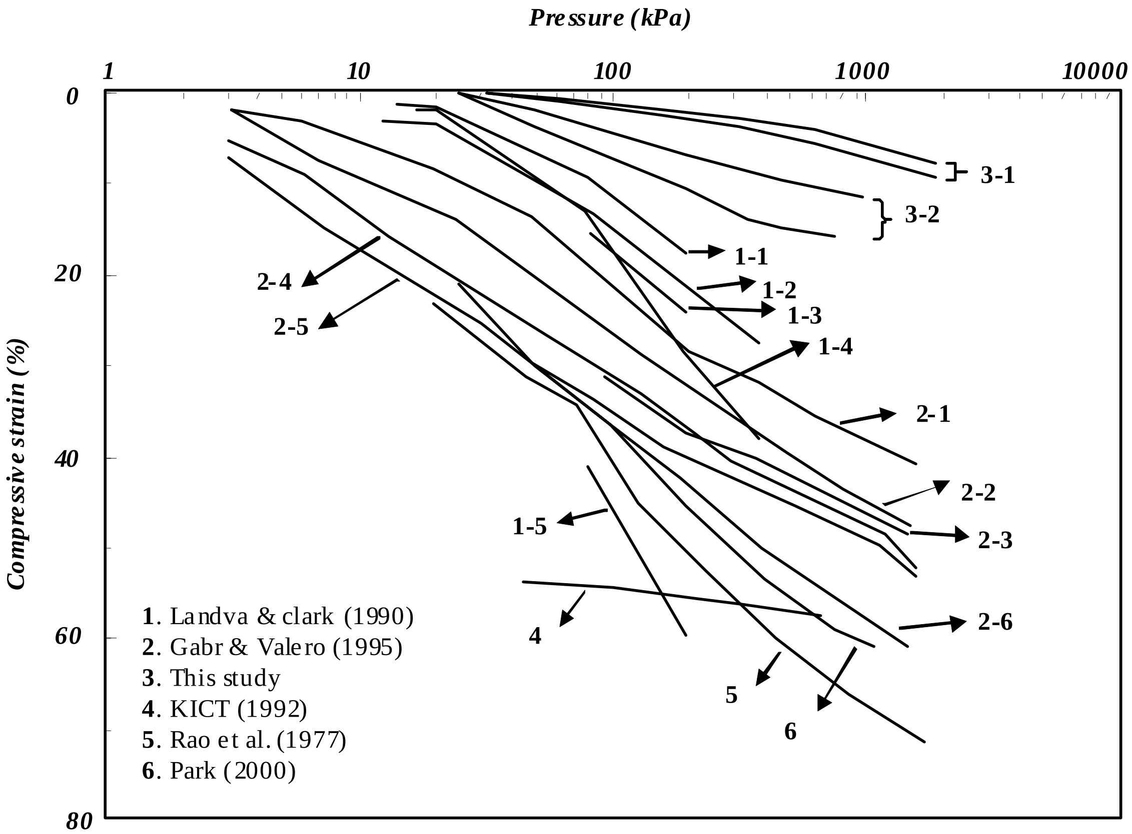


Fig. 8. Compressibility characteristics as measured from consolidation tests

Table 3. Reported consolidation test results

No	Reference	Sample Origin	$CR_{,ave.}$	Remarks
1	Landva & clark (1990)	1-1 Kingstone, Canada (old landfill)	0.17	45.0 cm Diameter Consolidometer
		1-2 Ottawa, Canada (old landfill, Ridge Road)	0.21	
		1-3 Hantsport, NS, Canada (old landfill & woodwaste)	0.22	
		1-4 Edmundston, NB, Canada(woodwaste)	0.36	
		1-5 Edmonton, Alberta, Canada	0.35	
2	Gabr & Valero (1995)	2-1~2-6 Exeter Township, USA (old landfill)	0.15~0.22	6.4cm Diameter Consolidometer
3	By Authors	3-1Busan-Whamyung, Korea (old landfill)	0.04	7.5 cm Diameter Consolidometer
		3-2 Busan-Whamyung, Korea (old landfill)	0.09	25.0 cm Diameter Consolidometer
4	KICT (1992)	Nanji landfill, Seoul, Korea (old landfill)	0.13	7.5 cm Diameter Consolidometer
5	Rao et al. (1977)	USA (fresh landfill)	0.19	60.0 cm Diameter Consolidometer
6	Park (2000)	Simulated MSW, Korea (fresh waste)	0.24	25.0 cm Diameter Consolidometer

The values of the secondary compression coefficient, C_α (strain/ log time), from the literature data and this study are presented in Table 4. The values from the present study are considerably smaller than the results from fills whose ages are about 8 ~ 30 years. That is because very small amounts of creep-inducing materials such as textiles, rubbers, and papers were contained in the sample of this study, as illustrated in Table 1. In Fig 9, C_α values are not affected significantly when the stress intensity and the unit weight change. The values of for the fresh waste are approximately three times greater than that of the old wastes. Landva and Clark (1990) also reported that values increased with an increase in organic content. It was previously observed that the rate of secondary compression is comparatively insensitive to the intensity of pressure and density (Rao et al., 1977; Jessberger and Kockel, 1993; Gabr and Valero, 1995).

Shear resistance is a geotechnical parameter of primary concern in describing the properties of MSW. Shear strength of MSW is usually defined using the Coulomb failure criterion as follows:

$$\tau = \sigma \tan \phi + c \qquad (3)$$

Determination of MSW shear strength properties is difficult and costly due to the inconsistent composition of landfill material, difficulties in sampling and testing, and time-dependent properties. Four general approaches are used to estimate the shear strength of MSW: (1) back calculation form field tests and operational records, (2) in-situ testing, (3) triaxial compression testing, and (4) direct shear testing. Back-calculation of the shear strength of MSW has been carried out using plate load. This approach can provide information on the shear strength of a large mass of waste, but poor quality input data makes such analyses problematic and often unreliable. In situ techniques

Table 4. Secondary compression coefficient obtained from several test results

$C_{\alpha,\ ave}$ (strain/log time)	Test scale (Diameter, mm)	Aging level	Reference
0.03	250	Fresh	Park (2000)
0.05	610	Fresh	Rao et al. (1977)
0.001	80	10 years old	This study
0.001	250		
0.01	1000	15 years old	Jessberger & Kockel(1993)
0.005	250	8 years old	KGS(1994)
0.009	63	15~30 years old	Gabr & Valero (1995)

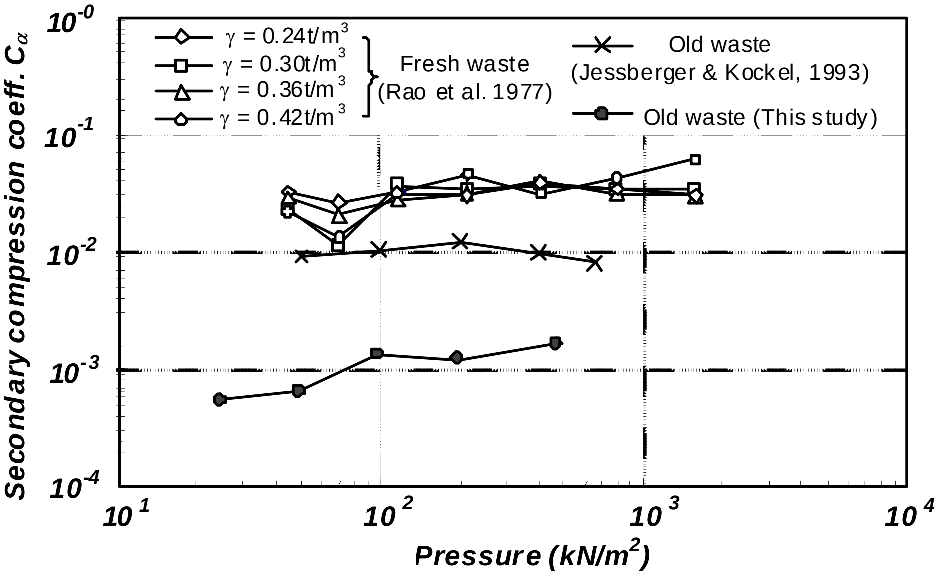
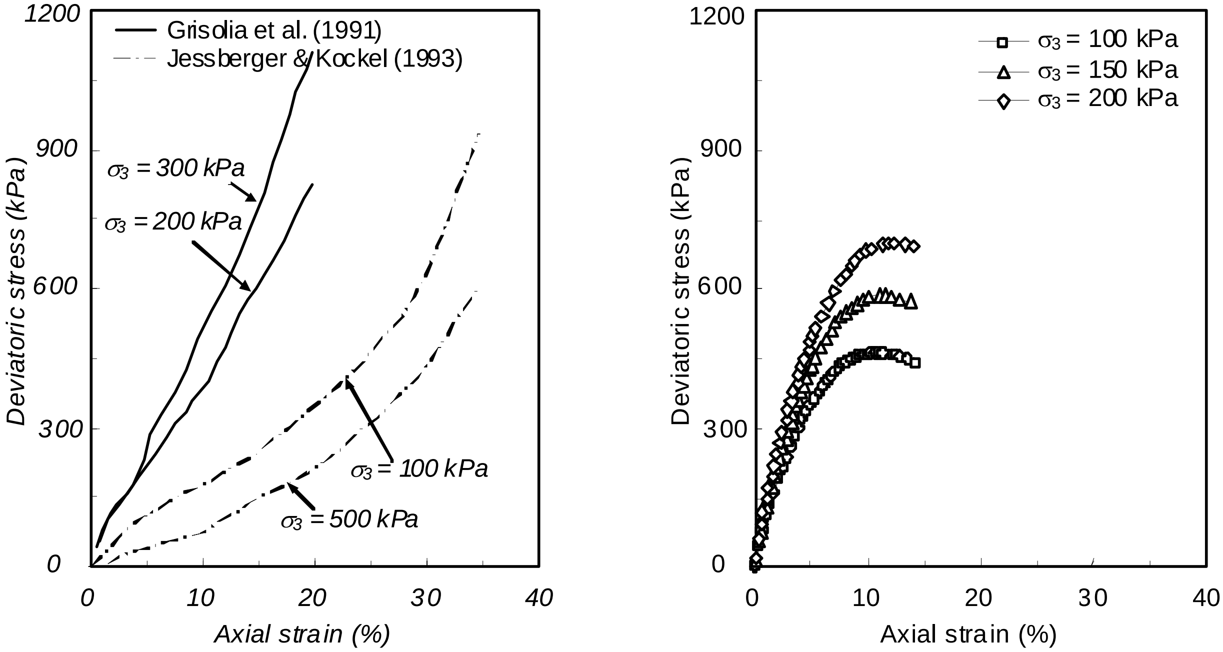


Fig. 9. Effects of pressure, density, and decomposition level on secondary compression coefficient (C_α)

for measuring the shear strength of MSW are presently inadequate and unreliable. It is known that the MSW shear strength from field penetration tests does not have a meaningful correlation with the penetration resistance (Mitchell and Mitchell 1992). Also, in situ testing equipment such as CPT and DMT cannot easily penetrate the landfill due to the existence of large radius materials. Kavazanjian (2001) stated that the triaxial test was not an appropriate technique for measuring the shear strength of MSW. The reason for this is MSW material can sustain very large shear strain without reaching a failure point [Fig. 10(a)], which leads to shear strength being related to levels of strain. This approach has some merit if used in design to try to control strains in the waste body. Even though the triaxial test is in general efficient for the evaluation of shear strength based on a possible failure plane, its use in determining the shear strength of MSW is considered to be inappropriate. However, the stress-strain relationship obtained in this study diverged from the typical triaxial results of MSW, as shown in Fig. 10(b). According to Bouazza and Amokrane (1995), this type of stress-strain relationship could be regarded as a reinforced earth-like behavior, as shown in Fig. 11. Bouazza and Amokrane illustrated that fibrous waste components such as plastics, textiles, rubbers, and woods may act as reinforcement in waste landfill to provide more cohesion or friction. In this respect, the MSW sample in this study, whose soil materials accounted for 90 % of its total weight, was reinforced by the existing fibrous waste components. It can be concluded that old MSW containing dominantly soil materials with a small amount of fibrous components displays more soil stress-strain-like behavior as compared to typical wastes. Therefore, it is appropriate to perform a triaxial test if the waste contains mostly soil in its composition.

Fig. 12 shows the wide variation in values of waste shear strength parameters. The values of shear strength obtained by the direct shear test and triaxial compression test in this study are compared with those evaluated by the various methods noted above. Similar to the tendency of soil, the results derived through the direct shear test were greater than those found through the triaxial compression test. The friction angles in this study ranged from 37° to 45° and were comparatively greater than the results of other researchers (24~42°). In this study, higher friction angles and intercept cohesion are possibly due to the mixed matrix of the material (soil-waste). Effective cohesion of wastes is generally induced by organic material such as fibers, and its magnitude decreased with decomposition of organic materials. Landva and Clark (1990) reported that the shear strength of waste is highly variable depending on the type of material involved. The wide range in reported shear strength parameters of wastes could result from such factors as waste aging level, composition, size, and density.



(a) (b)

Fig. 10. Stress-strain relationship for MSW

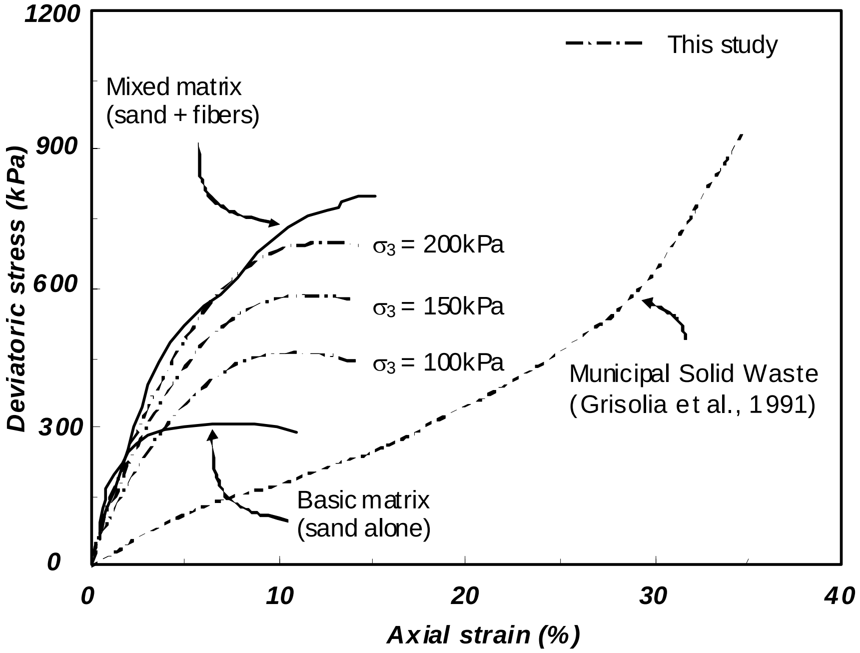


Fig. 11. Deviatoric stress versus axial strain for various materials

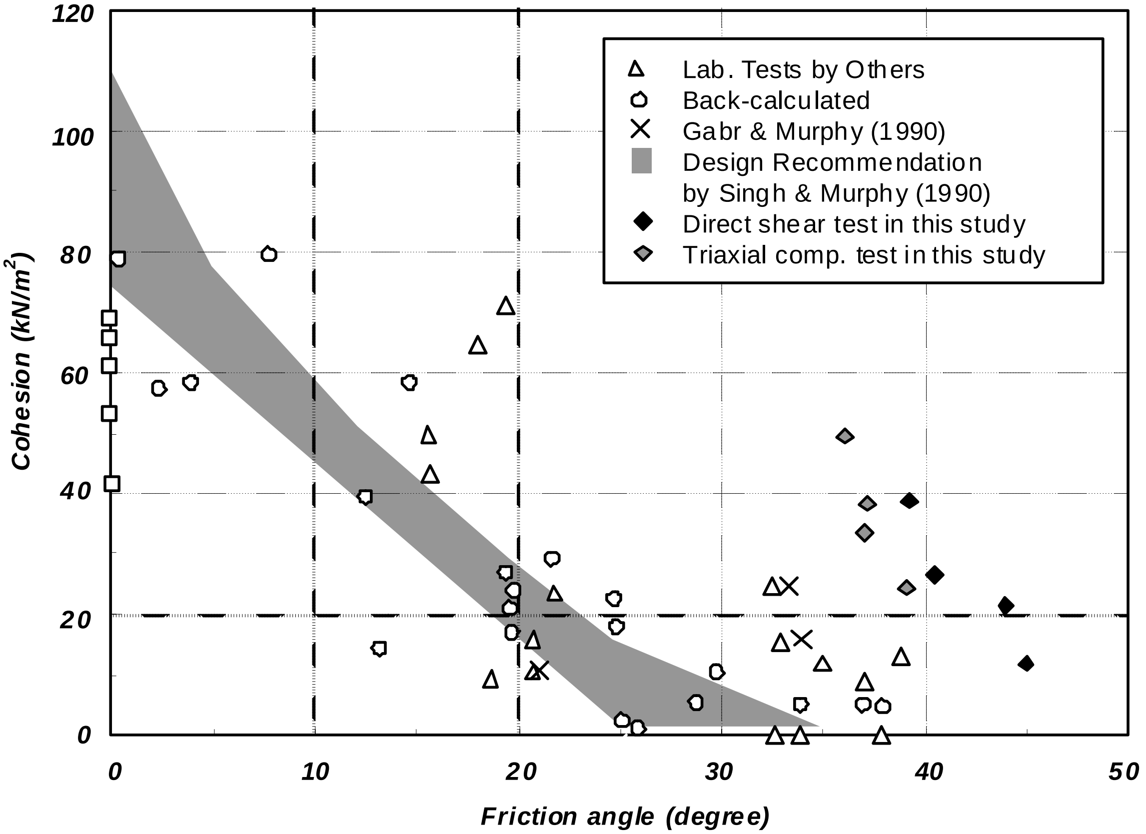


Fig. 12. Shear strength parameters of MSW estimated with different testing methods

CONCLUSION

Laboratory tests were performed to investigate the geotechnical engineering properties of old municipal solid waste. The conducted tests included water content, specific gravity, Atterberg Limits, grain-size distribution, small scale consolidation (oedometer), large scale consolidation, triaxial compression (CU), and direct shear tests. The obtained geotechnical engineering properties were compared to data reported in the literature. Ninety percent of the total weight of the samples was comprised of soil materials.

In laboratory consolidation tests, compression index, CR, values derived from small scale and large scale tests ranged between 0.04 and 0.11 and also increased with an increase of the consolidometer size. The secondary compression coefficient, C_α, was estimated in this study to range between 0.0003 and 0.0026. It is of note that CR values for old waste in this study are comparatively less than those of the fresh wastes. Also, the C_α values of the waste in this study wastes were approximately three times less than those of the fresh wastes.

In triaxial compression and direct shear tests, friction angles and cohesion were evaluated as 36~46^{o} and 25~60 kN/m^2, respectively. The shear strength parameters obtained from this study were compared with those reported in the literature. The wide scatter in reported shear strength parameters could result from factors such as waste aging level, composition, size, and density. Although it is difficult to draw any constructive conclusion owing to the very wide scattering in the results, the shear strength parameters in this study as the(37~45^{o}) in this study are comparatively greater than the results of other researchers (24~39^{o}). This is possibly attributable to the higher friction angles and intercept cohesion in this study, which might be due to the mixed matrix of the material (soil-waste).

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