Geotechnical behavior of the MSW in Tianziling landfill*

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Abstract: The valley shaped Tianziling landfill of Hangzhou in China built in 1991 to dispose of municipal solid waste (MSW) was designed for a service life of 13 years. The problem of waste landfill slope stability and expansion must be considered from the geotechnical engineering point of view, for which purpose, it is necessary to understand the geotechnical properties of the MSW in the landfill, some of whose physical properties were measured by common geotechnical tests, such as those on unit weight, water content, organic matter content, specific gravity, coefficient of permeability, compressibility, etc. The mechanical properties were studied by direct shear test, triaxial compression test, and static and dynamic penetration tests. Some strength parameters for engineering analysis were obtained.

Key words: Municipal solid waste (MSW), Engineering properties, Laboratory test, In-situ test
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INTRODUCTION

The Tianziling waste landfill built in 1991 to properly dispose of municipal solid waste (MSW) has a designed service life of 13 years. It was filled stage by stage at the beginning of the elevation of +50.5 m. By now, the landfill has reached the level of +102.5 m, which exceeds the top of the waste dam (+66 m) by 37 m; three platforms (+77.5 m, +90 m, +102.5 m) have come into being. The Hangzhou government is to seriously consider whether the waste landfill can be in regular service past its life.

It is important to choose suitably the engineering properties indexes of the MSW during geotechnical engineering analysis (Qian *et al.*, 1998). The local economic development level, customs, climatic conditions, geological conditions and filling time can influence the MSW's complex physicochemical ingredients and engineering properties, which are not determined easily. In this work, the engineering properties of the MSW were studied by analyzing its physicochemical composition, by laboratory test, and in-situ test.

LABORATORY TEST

1. Ingredients

The landfill's various and different ingredients were the major reasons for its complex engineering properties. The soil samples were from the +102.5 m and +90 m platform. The grain of the MSW appeared very uneven. The shallow samples with high water content, were in semi-plastic state, and often exuded the leachate; the deep ones were in the state of black semi-solid. The results are shown in Table 1.

In general, the organic content gradually decreased with depth because of thorough biochemical degradation of the deep organic matter; but the inorganic matter decomposed slowly, so its relative content increased with the reduction of organic content and increased soil pressure. The pH value exceeded 7.0, which indicated that the chemical reaction occurred under alkaline condition; and that the intensity of the reaction depended on the change of temperature.

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Table 1 Ingredients of the MSW in Tianziling landfill

Platform(m)	Boring	Depth(m)	Plastic(%)	Organic material(%)	Impurities(%)	Mineral(%)	Temperature(℃)
90	16	5	31	11.9	7.1	50	30
		10	15	12.5	5	67.5	40
		15	24.7	10.8	7.5	57	40
		25	5.6	8	1.6	84.8	38
	18	5	23.5	11.8	3.9	60.8	38
		10	20.7	13.8	6.9	58.6	38
		15	16.3	11.2	7.1	65.4	39
		20	18.9	7.8	5.6	67.7	39
102.5	13	5	16.5	25	2	56.5	42
		10	21.4	25		53.6	44
		15	13	5.2		81.8	42
		20	17.5	21.3	1.3	60	44
		24	12.8	17.6		69.5	46
	15	5	20	23.3	3.3	53.3	45
		10	11.4	1.4	7.1	80	45
		15	10	12.5	5	72.5	
		20	15.7	17.1	2.9	64.3	
		25	13.6	11.8	4.5	70	

2. Unit weight

The results of tests of thirty-one samples from the +102.5 m, +90 m and +77.5 m platforms of the landfill are shown in Fig. 1, the data were discrete. In general, the unit weight increased with depth, and ranged from 8 kN/m^3 to 16.8 kN/m^3. The typical range was 8 kN/m^3 to 14 kN/m^3 (Fungaroli, 1979; Oweis *et al*., 1986; Landva *et al*., 1990; Qian *et al*., 1994; Fassett *et al*., 1994; Timothy *et al*., 2000). The range of unit weight from this test was wider than others. The reason could be that on one hand, the unit weight decreased for MSW containing much plastic material and branch; on the other hand, it might have increased because of the gravel in the landfill covers.

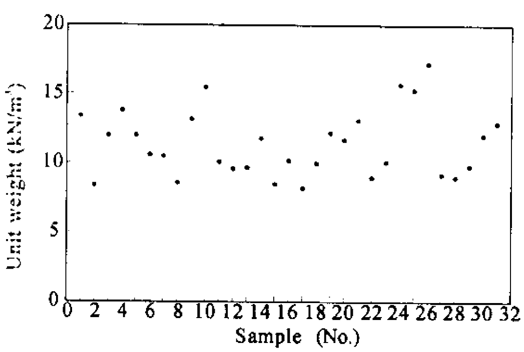

Fig. 1 Unit weight of the MSW

3. Water content

The water content ranged from 20% to 60% and mostly about 30% (Fig. 2); and in several samples was as high as 100.6% because of its content of silky textile with strong water retention property. The data discreteness is very distinct, even for the samples of the same depth and the same platform.

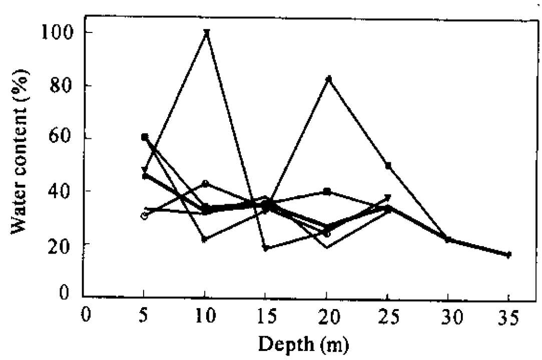

Fig. 2 Water content of the MSW

→77.5m; →77.5m; →90m; →90m; →102.5m; — trendline

As depth increased, the water content gradually decreased. It was obvious that the water content closely related to the local climate and the filling mode (Mitchell *et al*., 1992). It was higher in rainy and humid areas. It is important for reducing water content to classify the MSW before filling, to use covering clay whose coefficient of permeability was less than 10^{-7} cm/s, and to keep drainage unobstructed.

4. Specific gravity

In view of the MSW's high organic content and the possibility of containing some soluble salts in the MSW, waste material with grain size larger than 0.5 cm must be removed. The specific gravity ranged from 1.96 to 2.62 (Fig. 3), except for a few singular data. Compared with common soil (from 2.64 to 2.75), the specific gravity values were relatively low and greatly discrete because of the higher organic content. It was found that the specific gravity of the MSW below 20 m was uniformly, about 2.2 (Fig.3).

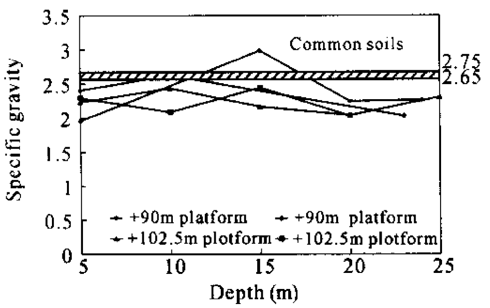

Fig.3 Specific gravity of the MSW

5. Coefficient of permeability

Because the impurities such as plastic, gravel, and metal had great effect on the coefficient of permeability, waste material with sizes larger than 0.5 cm were eliminated. The results suggested that the coefficient of permeability ranged from 2×10^{-4} cm/s to 4×10^{-3} cm/s; and in general, reduced with increasing time and filling depth.

Generally, a lot of broken stones in the landfill cover could increase the MSW's permeability, so when the coefficient of permeability of the landfill cover was less than 10^{-7} cm/s, they could effectively reduce the MSW's coefficient of permeability.

6. Compressibility

The seventeen samples from different depth of + 90 m platform were used. The e-log*p* curves of the MSW had a clear linear segment like that of common soils (Fig. 4). Use of the Casagrande method led to the conclusion that the preconsolidation pressure was 32.5 kPa, 47 kPa and 225 kPa corresponding to depth of 10 m, 20 m and 25 m respectively; and that the self-weight was 98 kPa, 220 kPa, and 281 kPa. Obviously, the preconsolidation pressure was much smaller than the self-weight stress, probably because of the smaller soil pressure around soil samples due to the large voids and the disturbed samples.

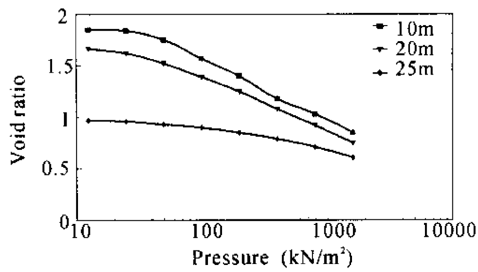

Fig.4 E-log*p* curve of the sample on + 90 platform

The coefficient of compressibility ranged from 0.48 MPa^{-1} to 2.25 MPa^{-1} (Fig.5), so

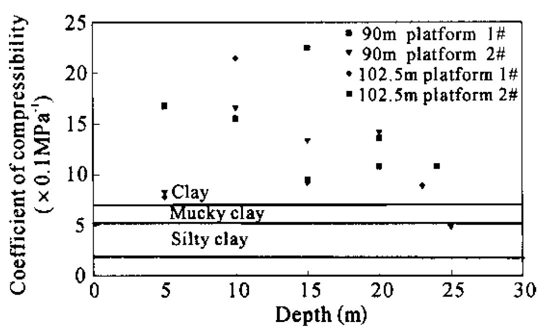

Fig.5 Distribution of coefficient of compressibility

the MSW was classified as high compressibility soil. The coefficient of compressibility decreased with depth. The modulus of compressibility varied from 1.23 MPa to 4.4 MPa, and averaged 2.27 MPa (Fig. 6). The compression index ranged from 0.26 to 0.56 for most samples, which was larger than the 0.17 – 0.36 published by Sowers (1968). However, the results of some other samples were comparatively discrete; the minimum was 0.16 and the maximum was 0.75 (Fig.7).

Because of the complex structure and large variations of physical, chemical, and biochemical reactions in the process of being compressed, the distribution of the coefficient of compressibility, the modulus of compression, and the index of compressibility was obviously discrete (from Fig.5 to Fig.7).

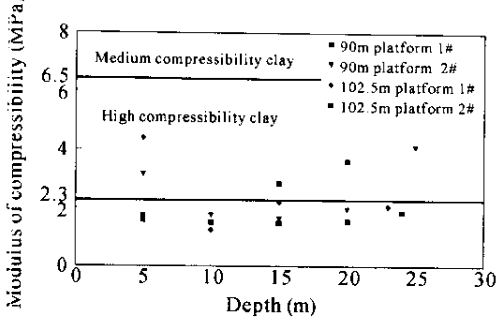

Fig.6 Distribution of modulus of compressibility

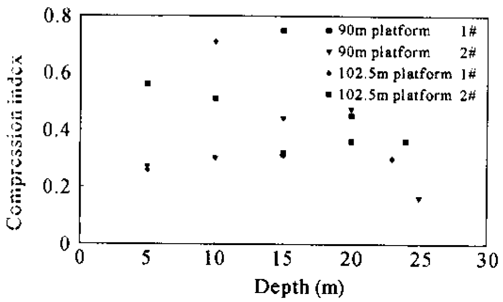

Fig.7 Distribution of compression index

7. Shear strength

Determination of the MSW's shear strength was difficult because of the variable ingredients of waste material, and the difficulty in testing (Hisham *et al*., 2000). Different methods, including laboratory, field tests, and back-analysis have been used. Laboratory tests have been performed using small-scale axial compression tests (Gabr and Valero, 1995); large-scale axial compression tests (Jessberger and Kockel, 1991); small-scale unconfined compression tests (Fang *et al*., 1997); small direct shear tests (Gabr and Valero, 1995); and large direct shear tests (Edincliler *et al*., 1996; Geosyntec, 1996). Field tests have been made using large direct shear tests (Houston *et al*., 1995); vane shear tests (Earth Technology, 1988); standard penetration tests (Earth Technology, 1988); and cone penetration tests (Oakley, 1990; Jessberger and Kockel, 1991). Back-analysis of the MSW's shear strength has also been studied (Chilton *et al*., 1994; Timothy *et al*., 2000).

(1) Direct shear test

The standard sample (30 cm^2 × 2 cm), including grain sizes no larger than 5 mm, were studied in strain control direct shear apparatus. The MSW Mohr envelope is shown in Fig.8. The cohesion varied from 6.4 kPa to 31.4 kPa, and the angle of internal friction from 40.4° to 49.6°. The results were slightly higher than results published by others, for example, Landva *et al*. (1990), Richardson *et al*. (1991), and Houston *et al*. (1995).

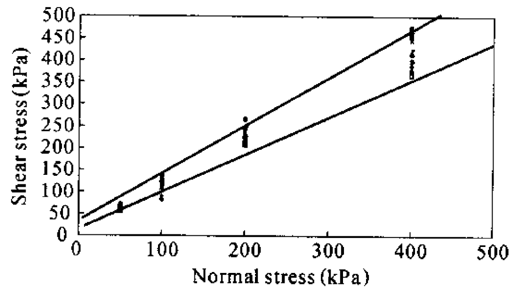

Fig.8 Shear strength envelope curve of the MSW

(2) UU test

The 12 samples (ϕ10 cm × 20 cm) were studied in strain control triaxial compression apparatus. The three-class loading mode was adopted, the first class confining pressure was 58.8 kPa, and the subsequent class confining pressure was more than the maximum shear stress caused by the preceding test. The loading rate was 1.2 mm/min. The relation of the primary stress and the axial deformation reflected strain hardening (Fig.9). The shear strength increased with increasing normal stress.

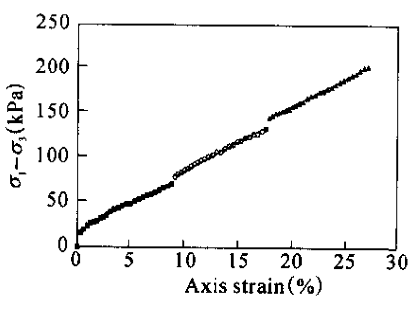

Fig.9 Typical stress-strain curves of UU test

Strength parameters C_u ranged from 0 kPa to 10.2 kPa, and φ_u from 10.5° to 19° (Table 2). In contrast to the direct shear test, triaxial test could yield convincing strength parameters because of the use of large-scale samples.

Table 2 Strength parameters of UU test for the MSW

Sample	C_u(kPa)	φ_u(°)	Sample	C_u(kPa)	φ_u(°)
1	8	13	7	7.5	12.3
2	10.2	12	8	8	14.7
3	5.3	18	9	9	12
4	7.4	17	10	0	10.5
5	1.4	6	11	0	7.5
6	0	18	12	6.8	19

(3) CU test

The sample size, loading mode, and loading rate of the CU test were the same as those of the UU test. The shear strength increased with increasing consolidation pressure (Fig. 10). Four groups of samples were taken from the +90 m platform with filling depth of 7 m, 10 m, 15 m and 20 m respectively corresponding to filling time of 2 a, 3.5 a, 4.5 a and 5.5 a. The stress-strain relation was obtained under the confining pressure of 58.5 kPa (Fig. 11). The shear strength increased with filling depth.

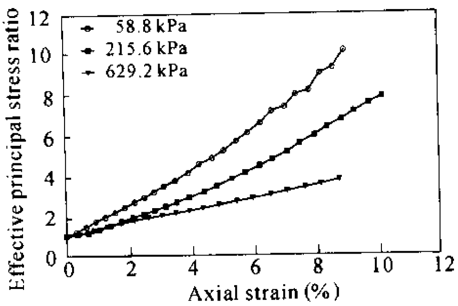

Fig.10 Stress-strain relation of certain sample by CU test

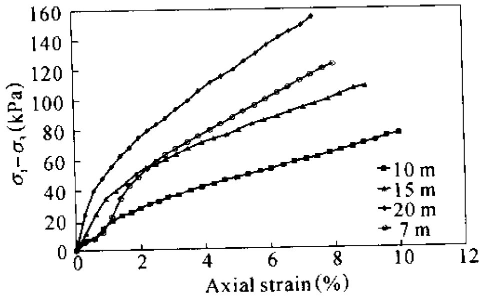

Fig.11 Stress-strain relations with different filling depth

Three samples at the same depth (+15 m) were respectively from +77.5 m, +90 m and +102.5 m platform corresponding to filling time of 7 a, 5 a, and 3 a. The sample with the longest filling time showed the highest strength (Fig. 12). So it was concluded that the filling time actively improved the shear strength. The Mohr-Coulomb effective stress and total stress strength parameters of the test are shown in Table 3.

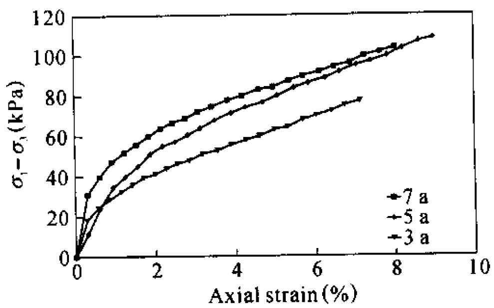

Fig.12 Stress-strain relations with different filling time

Table 3 Effective stress strength and total stress strength indexes of CU test for the MSW

Sample		13	14	15	16	17	18	19	21
Effective stress strength indexes	C′(kPa)	3.8	1.3	6.3	10.9	6.7	6.6	5.9	3.1
	φ(°)	38.7	36.9	36.9	34.5	41.4	25	32.1	36.9
Total stress strength indexes	C_u(kPa)	0	6.2	–	12.8	4.6	3.5	0	2.55
	φ_u(°)	25.2	21	–	21	29.5	21	21	24.2

IN-SITU TEST

1. Static cone penetration test (CPT)

There were four borings (J_1, J_2, J_3, J_4) on different platforms. They could not penetrate deeper than 17.8 m depth in J_1, 18 m in J_2, 22 m in J_3, and 22.3 m in J_4 respectively due to stone block. The distribution of the cone resistance (q_c) and the lateral friction resistance (f_s) was comparatively discrete, but the total tendency was that they increased with increasing filling depth (Table 4).

Table 4 Results of the CPT

Sample	Indexes	Boring platform(m)	Depth(m) 5	10	15	20
J_1	q_c(MPa)	+102.5	4	2.2	2.7	
	f_s(kPa)		45	53	68	
J_2	q_c(MPa)	+ 90	2.6	2	5.2	
	f_s(kPa)		57	55		
J_3	q_c(MPa)	+ 77.5	1.2	2.5	3.2	4.5
	f_s(kPa)		33	65		
J_4	q_c(MPa)	+ 77.5	1.7	2.6	2.3	2.8
	f_s(kPa)		35	80	70	

The specific penetration resistance P_s was calculated based on Chinese Foundation Treatment Manual (Table 5). It increased with depth, which was similar to the results of the laboratory tests (Wang, 1999).

2. Dynamic penetration test (DPT)

Six borings (Z_1, Z_2, Z_3, Z_4, Z_5 and Z_6) were located respectively on the +102.5 m, +90 m and +77.5 m platforms. The depth ranged from 17.2 m to 44.5 m. Because the borings were liable to collapse and the MSW contained many broken stones, SPT was adopted in the borings of the upper platform, and heavy DPT was used in those of the lower platform. The DPT results of Z_1, Z_4, Z_5 and Z_6 borings were almost similar to those of common soils. The blow count in the lower borings was more than that of the deeper ones (Table 6).

Table 5 Relation between P_s and shear strength of the MSW

Sample	J_1				J_2			J_3				J_4		
Depth(m)	5	10		15	5	10	15	5	7	10	15	5	10	15
P_s(MPa)	4.3	2.5		3.1	1.4	2.9	3.76	3	1.83	2.4	6.12	1.9	3.1	2.75
Calculated shear strength(kPa)	23.2 UU	33.3 89.4	UU CU	134.4 CU	20.1 UU	36.2 UU	72.6* CU	45.3 CU	60.9 CU	19.3 UU	20.5 UU	20.1* UU	36.2* UU	72.6 CU

* Calculated according to the test parameters

Table 6 Results of the dynamic penetration test

Z_1 Depth (m)	Z_1 Blow count	Z_2 Depth (m)	Z_2 Blow count	Z_3 Depth (m)	Z_3 Blow count	Z_4 Depth (m)	Z_4 Blow count	Z_5 Depth (m)	Z_5 Blow count	Z_6 Depth (m)	Z_6 Blow count
6	12(3)	3	73	5	7(3)	5	10(4)	5	10(4)	5	10(3)
11	10(3)	7	74	10	8(3)	10	8(3)	10	9(3)	10	11(4)
15	9(3)	10	92	13	10(3)	17	11(4)	15	13(5)	15	8(3)
20	13(4)	15	12(4)	20	15(5)			20	13(4)	20	10(3)
25	12(4)	21	13(5)					25	12(6)	27	15(4)
		25	17(6)					30	15(4)	*29	46(10)
								*35	18(10)	*31	32(10)
								*40	16(10)	*34	11(10)
								*43	25(10)	*35.5	19(10)
								*44	36(10)	*37	50(5)
								*45.5	50(5)	*40	50(5)

* by heavy DPT, others by SPT; 2 Penetration depth (cm), in the bracket behind the heavy dynamic penetration blow count; 3 Pre-penetration blow count, in the bracket behind the SPT blow count

CONCLUSIONS

MSW engineering properties relate to its ingredients, ratio of every ingredient, environmental conditions, filling depth, time, etc.

MSW inorganic matter content varies from 50% to 100%, plastics content ranges from 0 to 20%, and organic matter and impurities content ranges from 0 to 20%. As the filling depth and time increase, the relative contents of the inorganic matter and impurities increase but the organic matter contents gradually decrease.

The density of the MSW ranges from 8kN/m^3 to 16.8 kN/m^3; the average water content is about 30%; the specific gravity ranges from 1.92 to 2.62, which is smaller than that of common soil; the coefficient of permeability ranges from 2×10^{-4} cm/s to 4×10^{-3} cm/s.

The MSW has the characters of high compressibility; the coefficient of compressibility ranges from 0.48 MPa^{-1} to 2.25 MPa^{-1}, the modulus of compressibility ranges from 1.23 MPa to 4.4 MPa. The index of compressibility ranges from 0.26 to 0.56.

Generally, the shear strength of the MSW gradually increases with increase in the normal stress, filling depth, and time. Among total stress strength parameters of the UU test, C_u ranges from 0.0 kPa to 10.2 kPa and angle of internal friction φ_u ranges from 10.5° to 19.0°; effective stress strength parameters of the CU test, C' ranges from 1.3 kPa to 16.0 kPa, and φ' ranges from 25.0° to 41.4°; among total stress strength parameters of the CU test, C_u ranges from 0.0 kPa to 12.8 kPa, and φ_u from 21.0° to 29.5°.

According to the CPT, the cone resistance and the lateral friction resistance increase as the filling depth increases. The blow count in the lower part of the MSW is more than that in the deeper part, which can be concluded from the SPT.

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