Shear Strength Behavior of Soil-Sized Material Obtained from Landfill Mining, Waste-to-Energy Plants and C&D Processing Plants

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Abstract. The quantity of waste produced in Delhi is around 10,000 tons/day, and all the existing landfills are running out of their capacity. Due to the scarcity of available land, the focus is on reuse of waste. The bulk utilization / high-volume reuse of waste material is possible in geotechnical applications such as earthfills and embankments. For assessing the potential of a waste material, shear strength behavior has to be studied. In this experimental study, strength behavior of soil-sized material (less than 4.75mm) obtained from (a) landfill mining of aged waste (Mined MSW), (b) waste-to-energy plant (MSW Incineration Bottom Ash) and (c) C&D processing plant (C&D waste) has been evaluated. The shear strength behavior of these soil-like materials from MSW is compared with that of locally available soil, i.e., Badarpur sand and Delhi silt. Direct shear tests (DST) on dry samples of all the materials and DST (saturated) on Mined MSW, Delhi silt and triaxial tests on saturated samples of MSWI bottom ash, C&D waste and Badarpur sand were conducted. From the results, it was observed that all three materials exhibit effective angle of shearing resistance (ϕ’) in the range of 36º to 49º. The maximum value of shear strength was obtained for C&D waste (ϕ’ in the range of 45º to 49º) followed by MSWI bottom ash (ϕ’ in the range of 42º to 43º) and then by mined MSW (ϕ’ in the range of 36º to 42º).

Keywords: Mined MSW; MSW Incineration Bottom Ash; C&D Waste.

1 Introduction

1.1 Background

In the past few decades, booming industrialization, rapid urbanization and rampant growth of population has led to a significant increase in the generation of municipal solid waste (MSW) (Somani et al., 2018). In developing countries like India, local authorities are struggling to find a sustainable and effective solution to manage the overwhelming growth of MSW. This has resulted in open dumping of waste in the form of mounds of garbage in the periphery of most of the metropolitan cities. As per the recent reports around 55 million tons of waste is produced by India per annum

(Kumar et al., 2017). Delhi in particular generates around 10000 tons per day. At present in Delhi there are three dumpsites (Ghazipur, Bhalswa and Okhla) which have exhausted their capacities years back and running out of their capacities. Due to the scarcity of land available for dumping waste, several MSW incineration plants are being setup. This reduces the volume of the waste by 80-90 percent (Gupta et al., 2017). But the residues of these plants are sent back to the dumpsites. Recently construction and demolition (C&D) plants have been setup in Delhi with the aim of recycling of C&D waste. However the use of C&D waste is a matter of concern in terms of its quality and demand.

1.2 Objectives

The primary objective of the study is to assess the shear strength behavior and other characteristics of soil-like material (SLM) obtained from the mining of landfills (Mined MSW), residues of the incineration plants (MSWI bottom ash) and processed waste from C&D recycling plants (C&D waste) and assess their suitability for earthfills and embankments. Also the shear strength behavior and other characteristics of the materials are compared amongst themselves and with locally available material i.e. Badarpur sand and Delhi silt. SLM in the present study has been defined as the material having the particle size of less than 4.75mm.

1.3 Literature Review

Landfill mining is still an evolving subject and is being improved in terms of utility of mined materials (Gaintanarou et al., 2014).Numerous researchers have investigated the geotechnical characterization of mined MSW on different fraction (Hyun et al., 2011; Gabr and Valeo., 1995 and Naveen et al., 2014). However due to the heterogeneity of the waste, there is wide variation in the values of the shear strength reported. Research on geotechnical behavior of MSWI ash of particle size less than 12 mm was carried out (Zekkos et al., 2013 and Becquart et al., 2009) but for SLM very few studies are conducted on shear strength behavior. Tay and Goh (1991) carried out the triaxial CD test in Singapore on sand sized particles of MSWI ash. Cristelo et al., 2016 carried out research on C&D material from Portugese recycling plant to assess the shear strength behavior.

2 Materials and Methodology

2.1 Materials

The material used in the current study was collected from various solid waste management facilities located at Delhi. The general information about all these facilities is presented in Table 1.

Table 1: General information about the selected sites

Waste Type	Location	Remarks
Mined MSW	Waste dump, Delhi	Aged MSW
MSWI Bottom Ash	Waste-to-Energy plant, Delhi	-
C&D Waste	C&D plant, Delhi	Processed C&D waste

2.2 Methodology

Loss on ignition (LOI), Grain size distribution (GSD), Shear strength parameters were determined for the SLM obtained from all the sites. The standards adopted are listed in Table 2. Shear strength parameters in dry condition in all the samples were determined from direct shear test (DST). Shear strength parameters in saturated condition for mined MSW were determined from DST (saturated). Consolidated drained (CD) triaxial tests were carried out on samples of saturated MSWI bottom ash and C&D waste.

Table 2 : Standards adopted for tests

Property	Method	Standards
Organic Content	Loss on ignition	ASTM D 2974-14 and Zekkos et al., (2010)
Grain Size Distribution	Sieve analysis	IS2720(Part IV): 1985
Specific Gravity	Density bottle	IS2720(Part III): 1980
Shear Strength Parameters	Direct shear and triaxial test	IS2720(Part XIII): 1986 and IS2720(Part XII): 1986

3 Results and Discussions

3.1 Loss on Ignition

The possible end use of the waste materials depends on the organic content (Parrodi et al., 2017). LOI studies have been conducted by various researchers to estimate the percentage of organic material. LOI value of the samples are reported in LOI value ranges from 0-9 percent in all the materials studied. LOI above 5% indicates that organic content is higher than normally acceptable in earthworks.

Table 3: Loss on Ignition

Material	**Loss on Ignition (LOI) %**
Mined MSW	8.5-9
MSWI Bottom Ash	3-4
C&D Waste	2.5-2.8
Badarpur Sand	0.3-0.4
Delhi Silt	1-1.2

3.2 Grain Size Distribution

Figure 1 shows the grain size distribution (GSD) of all the tested materials. The coarsest material out of all the materials is C&D waste which is well graded. The fine content is less than 8 percent. After C&D waste, MSWI bottom ash is also coarse and well graded. Mined MSW has high content of fine fraction. Badarpur sand is medium coarse sand. Delhi silt is the finest of all the materials studied in this investigation.

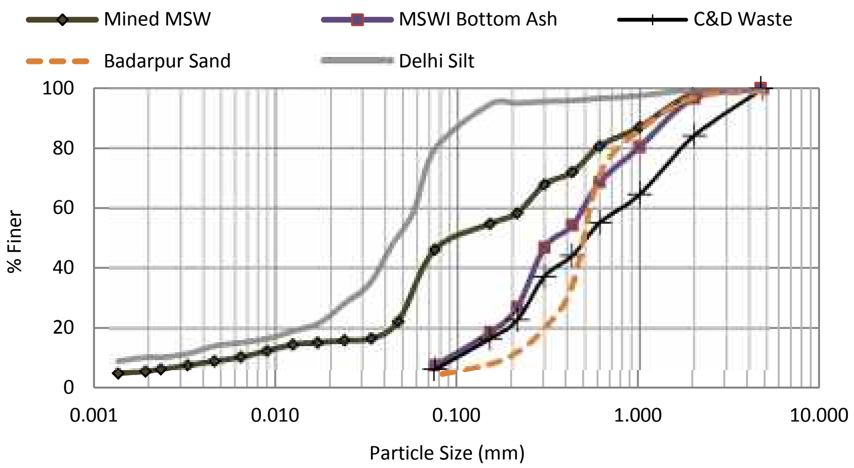

Figure 1: GSD curve

3.3 Specific Gravity

The range of specific gravity of all the five samples is reported in Table 4. The sample with high organic content is found to have low specific gravity and vice-versa. The effect of organic content on the specific gravity is well reported in the literature (Sen et al., 2014). Mined MSW has the lowest specific gravity due to the high organic content.

Table 4: Specific Gravity

Material	**Specific Gravity**
Mined MSW	2.38-2.42
MSWI Bottom Ash	2.44-2.48
C&D Waste	2.55-2.60
Badarpur Sand	2.67-2.69
Delhi Silt	2.65-2.66

3.4 Shear Strength

Mined MSW: DST (dry) and DST (saturated) were performed on mined MSW in order to investigate the shear strength parameters (c' and ϕ'). The sample was prepared by static compaction to get the dense sample. In contrast to the values reported in literature (Naveen et al., 2014), the values are high in dry condition and due to the presence of high fine content, the saturated strength of the sample is significantly lower than the dry strength. The results are summarized in Table 5.The stress-displacement and volume change displacement graph for both dry and saturated states are shown in Figure 2.

Table 5: Shear Strength Behavior of Mined MSW

Test	c' (kPa)	Φ' (degree)	Failure Strain (%) (Range)
DST (Dense, Dry)	0	42.9	3.3-6.6
DST (Dense, Sat.)	0	36.1	4.0-8.0

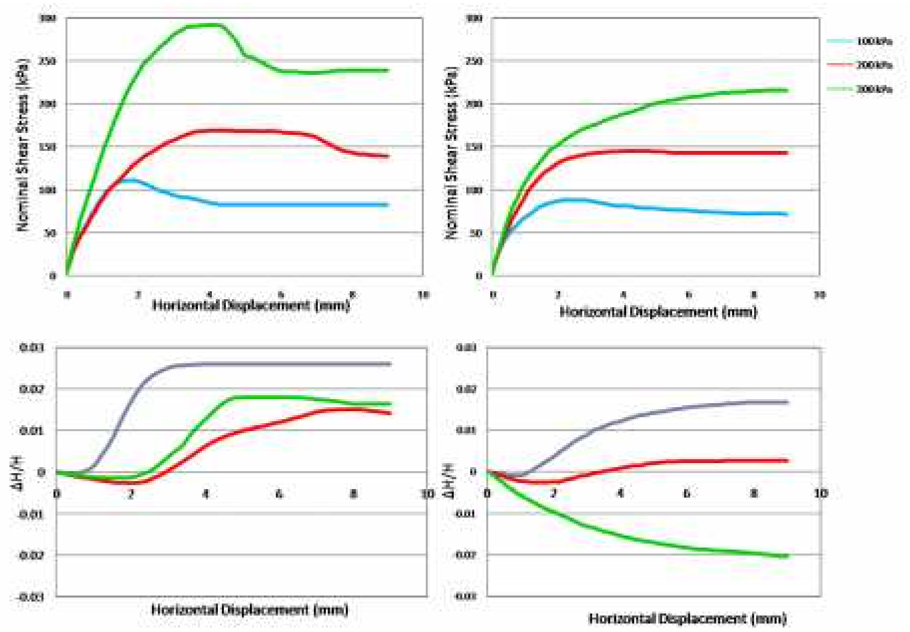

Figure 2: Stress-displacement and volume change-displacement graph of mined MSW [DST dry (left) and DST saturated (right)]

MSWI Bottom Ash: DST (dry) and triaxial (CD) test (saturated) were performed on the material in order to investigate the shear strength parameters (c' and ϕ'). The dense sample was prepared by giving 30 blows in 5 layers using rubber tamping rod. The results obtained in the study are in accordance with the values reported in literature (Zekkos et al., 2013) The material being coarser and freely draining have almost same angle of shearing resistance in dry and saturated condition. The results are summarized in.Table 6 The stress-displacement and volume change displacement graph for both dry and saturated states are shown in Figure 3

Table 6: Shear Strength Behavior of MSWI Bottom Ash

Test	c' (kPa)	Φ' (degree)	Failure Strain (%) (Range)
DST (Dense Dry)	0	43.9	7.5-10.0
Triaxial CD test (Dense Sat.)	0	43.3	7.4-10.9

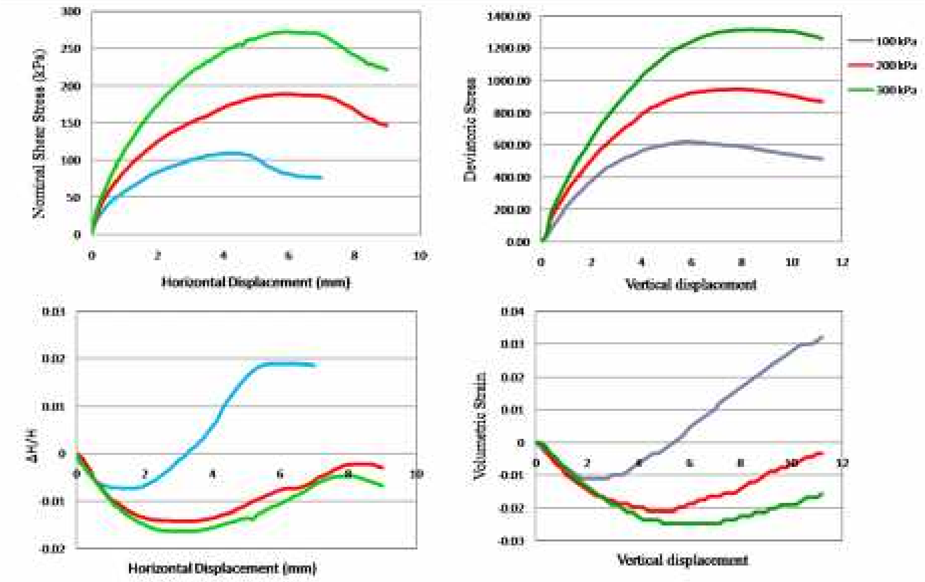

Figure 3: Stress-displacement and volume change-displacement graph of MSWI bottom ash [DST dry (left) and Triaxial (CD) test saturated (right)]

C&D Waste: DST (dry) and triaxial (CD) test (saturated) were performed on the material in order to investigate the shear strength parameters (c' and ϕ'). The dense sample was prepared by giving 30 blows in 5 layers using rubber tamping rod. In contrast to the values reported in literature (Cristelo et al., 2016) the values are high for both dry and saturated condition, The material being coarser and freely draining have high angle of shearing resistance in saturated condition also. The results are summarized in Table 7. The stress-displacement and volume change displacement graph for both dry and saturated states are shown in Figure 4.

Table 7: Shear Strength Behavior of C&D Waste

Test	c' (kPa)	Φ' (degree)	Failure Strain (%) (Range)
DST (Dense Dry)	0	49.4	4.5-8.0
Triaxial CD test (Dense Sat.)	0	45.6	5.2-7.4

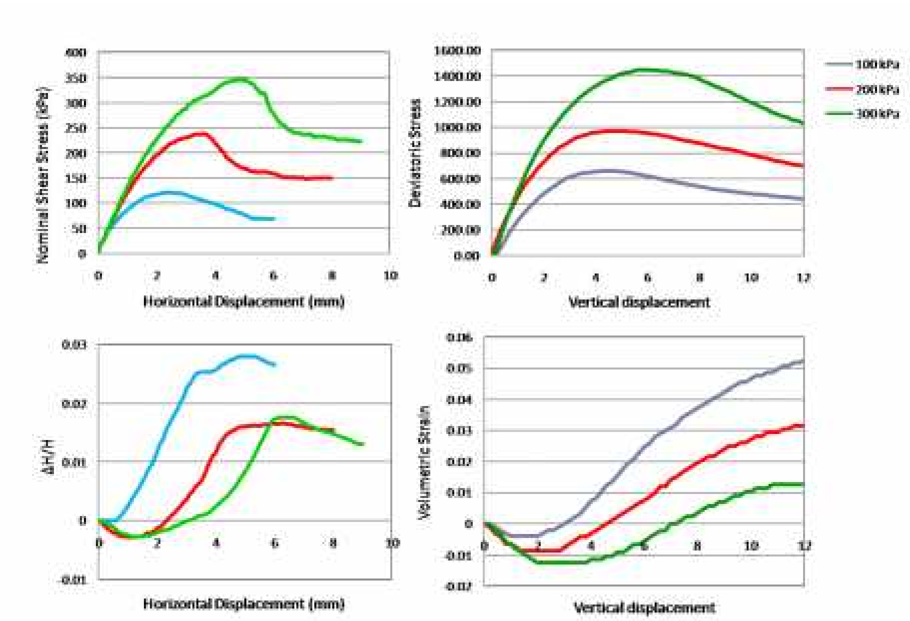

Figure 4: Stress-displacement and volume change-displacement graph of C&D Waste [DST dry (left) and Triaxial (CD) test saturated (right)]

Badarpur Sand: DST (dry) and triaxial (CD) test (saturated) were performed on the material in order to investigate the shear strength parameters (c' and ϕ'). The dense sample was prepared by giving 30 blows in 5 layers using rubber tamping rod The material being coarser and freely draining have almost same angle of shearing resistance in dry and saturated condition also. The results are summarized in Table 8. The stress-displacement and volume change displacement graph for both dry and saturated states are shown in Figure 5.

Table 8: Shear Strength Behavior of Badarpur Sand

Test	c' (kPa)	Φ' (degree)	Failure Strain (%) (Range)
DST (Dense Dry)	0	43.1	3.3-6.0
Triaxial CD test (Dense Sat.)	0	42.2	2.5-5.0

Delhi Silt: DST (dry) and DST (saturated) were performed on the material in order to investigate the shear strength parameters (c' and ϕ'). The sample was prepared by static compaction to get the dense sample. The results are summarized in Table 9. The stress-displacement and volume change displacement graph for both dry and saturated state is shown in Figure 6.

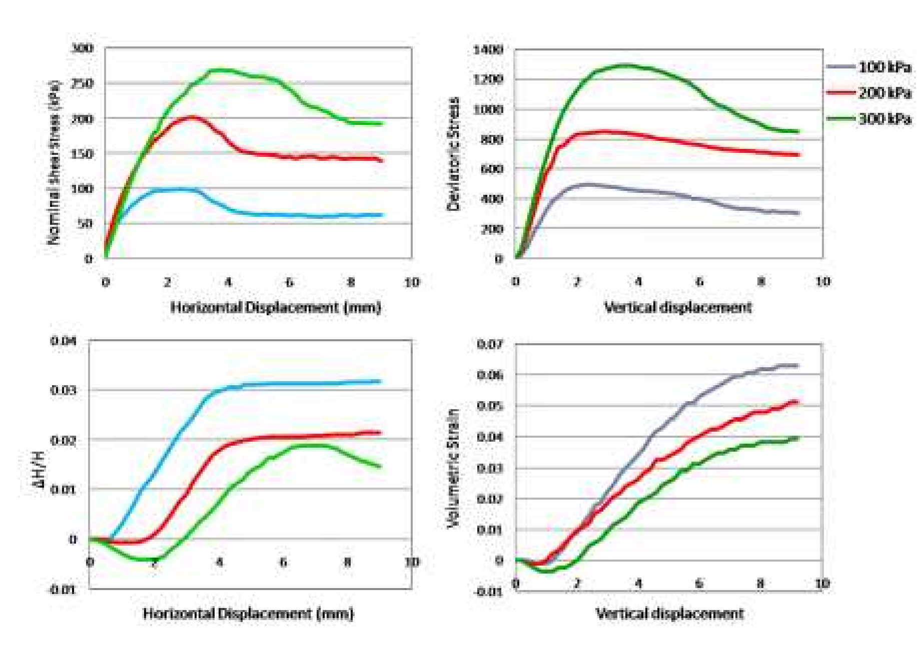

Figure 5: Stress-displacement and volume change-displacement graph of Badarpur Sand [DST dry (left) and Triaxial (CD) test saturated (right)]

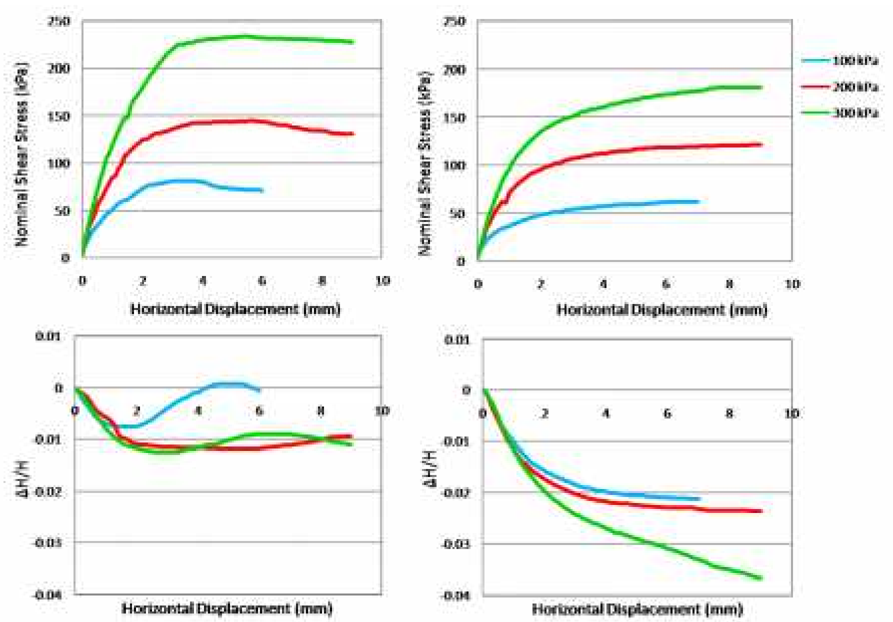

Figure 6: Stress-displacement and volume change-displacement graph of Delhi Silt [DST dry (left) and DST saturated (right)]

Table 9: Shear Strength Behavior of Delhi Silt

Test	c' (kPa)	Φ' (degree)	Failure Strain (%) (Range)
DST (Dense Dry)	0	35.9	4.1-6.7
DST (Dense, Sat.)	0	32.0	10-12

4 Conclusions

In this experimental study, strength behavior of soil-sized material (less than 4.75mm) obtained from (a) landfill mining of aged waste (mined MSW), (b) waste-to-energy plant (MSW incineration bottom ash) and (c) C&D processing plant (C&D waste) has been evaluated to assess if they can be used in earth fills, embankments. The shear strength behavior of these soil-like materials from MSW is compared with that of locally available soil, i.e., Badarpur sand and Delhi silt. The following conclusions can be drawn based on the results:

a) All the three materials exhibit effective angle of shearing resistance (ϕ') in the range of 36º to 49º. The maximum value of shear strength is obtained for C&D waste (ϕ' in the range of 45º to 49º) followed by MSWI bottom ash (ϕ' in the range of 42º to 43º) and then by mined MSW (ϕ' in the range of 36º to 42º).

b) C&D waste exhibits effective angle of shearing resistance (ϕ') high in comparison to the locally available material i.e. Badarpur sand (ϕ' in the range of 41º to 43º) and Delhi silt (ϕ' in the range of 32º to 36º). MSWI bottom ash exhibits effective angle of shearing resistance (ϕ') almost same as that of Badarpur sand and higher than that of Delhi silt. Mined MSW exhibits effective angle of shearing resistance (ϕ') lower than that of Badarpur sand and higher than that of Delhi silt.

c) Mined MSW has high angle of shearing resistance in dry state but this reduces upon saturation. As the organic content is more than 5 percent, mined MSW cannot be used directly for embankments or earthfills since degradation of organic material will lead to excessive settlements. The use of this material can be undertaken in landfills as daily, intermediate or final cover

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