Large Box Direct Shear Test of Municipal Solid Waste: A Case Study

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Abstract. Improper disposal of Municipal Solid Waste in landfill sites in the form of huge dump slopes led to various slope instability problems in metro cities. The stability of such slopes is largely governed by the shear strength parameters of the slope. In the present study the shear strength parameters of a Municipal Solid Waste Disposal Site were determined by conducting Consolidated Undrained Direct Shear Test with a shear box size of 300 x 300mm. Effective Shear Strength parameters were evaluated considering peak shear stresses corresponding to 25mm shear displacement. Apparent Cohesion, c', of 7.4 to 14.5 KPa with effective friction angle, φ', of 27.5 to 30.10° were evaluated from the Direct Shear Results. The results of these tests will lead to a better understanding of shear strength properties of Municipal Solid Waste material and ensuring safe disposal of the material in the form of sustainable dump slopes.

Keywords: MSW; DST; Landfill; Shear Strength.

1 Introduction

Improper management and uncontrollable disposal of Municipal Solid Waste (MSW) at Large Landfill sites in India pose a huge risk in environment degradation and has led to various slope stability problems. As per Energy Alternatives India, the MSW generation is estimated to increase at the rate of 5% per annum and per capita waste generation is estimated to increase at 1.33% per annum. The increased waste generation and improper dumping of waste at landfill sites will lead to landfill slope failures causing loss of life and degradation of surrounding environment. The proper knowledge of shear strength properties of waste material is vital for safe and sustainable landfill design. The shear strength of waste governs the stable profile of landfill slope and hence dictates the overall landfill capacity (Sharma & Reddy 2004).

2 Background

Numerous studies have been carried out to ascertain shear properties of MSW (Landva & Clark 1990, Fassett et al. 1994, Gabr & Valero 1995, Hossain 2002, Sharma & Reddy 2004, Dixon et al. 2005, Gabr et al. 2007). The available literature shows a clear distinction in behavior of MSW with soil (Canizal et. at. 2011). Models derived from soils usually, The Mohr-Coulomb failure criterion, defined by cohesion (c) and friction angle (φ) can be used to study the behavior of MSW in landfill stability analysis (Landva & Clark 1990).

The overall strength characteristics of MSW can be summarized as follows (Bray et al. 2009, Stark et al. 2009):

- There is an increase in shear strength of MSW with increase in confining pressure in a non-linear way;
- The fibrous material present in the waste gives rise to an equivalent cohesion at very low confining pressure;
- Presence of plastic bags, paper and cardboard reduces friction angle (φ) of MSW (Bareither et al. 2012);
- An increasing fraction of soil-like, gravel and inert waste increases the friction angle (φ) of MSW (Bareither et al. 2012);
- There is no change in strength of MSW due to variation of density of MSW;
- Age and degradation of MSW plays an important role in the shear strength, there is an increase in friction angle and decrease in cohesion with the increment of age of waste material;
- There is a noticeable hardening observed in the shear stress-strain curve and a horizontal asymptotic level is generally not obtained even with large deformations (Jessberger et al. 1993, Grisolia et al. 1995, Eid, 2000). Hence it is important to describe a certain level of deformation at which it is assumed that the failure situation has been reached.

As per available literature, about 48% researchers have used laboratory Direct Shear Test to estimate the shear strength properties of MSW (Stark et al. 2009). Direct Shear Test is one of the standard tests employed for the estimation of shear strength properties of MSW. Advantages of Direct Shear Test over alternative test methods are well documented (Saada & Townsend 1981, Takada 1993, Terzaghi, Peck and Mesri, 1996). Some documented aspects of direct shear test are listed as under:

- Samples with large particle sizes can be tested with relative ease;
- The sample can be made to shear in a predefined plane;
- Consolidation is relatively one-dimensional (K_o-consolidation);
- Preparation of sample and test conditions influence test results;
- For appropriate sample dimension, the shear deformation is generally plane strain and occurs by simple shear;
- The test operation is relatively simple and easy;

However, Changes in shear surface area during shearing stage and uncertainty in interpretation of results due to non-uniform stress-strain behavior across the shear surface are the major disadvantage of Direct Shear Test.

3 Methodology

Consolidated Undrained Direct Shear Tests were conducted in accordance with IS: 2720 (Part-13). Tests were conducted on MSW obtained from four different location of a landfill site. The first two specimens were tested under imposed normal stresses ranging from 50kPa to 200kPa, while the last two specimens were tested under imposed normal stresses ranging from 100kPa to 400kPa. The main objective of these tests was to study the behavior of shear strength under different imposed normal stresses.

4 Apparatus and Sample Preparation

The direct shear test was carried out using a large-box direct shear apparatus having box size of 300 x 300mm and depth 200mm. The DST machine developed in-house by Aimil is capable of strain controlled semi-automatic load application and real-time logging of load and displacements in both directions. All instrumentation data was displayed digitally and output were interfaced graphically with a personal computer during testing. A constant shearing rate of 0.6 mm/min was adopted for shearing. Figure-1 shows the Aimil direct shear test apparatus used to carry out these tests.

Fig. 1. Large-box Direct Shear Test Apparatus, Aimil make

Landfill MSW samples were collected from four different pit locations. Samples were packed and transported to the testing facility in gunny bags of 80kg capacity each. Figure-2 shows the sample preparation and segregation process. The composition of collected sample is shown in Table-1. The samples were air dried and properly segregated. Particle size greater than 50 mm diameter including inert wastes such as glass pieces, plastic bottles, metal parts and other organic biodegradable wastes such as garden wastes were removed before testing the specimen.

Table 1. Composition of Collected Sample

Category	Composition (% by dry mass)			
	Pit-02	**Pit-09**	**Pit-14**	**Pit-04**
Biodegradables	42.8	43.1	40.6	45.2
Paper	9.5	9.9	9.6	7.9
Inert Waste	28.2	21.3	27.3	28.6
Others (Residual Fines)	19.5	25.7	22.5	18.3

Moisture-density relation obtained from standard proctor test on samples Pit-02, Pit-09 and Pit-14 yielded a maximum dry density of 0.735gm/cc at 57.82% optimum moisture content. A maximum dry density of 0.820gm/cc at 52.43% optimum moisture content was obtained for sample Pit-04. The organic content of the samples ranged between 6.2% and 9.1%. The samples were compacted using a tamping rod in three different layers in the shear box before consolidation process.

Fig. 2. Removal of inert waste and organic biodegradable waste from air dried samples

The typical arrangement of sample and application normal and shear load on the sample is shown in a schematic diagram in figure 3.

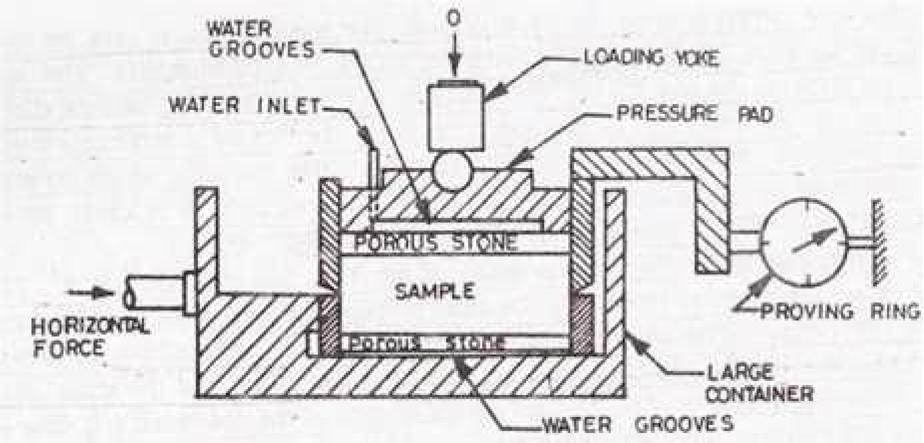

Fig. 3. Schematic Arrangement of Sample in a Typical DST Setup

5 Result & Discussion

The shear stresses reported were calculated by considering the shear load corresponding to 25mm shear displacement and initial maximum shear area without applying area correction. The summary of tested samples subjected to different Normal Stresses is tabulated in table no. 2.

Table 2. Summary of Tested Samples

Sample ID	Normal Stress, kPa		Shearing Rate, mm/min
	During Consolidation	During Shearing	
Pit 02 & Pit 09	50	50	0.6
	100	100	
	200	200	
Pit 14 & Pit 04	100	100	
	200	200	
	400	400	

The unit weight of the samples before and after consolidation stage was calculated, with increase in the normal stress applied during consolidation stage there is an increase in the unit weight of the samples tabulated in Table 3.

Table 3. Unit Weight of MSW samples pre and post consolidation stage

Sample ID	**Compacted Total Unit weight before Consolidation (kN/m^3)**	**Applied vertical stress (kPa)**	**Total unit weight after Consolidation (kN/m^3)**
Pit 02	11.6	50	13.3
	11.6	100	14.3
	11.6	200	15.4
Pit 09	11.6	50	13.3
	11.6	100	14.8
	11.6	200	16.0
Pit 14	11.6	100	14.5
	11.6	200	15.7
	11.6	400	16.2
Pit 04	12.5	100	13.3
	12.5	200	13.5
	12.5	400	14.4

Figure 4 shows the individual trends of Shear Stress vs. horizontal shear strain at different normal stresses for all the tests reported in this study.

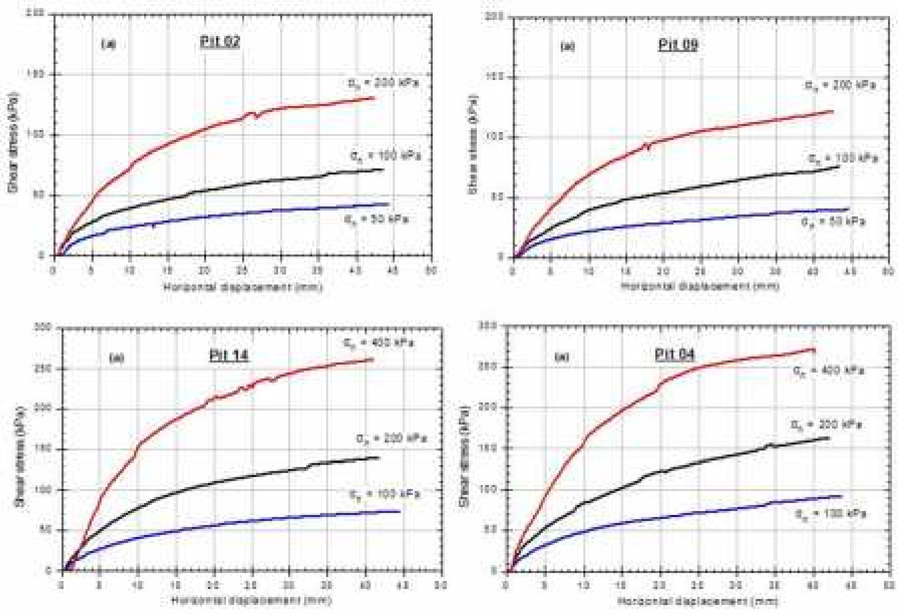

Fig. 4. Shear Stress-Horizontal Displacement results for the tested MSW specimens

As evident from figure 4 the MSW samples undergo strain hardening, as there is an increase in shear stress with the increase in horizontal displacement. Accordingly the peak shear strength is interpreted specifically at 25mm shear displacement from the graphs of shear stress vs. shear displacements. The peak shear strength of MSW is plotted as a function of normal stress and the shear strength parameters obtained are presneted in table 4. A linear mohr columb trend has been fitted in each data set to obtain the values of apparent cohesion, c', and effective friction angle, φ', as shown in figure 5.

Table 4. Summary of Results of Direct Shear Test

Sample ID	**Applied vertical stress (kPa)**	**Peak Shear Stress at 25 mm shear displacement (kPa)**	**Apparent cohesion, c´ (kPa)**	**Effective friction angle, Φ´ (°)**
Pit 02	50	36.00	8.3	27.5
	100	60.30		
	200	116.60		
Pit 09	50	34.10	8.8	25.6
	100	60.20		
	200	106.00		
Pit 14	100	62.70	7.4	28.8
	200	118.40		
	400	225.00		
Pit 04	100	69.50	14.5	30.1
	200	127.50		
	400	247.00		

The results obtained from the tested samples indicate that the values of Apparent Cohesion, c', ranges from 7.4 to 14.5 KPa with effective friction angle, φ', of 27.5° to 30.10°. The average value of apparent cohesion, c', is 9.75 kPa with average effective friction angle, φ' as 28°. The results obtained show close conformity with Direct Shear Test results reported by Gabr and Valero, 1995 on MSW with resulting shear strength properties ranging from 0-28 kPa and 20-39°. Specimen No. Pit-04 shows relatively high value of apparent cohesion, this may be due to presence of high organic matter which adds to the cohesion value.

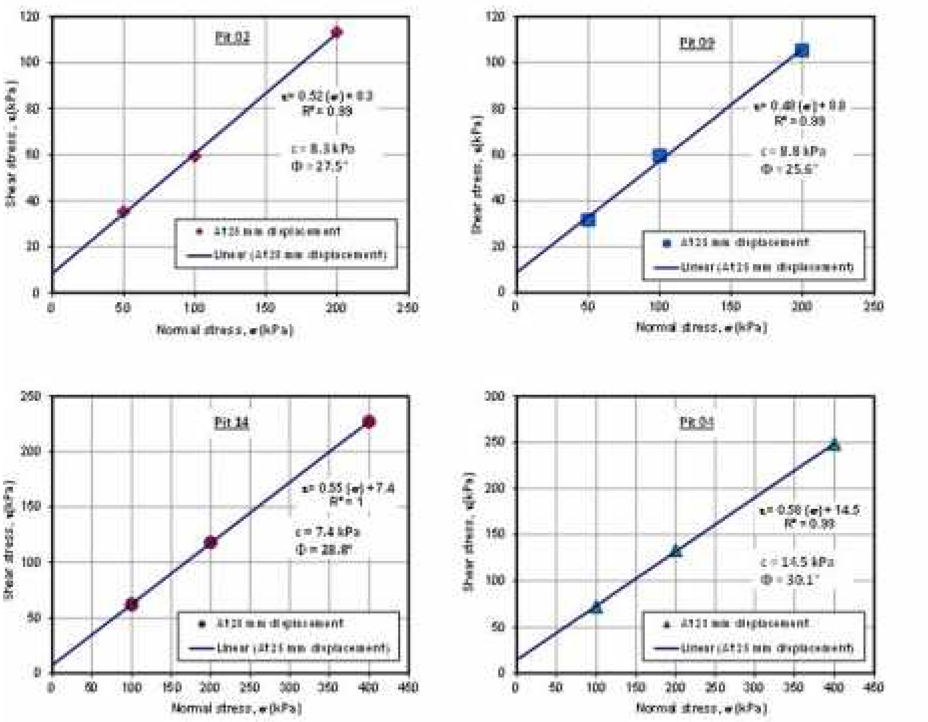

Fig. 5. Shear Strength parameters of Tested Samples

6 Conclusion

Apparent Cohesion, c', of 7.4 to 14.5 KPa with effective friction angle, φ', of 27.5 to 30.10° were evaluated from the Direct Shear Results. Based on the presented study, it can be suggested that carrying out the large direct shear tests on MSW samples provides critical engineering parameters for safe design and construction of landfill slopes.

The results of these tests will lead to a better understanding of shear strength properties of Municipal Solid Waste material and ensuring safe disposal of the material in the form of sustainable dump slopes.

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