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Research Article

Experimental Study of the Consolidation Characteristics of Saturated and Unsaturated Municipal Solid Waste (MSW) Using Large Scale Consolidometer

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Abstract

Municipal Solid Waste is a heterogeneous mixture of various materials such as food, glass, soil, ash, plastic, etc. Since there are no generally accepted sampling and testing procedures for waste materials, principles of soil mechanics. A good understanding of the properties of unsaturated Municipal solid waste is required for the design of the underground pipelines. Settlement prediction is an important issue to guarantee any post-closure structures on landfills. The present study is an attempt to determine the consolidation characteristics of saturated and unsaturated MSW from the Pirana landfill site, Ahmedabad (India) using a large size Consolidometer having an aspect ratio of 1:0.635. At present five tests were conducted on saturated municipal solid waste for 100% saturation and five on unsaturated MSW keeping a degree of saturation=50% at different water contents. The tests were carried out at the pressure of 20kpa, 40kpa, 80kpa, 160kpa, and 320kpa respectively. The consolidation settlement resulted in both types of waste being compared. It was concluded that the saturated MSW compacted on the dry side of the optimum has less settlement compared to the MSW compacted on the wet side of the optimum while the time taken for the unsaturated MSW was slightly higher as compared to that of the saturated MSW.

Keywords: Municipal Solid Waste, Consolidation, Unsaturated, Compressibility

Abbreviations

MSW: Municipal Solid waste
AMC: Ahmedabad Municipal Corporation
OMC: Optimum Moisture Content
MDD: Maximum Dry Density
G: Specific Gravity
W: Water Content
e: Void Ratio
n: Porosity
C: Cohesion
Φ: Angle of Internal Fraction
a_v: Coefficient of Compressibility

C_c: compaction Index

C_v: coefficient of consolidation

Introduction

Although in recent years, recycling efforts were increased and new techniques were adopted, land filling is still considered to be the most common MSW management strategy since it is the simplest and most economically available today. Problems with sampling under non-hygienic conditions and the need for large-scale samples lead to difficulties in laboratory testing. MSW is also called problematic due to low shear strength, high amount of moisture content, and compressibility. Although the use of conventional small-scale devices to investigate the physical and engineering properties of MSW is a common practice (Landva and Clark 1990; Grisolia et al. 1991; Gabr and Valero 1995; Powrie et al. 1998), unconventional large-scale devices have usually been preferred to investigate the coefficient of permeability (Chen and Chynoweth 1995), mechanical properties (Grisolia et al. 1991; Jessberger and Kockel1995; Kavazanjian et al. 1999; Landva et al. 2000; Hudsonet al. 2004), or settlement characteristics of MSW (Chenet al. 1977; Wall and Zeiss 1995). Unsaturated MSW soil is a three-phase soil skeleton, Pore liquid and pore gas are more complex than Saturated MSW and the uniform specimen is difficult to reach. The compressibility of MSW is commonly estimated using the theory of one-dimensional consolidation. Compression of MSW would result in the reduction of its void ratio (e) and porosity (n).This will affect both the density and coefficient of permeability values of MSW. The size of the test apparatus could be a factor affecting the results of laboratory studies. MSW usually has higher water content, void ratio, and organic content ranging from 50 to 80%.The voids also include gas which is generated during the decomposition of the organic part of MSW. The objective of the present study is to determine the consolidation characteristics on large scale Consolidometer of diameter(254mm) and height (400mm) having an aspect ratio of 1:0.635 of Municipal Solid Waste collected from the landfill site called Pirana, India.

Materials and Methods

Municipal Solid Waste Samples

The municipal Solid Waste samples (MSW) were collected from the Pirana site located in Ahmedabad city in India. Ahmedabad is the 7th largest city in India and the largest city in Gujarat. The city produces 4000 tons of waste daily and the waste is disposed of in Piranal and fills. These landfills contain a very large amount of waste and are composed of 70-80% or more of the soil and should be used as landfills. The waste collected for the research purpose is about 10-15 years old. The entire Pirana site was managed by Ahmedabad Municipal Corporation (AMC). They face many problems with landfill stability against heavy rains and methane production from landfills, and landfills often become fires due to methane production. Since the landfill is exposed above the water table, unsaturated soil mechanics determine the stability of the landfill, and ultimately the suction of household waste is very important. The Pirana landfill has reached a height of about 22 meters and has recently slipped off due to heavy rains in 2017. Solid municipal waste is disposed of at Pirana sites, which cover an area of 84 hectares. The current waste generation rate is 2400 TPD. 400 TPD of this waste will be composted and the rest will be landfilled at Pirana sites.

Figure 1: Piran.la landfill Site, Ahmedabad, India.

Test Equipment

The size of the test specimen can influence the results obtained from a consolidation test. Ideally, the specimen should be as large as possible, so that it can be representative. Large specimens are less susceptible to disturbance than small ones, and the greater the specimen height the better the relative accuracy of settlement readings. To conduct a more reliable experiment with representative MSW samples, a large-scale Consolidometer has been constructed in Fig. 2.

The large sizeoedometer cell has an inner diameter of 254 mm, a height of 450 mm, and a thickness of 8 mm. The cell is set on a removable 300 mm square base plate. The base plate of the apparatus has a circular hole in the center of 38mm for drainage from the bottom of the specimen, as well as circular holes at three radial distances of 120° each with r/4, r/2, and 3r/4 correspondingly of 25mm. The valves are installed in the bottom hole to help manage drainage. In addition, on two opposing surfaces of the cell, there are three circular holes of 6mm (Quarter BSP) in the vertical curvature surface of the wall at regular equal distances from the bottom of the plate. To prevent particles from the specimen from clogging the perforations, use a circular porous plate made of acrylic with a diameter of 25mm or 38mm. A porous circular plate made of acrylic material with a thickness of 6 mm is used to drain water from the specimen's top surface. Holes in the upper porous plate are about 3- 4 mm in diameter and occupy about 45-50 percent of the surface. To avoid direct contact between the porous circular plate and the cell sidewall, a minor tolerance is assumed between the porous circular plate and the cell wall. At the top and bottom of the specimen, circular man filter paper with a diameter of 254 mm is used to protect the hole on the plate from tiny particles that may enter and block it.

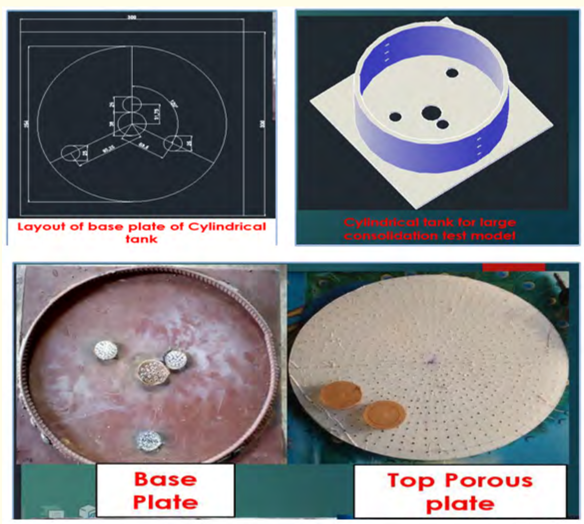

Figure 2: Layout for large scale Consolidometer.

The index properties of procured Municipal Solid Waste are discussed in table 1.

Sample Preparation for Saturated MSW

The Municipal Solid Waste used in this test was acquired from the Pirana landfill site, Ahmedabad. For the saturated municipal solid waste, the tests were conducted at 100% degree of saturation by taking variations in water content such as (-4%OMC, -2%OMC, OMC, +2%OMC, and +4%OMC) by calculating the corresponding dry densities. The sample after being prepared was transferred into the oedometer to a height of 400mm after the cell body had been lightly coated with a thin layer of silicon grease to minimize side friction. Sample filled into the cylindrical tank up to predetermine height and it is shown in Fig 3. Care should be taken that no air voids remain present in the sample.

S. No	Description	Indian Standard	Symbol	Results
1.	Specific Gravity	IS:2720-3	G	2.3
2.	Grain Size Distribution	IS:2720-4	C_u, C_c	$C_{u-5.68}$ $C_{c-1.21}$
3.	Soil type	IS:1948	SW	Well Graded Sand
4.	Standard Procter Test	IS:2720-7	OMC MDD	19.5%, 15.5kN/m^3
5.	Direct Shear Test	IS:2720-13	C, φ	C-4.54KN/m^2 Φ-38.65

Table 1: Engineering Properties of MSW.

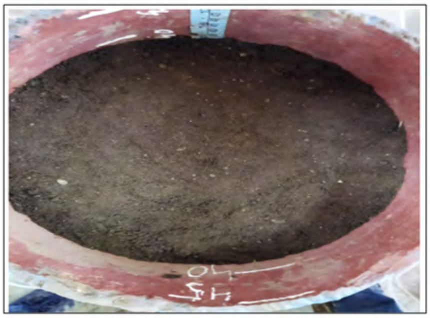

Figure 3: Preparation of sample for saturated MSW.

Sample Preparation for Unsaturated MSW

The Municipal Solid Waste used in this test was acquired from the Pirana landfill site, Ahmedabad. For the unsaturated municipal solid waste, the tests were conducted at 50% degree of saturation by taking variations in water content such as (-4%OMC, -2%OMC, OMC, +2%OMC, and +4%OMC) by calculating the corresponding dry densities. The samples were prepared in a bucket of 15 litter's capacity by applying the vacuum pump of the capacity of 0.25hp shown in Fig 4. After the preparation of the sample same procedure follows as indicated in the saturated sample. Care should be taken that no air voids remain present in the sample.

Figure 4: Preparation of sample for Unsaturated MSW.

$$S_r = \frac{m}{\frac{\gamma_m}{\gamma_d} - \frac{1}{G_s}}$$

Where,

S_r = Degree of saturation

G_s = Specific Gravity of sample

γ_d = Unit weight of dry soil

m = Water Content (%)

Experimental Procedure

To carry out the compression tests on Municipal Solid Waste (MSW), the compressive load is applied by a mechanical jack of capacity 6 tons. This mechanical jack is fixed at the inner side of the top section channel at an equal distance from both extreme ends of the loading frame and this mechanism is shown in Fig 5. In the compression test, a proving ring of the capacity of 5 tons is used to measure compressive load. The proving ring is attached to a steel rod so that there is a complete transfer of axial compressive load at the center of the column. The proving ring is placed above the test soil and the mechanical jack just above it within the frame. To measure the settlement of soil, two dial gauges having a sensitivity of 0.001 mm were used. The Municipal Solid Waste used in this test was acquired from the Pirana landfill site, Ahmedabad. For the unsaturated municipal solid waste, the tests were conducted at 50% degree of saturation and for saturated MSW taking 100% degree of saturation by taking variations in water content such as (-4%OMC, -2%OMC, OMC, +2%, OMC, and +4%OMC) by calculation the corresponding dry densities. The samples were prepared in a bucket of 15 liters capacity by applying the vacuum pump of capacity 0.25hp.

Figure 5: Experimental Procedure for testing for saturated and Unsaturated MSW.

Results and Discussion

Comparison of Compression ratio For Saturated and Unsaturated MSW

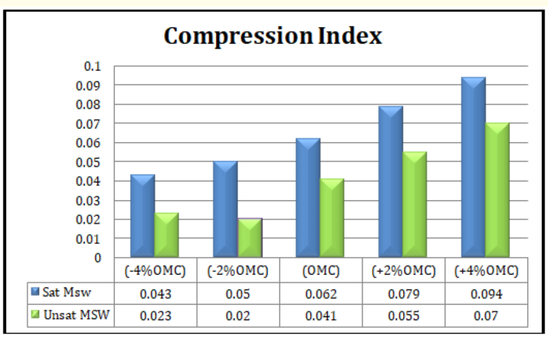

Figure 6: Comparison of Compression Index for saturated and Unsaturated MSW.

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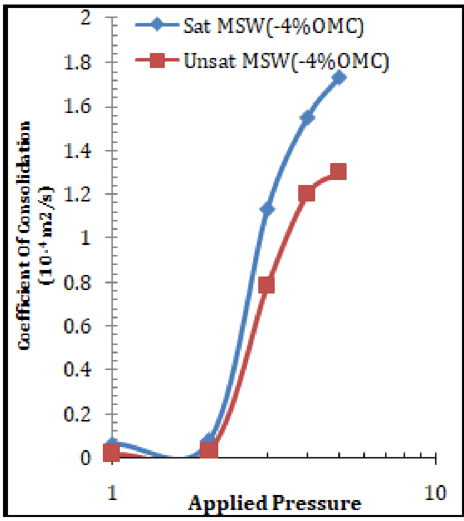
The consolidation test is performed on the MSW sample using IS *2720 – part 15 (1965)* at variable moisture content. The values of compression index for the unsaturated MSW are lower compared to saturated MSW because the partially saturated soils have a continuous path in voids but not for the water phase where the soil approaches the minimum value of relative density as a result of increasing the water content the compression ratio increase at MSW at higher water content is more compressible compared to the lower degree of saturation.

Comparison of coefficient of consolidation for Saturated and Unsaturated MSW



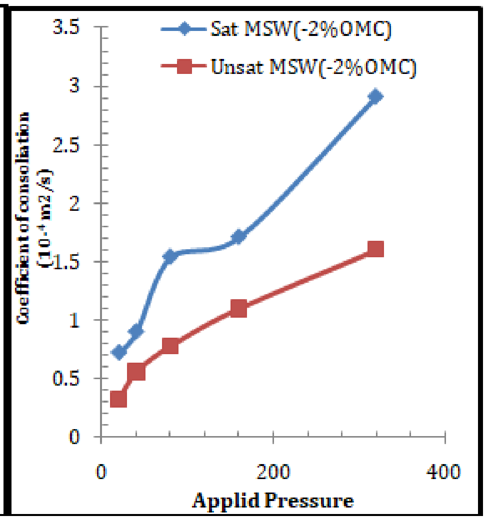
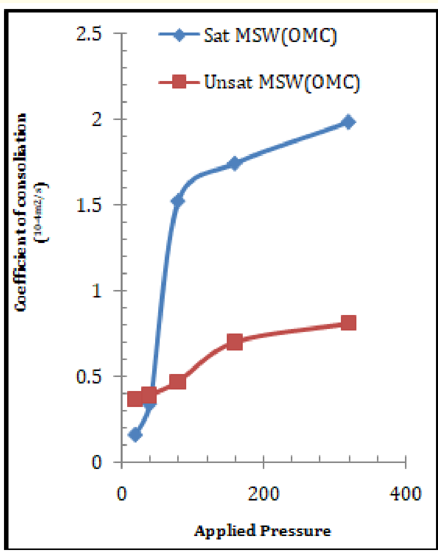


Figure 7: Cv vs. Applied Pressure for (-4%OMC). ***Figure 8:*** Cv vs. applied Pressure (-2%OMC).



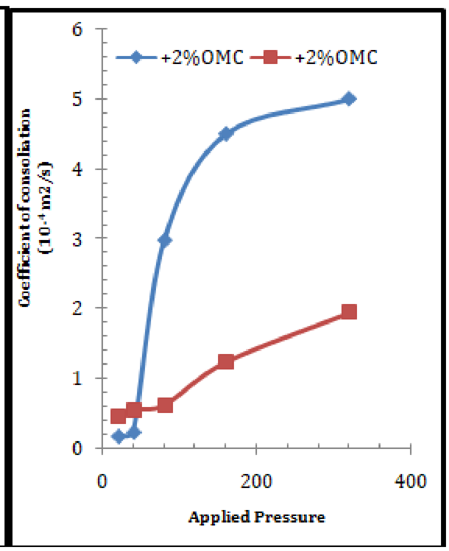


Figure 9: Cv vs. Applid Pressure for (OMC). ***Figure 10:*** Cv vs applied Pressure (+2%OMC).

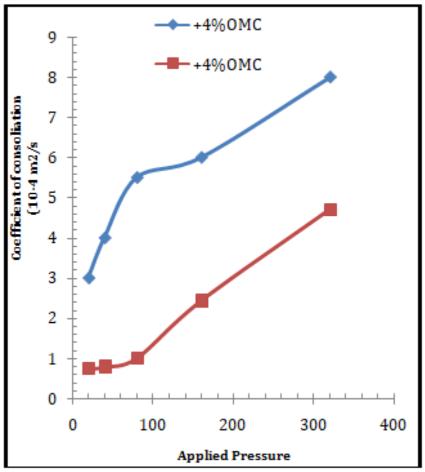
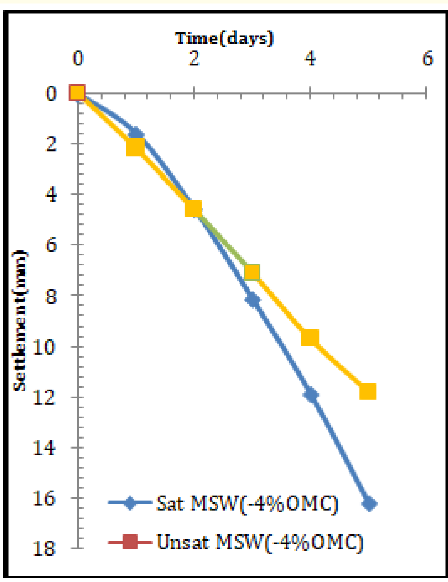


Figure 11: Cv vs Applied Pressure (+4%OMC).

Fig. 7 to Fig. 11 indicated the variations in the coefficient of consolidation in saturated and unsaturated soils. From the above Fig 11, it is concluded that the rate of consolidation in the unsaturated soils is less as compared to the saturated soils because of the presence of pore air in the unsaturated soils which ultimately results in more time for the expulsion of water from voids as compared to that of saturated soils in which the rate of consolidation is more.

Comparison for Settlement vs. Time for Saturated and Unsaturated MSW

The below Fig 12 to Fig 16 indicate the settlement for various water contents variations such as (-4%OMC,-2%OMC,OMC,+2%OMC, and +4%OMC).The time required for the consolidation tests For Unsaturated MSW is more due to the presence of air voids in the structure of particles. While soils when fully saturated, the water can expel out easily so Saturated MSW required less time for the settlement and the settlement observed was also more compared to unsaturated soils.



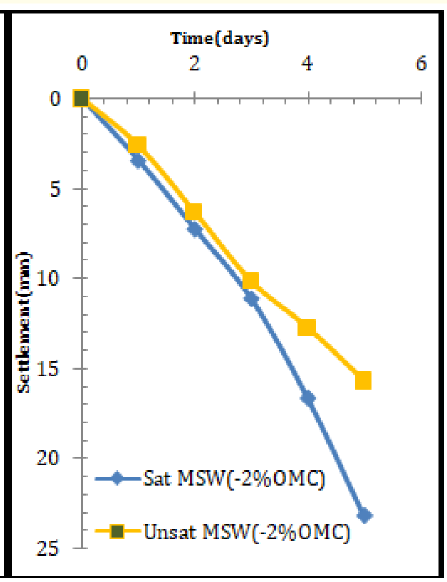
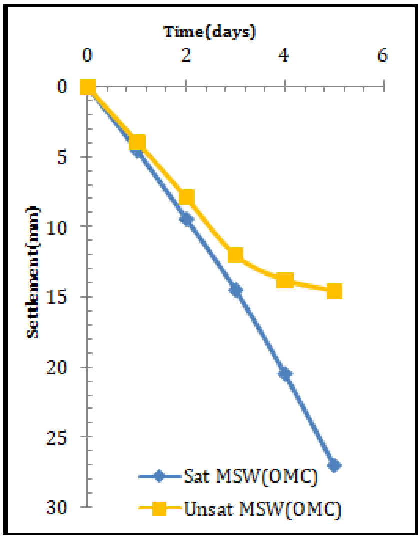


Figure 12: Settlement vs. time for (-4%OMC). ***Figure 13:*** Settlement vs. time for (-2%OMC).



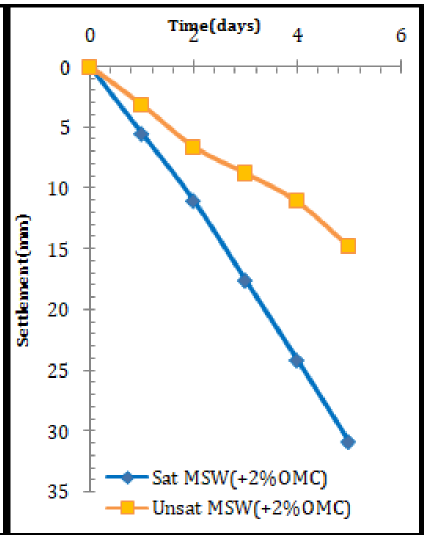


Figure 14: Settlement vs. time for (OMC). ***Figure 15:*** Settlement vs. time for (+2%OMC).

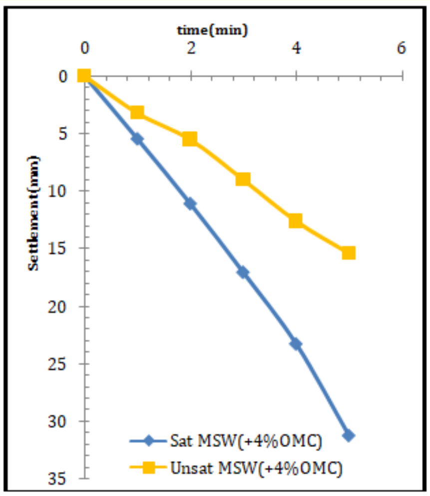


Figure 16: Settlement vs. time for (+4%OMC).

Comparision for total settlement in saturated and Unsaturated MSW

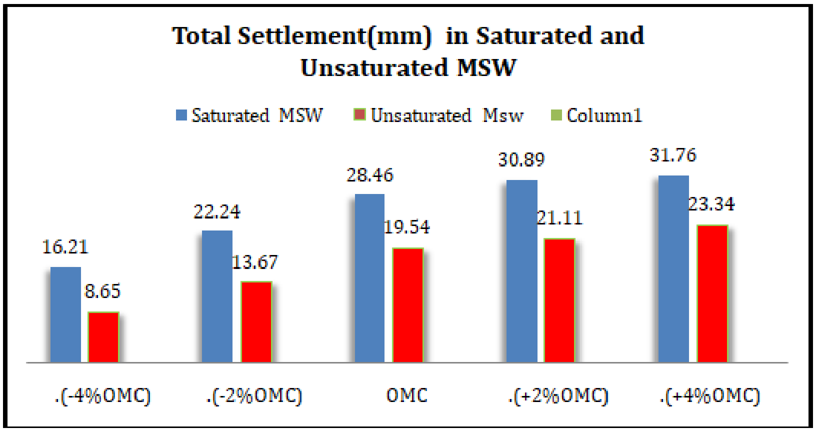


Figure 17: Total Settlement for Unsaturated and Saturated MSW.

The total settlement in each of the cases of saturated and unsaturated MSW is been shown in Fig 17. The total settlement increases with an increase in moisture variation because with an increase in moisture content there is a reduction in voids or spaces between the soil particles due to applied load and hence water moves out quickly. The strain rate at (-4%OMC) is about 87%, for (-2%OMC) is about 62.26%, for (OMC) is about 45.64%, for (+2%OMC) is about 38.86%, and (+4%OMC) is about 36.65%. The decrease in the strain rate is because in sand maximum dry density is achieved when soil is fully dry or saturated. Hence the soils compacted on the dry side of optimum develop less pore pressure than those compacted on the wet side, so it is advisable to consider the dry side of optimum.

Conclusion

This study analyzed the consolidation characteristics according to the large size Consolidometer test of Pirana waste material. Below summarize the results obtained from the comparison evaluation on Pirana waste of consolidation and settlement characteristics.

- The time required for the 50% consolidation in the case of the unsaturated MSW is more as compared to that of saturated MSW because of the presence of air in the sample. The compression takes place at a rate lower compared to that of MSW which is fully saturated.
- The settlement in the case of Saturated MSW was more because water comes out from the voids more easily and also the time required for 50% consolidation is less compared to that of the unsaturated soils.
- Saturated MSW has water pressure that is zero or positive and this water can flow out of the MSW easily while for Unsaturated MSW water pressure are negative or less than atmospheric so water is held under a tension or suction force.
- The settlement for Saturated and Unsaturated MSW for (-4%OMC) was about 16.21 mm and 8.65mm which indicates the strain of about 46.63% while for the (+4%OMC) the strain is about 26.51% which is less compared to the MSW compacted on the dry side.

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