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INFLUENCE OF COMPOSITION ANALYSIS ON UNIT WEIGHT OF SYNTHETIC MUNICIPAL SOLID WASTE

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ABSTRACT: The unit weight of municipal solid waste is a critical parameter in engineering analyses of landfills execution, design, and stability of landfills, but significant uncertainty as of now exists with respect to its value. By using synthetic municipal solid waste (SMSW) that replicates the typical composition of waste produced in India. To determine the relation between Maximum Dry Density (MDD) & Optimum Moisture Content (OMC) of fresh SMSW "Modified Proctor Test" has been performed. MSW is a very heterogeneous material, numerous efforts have been made in the past to generalize the density of MSW, but still, the effect of each material on the density is Obscure. In this paper, the variation in MDD & OMC has been provided depending on the varying percentage of each material (Paper, Plastic & Organic Content) present in it. As a result of regulations and shifting consumer habits, waste is continually changing. Engineers must therefore be mindful of the evolving mechanical characteristics of trash, and it's possible that prior findings may not be a reliable indicator of how waste will behave in the future. Therefore, Calculating the variation in unit weight can be useful in designing engineered MSW landfills and for future references.

Keywords: Synthetic municipal solid waste, Density, Unit weight, Compaction, Maximum dry density, Optimum moisture content

1. INTRODUCTION

The Municipal solid waste (MSW) landfills is an engineered geotechnical structure. The foundation's rainfall infiltration, leachate, and slope stability-bearing capacity are some of the problems related to landfills. Therefore, based on the information available at the landfill site, a landfill design plan should be chosen based on the appropriate values of geotechnical Parameters of MSW such as density, shear strength, and permeability.

Specific guidelines on the likely range of MSW characteristics must be provided if the data are insufficient for analysis in order to evaluate the safety of MSW slopes and landfill design. The MSW exhibit a wide range of uncertainty related to unit weight depending upon the vulnerability related to the heterogeneity of waste, age of waste, different degrees of deterioration, filling method, construction practices, compaction method, and leachate levels. Without taking into account, the variability in the geotechnical parameters, the design of the MSW landfill could result in stability or slope failure [1]. Even now, it is common practice to access the stability of slopes using the little data that is currently accessible. Less reliability will be achieved by planning the landfill using the minimal information that is now available. The parameters density (γ), cohesion (c), and internal friction angle (ϕ) control the stability of an MSW landfill. Therefore, in this research paper efforts have been made to analyze the composition effect on the Unit Weight of MSW. Providing design parameters with a known range will provide high-performance landfills with less possibility of failure [2,3].

The rate of change could accelerate over the following years as many attempts are made to recycle and pretreat MSW using mechanical and biological methods. Additionally, it is anticipated that degradation changes a deposit's mechanical properties with time. Due to the heterogeneity of waste, it is impossible to fully characterize its engineering properties; however, it is crucial to understand basic behavior and to be aware of the likely ranges of the relevant engineering properties.

2. RESEARCH SIGNIFICANCE

The assessment of the literature demonstrates unequivocally that there is confusion surrounding the unit weight of MSW because of its heterogeneity, which demands a systematic investigation. It is currently unclear how the composition will affect the MSW unit weight. There have been numerous investigations into the engineering characteristics of MSW however, there have been few investigations into the effects of waste type (synthetic and natural), age, and waste material (fibrous, organic, and inorganic) on the shear strength behavior of MSW.

The current study suggested calculating the impact of paper, plastic, and organic material on the unit weight behavior of MSW. The magnitude of MSW unit weight is very heterogeneous based on the content of waste but the behavior with respect to the change in the composition will follow a trend. Calculating the influence of material composition on the unit weight of MSW will help us create a generalized range of values of the unit weight and help us in further analysis and design of MSW landfills.

3. UNIT WEIGHT

Laboratory results of MSW show the variation in Unit Weight of waste ranging from 8-10 kN/m^3 and 15 – 20 kN/m^3 for dry and degraded waste. Many of them have analyzed the effect of degradation on the unit weight of MSW [4,5]. For fresh waste, the unit weight is mainly influenced by its composition calculated the unit weight of waste range from 3 - 18 kN/m^3 [6]. The unit weight of MSW landfills also varies with the depth performed test on bored samples which reported a range of 10 – 15 kN/m^3.

It is quite surprising that there has been so little thorough research on unit weight because it is important information for landfill design. Due to the various waste types and dumping techniques, unit weight varies greatly. Common challenges in determining MSW unit weight include clearly separating out the contribution of daily soil cover, determining how unit weight changes over time and with depth and assuming that the most of reported values correspond to waste that is close to the surface [6].

Table 1 Engineering properties required for design

Design Case	Unit Weight	Shear Strength	Hydraulic conductivity	Lateral Stiffness	Compressibility	Horizontal In situ stress
Subgrade Stability	✓	✓				✓
Subgrade Integrity	✓	✓		✓		✓
Waste Slope Stability	✓	✓	✓		✓	
Liner slopes stability	✓	✓	✓	✓	✓	✓
Steep slope liner stability	✓	✓	✓	✓		✓
Cover system	✓	✓			✓	
Drainage system	✓					✓
Gas / Leachate collection	✓	✓	✓	✓	✓	✓

From above Table 1, it can be seen that the density of the MSW plays an important role in the design of engineered landfills. Therefore, in this research, the focus has been given to analyzing the density of MSW. The requirement of a better understanding of the density of MSW will provide better efficiency and stability in engineered landfill designs.

3.1 Material Description

MSW is a collection of waste largely from household and commercial sources. The two primary categories of MSW are organic waste and inorganic garbage. Food trash, paper, garden waste, soil, and textiles are examples of organic waste, while plastic, metals, rubber, and glass are examples of inorganic waste. The content of waste varies greatly depending on the source of waste formation. The MSW has a vast array of particle sizes, from little soil fragments to large building stones. These materials' composition varies from location to location, site to site, and even from country to country.

It is necessary to have a classification system to characterize component qualities in both their initial state, or as they are brought to a landfill, and in any altered states. Due to physical forces including compaction, overburden, and degradation over time, dumping waste in a landfill alters component qualities like size and shape. Materials utilized in this investigation have been classified according to Dixon and Langer's proposed scheme from 2004 [7].

3.2 Waste Mechanism

The current awareness of MSW/Waste behavior is relatively incomplete. Engineers and scholars have relied on the mechanics of soil for waste disposal [7]. Although this has been beneficial to some level, using soil behavior and designing the engineered landfill structure is not the best course of action.

The landfill was designed using the principles of soil theory, and changes in the geotechnical properties of waste due to degradation over time haven't been considered often, as well as since the lateral pressure of MSW hasn't been completely predicted lateral pressure analysis of MSW is also based on the principles of soil theory. Used for vertical extension of the landfill using retaining walls.

The soil homogenous pressure hypothesis is highly challenging to apply because of the heterogeneity related to MSW. Instead, MSW landfills should be designed using geotechnical properties and also considering the change in properties with respect to time in mind. While analyzing the similarities and differences of MSW with other soil materials will offer assistance to us to create and understand the engineering properties of MSW. It is always preferable to conduct tests on original materials in undisturbed conditions [8].

But it is not always possible to obtain the material in an undisturbed state and conduct the laboratory test on a real sample. Additionally, it can be challenging to generalize waste behavior due to the great variance in the sample.

3.3 Factors Affecting Unit Weight of MSW

The unit weight of MSW changes due to numerous reasons, a few of which are compaction effort, layer depth, layer thickness, and overburden pressure [9]. In contrast to soils, there are multiple materials present, and the state and level of deterioration affect the unit weight.

Table 2 Bulk unit weight of fresh waste [6]

Items (kN/m^3)	Good Compaction	Moderate Compaction	Poor Compaction
Range	8.8-10.5	5.0-7.8	3-9
Average	9.6	7.0	5.3
Standard Deviation	0.8	0.5	2.5
COV (%)	8	8	48

According to this theory, the fresh waste density mostly depends on the waste composition, however, when the waste ages (degrades), the unit weight primarily depends on depth.

It is extremely common to deposit the waste in a layer thickness of 2 to 3 m, which accomplishes moderate compaction and results in low poor density. The layer thickness is 0.5 - 1.0 m, which will achieve good compaction and therefore it exhibits high unit weight [4]. Depending on the level of compaction attained, a statistical analysis of the data is displayed in Table 2.

4. MATERIAL CHARACTERIZATION AND METHODOLOGY

In total, nine distinct compositions of synthetic municipal solid waste were created in the lab. By doing a waste composition analysis on a sample taken from the Jawahar Nagar Landfill, Hyderabad India, it was possible to determine a reference classification for "typical" MSW. To choose synthetic waste elements that can mimic those found in MSW, this reference MSW has been employed. Following the construction of several synthetic wastes with a variety of categories (Fig. 1) using these synthetic components, the relationship between classification and mechanical behavior was evaluated. Except for the components that represented the organic substance described below in Table 3.

Table 3 Composition of Jawahar Nagar Dumping Yard, Hyderabad India

Material	Fraction %	Size (mm)
Sample	SW-1	
Metal	5.10	< 40
Paper	21.20	15 – 200
Yard- Trimming	2	50 - 100
Cardboard	4.10	50 - 100
Wood	6	10 - 150
Textile	3.65	10 - 100
Plastic	15.10	10 - 150
Sand	9	< 4.75 u
Peat moss	30	40 – 120
Soil	4	> 4.75 u
Total	100	

The ASTM D1557-91 Proctor test method has particle-size limitations. Thus, the synthetic MSW samples were produced according to particle-size limitations in the laboratory as shown in Table 2 below [12]. However, there are too many combinations of material and component sizes to realistically represent each with a synthetic alternative.

Table 4 Composition of SMSW used for performing the experiments for paper

Sample	SW-2	SW-3
Metal	6.34	4.13
Paper	10	30
Yard- Trimming	4.84	2.63
Cardboard	16.34	14.13
Wood	7.24	5.03
Textile	3.24	1.03
Plastic	5.24	3.03
Sand	10.24	8.03
Peat moss	31.24	29.03
Soil	5.24	3.03

The composition of MSW is varied in such a way that it comprises the maximum range of each material. Ten different materials were used to make the Synthetic waste (Kitchen waste, paper, plastic metal, sand, cardboard, metals, textile, wood shaving, peat moss, and medium-grained soil) [10,11].

The % of each material of the constituted synthetic waste sample obtained from the landfill is presented below in Table 3. All the % of each test are also shown in Table 4, Table 5, and Table 6, which represent Paper, Plastic and Organic matter. To determine how each material will affect the unit weight of MSW by considering various compositions.

Therefore, the component fractions had to be minimized in order to get a simpler but still representative synthetic waste. The sample of each composition has been made in Lab and tested.

Table 5 Composition of SMSW used for performing the experiments for plastic

Sample	SW-4	SW-5	SW-6
Metal	5.67	4	3.45
Paper	21.77	20.10	19.55
Yard-Trimming	2.57	0.90	0.35
Cardboard	4.67	3.0	2.45
Wood	6.57	4.90	4.35
Textile	4.22	2.55	2.0
Plastic	10	25	35
Sand	9.57	7.90	7.35
Peat Moss	30.57	28.90	28.35
Soil	4.57	2.90	2.35

Table 6 Composition of SMSW used for performing the experiments for Organic content

Sample	SW-7	SW-8	SW-9
Metal	6.77	3.43	2.32
Paper	22.87	19.53	18.22
Yard-Trimming	3.67	0.33	0
Cardboard	5.67	2.33	1.22
Wood	7.67	4.33	3.12
Textile	5.27	1.93	0.82
Plastic	16.77	13.43	12.2
Sand	10.67	7.55	6.12
Peat Moss	15	45	55
Soil	5.64	2.33	1.18

Components such as beverage cans, rigid and flexible plastic packaging paper/cardboard, and textiles can be employed provided that they are in an unsoiled state [13]. The maximum size of each material has been taken from the literature review, and each particle has been cut by hand using the cutting machine to keep the particle size in the given range. Mineral material was represented by sand, gravel, and soil. Synthetic waste components were selected based on consideration of both shape and size Table 3. Fig. 1 shows the different components used in this experiment. Each material has been cut and weighted in a particular fraction to simulate the waste composition.

Fig. 1 Material Used in the Present study to build the synthetic waste

Organic content, the composition varies from 15%, 30%, 45%, and 55%. By utilizing the above-mentioned composition, we have tried to analyze the unit weight of MSW by doing the standard proctor test as shown in Fig.2 and Fig.3.

Fig. 2 Proctor Test Apparatus used to calculate the density of SMSW

From above Table 4, the composition of paper has been fixed for each sample (i.e., SW-2= Paper 10% and SW-3= paper 30%) and all the other material fractions have been calculated depending on the fixed fraction of paper. A similar, process was followed for calculating the composition fractions of plastic and organic matter as can be seen in Table 5 and Table 6. Some previous studies have also studied the engineering properties of MSW using SMSW. Table 5 shows the composition of SMSW used to find the influence of composition on Unit weight by a varying paper by 10%, 21.20%, and 30%. For Plastic the composition varies from 10%, 15%, 25%, and 35%.

The SMSW is filled in three layers inside the mold and each layer has been compacted with 25 blows from a constant height of 18 in. The water has been added in a range from 15% to 90% for every test.

$$\text{Bulk Unit Weight, } \gamma_b = \frac{W}{V} = \frac{\text{Weight of MSW}}{\text{Volume of Mold}} \quad (1)$$

$$\text{Dry Unit Weight, } \gamma_d = \frac{\gamma_b}{1+M.C} \quad (2)$$

Eq. (1) and Eq. (2) were used to calculate the unit weight and dry density of the SMSW. The obtained moisture content (M.C) following oven drying is used for the calculation of dry unit weight. The testing mold dimensions are 15 cm inner diameter and 17.5 cm in height. The drop hammer used has a weight of 2.5 kg and a constant drop height of 45 cm as shown in Fig.2. Fig.3 shows the weighing of the sample after every compaction of testing material.

Fig. 3 Sample weighing after Compaction

5. RESULTS & DISCUSSION

The Unit weight of SMSW in each sample differs very much therefore it helped us in creating a range of values depending upon the material present on it. This laboratory-produced SMSW mix fraction was chosen to resemble the typical MSW composition of India. The maximum particle size tested in this investigation is 20 cm, and the average specific gravity was reported to be 1.52. One of the primary causes of a variation between MDD values is thought to be a difference in the maximum particle size [14]. The dry unit weight of SMSW increased as the water content increased to its maximum and then began to drop as the water content increased further.

Similar to soils, the additional increase in water solid content per unit volume was contributing to lubrication, which led to a denser arrangement of particles. Additionally, as the water content rises, solid materials become softer, which enhances deformation, compressibility, and rebound in response to compaction. “However, compared to soils, waste does not show a significant decrease in dry unit weight at high moisture content, because the relative difference between the unit weight of “waste” and “solid” is lower for waste than for soils” [1].

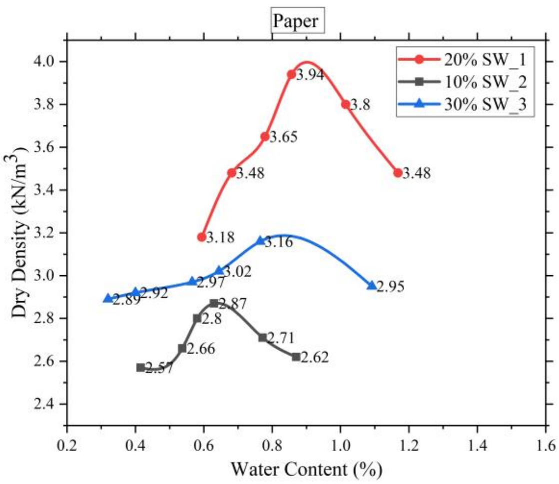

Fig. 4 Variation of Density with different combinations of paper percentage

The effect of increasing paper % on the unit weight of SMSW is in the range of 2.87 kN/m^3 for 10%, 3.95 kN/m^3 for 20%, and 3.16 kN/m^3 for 30%. As for the paper, % increases the density increases reached their maximum and then started to decrease with the increase in paper %. With the inclusion of paper, the SMSW mix behaves denser than other mix proportions, unit weight tends to increase from 10 – 20 % from 2.87 to 3.95 kN/m^3. Larger and lighter particle sizes make materials more compressible. Components deform at relatively low vertical stresses, with component rearrangement behavior predominating.

Similarly for Plastic, the % increases for the first two cases of unit weight, and with a further increase in % of plastic, the MDD tends to decrease. Plastic takes more volume compared to other materials such as paper, metal, etc. Low unit weight is again caused by the inclusion of light and highly compressible material components deformed from the start of the stress application while compacting. Plastic shows higher nature of compressibility and the SMSW mix with more plastic % tends easier to slip, therefore in the landfill if there is more % of plastic than 15 – 20 % it will be more prone to slope failure.

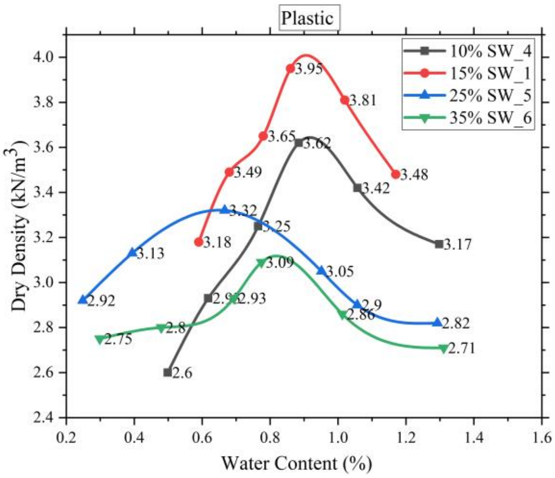

Fig. 5 Variation of Density with different combinations of plastic percentage

For plastic content 3.61 kN/m^3 for 10%, 3.95 kN/m^3 for 15%, 3.32 kN/m^3 for 25%, and 3.09 kN/m^3 for 35%. As can be seen below Fig. 6 shows the influence of material on the unit weight of SMSW for organic content. Similarly, for organic content, the effect on unit weight is calculated as follows 3.73 kN/m^3 for 15% peat moss, 3.95 kN/m^3 for 30%, 4.14 kN/m^3 for 40%, and 3.80 kN/m^3 for 55%.

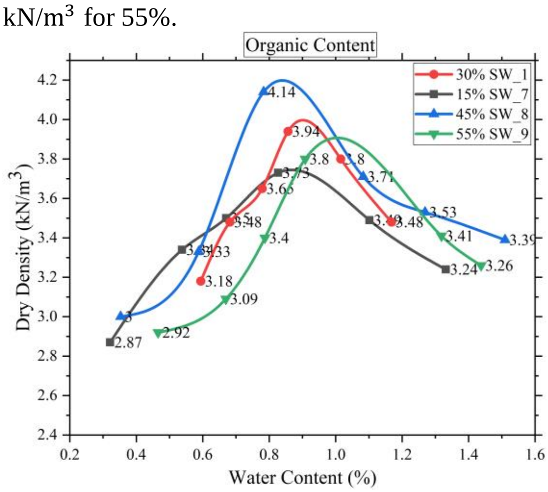

Fig. 6 Variation of Density with different combinations of organic content percentage

As the organic content increases the MDD also increases in the first three tests but with a further increase in % of organic matter, the MDD decreases. The reason for this behavior is as organic material is very compressible and also it can break easily while compacting, due to the presence of water it tends to stick to other materials leading to greater interlocking of materials. A denser packing arrangement was achieved by increasing the solid content per unit volume, which assisted in lubricating the particles from the addition of water. Therefore, it exhibits less volume which results in an increase in MDD reaching its peak at a certain point i.e., 30 – 35% of organic matter.

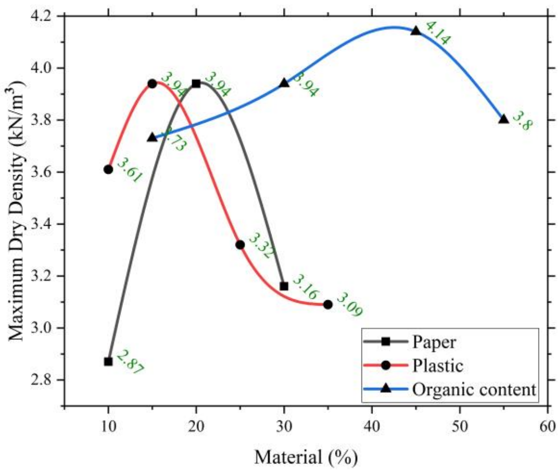

Fig. 7 Influence of different materials on the Maximum Dry density of SMSW

Despite the difference in moisture content and overburden pressure between synthetic waste and real waste, it has been shown that SMSW used in this study has shown magnitude and trends that are comparable to real waste. The MSW is a heterogeneous material it also shows wide variation in magnitude, but the trends followed by the MSW are quite similar.

From the above Fig.7 shows the variation of maximum dry density depending on the variation of different testing materials. This gives us a clear idea of how the material composition affects the density of SMSW. After the results, it has been proved that changes in the composition of MSW will affect the geotechnical properties of synthetic municipal solid waste. Further study is also required to find out the effect of each material on the geotechnical properties of SMSW such as shear strength, permeability, and compressibility.

6. CONCLUSION

This article presents the unit weight characteristics of SMSW of Hyderabad India. There are several failures of landfills happening around the world which have also caused loss of lives. Therefore, much more effort must be given to analyze the MSW properties more effectively and design the landfill more efficiently by utilizing the more elaborated waste properties. One of the major obstacles to determining MSW's geotechnical characteristics through traditional geotechnical testing is their variability. The wide range in the specific gravity of the material used (2.65 for sand to 1.0 for plastic) made it difficult to create a consistent SMSW mix. The mix's uniformity within a specific composition was maintained throughout the testing. The relatively low unit weight of synthetic municipal solid waste is the result of the use of light components and minimal placement compaction forces. Although laboratory techniques have been employed extensively, outcomes from this research should be carefully evaluated because of their connection to disturbed samples.

From the literature, it has been demonstrated that for the same landfill waste at field capacity, the dry unit weight of SMSW on the order of 2–4 kN/m^3 is equivalent to the bulk unit weight of 6–9 kN/m^3 [9].

- When the composition of the synthetic waste varies there are significant changes in the unit weight of the testing samples.
- When a paper percentage is increased from 10 to 20 %, the maximum dry density increases by 41.7 %, and when it is increased from 20 to 30 %, it lowers by 21.2 %.

For SW-1, SW-2, and SW-3

Paper %	10	20	30
MDD	2.87	3.94	3.16
OMC	0.62	0.85	0.76

- The maximum dry density increased by 15.56 % when the plastic percentage was increased from 10 to 15 %; from 15 to 25 %, it decreased by 22.69 %; and from 25 to 35 %, it decreased by 6.45 %.

For SW-4, SW-1, SW-5, and SW-6

Plastic %	10	15	25	35
MDD	3.61	3.94	3.32	3.09
OMC	0.88	0.86	0.77	0.67

The reason for this kind of density variation for paper and plastic is mainly due to the compressible nature of the material. The material tends to soften when water is added, which makes for a dense arrangement and also reduced the compaction rebound.

- The maximum dry density when Organic content % is increased by 15 to 30% increased by 21.52% with further increase of 30 to 45% increased by 4.24% and from 45 to 55% it decreased by 24.16%.

For SW-1, SW-7, SW-8, and SW-9

Organic %	15	30	45	55
MDD	3.73	3.94	4.14	3.80
OMC	0.82	0.85	0.78	0.90

Nearly every step of landfill design and analysis uses knowledge of the unit weight of waste. In the beginning, factors such as waste composition, age, cover system, degree of compaction, and biodegradation have a greater impact on the unit weight of garbage. From the above discussion, it is clear that the effect of each individual material on MSW is very prominent, and doing this composition analysis on fresh SMSW has provided us with a definite range of unit weight corresponding to the change in the composition of materials. The findings of this study showed that waste unit weight substantially relies on the composition of waste, hence a site-specific assessment is advised [15].

The composition of MSW should be taken into account when the compaction characteristics are interpreted. The findings of this study showed that waste density substantially relies on composition, hence a site-specific assessment is advised. Once the individual contribution from each waste type is understood, then the particle sizes need to be made representative as well. Representative particle sizes might be the key to understanding the contribution of geotechnical properties due to the interlocking of particles.

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