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Physical Characterization and Geotechnical Properties of Municipal Solid Waste

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Abstract: *Municipal Solid Waste (MSW) is complex refuse consisting of various materials with different properties. Some of the components are stable while others degrade as a result of biological and chemical processes. Leachate resulting from this is hazardous pollutant to the soil and ground water underlying. Leaching of this leachate and heavy metals into the soil leads to the contamination of both soil and groundwater. Municipal solid waste disposal on land has become one of the challenges in landfill engineering design. The stability of landfill is governed by the strength parameters and physical properties of MSW. For the analysis of MSW, geotechnical properties of the MSW play an important role in designing of the landfill and slope stability issues. In this paper results of laboratory investigation of the geotechnical properties of MSW are presented. Waste samples collected were subjected to specific gravity, moisture content, particle size analysis, compaction, permeability, consolidation and direct shear tests. The influence of these properties on the stability of the landfill and other issues of MSW in the designing of landfill are discussed.*
Keywords: *Geotechnical properties, Leachate, Municipal Solid waste (MSW), Physical characterization, Stability.*

I. Introduction

Municipal Solid Waste (MSW) is complex refuse consisting of various materials with different properties. Some of the components are stable while others degrade as a result of biological and chemical processes. Leachate resulting from this is hazardous pollutant to the soil and ground water underlying. Leaching of this leachate and heavy metals into the soil leads to the contamination of both soil and groundwater.

Municipal solid waste mainly consists of kitchen waste, plastics, paper product, textile, garden waste, construction demolition waste, metals, and wood waste etc. However the composition of MSW varies from region to region and it depends upon lifestyle, demographic features and legislation. Open dumping has been the most accepted practice of solid waste disposal. On an average, 5–6% of the wastes are disposed of by using various composting methods [1]. The scope of waste reduction programs and other eco-friendly methods of waste disposal decreases because of lack of technical infrastructure, political willpower, and awareness among people [2].

Proper management of growing quantities of municipal solid wastes (MSW) has been a major concern of environmental professionals. Despite recycling and reuse efforts as well as incineration, huge quantities of MSW are still required to be disposed of in engineered landfills. The collection of reliable data regarding generation and characterization of the waste is the key to a successful MSW management. Presently, lack of reliable information and data regarding generation rate, amount, and nature of solid waste creates a hurdle in developing an appropriate waste management plan.

The geotechnical properties of municipal solid waste (MSW) are of paramount importance in designing and assessing the performance of landfill and in ensuring safe long-term containment of MSW so that human health and the environment are not exposed to undue risk. Geotechnical properties of MSW are difficult to determine because the heterogeneity, wide variation in particle size distribution and time dependent degradation. Geotechnical properties of MSW are determined through in-situ and laboratory tests and /or back analysis of field performance data [3]. In landfill design and stability analysis the characterization of the mechanical behavior of the MSW is necessary as well as other specific physical properties such as composition, unit weight, water and organic contents and permeability. The water and organic content have a direct effect on the long-term mechanical response of the MSW as they affect the processes of biodegradation [4].

Several landfill failures worldwide emphasized the dire need for the proper determination of waste properties to ensure safety and stability of landfills. Dixon and Zones (2005) indicate that measuring and interpreting MSW characteristics is extremely difficult task. However, knowledge of unit weight, vertical compressibility, shear strength, lateral stiffness, in situ stresses and hydraulic conductivity is fundamental to the assessment of landfill stability and integrity of both geosynthetic and mineral lining components. The safety and stability of the landfills need to be assessed based on data from landfills. In this context characterization of MSW is important [5].

Study Area: The waste samples for the tests were collected from one of the dumping (landfill) site located on the Khermai Road, Satna. The city is located on 24^0 34’ N latitude and 80^0 55’ E longitudes at an altitude of 315 m above mean sea level. The place is renowned for Dolomite mines and Limestone. The landfill is surrounded by some small ice factories, two nursing homes, a motor park, four to five automobile repair workshops and road network act as the sources of waste and pollution discharge in addition to the transported waste discharge into the landfill. The wastes deposited in the landfill are predominately solid wastes from domestic sources including market wastes.

Fig-1 Image of dumping site shown by the circle. (Source: Google earth)

II. Physical Characterization Of MSW

The physical characterization of municipal solid waste is done in order to measure the quantity of the recoverable and to study the effect of the physical composition on the strength and stability characteristics of the MSW. A number of existing classification systems are simply based on material groups (e.g. paper, plastic, metal, etc.) or on the distinction between soil-like (3-D structure) and non-soil-like (2-Dstructure), or fibrous, appearance (Dixon and Langer, 2006). [6]

Some of the classification systems are MSW component-based systems that are primarily used to facilitate physical (reuse and recycle), biological (compost) and chemical (chemical additives) processing of majority of waste material (US EPA, 2003; European Commission, 2003). Component based systems identify MSW as: (1) material type; (2) product type (US EPA, 2001). Material type classification may include paper and paperboard, glass, metals, plastics, rubber and leather, textiles, wood, and others. Product type classification may include durable goods (e.g. appliances, furniture, tires), non-durable goods (e.g. newspaper, office papers, trash bags, clothing), containers, and packaging (e.g. bottles, cans, corrugated boxes), and other wastes (e.g. yard trimmings, food scraps and miscellaneous inorganic wastes). The rest of available classification systems are used to facilitate land filling process with minimal damage to protective landfill base-liner [7].

Table - 1 Overview of existing classification systems of municipal solid waste

Author	Basis for differentiation	Parameters used for differentiation
Turczynski, 1988	Waste type	Density, shear parameters, liquid/ plastic limit, permeability
Siegel et al., 1990	Material groups	Part of composition
Landva and Clark, 1990	Organic, inorganic Materials	Degradability (easily, slowly, non) shape (hollow, platy, elongated, bulky)
ADEME(1993)	Particle size distribution and composition	Size, material groups, moisture content and degradability
Grisolia et al., 1995	Degradable, inert, deformable material groups	Strength, deformability, degradability
Kolsch, 1996	Material groups	Size, dimension
Manassero et al., 1997	Soil-like, Other	Index properties
Thomas et al., 1999	Soil-like, non-soil-like	Material groups
Dixon and Langer, 2006	Shape- related subdivisions	Material groups, size, shape, organic, inorganic, soil-like, non-soil-like

Source: Dixon and Langer, 2006.

2.1. Waste composition

Municipal solid waste is a mixture of wastes that are primarily of residential and commercial origin. Many categories of MSW are found such as food waste, rubbish, commercial waste, institutional waste, street sweeping waste, industrial waste, construction and demolition waste, and sanitation waste. MSW contains compostable organic matter (fruit and vegetable peels, food waste), recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), and soiled waste (blood stained cotton, sanitary napkins, disposable syringes). MSW composition at generation sources and collection points ,determined on a wet weight basis, consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%).

The waste is segregated by hand sorting into paper, plastics, inerts (rubber, leather), glass, stones and the organic fraction of the waste. The physical characterization of the waste passing through 100 mm sieve was done by hand sorting and on the weight basis. The age of the sample was 4- 5 weeks. The quantity of waste taken for composition analysis was 100 kg regarding the composition of MSW generated by the Satna City over the entire study period. The MSW samples used for all the experiments were those passing through the 20 mm sieve and retained by the 4.75 mm sieve. Therefore the composition analysis of the 4.75 mm sieve retained waste was done and found to be: pastel - 39.25%, paper and cardboard - 20.50%, plastic - 17.25%, cloths-7.50%, glass-2.75%, stones – 1.75%, rubber, wood, metals (each less than 1%) and etc.

Fig. 2 shows waste composition of the municipal solid waste. According to this figure the percentage of the main MSW components are paste (food scrap), plastic and paper/cardboard.

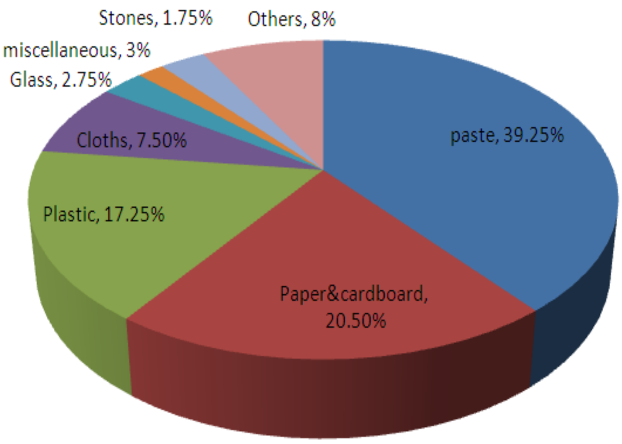

Fig. 2 composition of municipal solid waste

2.2. Water content

The water content of a typical MSW may include both water held in macro or freely draining pores and water absorbed into micro pores within individual waste component such as paper, cardboard, textiles, food etc. In general water content of MSW within a landfill vary between its initial water content on collection and a water content representing fully saturated conditions [8].

The moisture content and organic content of the waste material smaller than 10 mm were measured. Moisture content of the waste smaller than 10 mm material was calculated as the ratio of the weight loss to the weight that remained after heating at a temperature of 70°C until the specimen has dried to a constant mass. Moisture contents measured were ranged from 90% to 145% on dry weight basis, equivalent to 47% to 51% on wet weight basis.

2.3 Specific Gravity

Pycnometer method was employed to determine specific gravity for MSW in laboratory for finding the specific gravity of MSW. Specific gravity of MSW in the present study was found to be 2.22. The lower value of specific gravity can be attributed to the presence of decomposed organic matter.

3.4. Particle size distribution

In the laboratory the MSW used for the experiments were the waste passings through 10mm sieve. Most of the traditional laboratory geotechnical testing equipment cannot accommodate field MSW samples with large particle sizes. Therefore sieve analysis of the waste retained by the 4.75 mm sieve was done on weight basis and in accordance with the ASTM D422 standards. The maximum quantity of MSW retained was 34% on the 2.36 mm sieve. The maximum percent passing was 85% through the 4.75 mm sieve. The results are shown in the Fig. 3. The Cu and Cc values for the samples were calculated as and 15 and 1.66. The values indicate that the samples are well graded and the absence of coarse sand and clay like particles. The MSW constituted of fine sand and silt like particles.

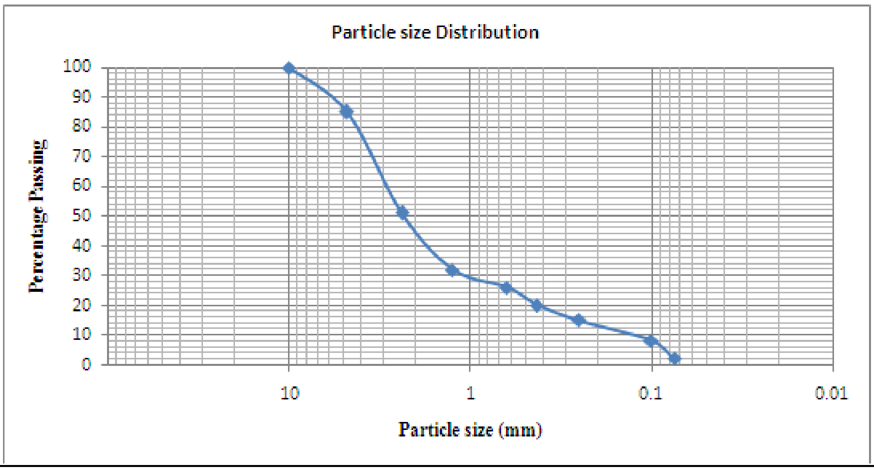

Fig -3 Particle Size Distribution of waste sample

III. Geotechnical Testing Of MSW

In this study, the MSW samples collected from the field and geotechnical testing was conducted using these samples. Compaction, hydraulic conductivity, compressibility, and shear strength tests were conducted.

3.1 Compaction Test

Compaction is the process of densification of soil mass by reducing air voids. The degree of compaction is measured in terms of its dry density. The degree of compaction mainly depends upon its moisture content, compaction energy and type of soil. The compaction test is carried out based on ASTM D698 Standard Proctor Test on MSW using a 100 mm diameter mould. The waste is compacted with 25 blows for 3 layers using standard Proctor hammer. The test is repeated for another five determinations. A dry density is plotted against moisture content, to determine the maximum dry density and optimum moisture content.

3.2 Compressibility Test

Compressibility testing was carried out in an oedometer in order to determine the compressibility characteristics of MSW. The test was performed for a water content of 45% and a bulk density 1100 kg/m^3. The size of the sample was 60mm diameter and 15 mm height. The maximum load applied was 800 kPa. The waste was compacted into the mould using a circular tamping plate and placed in between the porous stones. Since the MSW constituted of fine sand and silt like particles the oedometer tests were conducted.

3.3 Hydraulic conductivity

To determine hydraulic conductivity of MSW laboratory tests were conducted by constant head and falling head methods. Small-scale laboratory tests were conducted to determine hydraulic conductivity by constant head and falling head methods. Fresh waste was collected from a landfill site. The tests were performed according to ASTM D2434 and ASTM D5084 (2007). The waste was compacted into the mould of 85 mm diameter and 127.3 mm height. The permeability was calculated based on the Darcy's law. The water content and the bulk density of MSW were 45% and 11 kN/m^3. MSW samples were tested at confining pressures 50, 100 and 200 kPa.

3.4 Direct Shear tests

Shear resistance is a geotechnical parameter of primary concern in describing the properties of MSW. Direct shear tests were conducted to determine the shear strength parameters (cohesion and friction angles) of municipal solid waste. Tests were performed in accordance to ASTM D3080. The samples were compacted in a square shear box of 60 mm x 60 mm. The height of the box is 50 mm. In the present study the direct shear tests were performed with bulk density 1100 kg/m^3 and for confining pressures of 50, 100 and 200 kPa. The size of sample was 60 mm in length, 60 mm in width and 30 mm in height. The stress-strain response of the waste are plotted and the cohesion and the friction angle values were obtained.

IV. Result And Discussion

4.1 Compaction tests

Standard Proctor compaction test was conducted in accordance with ASTM D698 on MSW using a 100 mm diameter mould. Three layers with 25 blows each were compacted into the mould. The testing was performed on samples with five initial moisture contents of 20%, 30%, 40%, 50%, and 60% as shown in Fig. 4. The maximum dry density of the MSW of particle size <10 mm are greater than those >10 mm in size. The moisture content may also vary with the age of the waste and the placement conditions in a landfill. The high maximum dry density of 1100 kg/m^3 obtained in the present study could be due to the presence of high percentage of organic content and soil like particles. The compaction test result gives the maximum dry density of 1100 kg/m^3 at 45% optimum moisture content.

Based on Reddy et al (2009), the Standard Proctor compaction conducted at fresh landfill, Orchard USA gives maximum dry density of 420 kg/m^3 at 70% moisture content. Hettiarachchi (2005) reported a maximum dry density of 525 kg/m^3 at 62% optimum moisture content for a MSW sample generated in the laboratory. There were approximately 66% differences between the result of maximum dry density from open dumping area and fresh landfill. The difference is approximately 40% in the optimum moisture content. The samples from open dumping area are less moisturized due to the exposed of the samples to the air without any daily cover.

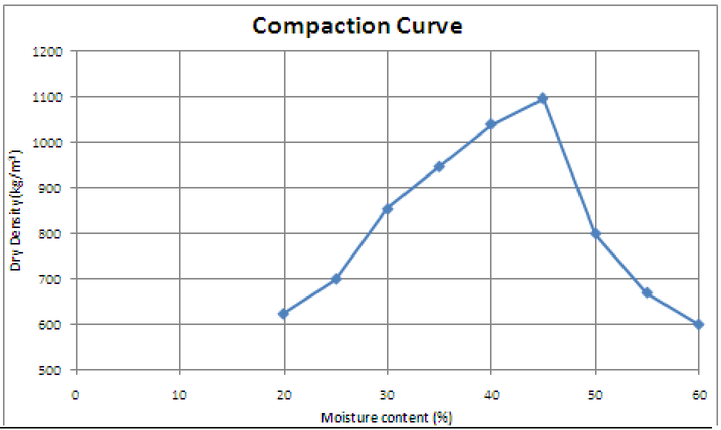

Fig -4 Dry density – moisture content curve

4.2 Compressibility Test

Compressibility of MSW was tested in general accordance with ASTM D2435 (ASTM, 2007). MSW specimen was compacted in layers with the tamper to achieve initial wet unit weight ranging from 7.8 -11.8 kN/m^3. The specimen was placed in the brass ring with one porous stone on the top and another one at the bottom of the sample. Compression ratio (slope of strain Vs log pressure curve) calculated from this study is 0.25. Compression ratios reported in literature are summarized in Table-2. Hence the value obtained in the present study falls in the range of values reported in the published literature.

Table-2 Compressibility of SMSW and fresh MSW reported in literatures

Source	Compression ratio
Reddy et al.(2009) (63 mm diameter oedometer test, SMSW particles were of average size 1.5 mm, 10% particles were greater than 10 mm and 35% particles were finer than 0.1 mm)	0.16 - 0.31
Reddy et al.(2008) (63 mm diameter oedometer test, shredded fresh MSW, maximum particle size 40 mm)	0.24 - 0.33
Dixon et al. (2008) (Large scale test of size 500 x 500 x 750 mm, SMSW, maximum particle size 120 - 500mm)	0.30
Hettiarachchi (2005) (63 mm Teflon cell, SMSW, maximum particle size approximately 5mm)	0.18 - 0.21
Langer (2005) (0.5 x 0.5 x 0.75 m compression box, shredded SMSW control samples, maximum particle size10 mm x 40 mm)	0.30
Hossain (2002) (63.5 mm diameter Oedometer tests, shredded relatively fresh MSW in control samples maximum particle size 120 - 500 mm, majority was 40 - 120 mm)	0.16 - 0.25
Waif and Zeiss (1995) (570 mm diameter cell, shredded fresh MSW, maximum size 4.7 mm)	0.21 - 0.25
Landva and Clark (1990) (470 mm diameter consolidometer, shredded fresh MSW samples from Edmonton, Canada)	0.35

4.3 Hydraulic Conductivity Tests

To determine hydraulic conductivity of MSW laboratory tests were conducted by constant head and falling head methods. The hydraulic conductivity obtained from the tests was $4.5\text{x}10^{-6}$ m/s and $5.3\text{x}10^{-5}$ m/s for falling head and constant head method respectively. The constant head method yielded greater values of permeability as compared to the falling head method. Hydraulic conductivity of MSW reported in the literature is summarized in Table-3. The general trend is that the hydraulic conductivity decreases with increase in dry density of MSW. The hydraulic conductivity was found to decrease with the increase in the confining pressure. The physical properties influencing the permeability in MSW are density, particle size, porosity, material type, degree of saturation, waste placement, compaction, stage of decomposition, and depth within the landfill. The large plastics and fiber like materials present in the waste tend to block the flow of moisture and hence reduce permeability.

Table-3 Hydraulic conductivity of SMSW and fresh MSW reported in literature

Source	Unit weight (kN/m^3)	Hydraulic Conductivity (cm/s)
Reddy et al. (2009) (50 mm diameter and 100mm height sample, flexi wall test, SMSW particles were of average size 1.5 mm, 10% particles were greater than 10 mm and 35% particles were finer than 0.1 mm)	4.7 - 6.0	1.20 x 10^{-5} to 7.62 x 10^{-8}
Reddy et al. (2008) (50 mm diameter and 100 mm height sample, flexiwall test and 63 mm diameter and 100 mm height rigid wall test with shredded fresh MSW, maximum particle size 40 mm)	5.78 - 10.0	10^{-4} to 10^{-8}
Powrie and Beaven (1999) (2000 mm diameter and 2500 mm height Pitsea compression cell, constant head test, unshredded fresh MSW collected from tipping face of a landfill)	3.8 -7.1	3.7 x 10^{-6} to 1.5 x 10^{-2}
Landva et al. (1998) (440 mm diameter, constant head, SMSW	8.6 - 9.5	3 x 10^{-6} to 3 x 10^{-5}
Chen and Chynoweth (1995) (375 mm diameter and 1220 mm height column, constant head test, nominal size of particle12.7 mm, SMSW consisted paper, plastics and yard waste)	1.5 - 4.7 (dry)	2.3 x 10^{-5} to 2.5 X 10^{-1}
Korfiatis et al. (1984) (constant head permeameter, unprocessed six months old MSW)	------	8.0 x10^{-3} to 1.3 x10^{-2}

4.4 Direct Shear tests

Determination of MSW shear strength properties is difficult and costly due to the inconsistent composition of landfill material, difficulties in sampling and testing, and time-dependent properties. Shear strength of MSW is usually defined using the Coulomb failure criterion as follows:

$$\tau = c + \sigma \tan\varphi \qquad \text{........ (1)}$$

Where τ is the direct shear strength of MSW, c is the cohesion intercept; σ is the total normal stress and φ angle of internal friction.

In the present study the direct shear tests were performed with bulk density 11.0 kN/m^3 and for confining pressures of 50, 100 and 200 kPa. The size of sample was 60 mm in length, 60 mm in width and 30-mm in height. The stress-strain response of the waste are plotted and the cohesion and the friction angle values were obtained. There is great variability in the reported direct shear strengths in the literature. Cohesion values from 0 to 50 kPa and friction angles from 27^0 to 41^0 have been reported. The stress-strain response of the waste are plotted as shown in Fig. 5. The deviator stress increased constantly in the initial stages until 30% strain and there was a sudden increase in the rate of stress from 40% to 50% strain levels. The cohesion and the friction angle values were obtained as 12kPa and 38° for 20% deformation.

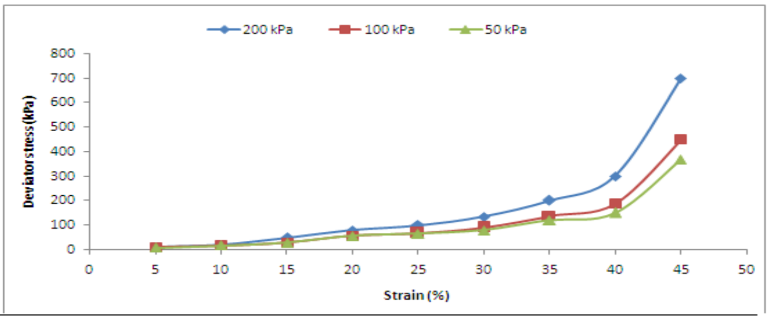

Fig. – 5 Deviator stress-strain curves of direct shear tests.

V. Conclusion

The municipal solid waste was collected from open dumping area near Khermai Road, Satna for physical and geotechnical characterization of MSW. The characterization include the physical composition, water content, specific gravity Grain size distribution, hydraulic conductivity, compressibility and strength properties were measured. The obtained geotechnical engineering properties were compared to data reported in the literature.

The water content in the MSW passing the 10 mm sieve measured was ranged from 90% to 145% on dry weight basis, equivalent to 47% to 51% on wet weight basis. A maximum dry density of 1100 kg/m^3 was recorded at optimum moisture content of 45%. Specific gravity of MSW in the present study was found to be 2.22. The lower value of specific gravity can be attributed to the presence of decomposed organic matter. The hydraulic conductivity obtained from the tests was $4.5x10^{-6}$ m/s and $5.3x10^{-5}$ m/s for falling head and constant head method respectively. The hydraulic conductivity varied in the range of $3.12x10^{-6}$ to $3.82x10^{-5}$ m/s. It is found that hydraulic conductivity decrease with the increase in confining pressure. The cohesion and friction angle values were found to be 12kPa and 38° respectively for 20% strain levels in the direct shear test. Hence proper understanding of slope stability issues in landfill is very essential and improper data or lack of data may lead to failures.

These findings will help in guiding geotechnical engineers when designing and constructing foundations for buildings and other related structures on these types of soils.

References

[1]. Sharholy, M., K. Ahmad, G. Mahmood & R. C. Trivedi, (2008), Municipal solid waste management in Indiancities – A review. Waste Management **28:** 459-467.

[2]. Sethi Sapna et al. (2013) Characterization of Municipal Solid Waste in Jalandhar City, Punjab, India, J. Hazard. Toxic Radioact. Waste 2013.17: 97-106.

[3]. Reddy, K. R., Hettiarachchi, H., Gangathulasi, J., Bogner, J. E., and Lagier, T. (2009c). “Geotechnical properties of synthetic municipal solid waste.” Int. J. Geotech. Eng., 3(3), 429–438

[4]. Sandro Lemos Machado et al. (2010), Evaluation of the geotechnical properties of MSW in two Brazilian landfills Waste Management 30 (2010) pp 2579–2591

[5]. Sivakumar Babu G.L et al. (2012), Study Of Engineering Properties Of Municipal Solid Waste Of BangaloreCity Proceedings of Indian Geotechnical Conference December 13-15, 2012, Delhi, (Paper No G 705).

[6]. Dixon, N., and D. R. V. Jones. (2005). Engineering Properties of MSW. Geotextiles and Geomembranes. (23)3. Pg. 205 – 233.

[7]. Phani K Adappa et al.(2006) Municipal Solid Waste – A Review of Classification System A CSBE/ASABE Inter Sectional Meeting Presentation Paper Number: MBSK 06-209.

[8]. Ayininuola, G.M.(2014), Decomposed solid waste impact on soil shear strength and California bearing ratioIOSR-JMCE Volume 11, Issue 3 Ver. VII (May- Jun. 2014), PP 15-17

[9]. ASTM. (2007), Standard test method for laboratory compaction characteristics of soil using modified effort, D1557, West Conshohocken, PA.

[10]. Sivakumar Babu G.L., Krishna R.R., Sandeep K. C. and Hanumanth S.K. (2010) Prediction of long-term municipal solid waste landfill settlement using constitutive model, Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, ASCE, April 2010, 139-150.

[11]. Reddy, K.R et al.(2011),Geotechnical properties of municipal solid waste at different phases of biodegradation, Waste Management 31 (2011) pp 2275–2286

[12]. Reddy, K.R., Hettiarachchi, H., Parakalla, N., Gangathulasi, J., Bogner, J., 2009b. Geotechnical properties offresh municipal solid waste at Orchard Hills Landfill,USA. Waste Management 29 (2), 952–959.

[13]. ASTM, 2008, Annual Book of Standards. American Society of Testing and Materials,West Conshohocken, PA.

[14]. Gabr, M.A., Valero, S.N., (1995), Geotechnical properties of municipal solid waste. Geotechnical Testing Journal, ASTM 18 (2), 241–251.

[15]. Gabr, M.A., Hossain, M.S., Barlaz, M.A., 2007. Shear strength parameters of municipal solid waste with leachate recirculation. ASCE Journal of Geotechnical and Geoenvironmental Engineering 133 (4), 478–884.

[16]. Jones, D.R.V., Taylor, D.P., Dixon, N., 1997. Shear strength of waste and its use in landfill stability. Proc. of the Geoenvironmental Engineering Conference, Thomas Telford, 343–350.

[17]. Musa Alhassan (2012), Effect Of Municipal Solid Waste On Geotechnical Properties Of Soils, IJESMER Vol.1 (5), Pp. 204 - 210, Sept. - Oct., 2012

[18]. Vilar, O. M., and Carvalho, M. F. (2004). “Mechanical properties of municipal solid waste.” J. Test. Eval., 32(6), pp 438–449.