Utilization of Municipal Solid Waste from Okhla Landfill as a Highway Embankment Material

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1 Introduction

Rapid population growth combined with higher thrust on infrastructure development has immensely altered the land utilization pattern. The land uses for housing, industries and others have extremified, eventually demanding adequate connectivity. Upgradation of existing roads and construction of new networks are being planned and implemented on a large-scale putting enormous pressure on conventional road building materials such as natural soil and aggregates. The continuous usage of these natural resources is degrading our environment. Therefore, new technologies are required to reshape the dynamics of road construction with a renewed focus on sustainable development. Such emerging technologies include the use of materials such as recycled materials or plastics. One of these innovative materials that are being encouraged worldwide to lower the impact on environment is MSW. It is a heterogeneous waste consisting of various types of discarded domestic and commercial items like food scraps, wooden pieces, construction debris, metals, glasses, paper, hospital waste, sewage sludge, etc. The composition of MSW varies from one region to another depending on several factors like demographic features, disposal legislations by government, etc.

On the contrary, the generation of huge amount of MSW due to uncontrolled industrialization and urbanization has raised alarming concerns regarding its safe dumping, control and management. Environmental issues associated with MSW are another reason why it is significant to reduce its accumulation to safeguard human

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health and nature. The idea to use MSW in the building of efficient roads and highways to cater the growing demand of long-lasting, cost-effective infrastructure for future will be a paradigm shift. This initiative will simultaneously balance both the above-stated problems and lead to sustainable development. However, the nature of MSW is very complex as it is a blend of stable and degraded constituents. Also, it may contain hazardous substances which can contaminate the soil and groundwater. So, to analyze the potential use and adopt MSW as a road building material, it is very crucial to determine its geotechnical properties ensuring safety of human health and environment. The geotechnical characterization of MSW is a difficult task because of its heterogeneous nature and its properties like unit weight, organic content, shear strength, etc., widely varies. It is also very challenging because the properties keep changing with different phases of degradation that can influence its mechanical response. Emphasizing on the paramount importance of the geotechnical properties of MSW, this paper involves several studies that have been conducted worldwide in different landfills to present a range of values of different properties. Also, the physical, geotechnical and chemical properties of solid waste from Okhla Landfill have been identified to check its feasibility as a highway embankment material.

2 Literature Review

Abreu and Vilar [1] evaluated the shear strength properties of MSW samples with different ages collected from three landfill sites in Sao Carlos, Brazil. A specially designed direct shear testing device of capacity 250 KN was used to test 8 specimens under loads of 50, 150 and 200 kPa. The results showed that with the gain in age, the MSW transformed from material of high cohesion to material of low cohesion. For more degraded wastes, ϕ (friction angle) = 30° and c (cohesion) = 4.4 kPa and for less degraded wastes, $\phi = 22°$ and c = 13.7 kPa were obtained.

Havanagi et al. [2] investigated the feasibility of utilizing the MSW as highway embankment material, collected from Ghazipur Landfill Site, New Delhi, India. 200 tons of MSW of different ages were collected from three locations. Waste was passed through 80, 35, 16 and 4 mm sieves and then preliminary geotechnical properties were determined. A mixture of fractions passing through 16 mm and those retained on 37.5/35 and 16 mm was selected as a final material to be tested for embankment construction. The material was categorized as GM, i.e., silty gravel and of medium plasticity with liquid limit of different samples ranging from 32 to 34%. Results indicated that dry density does not vary much with moisture content as compaction curves obtained were almost flat. The MDD and OMC varied in the range 16.0–16.7 kN/m^3 and 14–17%, respectively. The free swelling index value was low and varied from 12 to 24%. It was found to be low to medium compressible soil with compressibility index ranging from 0.14 to 0.19. Permeability was reported between 1.55×10^{-9} to 1.21×10^{-8} m/s, ϕ in the range 28°–35° and average value of coefficient of consolidation in the stress range 79.0–628.0 kN/m^2 was 4.14×10^{-6} m^2/s. MSWs embankments of 3 and 5 m height were considered as fill material for widening of NH-24 and its feasibility as embankment was checked by conducting stability and settlement analysis. The reported values of settlement were 244 and 304 mm including primary and secondary consolidation for 3 and 5 m embankment that were less than allowable settlement of 300 and 600 mm, respectively. For critical draw down conditions, the factor of safety under seismic loads was found to be in the range of 1.64–1.79 and it exceeded minimum value of 1.25. It was concluded that final segregated sample was a non-hazardous material and 65–75% of it can be effectively used for embankment construction.

Feng et al. [3] analyzed MSW samples from Laogang Landfill, Pudong district of Shanghai, China. Three samples of ages 0, 0.3, 2 & 4 years were collected from depth of 0, 4, 11, 16 m along with three fresh samples. The results showed the alteration in composition of the MSW with age and time. For depth of 0 to 16 m, void ratio reduced from 2.5 to 1.76, whereas unit weight escalated from 7.2 to 12.5 kN/m^3. From 0 to 11 m depth, water content increased from 30 to 68.9% and from 11 to 16 m depth, it decreased. Constant head permeability test was used to find hydraulic conductivity which was observed to be 4.6×10^{-4} to 6.7×10^{-3} cm/s. For determining shear strength, four samples were compressed under load of 50, 100, 200, 400 kPa for 2 h. The results showed that shear strength improved with unit weight, normal stress and displacement rate and as samples in this study consisted of less fibrous materials, shear strength values obtained here were much below than the values estimated by other countries. With the increase in depth from 4 to 16 m, the friction angle ranged from 15.7° to 21.9° and cohesion ranged from 29.1 to 18.3 kPa.

Reddy et al. [4] studied the effect of degradation on geotechnical properties of MSW samples collected from Orchard Hills Landfill, Illinois, USA by using specially devised bioreactor cells with leachate recirculation. The assembly consisted of six identical bioreactor cells (S1–S6) to carry out degradation process and study the effect by allowing the growth of microbes at a temperature of 35°–38° C. In total six samples were prepared, three (S1–S3) by mixing waste with 70% leachate and 30% sludge and rest three (S4–S6) by mixing 50% leachate and 50% sludge. The samples were degraded to different levels in the bioreactor assembly and then tested. The results showed an increase in moisture content while for highly degraded stage (S6), organic content decreased from 84 to 58%, bulk unit weight escalated from 7.12 to 10.79 kN/m^3. The value of permeability also went down from 10^{-2} cm/s (fresh waste) to 10^{-4} cm/s (S6). The obtained value of primary compression ratio was between 0.24 and 0.32 and it increased with extent of degradation. Secondary compression ratio ranged from 0.012 to 0.015. From direct shear tests, the value of c obtained varied in the range 29–65 kPa and ϕ reduced from 30° to 12° for initial stage to (S6) while from triaxial testing, the value of c and ϕ ranged from 14 to 51 kPa and 7°–14°, respectively.

Zhao et al. [5] performed a number of laboratory experiments on fresh and degraded specimens collected from Chongqing Landfills under a controlled condition to examine the variation in shear strength parameters of MSW at different phases of biodegradation. A degradation-drained direct shear test was first carried out using a degradation apparatus on 45 fresh shredded samples reconstructed in a laboratory.

Then, the triaxial shear test under CD conditions was executed on one sample group each month and the results showed that as the strain escalated from 5 to 20%, *c* varied from 35.90 to 66.42 kPa and ϕ varied from 29° to 38°. The direct shear test done on fresh samples showed that as the extent of degradation grew from 0 to 76.54%, the value of c varied from 0 to 22.24 kPa, and ϕ varied from 14.41° to 27.86°. It was suggested that as decomposition takes place, friction angle diminishes while cohesion enhances. The direct shear test done on degradable samples revealed that as the moisture content hiked from 25.2 to 41.1%, ϕ advanced from 36.38° to 41.60°, and the c first increased from 2.22 to 6.29 kPa and then reduced to 2.01 kPa.

Naveen et al. [6] performed laboratory study to find out shear strength parameters and compressibility of municipal solid waste taken from dump site around Bangalore, India. The site was more than 10-years-old. Results revealed that the MSW consisted of 75% particles coarser than 4.75 mm and 88% particles coarser than 2.36 mm. Maximum dry density was found to be 9.28 kN/m^3 at 42.8% optimum moisture content. Compression ratio, friction angle and cohesion were determined to be 0.105, 25.6° and 10 kPa, respectively.

Zhang and Wu [7] utilized a new direct shear testing instrument to study the shear strength of municipal solid waste. The test samples were tested at different vertical loads and different void ratios as per standard in China. It was suggested that MSW is a combination of incompressible solid material, reinforced material and easily biodegradable material. First sample was put through a stress of 12.5 kPa for 24 h and then sheared at a velocity of 0.1 r/m till failure. Similarly, second, third and fourth samples were subjected to 25, 50 and 100 kPa till shear failure. Observations revealed that shear stress escalated with shear strain and also the natural shear strength of MSW was mainly influenced by shear strain. Another factor was initial void ratio which affected shear strength inversely. For shear strain of 5%, obtained values of c varied from 4.7 to 12.6 kPa and ϕ varied from 14.5° to 18.3° while for shear strain 20%, obtained values of c varied from 8.5 to 17.2 kPa and ϕ varied from 25.5° to 30.7°.

Hyun Il et al. [8] studied geotechnical properties of MSW from Whamyung Landfill site, Busan, Korea. Results obtained revealed that compression index was about 0.04 from small scale and 0.09 from large-scale one-dimensional consolidation tests. The values of ϕ and *c* ranged from 36° to 46° and 25–60 kN/m^2, respectively, as obtained by conducting triaxial and direct shear test.

Wu et al. [9] determined the physical and chemical properties of MSW obtained from a landfill located south of Beijing, China. Samples were collected from shallow (1–4 m), medium (11–14 m) and deep layers (22–25 m) of ages 3, 6 and 10 years, respectively. Variation in results was observed with depth and age. The specific gravity obtained for different depths and ages lies between 1.51 and 2.14. The in situ unit weight of MSW samples increased with the increase of depth and varied in the range 6.98–14.32 kN/m^3. The dry bulk density ranged from 0.52 to 0.95 g/cm^3.

Stark et al. [10] used field and laboratory results of shear test along with back analysis of waste slope failure records to review shear strength of MSW. Results showed that several factors like waste type, moisture conditions, overburden pressure, composition, compaction, daily cover, degradation, etc., influence shear strength parameters for municipal solid waste. For direct shear tests, shear boxes of length 15–100 cm, width 15–100 cm and depth 22–30 cm were used. When maximum shear displacement of 250 mm was achieved, tests were terminated. It was observed that even after the termination of test, shear stress continued to increase and to obtain the peak shear resistance of MSW, shearing displacement should exceed 150 mm. For carrying out consolidated drained triaxial compression test, specimen of diameter 15–30 cm and length 30–60 cm were prepared. They were subjected to 46% axial strain corresponding to displacement of 21 cm. It was noted that with increase in displacement/strain, municipal solid waste shear resistance usually increased and this tendency was observed more in triaxial compression test. For the peak shear strength of MSW, shear displacement exceeding 60 mm or an axial strain exceeding 20% was suggested to be used in shear test. It was recommended that the vertical landfill slopes which remain stable for a long duration, peak shear strength is high at or near them. Also, the shear strength of MSW, at high normal stresses can be represented by a bilinear strength envelope that matches to 25 mm shear displacement and 10% axial strain. For normal stresses $\geq$200 kPa, $c = 30$ kPa and $\phi = 30°$ and for normal stresses <200 kPa, $c = 6$ kPa and $\phi = 35°$ were proposed.

3 Materials and Methods

3.1 Material Used

The MSW samples were collected from Okhla Landfill Site, New Delhi, India. The latitude and longitude of the landfill site are 28.5118° North and 77.2836° East, respectively. The location map of site is shown in Fig. 1. The site was decommissioned in 2018 and after that no fresh dumping of municipal waste was done at the landfill site.

Fig. 1 Location map of Okhla Landfill Site

Fig. 2 Samples collected from Okhla Landfill Site

The collected MSW was dark brown in color as shown in Fig. 2. It mainly consisted of three parts: incompressible solid material such as gravel, sand, glass pieces, construction and demolition waste, difficult to be biodegraded materials such as plastic, cloth and rubber, and easily biodegradable materials such as paper, food waste and wood.

3.2 Characterization Methods

To characterize MSW samples their physical, geotechnical and chemical characterization was done in the present study.

The grain size analysis was performed by sieving the soil sample through a series of sieves of sizes 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm and 150 μm for coarse fraction and the fraction of soil sample passing through 75 μm mesh sieve was analyzed by sedimentation method using hydrometer as per IS: 2720-Part-4 [11]. To determine the specific gravity of soil sample, pycnometer was used. About 10 gm of oven dry soil passing through 2 mm sieve was taken and various weights, i.e., weight of empty bottle, weight of bottle filled with water, weight of bottle filled with water and sample, etc., were taken and from these weights specific gravity of soil sample was calculated as per IS: 2720-Part-3 [12]. Atterberg limits test was done according to IS: 2720-Part-5 [13]. Standard compaction test was accomplished on soil samples following IS: 2720-Part-7 [14] to determine the maximum dry density and optimum moisture content.

Direct shear test was conducted on soil samples to determine shear strength parameters of soil, i.e., angle of shearing resistance and cohesion. For this purpose, three soil samples were prepared to the estimated density and then tested under normal stresses of 50, 100 and 150 kPa, respectively, to obtain the strength parameters. The

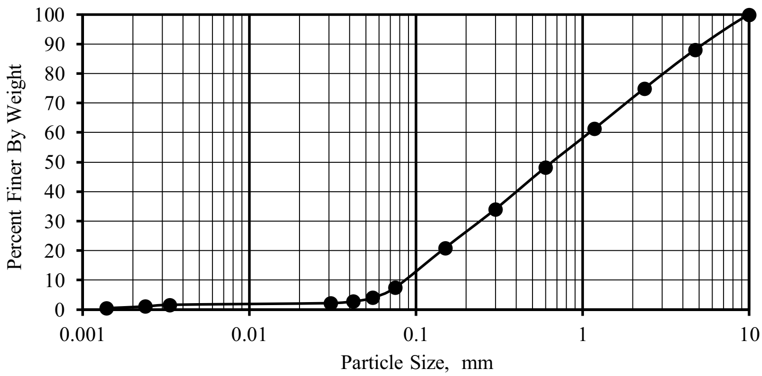


Fig. 3 Particle size distribution curve

test was performed as per IS: 2720-Part-13 [15]. California bearing ratio test was conducted according to IS: 2720-Part-16 [16] and falling head method was adopted for permeability test following IS: 2720-Part-17 [17].

The presence of salts also needs to be checked in soils prior to their use in construction as they may alter the soil properties. In this study, the concentration of sulfates was obtained as per IS: 2720-Part-27 [18]. Another unacceptable component in soil is organic matter as it can lead to swelling or shrinkage of the soil with fluctuating water content or implemented loads and it was determined as per IS 2720-Part-22 [19]. The chloride content was found out as per IS: 3025-Part-32 [20].

4 Results and Discussion

4.1 Grain Size Test

The grain size analysis result of MSW is shown in Fig. 3. From the results, the distribution came out to be 12% gravel, 81% sand, 6% silt and 1% clay. The uniformity coefficient and the coefficient of gradation were found to be 14.44 and 0.49, respectively. The MSW sample is concluded to be poorly graded sand with silt (SP-SM) as per Indian standard classification system.

4.2 Specific Gravity and Atterberg's Test

The specific gravity of MSW was calculated to be 2.27 which is considerably high than the fresh MSW samples which generally varies from 0.85 to 1.65 [9, 21]. The reason for high specific gravity may be due to degradation of MSW. However, specific

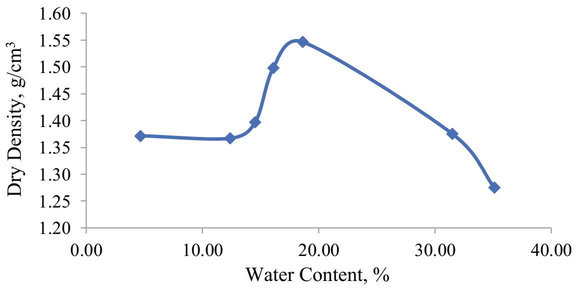


Fig. 4 Compaction curve

gravity is less than that of natural fill material which generally ranges from 2.65 to 2.85. Liquid limit of MSW sample was 18.5% and plastic limit was nil which shows that the collected MSW sample was non-plastic in nature.

4.3 Compaction Tests

The results of compaction test are presented in Fig. 4.

From the curve, the maximum dry density of MSW sample was determined to be 15.21 kN/m^3 at 18% optimum moisture content. Havanagi et al. [2] also measured values of MDD and OMC in similar range from municipal solid waste samples collected from Ghazipur Landfill. The MDD value for MSW sample is within permissible limit (MDD should not be less than 15.2 kN/m^3) as per Section 305.2.1.5 of Ministry of Road Transport and Highways [22], for an embankment of height 3 m.

4.4 Direct Shear Test

The shear stress-displacement curve for municipal solid waste sample is shown in Fig. 5. From figure, the value of cohesion and internal angle of friction for MSWsample was observed to be 0.12 kg/cm^2 and 26°, respectively.

4.5 California Bearing Ratio Test

The results of California bearing ratio test under unsoaked and soaked conditions are presented in Figs. 5b and 6a. In both the cases, the CBR value of 5.00 mm penetration was found to be higher than the 2.5 penetration even on repetition. For unsoaked samples, the CBR value was found to be 23.5%, whereas for soaked sample it reduced to 17%.

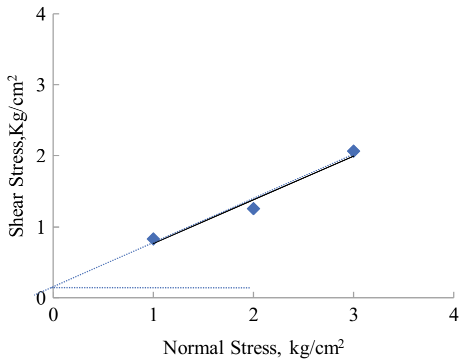
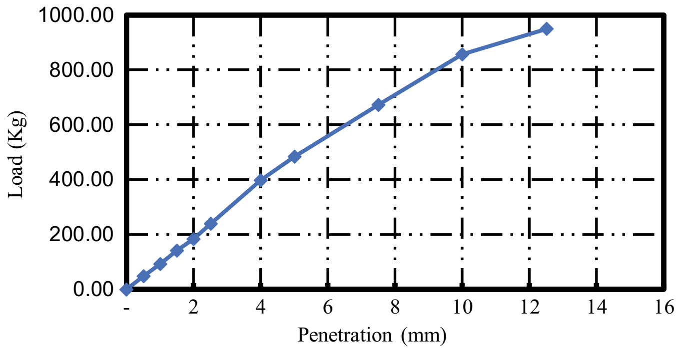
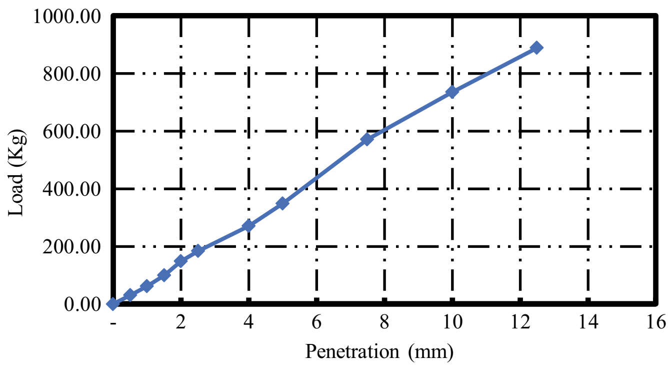


Fig. 5 Direct shear test



(a)



(b)

Fig. 6 California bearing ratio test results **a** unsoaked condition, **b** soaked condition

4.6 Permeability Test

The permeability of the municipal solid waste was found to be 2.45×10^{-4} cm/s which shows that it has poor drainage properties. This may be due to presence of plastic, rubber pieces and organic matter in MSW that cut the flow of water through it.

4.7 Chemical Characteristics

The sulfate content in the MSW sample was found to be 425 mg/Kg. According to the IARI manual for soil, the quantity of sulfates in soil should be less than 10,000 mg/kg. Hence, the concentration of sulfates in the municipal solid waste soil is well within permissible limits and can be safely used for construction. The organic matter of the sample was found to be 9.1% which is very high and can be considered for treatment before using in construction [23]. The chloride content of the sample was found to be 1699 mg/kg.

5 Conclusion

Based upon literature review and test results following observations have been made:

- There are number of studies conducted at international and national level to evaluate the properties of municipal solid waste obtained from different landfill sites. These studies revealed that the properties of municipal solid waste are dissimilar, site-specific, depends upon age and time. Hence, there is a requirement for individual descriptive research on properties and rather than its predictive assessment.
- The specific gravity of municipal solid waste is low that will be beneficial to use as fill materials as it will put forth lesser earth pressure.
- Results of compaction test showed that the value of max dry density is within the permissible limits as specified by Ministry of Road Transport and Highways for suitability of municipal solid waste in construction of an embankment of height 3 m.
- The organic matter found in the municipal solid waste soil is very high that can be considered for treatment before using in construction.

Based on the above conclusions, municipal solid waste from Okhla Landfill can be described as a suitable material for constructing highway embankments. This waste soil can also be mixed with the local soil or other available materials in different proportions to get more beneficial and profitable solutions.

References

1. Abreu AES, Vilar OM (2017) Influence of composition and degradation on the shear strength of municipal solid waste. Waste Manag. 68:263–274. https://doi.org/10.1016/j.wasman.2017.05.038
2. Havanagi VG, Sinha A, Parvathi GS, Chandra S (2017) Municipal solid waste in road embankment construction—a case study. J . Indian Roads Congr 78–90
3. Feng SJ, Gao KW, Chen YX, Li Y, Zhang LM, Chen HX (2017) Geotechnical properties of municipal solid waste at Laogang Landfill, China. China. Waste Manag. 63:354–365. https://doi.org/10.1016/j.wasman.2016.09.016
4. Reddy KR, Hettiarachchi H, Giri RK, Gangathulasi J (2015) Effects of degradation on geotechnical properties of municipal solid waste from Orchard Hills Landfill, USA. Int J Geosynth Gr Eng 1:1–14. https://doi.org/10.1007/s40891-015-0026-2
5. Zhao YR, Xie Q, Wang GL, Zhang YJ, Zhang YX, Su W (2014) A study of shear strength properties of municipal solid waste in Chongqing landfill, China. Environ Sci Pollut Res 21:12605–12615. https://doi.org/10.1007/s11356-014-3183-2
6. Naveen BP, Sivapullaiah PV, Sitharam TG (2014) Compressibility and shear strength of dumped municipal solid waste. J Solid Waste Technol Manag. https://doi.org/10.5276/JSWTM.2014.327
7. Zhang ZY, Wu DZ (2011) Study on the properties of natural shear strength for municipal solid waste. In: Applied mechanics and materials (2011)
8. Hyun Il P, Borinara P, Hong KD (2011) Geotechnical considerations for end-use of old municipal solid waste landfills. Int J Environ Res 5:573–584. https://doi.org/10.22059/ijer.2011.364
9. Wu H, Wang H, Zhao Y, Chen T, Lu W (2012) Evolution of unsaturated hydraulic properties of municipal solid waste with landfill depth and age. Waste Manag 32:463–470. https://doi.org/10.1016/j.wasman.2011.10.029
10. Stark TD, Huvaj-Sarihan N, Li G (2009) Shear strength of municipal solid waste for stability analyses. Environ Geol 57:1911–1923. https://doi.org/10.1007/s00254-008-1480-0
11. IS 2720 (Part 4)-1985: Methods of test for soils, Part 4 grain size analysis. Bureau of Indian Standards, New Delhi, India
12. IS 2720 (Part III/Sec 1)-1980: Methods of test for soils Part III Determination of Specific Gravity Section 1 Fine Grained Soils. Bureau of Indian Standards, New Delhi. https://doi.org/10.1093/jaoac/20.3.535
13. IS 2720 (Part 5)-1985: Methods of test for soils, Part 5 Determination of liquid limit and plastic limit. Bureau of Indian Standards, New Delhi, India
14. IS 2720 (Part VII)-1980: Methods of test for soils, Part 7 determination of water content-dry density relation using light compaction. Bureau of Indian Standards, New Delhi
15. IS 2720 (Part 13)-1986: Method of test for soils, Part 13 direct shear test. Bureau of Indian Standards, New Delhi
16. IS 2720 (Part 16)-1987: Method of test for soils, Part 16 laboratory determination of CBR. Bureau of Indian Standards
17. IS 2720 (Part 17)-1986: Methods of Test for Soils, Part 17 laboratory determination of permeability. Bureau of Indian Standards, New Delhi
18. IS 2720 (Part XXVII)-1977: methods of test for soils, Part XXVII determination of total soluble sulphates. Bureau of Indian Standards, New Delhi
19. IS:2720–22 (1972): Indian Standards, methods of test for soils, Part 22: determination of organic matter. Bureau of Indian Standards
20. IS 3025 (Part 32)-1986: Method of sampling and test (physical and chemical) for water and wastewater, Part 24 Chloride. Bureau of Indian Standards, New Delhi
21. Breitmeyer RJ, Benson CH (2011) Measurement of unsaturated hydraulic properties of municipal solid waste. In: Geotechnical Special Publication

22. Indian Roads Congress (IRC), Ministry of Road Transport & Highways (MORTH): Section 305.2.1.5. In: MORTH specifications for road and bridge works. In: 5th revision. Indian National Congress (2013)
23. Somani M, Datta M, Ramana GV (2017) Critical aspects relating to re-use of aged municipal solid waste for geotechnical purposes. In: Indian Geotechnical Conference 2017 GeoNEst (2017)