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Study of Compacted Sand-Bentonite Mixture as Material of Low Hydraulic Conductivity Liner of Landfill for Solid Waste Disposal

Anup Tiwari[1], Sanjeev Suman[2] & Subir Sharma[3]
[1]M. Tech. Scholar, Department of Civil Engineering, Govind Ballabh Pant University of Agriculture & Technology, Pant Nagar.
[2&3]Assistant Professor, Department of Civil Engineering, Govind Ballabh Pant University of Agriculture & Technology, Pant Nagar

Abstract : *Solid waste disposal is a major problem in developing countries; proper disposal of solid waste by landfill is important from ground water contamination point of view. The compacted Sand-Bentonite mixture may be used as buffer and backfill materials for engineering barriers for hazardous waste. It is important to evaluate the hydraulic conductivity of the mix to avoid percolation of leachate in ground water reserve. In present research, sand procured from the bank of River Gaula at Haldwani, distt. Nainital, (Uttarakhand) was mixed with different proportions of sodium bentonite. Hydraulic conductivity test was conducted to determine suitability of mix using Jodhpur Permeameter apparatus. Direct Shear Test was conducted to determine the shear strength properties of sand-bentonite mixture. The present paper discuss the results obtained from the test conducted.*

1. Introduction

Humankind has been generating and disposing of solid waste throughout its history. The less volume of waste generated and disposal in pit as landfill and rare presence of these landfills in closed vicinity of mankind, caused negligible impact on health and environment in past. As the world hurtles toward its urban future, their economic wealth increases. As standards of living and disposable incomes increase, consumption of goods and services increases, which results in a corresponding increase in generated solid waste. It is estimated that the total solid waste generated by 377 million people living in urban India is 68.8 million tonnes per year. The largest part of the solid waste generated is municipal solid waste (MSW), which is waste generated from the households and commercial establishments. About 1,27,486 tonnes of Municipal Solid Waste was generated daily in the country during 2009 to 2012 [9].

Landfilling is the common method of waste disposal adopted by many municipalities. As per information received from State Pollution Control Board only 70% of total waste generated in country is collected out of which 12.45% is processed or treated. Rest is left for disposal by landfilling or other methods, former being the commonly adopted method. Due to the biochemical reactions occurring within the waste body, landfills produces leachates, which pollutes the water and soil. Leachate is any liquid that in course of passing through matter extracts soluble or suspended solids, or any other component through which it has passed. When solid waste is disposed in un-engineered landfill site, water from rain and other sources comes in its contact and forms leachate. This leachate finds an access to the ground water, which may result in water borne diseases. Isolation of landfill with liner of impermeable material is safe method of solid waste disposal. Method of disposing solid waste at landfill site with impermeable liner is called sanitary landfilling.

2. Materials and methods

2.1 Materials

Sand used was obtained from the River Gaula at Haldwani, distt. Nainital, (Uttarakhand). The river sand was sieved through 2.36 mm IS sieve. Sand falls in the category of SP. Sand sample contained 1.7% coarse sand (i.e. sand fraction between 4.75 mm and 2 mm), 37.6% medium sand (i.e. sand fraction between 2 mm and 425 micron), and 58.94% fine sand (i.e. sand fraction between 425 micron and 75 micron) and fines (sand fraction smaller than 75 micron) was found to be 1.76%. Physical properties of sand used are given in Table 1.

Table 1. Physical properties of sand

Parameter	Value
Specific gravity (G)	2.685
Bulk Density (γ), g/cc	1.99
Plasticity Index	N-P
M.D.D ($\gamma_{d\,max}$), g/cc	1.689
(OMC), %	18
(ϕ), degree	17.22
Cohesion (c), kg/cm²	Negligible
Grain size distribution Sand size fraction (%) Silt size fraction (%)	 98.24 1.76
Soil type as per IS: 1498-1970	SP

Bentonite used in the present study was manufactured by S D Fine-Chem Limited Mumbai, Maharashtra. Bentonite is an absorbent aluminium phyllosilicate, impure clay consisting mostly of montmorillonite. Bentonite usually forms from weathering of volcanic ash, most often in the presence of water. Bentonite used was sodium Bentonite. Sodium Bentonite expands when wet, absorbing as much as several times its dry mass in water. The property of swelling on contact with water makes sodium Bentonite useful as a sealant, since it provides a self-sealing, low permeability barrier. Physical properties of bentonite used are shown in Table 2.

Table 2. Physical properties of bentonite

Parameter	Value
Specific gravity (G)	1.56
Liquid Limit (%)	116.33
Plastic limit (%)	67.04
Plasticity Index (%)	70.32
(ϕ), degree	0
Cohesion (c), kg/cm²	1.3
Soil type as per IS: 1498-1970	CH

2.2 Sample preparation

Bentonite used was dried in air and then kept in temperature and moisture controlled environment. Sand used was oven dried and material retained on 2.36 mm sieve was rejected so that coarse material may not puncture other liner materials. Different proportions of Bentonite i.e., 3%, 6%, 9%, 12%, 15%, 18%, 21% and 24% were added with the sand. Mixing was done by properly mixing in the dry sample before sprinkling the desired amount of water and mixing simultaneously. Tests conducted on samples without mixing in dry state showed irrelevant results because of the inhomogeneity of the mix. Bentonite used, swelled immediately after coming in contact with water and prevented uniform mixing. This method was adopted for uniformity of the mix. Compaction test samples were prepared at different water content (i.e. 6%, 10%, 14%, 18%, and 22%) for all Bentonite proportions. Samples were kept in polythene bags to swell properly for a period of 7 days. Polythene bags avoided any change in moisture content but allowed mixture to swell. Compaction tests were performed on the samples after period of 7 days. Samples for Permeability test, CBR test and Direct Shear test were prepared at Maximum Dry Density and Optimum Moisture Content. Samples for Permeability test, CBR test and Direct Shear test were left for swelling in polythene bags for a period of 7 days.

2.3 Experimental program

Tests on the sand and Bentonite samples with different proportion of Bentonite were performed in two phases,

In the first phase, geotechnical characteristics of the sand samples and Bentonite samples were determined by conducting grain size analysis, specific gravity test, and consistency limits test.

In the second phase, geotechnical properties of different sand and Bentonite samples with different proportions of bentonite were determined. The sand was mixed with different percentages of bentonite (3, 6, 9, 12, 15, 18, 21 and 24%) by dry weight of total sample. Series of standard compaction test, specific gravity test, direct shear test, CBR test and the permeability test were conducted to determine geotechnical properties of sand and bentonite mixes.

3. Results and discussion

3.1 Compaction test

The compaction test were performed on the sand and Bentonite mix with different proportions of Bentonite in accordance with IS: 2720 (Part-7)-1980. The results for Optimum Moisture Content (O.M.C) and Maximum Dry Density (M.D.D) of sand and Bentonite samples presented in Table 3 are an average value of the three tests conducted on the same mix. Compaction curves for various sand and Bentonite mix is shown in Fig 1. The variation of M.D.D with different percentage of Bentonite is shown in Fig 2 and variation of O.M.C with different percentage of bentonite is shown in Fig 3.

Table 3. OMC and MDD of sand and bentonite mix

Material	OMC (%)	MDD (g/cm^3)
100% S + 0%B	18.0	1.689
97% S + 3% B	17.5	1.706
96% S + 6% B	17.2	1.738
91% S + 9% B	16.5	1.762
88% S + 12% B	15.3	1.802
85% S + 15% B	14.0	1.840
82% S+ 18% B	13.5	1.868
79% S + 21% B	13.2	1.875
76% S + 24% B	12.8	1.881

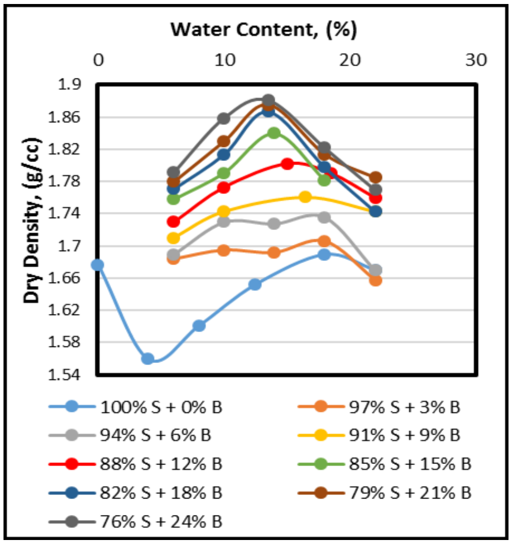

Fig 1. Compaction curve's

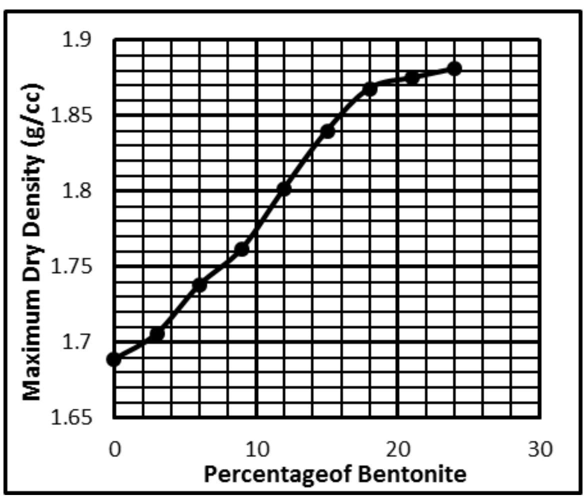

Fig 2. The variation of M.D.D with different percentage of bentonite

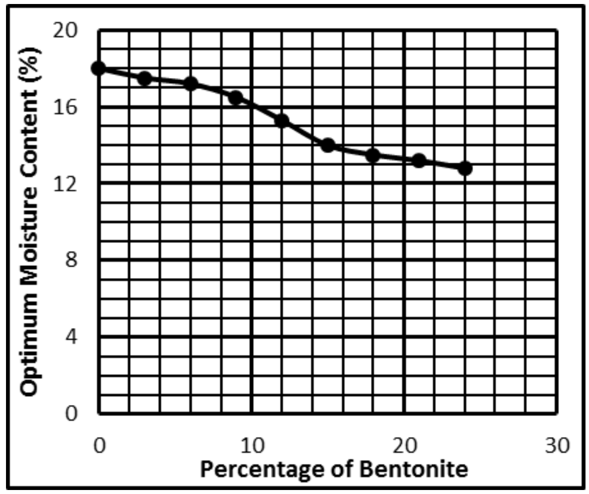

Fig 3. Variation of O.M.C with different percentage of bentonite

From Fig 1 of compaction curves for different sand and Bentonite mixes, it is clear that samples with lower Bentonite content (i.e. 0%, 3%, and 6%) behaves more like sand. These samples has shown an initial decrease in dry density before attaining Maximum Dry Density at Optimum Moisture Content. The curves from Fig.2 and Fig. 3 shows that with variation of Bentonite in sand samples, values of M.D.D increases from 1.689 g/cc at 0% Bentonite mix to 1.881 g/cc at 24% Bentonite mix and values of O.M.C decreases from 18.0% at 0% Bentonite mix to 12.8% at 24% Bentonite mix.

Dry density increases with incresed percentage of Bentonite, because the voids with in the sand are occupied by the fine Bentonite particles, which in result, increases the mass of soil solids for same volume. Due to this densification the chance for water to occupy the voids becomes less and water content (which is ratio of weight of water to weight of solids in a given mass of soil) decrease with increase percentage of Bentonite.

3.2 Direct shear test

Shear strength factors were determined in laboratory by direct shear test in accordance with IS: 2720 (Part 13) – 1986. Results obtained from direct shear tests are given as relation between normal stress and shear stress and value of cohesion and internal friction obtained from these plots is given in Table 4.

Table 4. Direct shear test result

Material	Cohesion (kg/cm^2)	Angle of internal friction (□)
100% S + 0% B	0.02	17.22°
97% S +3% B	0.04	16.17°
94% S + 6% B	0.07	15.60°
91% S + 9% B	0.12	15.11°
88% S + 12% B	0.16	14.60°
85% S + 15% B	0.20	14.00°
82% S + 18% B	0.23	13.50°
79% S + 21% B	0.27	13.00°
76% S + 24% B	0.31	12.40°

Value of cohesion shown in Table 4 is calculated as intercept on Y-axix of normal stress vs shear stress plot. Angle of internal friction is slope of the normal stress vs shear stress line. From the laboratory results of cohesion and angle of internal friction it is clear that cohesion which is function of clay content increases with increase of Bentonite percentage and angle of internal friction which is function of contact points between sand particles reduces with increase in percentage of bentonite.

3.3 Permeability test

Samples prepared for permeability test by compacting directly in permability mould at maximum dry density and optimum moisture content were left fully immersed in water for complete saturation. Complete saturation was indicated by discharge of water from outlet on surface of mould at lower end. Permeability test was performed on saturated samples in accordance with IS: 2720 (Part 17)-1986 under falling head condition. The results obtained from the permeability tests are shown in Table 5.

Co-efficient of permeability values as shown in Table 5 decreases from 1×10^{-5} m/s at 0% Bentonite mix to 9.64×10^{-10} m/s at 24% bentonite mix. Bentonite which swells after coming in contact with water occupies voids in sand matrix and permeability which is a measure of porosity is reduced. The rate of decrease of permeability is very large up to sample at 6% Bentonite. For the samples above 6% Bentonite content rate of decrease of co-efficient of permeability is very less.

Table 5. Co-efficient of permeability

Material	Permeability, (m/s)
100% S + 0% B	1×10^{-5}
97% S +3% B	3.88×10^{-7}
94% S + 6% B	3.39×10^{-8}
91% S + 9% B	2.48×10^{-8}
88% S + 12% B	2.03×10^{-8}
85% S + 15% B	1.96×10^{-8}
82% S + 18% B	1.8×10^{-8}
79% S + 21% B	6.75×10^{-9}
76% S + 24% B	9.64×10^{-10}

4. Conclusions

Following conclusions may be drawn on the basis of present study

1) Desired co-efficient of permeability should be less than or equal to 1×10^{-7} cm/s for a material to be used as landfill liner. This co-efficient of permeability is attained at 24% Bentonite content, which is 9.64×10^{-8} cm/s. The mix with 24% Bentonite content makes an impermeable liner, so mix with 24% Bentonite content is selected to prepare landfill liner.

2) MDD decreases with increasing proportion of Bentonite in the mix. Sand and Bentonite mix has maximum density at 24% Bentonite content that increases the stability of mix as liner material.

3) OMC followed a decreasing trend with increasing proportion of Bentonite in the mix, which is 12.8% at 24% Bentonite content.

4) Angle of internal friction reduced with increasing Bentonite proportion in the mix and reached minimum value of 12.40º at 24% Bentonite content.

5) Cohesion increased with increasing proportion of Bentonite and reached maximum value of 0.31 kg/cm^2.

5. Acknowledgements

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