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A Study on M-Sand Bentonite Mixture for Landfill Liners

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***Abstract*—In modern landfills, the waste is contained by a liner system. The primary purpose of the liner system is to isolate the landfill contents from the environment and, therefore, to protect the soil and ground water from pollution originating in the landfill. Due to high swelling and adsorption capability, bentonite is commonly used material for liners. Sand is the basic material used with bentonite to improve its properties. Mixing sand with appropriate bentonite contents yields sand bentonite mixtures having low hydraulic conductivity that can be used as hydraulic containment liners. A series of laboratory experiments were conducted to evaluate the changes in soil properties such as consistency limits, compaction characteristics, hydraulic conductivity, strength characteristics and free swell index. In this study, compaction tests were conducted to determine the OMC and MDD of compacted M-Sand-bentonite mixtures. Hydraulic conductivity tests were conducted to assess the hydraulic conductivity of compacted M-Sand-bentonite mixtures. The M-sand bentonite mixture is tested to find out the exact proportion of the mixture which satisfies the landfill liner requirements.**

***Index Terms*— M-Sand bentonite mixture, bentonite, hydraulic conductivity, liners, compaction, atterberg limits, UCC, Free swell index, combinations, leachete.**

I. INTRODUCTION

Waste liquids in the environment may result from several sources, e.g., uncontrolled dumping of pure solvents, spills, or infiltration of water through solid waste in landfill disposals resulting in contaminated leachate. Contaminants contained in this leachate can lead to significant damage to the environment and to the human health due to their mobility and solubility. One of the preferred methods of dealing with this kind of environmental problem is to dispose of the waste in landfills. In landfills compacted clay liners (CCLs) and geosynthetic clay liners (GCLs) are the most common materials used in construction of impermeable liners. According to international regulations, landfills must be constructed with containment systems with low hydraulic conductivity ($\leq 1x10^{-9}$m/sec) in order to avoid contamination of groundwater and soil.
Easy availability and economic feasibility make clayey soils the most preferred liner materials. Clayey soil liners are suitable as liners only when the temperature and moisture fluctuations are not high; otherwise, they can form cracks that cause the hydraulic conductivity to rise. Bentonite clay is widely used in these composites for waste containment due to its low hydraulic conductivity, high swelling potential and high cation exchange capacity. But exposed to high concentrations of inorganic pollutants, degradation of the bentonite clay can occur and a subsequent increase in the hydraulic conductivity.

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According to Daniel (1993), for any material to be used as a liner, it should have the following properties:

(i) The fluid transmission capability of a soil is defined as the permeability of the soil. Permeability is the measure of the materials ability to contain the leachate. A low permeability generally 10^{-9} m/s is required.

(ii) Durability and resistance to weathering is the quality of the material to withstand the forces of alternating wet/dry and freeze/thaw cycle.

(iii) Constructability, which means the material, should be reasonably workable in terms of placement and compaction under field conditions.

(iv) Compatibility with leachate: the liner material must maintain its strength and low permeability even after prolonged contact with leachate. For a landfill liner the following requirements are necessary.

- Hydraulic conductivity should be $\leq$ 1x 10^{-7} cm/sec
- % of fines $\geq$ 20-30%
- % Gravel $\leq$ 30%
- Plasticity index $\geq$ 7-10%

For most countries there is a need for a landfill liner that is natural, locally available, and that can be installed in an inexpensive way. The incorporation of bentonite fines into a naturally occurring soil, e.g. sand, will significantly alter the physical and chemical properties of the soil. One material that can meet the hydraulic conductivity criteria without suffering from shrinkage cracking is a sand-bentonite mixture [15]. Due to the unavailability of river sand M-Sand can be used as an alternative to river sand. The sand particles provide mechanical stability and prevent shrinkage of bentonite.

An investigation study is carried out on M-sand-bentonite mixtures with different percentages of bentonite additions, which starts from 5% to obtain the optimum M-Sand-bentonite mixture which satisfies the landfill liner requirements. Several standard tests were also performed to obtain properties of the M-Sand and the bentonite. Based on the test results, a suitable M-Sand-bentonite mixture that yields low hydraulic conductivity is selected for use as liner in hydraulic containment applications.

II. Materials and Properties

A. Bentonite

The bentonite used in this study was powdered sodium bentonite procured from Karnataka. This bentonite is generally used as drilling mud in boring activities. The liquid limit of this particular bentonite is obtained as 445% and free swell index as 220%. The basic properties of bentonite are presented in Table I.

B. M-Sand

Sand used in this study was local M-Sand which is typically used as a construction material. The basic properties of M-Sand are showed in Table II.

III. Experimental Programme

A. Atterberg Limits

Atterbergs limits were found out according to IS (2720: Part 5- 1985). Liquid limits shown to be useful indicators of clay behavior.

TABLE I: BASIC PROPERTIES OF BENTONITE

BASIC PROPERTIES OF BENTONITE	
Liquid Limit	445%
Plastic Limit	63%
Plasticity Index	382%
Specific gravity	2.6
Free swell index	220%
Moisture content(as supplied)	13.64%
Max Dry Density	10.69kN/m^3
OMC (%)	53%

TABLE II: BASIC PROPERTIES OF M-SAND

BASIC PROPERTIES OF M-SAND	
Uniformity Coefficient, C_u	0.76
Coefficient of Curvature, C_c	6.07
Percentage gravel (%)	0.70%
Percentage sand (%)	87.70%
Percentage fines (%)	11.60%
D_{10}	0.13
Specific gravity	2.70
Fineness modulus	3.32

B. Compaction test

Compaction tests were carried out in accordance with IS 2720 (Part 7) – 1973 for the M-Sand bentonite mixture for different combinations. The OMC and MDD for all the combinations are determined. The water content is determined by oven drying method.

C. Unconfined compression test

Unconfined compression test was conducted as per IS 2720(Part 10) - 1973 and strength behavior M-Sand bentonite mixture was found out.

D. Free Swell Test

Free swell tests were carried out in accordance with IS 2720 (Part XL) -1977 for the various combinations of M-Sand bentonite mixture.

E. Consolidation test

The experiments were carried out in a standard consolidation apparatus as per IS: 2720 (Part 15) - 1986 specifications. The samples were carefully filled in the consolidation mould and they were fully saturated, applied a seating load of 0.05kg/cm^2.

IV. RESULTS AND DISCUSSIONS

A. Atterberg limits for all Combinations

Liquid limit, Plastic Limit and Shrinkage Limit tests were conducted for four combinations of M-Sand bentonite mixture. Results obtained are shown in Table III.

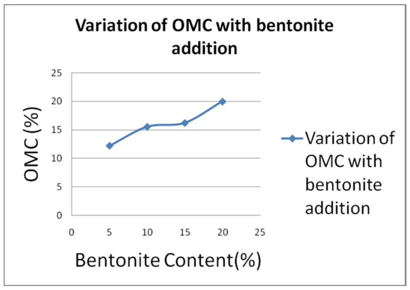
TABLE III: CONSISTENCY LIMITS

ATTERBERG LIMITS					
	Bentonite content(%)	LL (%)	PL (%)	PI	SL(%)
Comb. 1	5	27	-	NP	-
Comb. 2	10	31	-	NP	28.47
Comb. 3	15	36	25.11	10.89%	25.74
Comb. 4	20	40	26.98	13.02%	21.64

For combination 1 and combination 2 plastic limit cannot be determined and the combinations is reported as non plastic. For combination 4 plasticity index is obtained as 17.14% which is greater than 10%. Combination 4 satisfies the landfill liner criteria for Attterberg limits.

V. COMPACTION CHARACTERISTICS

The compaction tests were carried out for different combinations of M-Sand bentonite mixtures. Figure 1 and Figure 2 shows the variations of maximum dry density and optimum moisture content with the addition of bentonite content. When more bentonite was added, OMC increased and MDD decreased. This is due to the activity of bentonite. The volume of adsorbed water film around the clay particles increases the water content and decreases the dry unit weight.



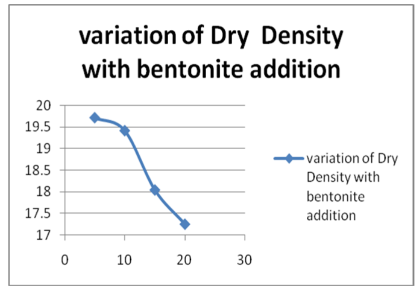


Figure 1: Variation of OMC with bentonite addition

Figure 2: Variation of MDD with bentonite content

When fine content (i.e., bentonite) is mixed with M-Sand, more water is required in compaction in order to achieve maximum dry unit weight. When water is added to the mixture, the water acts like lubricant that allows soil particles to move closer to each other, air void is minimized, and higher unit weight can be achieved.

When additional water was added after optimum water content, the dry unit weight of the compacted sand-bentonite mixtures drastically decreased particularly at high bentonite contents. The bentonite swelled further when more additional water was added. At this stage, the additional water and swelled bentonite which was lighter than sand, occupied more space in the compaction mould resulting in decreasing of dry unit weight of mixture.

A. Effect of Bentonite on Unconfined Compressive Strength of M-Sand Bentonite mixture

The unconfined compressive strength of M-Sand bentonite mixture increases as the bentonite content increases. Results are shown in the Figure 3.

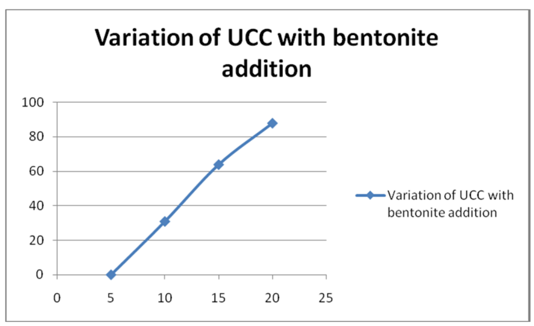


Figure 3: Variation of UCC value with bentonite addition

B. Free Swell Index

The results of free swell index are shown in Figure 4. From the test results it is observed that with increase in percentage of bentonite increases the free swell index. It is marginal upto 10% and is rapid beyond 15%.

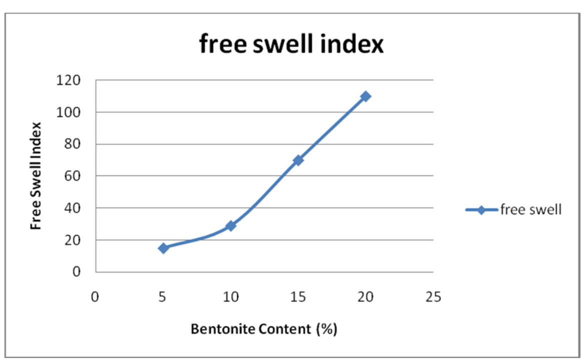


Figure 4: Variation of Free Swell index with bentonite addition

C. Effect of Bentonite on Hydraulic Conductivity of M-Sand - Bentonite Mixtures

The hydraulic conductivity of Msand-bentonite mixtures decreases with increasing bentonite content. Results are shown in Table IV.

The common regulatory requirement for compacted soil liners states that the hydraulic conductivity should be less than 1×10^{-9} m/s. Combination 1 itself satisfies the hydraulic conductivity criteria for landfill liners. The very low bentonite content leads to an uneven distribution of bentonite within the sand matrix and this resulted in preferential flow-paths.

TABLE IV: VARIATION OF COEFFICIENT OF PERMEABILITY WITH BENTONITE ADDITION

COEFFICIENT OF PERMEABILITY		
	Bentonite %	k
Comb. 1	5	$1.45\text{x}10^{-9}$ m/s
Comb. 2	10	$1.158\text{x}10^{-9}$ m/s
Comb.3	15	$7.356\text{x}10^{-10}$ m/s
Comb. 4	20	$6.86\text{x}10^{-10}$ m /s

VI. CONCLUSIONS

From this study conclusions can be drawn out that the hydraulic conductivity of M-Sand bentonite mixtures decreases as the bentonite content increases. A combination of 80% M-Sand and 20% bentonite is selected for the use of hydraulic containment liners. Table V shows the results of Combination 4 (80% M-Sand and 20% bentonite).For combination 4 the liquid limit is obtained as 40% and the plastic limit as 22.86%. Hence the plasticity index is obtained as 17.14% which is greater than 10%. The hydraulic conductivity is obtained as $6.86\text{x}10^{-10}$ m /s which are less than the required value $1\text{x}10^{-9}$m/s. Combination 4 satisfies all the criteria for landfill liners. Hence combination 4 is selected as the optimum mixture for the landfill liners.

TABLE V: RESULTS OF COMBINATION 4

Results of Combination 4	
LL	40%
PL	22.86%
P.I	17.14%
SL	21.64%
OMC	20.00%
MDD	17.27kN/m³
k	6.86x10^-10m/s

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