Study on Liner Material Using Red Soil, Bentonite Mixture for Engineered Landfill

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Abstract: ***Generation of leachate is one of the major pollution problems arising from municipal landfill. Modern landfills must be highly engineered containment systems, designed to minimize the impact of soiled waste on the environment and human health. A liner is an engineered system to contain and control the pollution of the land and water environments surrounding the land disposal operation. The design of a liner, in the case of economically developing countries, will vary depending on a number of factors, including the potential of the landfill polluting the land and water environments, the local hydrogeology and meteorology, and the availability of suitable materials and monetary resources. The main factor affecting the quality of compacted clay liners/covers is its permeability which should not be greater than 1.0 × 10–9 m/sec. Due to non-availability of suitable soil, it is necessary to develop alternative material for liners and covers. In the present study Red soil is used as a basic material. The properties of this material are altered by adding bentonite to achieve the required properties of a competent material for landfill liners. Tests were conducted on red soil with 4, 8,12,16,20 and 24% of bentonite clay by weight.***

Keywords: Atterberg Limit, Leachate, Permeability, Unconfined Compressive Strength

1. Introduction

Landfill liners are exposed to various types of physical, chemical and biological processes which affected by leachate produced from the decomposition of waste dumps. The aim is to avoid any hydraulic connection between the wastes and the surrounding environment, particularly groundwater. To ensure this, the important characteristics for compacted landfill liners are selection of materials, hydraulic conductivity, strength, compressibility and contaminant retention capacity.

Compacted clay liners are of low cost, large leachate attenuation capacity and resistance to damage. Natural clay is often fractured and cracked and due to non-availability of suitable soil at a site, it is necessary to mix imported clay materials with local non-productive soils and industrial process wastes to achieve a suitable material. Red soil is rich in clay minerals and it is used as compacted liner materials for their low hydraulic conductivity which is required to be less than 1.00×10^ -7 cm/sec.
Bentonite was mixed with Red soil in 8,12,16,20,24% by dry weight The appropriate Bentonite-Red soil mix and the range of compaction parameters was determined that would give the required hydraulic conductivity, strength characteristics and minimum desiccation crack for their use as liner material.

1.1 Landfill

It is a land disposal site for waste. Preparation, management and control of the landfill must be of the highest standard to minimize the risks to human health and the environment. . Well-constructed and maintained landfills are safer than open dumping sites.

1.2 Leachate

A Leachate is a liquid that forms when landfill waste breaks down and water filters through that waste and picks up toxins and it drains or leaches from a landfill. Leachate from a landfill varies widely in composition depending on the age of the landfill and the type of waste that it contains. It usually contains both dissolved and suspended material. In older landfills and those with no membrane between the waste and the underlying geology, leachate is free to leave the waste and flow directly into the groundwater.

1.3 Landfill Liner

The estimated service life of a liner in a particular exposure condition is also an important factor in selecting a liner material. Engineering landfill basically consists of bottom liner and a top cover. These components play very important role in reducing the leachate quantity and minimizing the ground water pollution. Hence these are considered as the most critical components of an engineered landfill facility.

1.4 Liner Requirements

The directive determines that landfill base and sides should consist of mineral layer with the following requirements:
1) Landfill for hazardous waste – the layer should be characterized by the hydraulic permeability k equal or lower than 10-9 m·s-1 and thickness equal at least 5 m.
2) Landfill for non-hazardous waste – the same permeability and thickness equal or higher than 1m.
3) Landfill for inert waste –hydraulic permeability of 10-7 m·s-1 or less and thickness of at least 1m.

1.5 Material Suitability

It is generally taken that the requirements of a material for use as a landfill lining is its capability of achieving permeability of 1×10^{-9} m/sec or less following compaction. In terms of plasticity the division between clays and silts is known as the A-Line.

The NRA also define suitable materials as those clays with a Liquid Limit (LL) of less than 90%, a Plasticity index (PI) of less than 65% and a clay content of greater than 10%. Materials in excess of these limits can give rise to problems in stability, deformation and compaction in earthworks.

The current project aims at finding an accurate mixture of red soil and bentonite as well as fly ash and bentonite mixture, feasible for being used as compacted clay liner. Bentonie has high swelling and shrinkage properties which possess the danger of formation of cracks, which can be stabilized by addition of red soil as it would minimize the fine fraction in the mixture.

2. Literature Review

A. R. Ajitha, R. P. Naveena and E. Y. Sheela, investigated the use of a marine soil enhanced with bentonite as landfill liner material. There is no large variation in the properties of liner mix with leachate. So the liners are compatible with leachate and hence can be used for field applications.

J.Alam et al (2012) studied that a 20% bentonite-fly ash mix can be safely used as liner material. Plain fly ash remained non-plastic until 20% bentonite was added to the mixture. Addition of bentonite enhanced the geotechnical properties of fly ash.

Kananika nayak concluded that as the bentonite content increased in the compacted mixture, the permeability decreased. 20% bentonite-fly ash mixture showed permeability less than 1 ×10-7 cm/sec, which fulfilled the criteria for landfill liner. Whereas for pond ash, it was achieved at 12% bentonite content in the mixture.

Kumar and Sharma (2004) concluded that in a bentonite-fly ash mixture the plasticity, hydraulic conductivity, swelling and shrinkage properties decreased and the dry unit weight and strength increased with the increase in fly ash content.

3. Proposed Study

The current project aims at finding an accurate mixture of Red soil and bentonite, feasible for being used as compacted clay liner, to reduce the migration of leachate to the ground water and reduced to reasonable amount and to investigate the physical and chemical properties of different liner material.

The factors considered for liner material suitability are:
1. Efficiency
2. Resistance to damage
3. Longevity
4. Availability

Red soil with the addition of bentonite, lower the hydraulic conductivity to fulfill the design criteria.

4. Experimental Work and Methodology of Materials collected

Bentonite used for the experimental purpose was brought from Sogyan Chemicals and Red soil was collected from Campus of Assam Down Town University, Panikhaiti. Bentonite was mixed with Red soil in 8,12,16,20,24% by dry weight The appropriate Bentonite-Red soil mix and the range of compaction parameters was determined that would give the required hydraulic conductivity, strength characteristics and minimum desiccation crack for their use as liner material.

4.1 Determination of Index Properties

4.1.1 Determination of Moisture Content:

To determine the water content of the materials by oven drying method.

Table 4.1: Moisture Content of materials.

Sl No.	Description	Materials	
		Red soil	Bentonite
1	Mass of the tray in gram, M_1	833	805
2	Mass of the tray + Soil in gram, M_2	3051	1106
3	Mass of the tray + Dry soil in gram, M_3	2602	1100
4	Mass of water, $M_4 = M_2 - M_3$	449	6
5	Mass of dry sand, $M_5 = M_3 - M_1$	1769	295
6	Moisture Content, $\frac{M_4}{M_5} \times 100\%$	25.38	2.03

4.1.2 Determination of Specific Gravity

The specific gravity of red soil and bentonite were found out according to IS: 2720 (part- III, section-1)1980 by using pycnometer. In case of bentonite kerosene was used as it is non-polar in nature and so kerosene will not react with bentonite.

Table 4.2: Specific Gravity of Materials.

Sl. no	Mate-rials	M1 (gm)	M2 (gm)	M3 (gm)	M4 (gm)	Specific Gravity
1	Red soil	70	80	130	126	1.66
2	Bentonite	70	80	151	144.5	2.85

Where,
M_1 = Mass of an empty Pcynometer in gram
M_2 = Mass of an Pycnometer + Sand in gram
M_3 = Mass of an Pycnometer +Sand + Water in gram
M_4 = Mass of an Pycnometer + Water in gram
Specific Gravity = $\frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$

4.1.3 Sedimentation Analysis

A sample to be tested is placed without drying in a 200cc measuring cylinder, so that the sample is up to the 100cc mark. Add clean water up to 150cc mark. Dissolve one spoon of common salt in half liter of water thoroughly and add this to the measuring cylinder. The mixture is then shaken vigorously, the last few shakes being in sidewise direction. Allow the solids to settle down for a period of three hours. First the sand and then silt and clay over it. The height of the fine silt visible as settled layer above the sand is expressed as a percentage of the height of the sand below the silt content.

Table 4.3: Sedimentation analysis

Materials	Percentage Content (%)		
	Sand	Silt	Clay
Red soil	25	20	55
Bentonite	0	**2 5**	85

Figure 2.1: Sedimentation test

Table 2.1: DFS of materials

Materials	V_d (ml)	V_k (ml)	FSI(%)
Red soil	11	9	22.22
Bentonite	96	5	540

Table 2.2: DFS of Red Soil – bentonite mixture

Materials	V_d (ml)	V_k (ml)	FSI(%)
Red soil+ 4% bentonite	18	11	63.64
Red soil+ 8% bentonite	19	11	72.73
Red soil+ 12% bentonite	30	12	150
Red soil+ 16% bentonite	33	10	230
Red soil+ 20% bentonite	38	10	280
Red soil+24% bentonite	44	10	340

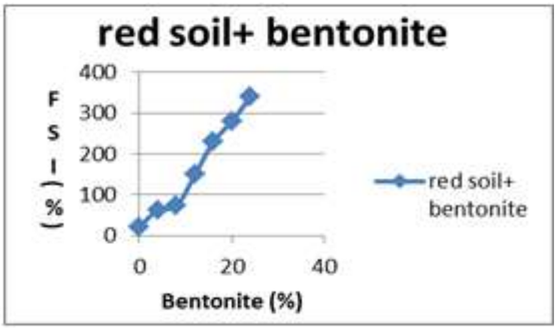

Figure 5.1: Free swell index

4.2 Determination of Geotechnical Properties

4.2.1 Free Swell Index

To determine the free swell index of soil as per IS: 2720 (Part XL) – 1977, the apparatus used are IS Sieve of size 425µ,Oven,Balance, with an accuracy of 0.01g,Graduated glass cylinder- 2 nos., each of 100ml capacity, and Kerosene. Take two specimens of 10g each of sample passing through 425µm IS Sieve and oven-dry. Pour each specimen into a graduated glass cylinder of 100ml capacity; now pour distilled water in one and kerosene oil in the other cylinder up to 100ml mark. Remove entrapped air by gently shaking or stirring with a glass rod, allow the suspension to attain the state of equilibrium (for not less than 24hours).Final volume of sample in each of the cylinder should be read out.

Free swell index = [Vd – Vk] / Vk x 100%

where,

V_d = volume of soil specimen read from the graduated cylinder containing distilled water.

V_k = volume of soil specimen read from the graduated cylinder containing kerosene.

4.3 Atterberg Limits:

4.3.1 Determination of Plastic Limit:

Plastic limit represents the water content at which a soil would just begin to crumble when rolled into a thread of approximately 3 mm diameter, this test were conducted to determine the plastic limit as per IS 2720(part V)-1985.

Table 2.3: Plastic limit of Red Soil – bentonite mixture

Sl no	Materials	Mass of container (M_1) in gm	Mass of container+wet thread sample (M_2)in gm	Mass of container + dry thread sample (M_3) in gm	Plastic limit
1	Red soil	22	28	26	50
2	Bentonite	22	26.5	24	125
3	Red soil+4%bento-nite	22	27	26	25
4	Red soil+8%bento-nite	22	26.33	25.6	20.27
5	Red soil+12%bento-nite	50	55	54	25
6	Red soil+16%bent-onite	57	68	65	37.5
7	Red soil+20%bento-nite	22	30	28	33.33
8	Red soil+24%bento-nite	22	32.5	30	31.25

4.3.2 Determination of liquid limit:

Test for liquid limit was conducted according to IS 2720 (part V)-1985 in the Cassagrande's liquid limit device.

Table 5.3: Observation of Liquid limit of red soil- bentonite mixtures

SN	Materials	No. of blows	Mass of container (M_1)in gm	Mass of container+ wet sample (M_2) in gm	Mass of container +dry sample (M_3) in gm	Liquid limit (%)
1	Red soil	39	22	34	30	50
		28	22	36	31	55.55
		25	22	33	29	57.14
		19	22	29	26	75
2	Bentonite	40	22	33	25	266.66
		35	22	35	25	333.33
		17	22	36	25	366.66
3	Red soil +4% bentonite	37	42	69	58	68.75
		30	50	79	67	70.58
		22	58	88	72	114.28

4	Red soil +8% bentonite	40	58	76	69	63.63
		22	50	73	64	64.28
5	Red soil + 12% bentonite	45	18	51	36	83.33
		37	18	52	36	88.88
		14	18	62	40	100
6	Red soil +16% Bentonite	38	4	29	18	78.57
		20	4	35	21	82.35
		15	4	33	19	93.33
7	Red soil +20% bentonite	40	22	53	41	63.15
		30	22	58	43	71.43
		23	22	59	43	76.19
8	Red soil +24% bentonite	43	22	59	46	54.166
		29	22	61	45	69.56
		16	22	66	44	100

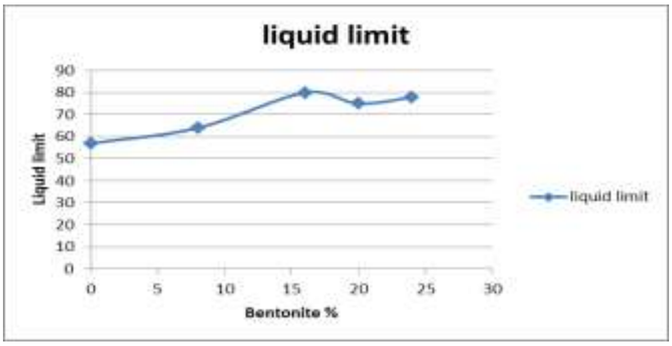

Figure 2.2: Liquid limit with increase in % of bentonite in red soil

4.3.3 Determination of Plasticity Index

Plasticity Index (Ip) is obtained by calculating the difference between Liquid Limit and Plastic Limit i.e., PI = (LL-PL).

Table 2.4: Plasticity index of red soil- bentonite mixtures

SN	Materials	Liquid limit	Plastic limit	Plasticity index
1	Red soil	57	50	7
2	Bentonite	355	125	230
3	Red soil + 4% bentonite	96	25	71
4	Red soil + 8% bentonite	64	20.27	43.73
5	Red soil + 12% bentonite	95	25	70
6	Red soil + 16% bentonite	80	37.5	42.5
7	Red soil + 20% bentonite	75	33.33	41.67
8	Red soil + 24% bentonite	78	31.25	46.75

4.3.4 Standard Proctor Test:

To determine the dry density and moisture content relation of soil and to find OMC and MDD from the relationship, standard proctor test is done.

Table 2.5: Red soil + 0% bentonite

Sl no	Percentage of water added by dry weight	15	30	40
1	Mass of mould (gm)	2064	2064	2064
2	Mass of mould + compacted sample(gm)	3480	979	3871
3	Mass of compacted sample(W_t) gm	1416	1915	1807
4	Volume of compacted sample (V) cc	981.75	981.75	981.75
5	Bulk density($\rho_t = W_t/V$) gm/cc	1.442	1.950	1.840
6	Average water content (w)	0.16	0.29	0.4
7	Dry density ($\gamma_d = \rho_t/(1+w)$) gm/cc	1.24	1.51	1.31

Table 2.6: Red soil + 8% bentonite

Sl no	Percentage of water added by dry weight	10	20	30
1	Mass of mould (gm)	2064	2064	2064
2	Mass of mould + compacted sample(gm)	3528	3950	3935
3	Mass of compacted sample(W_t) gm	1464	1886	1871
4	Volume of compacted sample (V) cc	981.75	981.75	981.75
5	Bulk density($\rho_t = W_t/V$) gm/cc	1.491	1.921	1.905
6	Average water content (w)	0.125	0.25	0.297
7	Dry density ($\gamma_d = \rho_t/(1+w)$) gm/cc	1.325	1.536	1.468

Table 2.7: Red soil + 12% bentonite

SN	Percentage of water added by dry weight	10	20	30	40
1	Mass of mould (gm)	2064	2064	2064	2064
2	Mass of mould + compacted sample(gm)	3212	3661	3938	3817
3	Mass of compacted sample(W_t) gm	1148	1597	1874	1753
4	Volume of compacted sample (V) cc	981.75	981.75	981.75	981.75
5	Bulk density($\rho_t = W_t/V$) gm/cc	1.169	1.626	1.908	1.785
6	Average water content (w)	0.11	0.19	0.32	0.428
7	Dry density ($\gamma_d = \rho_t/(1+w)$) gm/cc	1.053	1.366	1.445	1.25

Table 2.8: Red soil + 16% bentonite

SN	Percentage of water added by dry weight	10	20	30	40
1	Mass of mould (gm)	2064	2064	2064	2064
2	Mass of mould + compacted sample (gm)	3473	3813	3937	3822
3	Mass of compacted sample (W_t) gm	1409	1749	1873	1758
4	Volume of compacted sample (V) cc	981.75	981.75	981.75	981.75
5	Bulk density($\rho_t = W_t/V$) gm/cc	1.435	1.781	1.907	1.790
6	Average water content (w)	0.063	0.222	0.243	0.256
7	Dry density ($\gamma_d = \rho_t/(1+w)$) gm/cc	1.349	1.457	1.534	1.425

Table 2.9: Red soil + 20% bentonite

SN	Percentage of water added by dry weight	10	20	30	40
1	Mass of mould (gm)	2064	2064	2064	2064
2	Mass of mould + compacted sample (gm)	3575	3759	3961	3854
3	Mass of compacted sample (W_t) gm	1511	1695	1897	1790
4	Volume of compacted sample (V) cc	981.75	981.75	981.75	981.75
5	Bulk density($\rho_t = W_t/V$) gm/cc	1.539	1.726	1.932	1.823
6	Average water content (w)	0.125	0.208	0.314	0.354
7	Dry density ($\gamma_d = \rho_t/(1+w)$) gm/cc	1.368	1.428	1.470	1.346

Table 2.10: Red soil + 24% bentonite

SN	Percentage of water added by dry weight	5	15	25	35
1	Mass of mould (gm)	2064	2064	2064	2064
2	Mass of mould + compacted sample(gm)	3608	3714	3985	3888
3	Mass of compacted sample(W_t) gm	1544	1650	1921	1824
4	Volume of compacted sample (V) cc	981.75	981.75	981.75	981.75
5	Bulk density($\rho_t = W_t/V$) gm/cc	1.572	1.680	1.956	1.857
6	Average water content (w)	0.058	0.187	0.277	0.36
7	Dry density ($\gamma_d = \rho_t/(1+w)$) gm/cc	1.48	1.415	1.531	1.365

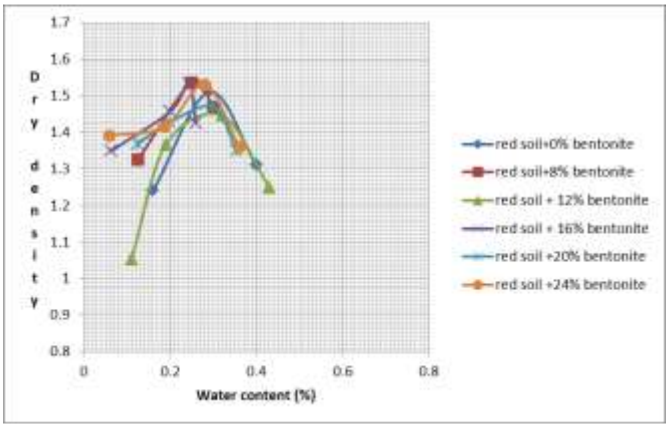

Figure 2.3: Standard proctor test results of red soil-bentonite mixtures

4.3.5 Determination of Permeability

Table 2.11: Permeability of red soil- bentonite mixtures

SN	Materials	Permeability (cm/sec)
1	Red soil+ 0% bentonite	0.7×10^{-5}
2	Red soil+ 8% bentonite	0.4×10^{-7}
3	Red soil+ 12% bentonite	0.98×10^{-8}
4	Red soil+ 16% bentonite	0.55×10^{-8}
5	Red soil+ 20% bentonite	0.33×10^{-8}
6	Red soil+ 24% bentonite	0.31×10^{-8}

4.3.6 Model of Landfill

4.3.6.1 Using Red Soil as Liner Material

A model of landfill is prepared using 25 liter container. At bottom make a hole and place plastic bag to collect the leachate, then 1/3rd of the container is filled with compacted red soil liner at MDD and OMC. Household waste are placed on the liner and covered with red soil. Two layers of waste are placed on the liner. Watered it at each layer. Sprinkle water every day and after some day's measure the quantity of the leachate collected. The stepwise process of engineered landfill model is shown in figures given below.

Figure 2.4: 25 Liters container

Figure 2.5: Leachate collection

Figure 2.6: Household waste on the layer of red soil.

Figure 2.7: Layer of red soil on the garbage

Figure 2.8: Compacted layer of red soil on garbage

Figure 2.9: Landfill model using red soil.

After 5 days 20ml Leachate has collected and 100ml in 15 days. Landfill model after 15 days has shown in figure below.

Figure 2.10: Landfill model after 15 days

Figure 2.11: Leachate collected after 15 days

4.3.6.2 Using Red Soil – Bentonite Mixture

A model of landfill is prepared using 25 liter container. At bottom make a hole and place plastic bag to collect the leachate.1/3rd of the container is filled with compacted red soil and 12% bentonite mixture liner at OMC. Then household waste are placed on the liner and covered with soil. Two layers of waste are placed on the liner, watered it at each layer. Sprinkle water every day and after some days measure the amount of laechate passes through liner. The stepwise process of engineered landfill model is shown in figures given below.

Figure 2.12: 25 liter container for landfill model

Figure 2.13: Household Garbage on the layer of red soil-12% bentonite mixture.

Figure 2.14: layer of red soil on garbage

Figure 2.15: Compacted layer of red soil -12% bentonite on garbage

After 5 days no Leachate has collected and 10ml leachate is collected after 15 days. Landfill model after 15 days has shown in figure below

Figure 2.16: Landfill model after 6 days

Figure 2.17: Leachate collected after 15 days

5. Conclusion

Based on the experiments done on red soil with bentonite for liner material the test results is observed that when the percentage of bentonite increases, consistency properties such as liquid limit, plastic limit and plasticity index are increasing. The Differential Free Swell of the mixture increased with the addition of bentonite, resulting as a better sealant. At addition of 12% bentonite in red soil, the material has 0.98×10^-8 cm/sec which is less than 1×10^-7 cm/sec (recommended permeability of liner). Haudraulic conductivity of red soil- bentonite mixture decreased linearly with increased amount of bentonite. Hence Red soil-bentonite mixture is suitable as liner material with 12% - 20%bentonite.

Based on model of engineered landfill it is observed that red soil as liner material alone cannot be good material for engineered landfill whereas red soil and 12% bentonite mixture is good for liner material for engineered landfill.

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