Desiccation Potential of Compacted Soils for Landfill Liners

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Abstract - *Desiccation is the phenomenon by which moist soil undergoes reduction in volume due to rise in temperature to attain a thermal equilibrium. Reduction in volume induces cracks on the soil surface which further propagates downwards. Crack induced failure of topsoil of various earthen structures is most commonly seen in arid and semi-arid climatic regions. Crack induced failure of earthen structures such as landfill liners and covers, earthen roads, agricultural fields, earthen dams are most commonly found. Desiccation induced cracks formed on the surface encourage the rain water infiltration to higher extents and results in adverse conditions. The phenomenon of desiccation is more likely to be affected by the amount of clay content, moisture content, soil density, foreign matter, rate of change in temperature. During compaction, water is added to soil for lubrication purpose. Compacting soils at optimum moisture content yields maximum dry density. However, this moisture content may result in volumetric shrinkage of soil mass. Hence balancing the right amount of moisture content to satisfy both the maximum density and minimum shrinkage requirement is a critical task in geotechnical engineering applications particularly in Landfill liners. To reduce the shrinkage or desiccation cracks, optimum moisture content was reduced by 5% for locally available soil and volumetric shrinkage was found at 8.1%. Permeability of model clay liner was found at 2.85 x 10^{-5} cm/s which was considerably higher for landfill liner. To reduce the volumetric shrinkage further, optimum moisture content was reduced by 10% which resulted in shrinkage of 4%. To reduce the permeability, about 6% of bentonite clay was added and tests revealed that liner was almost impermeable.*

Key Words: **Desiccation, Landfill liner, Shrinkage, Swelling, Solid waste**

1. INTRODUCTION

Desiccation is the process by which soil undergoes reduction in volume due to elimination of air voids and water. When the soil undergoes reduction in volume, cracks are induced in the soil. The cracks reduce the strength of the soil and results in failure of the soil and the structure above the soil. The amount of desiccation is different for different soils. Soils with more clay content, more water content undergo more desiccation whereas soil with less clay content and less water content undergoes less desiccation. Desiccation cracking affects the performance of the soil.

Desiccation in clay soils results is volumetric shrinkage of the soil mass. As the soil rehydrates it may swell. Upon drying of water differential movement may occur and it causes damage to the structure lying above it. The cracks appeared due to desiccation expose the deep soil and results in more evaporation of water affecting agricultural growth. Hence before constructing on the soil, care should be taken to properly investigate the soil conditions, compositions, environmental conditions and their effects on the soil.

1.1 Soil compaction

Soil compaction is the process of densification of soil due to expulsion of air voids. During compaction, water is added to soil for lubrication purpose. Heavy compacting equipments are used for compaction process. The type of equipment, amount water to be added and method compaction depends upon the type of soil. The recovery of soil from this type of compaction depends on mineralogy.

1.2 Desiccation

Desiccation is the phenomenon by which moist soil undergoes reduction in volume due to rise in temperature to attain a thermal equilibrium. Reduction in volume induces cracks on the soil surface which further propagates downwards. Crack induced failure of topsoil of various earthen structures is most commonly seen in arid and semi- arid climatic regions. Crack induced failure of earthen structures such as landfill liners and covers, earthen roads, agricultural fields, earthen dams are most commonly found in arid and semi-arid climatic conditions. Desiccation induced cracks formed on the surface inside the soil mass encourage the rain water infiltration to higher extents and results in adverse conditions. The phenomenon of desiccation is more likely to be affected by the amount of clay content, moisture content, soil density, foreign matter, rate of change in temperature. Soils shrink when they become dry. This type of shrinkage will be more in fine grained resulting in volume change. It can cause cracks, increase permeability and reduce strength.

1.3 Landfill Liners

Industrialization and rapid economic development increased the standard of living across the globe. With the growing affluence, waste generation has reached its alarming level. Industrialization brought forth with it the associated problems. The industrial activities generated large quantities of wastes. Part of these wastes in different physical forms such as solids liquids and gases turn as pollutants in due course. Based on the safety level, these wastes can be hazardous or non-hazardous. Wastes can be controlled by different options such as waste reduction at source, resource recovery through separation and recycling, resources recovery through waste processing, waste transformation and environmentally sustainable disposal on land. Despite all efforts, to minimize waste, and to neutralize it, the various methods of solid waste disposal are being practiced in different regions. Landfill is one of the most common methods due to various reasons. Different types of materials are used for Landfill liners. First generation of landfills were constructed with soil liners. Modern landfills are constructed with multiple liners. Soil and geosynthetic liners are commonly used. In view of low permeability, clay soils are used as liners. The major drawback with clayey soils is volumetric instability due to change in moisture content. Dry season causes clayey soils to shrink and during wet season, it swells. This type of volumetric instability may lead to cracks in the upper surface and may become passage for rain water. This may lead to aggravate the size of cracks and affects overall stability and strength of soil liner. These cracks may allow leachate to pass through and contaminate ground water aquifer.

2. LITERATURE REVIEW

In this work [1] both fresh water and leachate were used for compaction of residual soils for landfill liners. Both fresh water and leachate had same effect on optimum moisture content and maximum dry density. When the leachate was used as permeating fluid, the soil showed increase in unconfined compressive strength and less hydraulic conductivity.

This study [2] informs that both cracks in the clay liner and leachate composition had effect on the hydraulic conductivity of compacted clay liner. In this study, three types of liquids were used as permeating fluids. When tap water was used as permeating fluid, desiccation cracks increased the hydraulic conductivity by 25 times. Leachate The paper concluded that desiccation cracks and bentonite had more effect on hydraulic performance than leachate.

In this study [3], the sandy soils were compacted with bentonite to test its suitability as landfill liner. The test results showed that at 8% bentonite with sand, hydraulic conductivity was 3.2×10^{-8} cm/s. The cohesion and angle of internal friction obtained from direct shear test was 250 kN/m^2 and 20^0. The CBR value was 23.8%. These results concluded that with proper compaction techniques, sandy soils with bentonite may also be used as landfill liners.

3. METHODOLOGY

3.1 Experimental setup

Six numbers of steel moulds of square and cylindrical shapes were fabricated for experimentation. A typical square moulds is shown in Figure 1 and Cylindrical mould in Figure 2

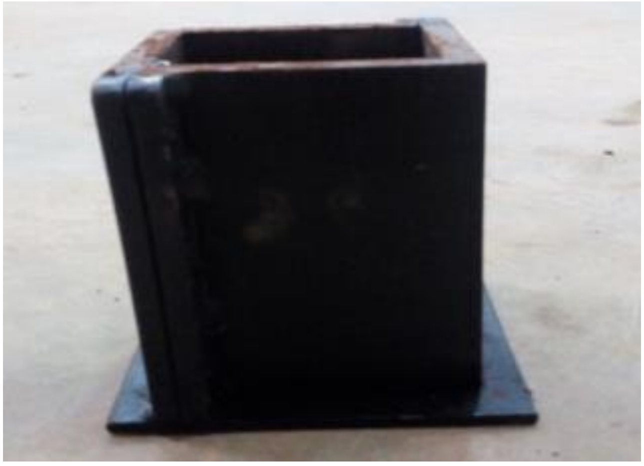

Figure 1: Square mould

Figure 2: Cylindrical mould

The details of these moulds are appended in Table1.

Table -1: Mould details

Sl no.	Mould	Size (cm)
1	Square mould-A	7.5 x 7.5 x 7.5
2	Square mould-B	7.5 x 7.5 x 15.6
3	Square mould-C	15 x15 x 15
4	Cylindrical mould-A	7.6 x 15.2
5	Cylindrical mould-B	10 x 20
6	Cylindrical mould-C	15 x 30

A scaled down model of landfill was fabricated as shown in Figure 3. The size of base plate of the landfill was 40 cm x 40 cm. The vertical height of the landfill set up was 15 cm and the sides slopes were maintained at 40^0.

Figure 3. Landfill setup

3.2 Experimental procedure

A. Measurement of Shrinkage

Fine grain soil sample was filled in moulds at different water content and shrinkage tests of soil were conducted. In the trials water content equal to optimum moisture content OMC, OMC – 5%, OMC + 5% were added to the soil and the mixed thoroughly. This soil water mixture is filled in three square moulds and cylindrical moulds and initial dimensions such as width and height for square mould and diameter and height for cylindrical mould are noted down. After filling, the moulds are allowed to dry in air for a period of 6 days and it is oven dried for a period of 1 day. After drying, the moulds are removed and the final dimensions such as width and height for square mould and diameter and height for cylindrical mould are noted down. The percentage change in linear shrinkage and percentage change in volumetric shrinkage were calculated.

B. Measurement of desiccation cracks

Desiccation crack or shrinkage cracks were measured by passing a steel wire to the entire depth of the cracks on the surface of the moulds and measuring the length of the cracks. These crack depths were noted.

C. Experimentation work

The results of shrinkage tests are analysed and the moisture content at which minimum shrinkage occurs is selected for laying clay in clay liners. The soil is mixed thoroughly with the recommended water content and the soil is laid in a layer of 2 cm on all sides of the liner as shown in Figure 4. The setup is allowed to dry for a period of 7 days. After drying, the set up is placed on a tray and a known quantity of water is put in the clay liner setup. The water is allowed to pass through the soil for a period of 3-4 days and the water passing through the soil and collected in the tray is measured and permeability of the clay soil used is measured.

Figure 4: Landfill Liner

4. RESULTS AND DISCUSSION

The basic geotechnical properties of soil are shown in Table 2.

Table -2: Geotechnical properties of soil

Sl no.	Test	Result
1	Specific gravity	2.42
2	Grain size distribution	Fine grain soil.
3	Liquid limit	21.8 %
4	Plastic limit	12.6%
5	Maximum dry density optimum moisture content	1.8 g/cm^3 17.6%
6	Hydraulic conductivity	2.85 x 10^{-5} cm/s

Table 3: Linear Shrinkage details.

Sl No	Mould	OMC-5%	OMC	OMC+5%
		Shrinkage along horizontal and vertical plane	Shrinkage along horizontal and vertical plane	Shrinkage along horizontal and vertical plane
1	Square mould – A Horizontal Vertical	2.6% 1.3%	3.9% 1.3%	5.2% 5.2%
	Square			

2	mould – B Horizontal Vertical	2.7% 2.7%	5.5% 5.5%	6.944% 6.944%
3	Square mould – C Horizontal Vertical	1.3% 1.3%	3.3% 0.6%	4.66% 3.33%
4	Cylindrical mould – A Horizontal Vertical	2.6% 1.9%	3.9% 1.9%	7.0% 5.2%
5	Cylindrical mould – B Horizontal Vertical	2% 1%	5% 3%	7% 3%
6	Cylindrical mould – C Horizontal Vertical	1.3% 0.6%	2.6% 2.3%	3.3% 3.3%

The linear shrinkage details are shown in Table 3.

From the data it is observed that shrinkage increases with increase in moisture content. For example in square mould–B, at OMC – 5% the maximum shrinkage is 8.1%, at OMC.

Table 4: Volumetric Shrinkage details

Sl no.	Mould	OMC-5%	OMC	OMC+5%
		Volumetric shrinkage	Volumetric shrinkage	Volumetric shrinkage
1	Square mould-A	6.4%	8.9%	14.9%
2	Square mould-B	8.1 %	15.7%	19.4%
3	Square mould-C	1.9%	7.1%	12.1%
4	Cylindrical mould-A	7.0%	9.5%	19.6%
5	Cylindrical mould-B	4.9%	12.4%	16.1%
6	Cylindrical mould-C	3.2%	7.4%	9.7%

Volumetric shrinkage details are shown in Table 4.

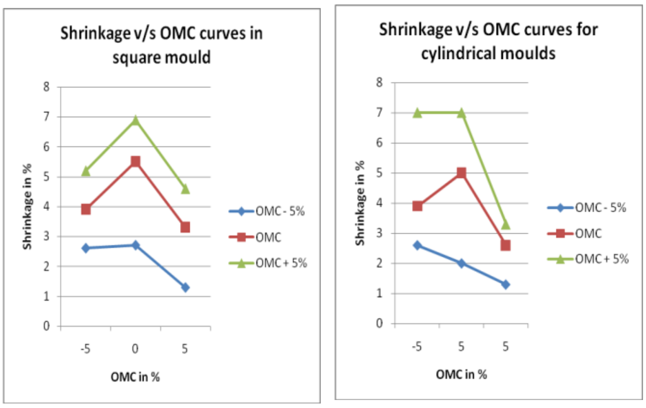

Figure 5 Linear shrinkage in square and cylindrical moulds

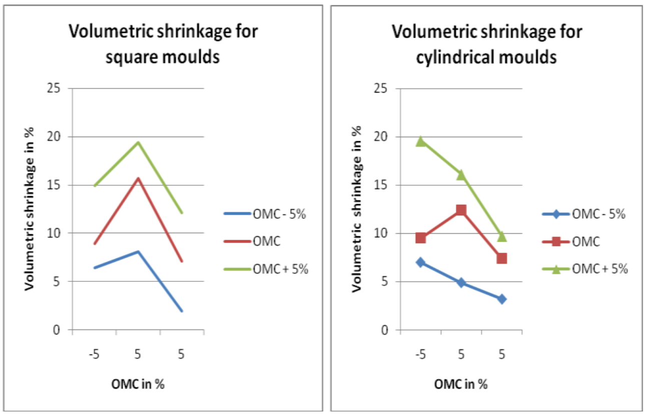

Figure 6. Volumetric shrinkage in square and cylindrical moulds

Figure 5 shows linear shrinkage and Figure 6 displays volumetric shrinkage of soil in square and cylindrical moulds.

Table 5: Depth of cracks in soil sample (mm)

Sl No.	**Mould**	**OMC - 5%**	**OMC**	**OMC +5%**
		Depth of cracks	**Depth of cracks**	**Depth of cracks**
1	Square mould - A	0.5	1.2	8.0
2	Square mould - B	0.8	5.0	12.0
3	Square mould - C	1.0	6.2	12.3
4	Cylindrical mould - A	0.4	1.0	6.0
5	Cylindrical mould - B	0.65	4.2	11.0
6	Cylindrical mould - C	0.9	5.0	10.4

As shown in Table 5, the depth of cracks are significantly lesser at lesser OMC.

To validate the laboratory test results, tests were also conducted on liner set up. The setup was dried for a period of 7 to 8 days and found that there was no visible hydraulic conductivity or shrinkage of liner.

5. CONCLUSIONS

- The volumetric shrinkage of the compacted soil at (-5% OMC) was 8.1%. After reducing the OMC by 10%, the shrinkage was reduced to less than 4%.
- The hydraulic conductivity of the liner before adding bentonite at (OMC-5 %) 2.85 x 10^{-5} cm/sec. After adding bentonite at 6%, the hydraulic conductivity of the liner reduced to (OMC -10 %) 2.9 $\times 10^{-8}$ cm/s .
- From the above discussions, it may be concluded that reduction in OMC will lead to reduction in both linear and volumetric shrinkage.
- The trend is similar in both square and cylindrical moulds.

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