CONSOLIDATION BEHAVIOR OF BENTONITE-AMENDED CLAYEY SOIL IN THE PRESENCE OF HEAVY METAL

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Abstract – *The landfill was the most widely accepted method of disposing of municipal solid waste (MSW). Clay soils that are used in landfill liners get exposed to physicochemical attacks by the leachates generated from the municipal solid wastes. Because of high specific surface area (SSA), high cation exchange capacity (CEC), contaminant adsorption capacity, and low hydraulic conductivity, bentonites are frequently used as a clay liner material at landfill. Compressibility is one of the most important properties that help in analyzing the settlement of the clay liner. This investigation was performed to study the effect of heavy-metal contaminant on the consolidation characteristics of clayey soil and bentonite-amended clayey soil. In this work the change in their various consolidation parameters such as coefficient of consolidation (C_v), and time requires for the completion of 90% of consolidation (t_{90}) in the presence of lead contaminant (1000 mg/L) were studied. The results showed that the t_{90} of the clayey soil and bentonite-amended clayey soil decreased, whereas C_v increased with the presence of heavy-metal contaminant. The results showed that the C_v of the samples decreases and the t_{90} increases with an increase in consolidation pressure. Since bentonite is a liner material widely used in landfills, the results of this study can provide a general guide to estimate the performance of the liner in the presence of contaminant.*

***Key Words*: Bentonite, Clay liner, Coefficient of consolidation, Heavy metal.**

1. INTRODUCTION

The increase in the amount of waste generated in cities has become a major concern in recent years. Landfilling has been the most widely accepted method of disposal of MSW in several countries around the world. The migration of heavy metals through leachate poses a threat to the subsoil and groundwater due to the serious impact of these contaminants on human health and the sustainability of ecosystems. To avoid the uncontrolled release of various contaminants into the environment, the waste materials must be completely encapsulated, which is taken care of by the use of liner system. An impermeable liner is required to prevent infiltration of highly contaminated leachate into soil or groundwater. Soil-bentonite mixture is commonly used as a liner material in a containment system to prevent the migration of leachate into the ground water.

The presence of heavy metal contaminants in the leachate influences the chemistry of pore fluids and controls the diffuse double layer thickness (DDL) of the clay particles. Although landfill leachate generally contains modest concentration of heavy metal contaminants, it is quite essential for a geotechnical engineer to understand the engineering properties of clay soils in the presence of contaminants. Compressibility of the liner material is one of the most important properties that help in analyzing the settlement of the clay liner. Since bentonite is a highly compressible material, it compresses significantly due to the weight of the waste accumulated at a disposal site. Consolidation is a process defined as compression that occurs when a surcharge load is applied to saturated clay. The consolidation of a soil gives rise to a settlement, the magnitude of which is determined after the complete dissipation of the pore-water pressure generated. In this study the consolidation behavior of clayey soil and bentonite amended clayey soil in the presence of heavy metals are compared.

1.1 Scope

- Consolidation is most important behavior of bentonite and clayey soil, which is required to be investigated for settlement calculation of landfill liner.
- This study provided a general guideline for estimating the liner performance in the presence of lead contaminant.

2. LITERATURE SURVEY

The presence of heavy metal contaminants in the leachate could affect the behavior such as swelling and sorption capacity of bentonite and reduce its usefulness as a liner material. Therefore, to design a clay liner it is very essential to study the behavior of bentonites in the presence of different chemicals present in the leachate. Two bentonites with different liquid limits and swelling capacity were studied by Bohnhoff G and Shackelford C [1], in order to determine the change in various consolidation parameters in the presence of zinc, lead and copper contaminants. The higher quality bentonite, defined by a higher swelling capacity, had a higher C_c, m_v and t_{90} than those of the lower swelling bentonite.

The physical, chemical and mineralogical properties of bentonite, influences the consolidation behavior of bentonite and consolidation properties of soil - bentonite mixtures [4]. Mishra et.al [9] studied the Controlling factors of the swelling of bentonites and their correlations with the hydraulic conductivity of soil-bentonite mixtures. The free swelling of the bentonites increased linearly with a percentage of exchangeable sodium that increases below 30% and almost remained constant over 30%. With the increase in the concentration of heavy metals, the liquid limit, free swelling, swelling pressure and the swelling potential of the bentonite decreased and the hydraulic conductivity increased. These reductions are attributed to the adsorption of heavy metals on bentonite and the decrease in the thickness of the double layer [5]. The adsorption characteristics of contaminated bentonite, the micro-structural change due to the lower pH level and the high concentration of heavy metal controls the rheological performance of compacted bentonite.

Du et.al [2] conducted numerous tests to evaluate the effect of lead (Pb) contamination in clay/ calcium bentonite backfills and observed that the liquid limit, compression index and pH decreased with the increase in the lead concentration, which has been attributed to the contraction of the DDL thickness of bentonite. Backfills contaminated with Pb show a maximum fifty-fold increase in hydraulic conductivity compared to clean backfills. The hydraulic conductivity of the backfills contaminated with Pb decreases slightly when there is an increase in the bentonite content for a given concentration of Pb, while the hydraulic conductivity ratio increases significantly with an increase in the bentonite content [6].

The results showed that the swelling pressure and swelling potential of the bentonites decreased significantly due to interaction with the various combinations of inorganic and heavy metals solution. The consolidation parameters such as C_c, m_v, C_v and t_{90} mainly depend on factors such as the mineralogical composition of bentonite, the types and concentration of heavy metal contaminants present in the pore water and the overload pressure.

3. METHODOLOGY

3.1 Materials

The soil used for this study was clay collected from Palakkad at a 1m depth. The soil was partially air dried and powdered to a fraction of less than 4.75 mm. As per IS soil classification system for fine grained soils, the clayey soil is classified as clay of high plasticity. The soil sample was subjected to geotechnical tests in the laboratory as per Indian Standard specification (IS 2720) and as shown in table 1.

Table -1: Basic Properties of Soil

Sl No	Properties	Result
1	Specific gravity	2.52
2	Liquid limit (%)	58
3	Plastic limit (%)	29.4
4	Shrinkage limit (%)	17.9
5	Clay content (%)	51
6	Silt Content (%)	18
7	Sand Content (%)	31
8	Maximum dry density (g/cc)	1.6
9	Optimum moisture content (%)	25.2
10	Soil classification	CH

The bentonite used for this project work was Sodium bentonie which is naturally occurring hydrated aluminum silicate clay and bought from Associated Chemicals, Kochi as shown in figure 1 (left). The properties of the bentonites are listed in Table 2. The bentonite content was restricted at 15% for clay soil-bentonite mixes based on literature survey [6], as the mixes were not workable and effective, if the bentonite was increased further because of the changes in hydraulic conductivity associated with the increase in bentonite content.

Table -2: Basic Properties of Bentonite

Sl No	Properties	Result
1	Specific gravity	2.61
2	Liquid limit (%)	216%
3	Plastic limit (%)	40%
4	Plasticity index	176%
5	Percentage of clay	68%
6	Percentage of silt	32%

Fig- 1: Na bentonite (left) and Lead powder (right)

Lead (Pb) is a contaminating agent of ground water and non biodegradable in soil and as shown in figure 1 (right). It does not undergo chemical or microbial breakdown. Working with lead can affect your health. Different tests were carried out at the concentration of 1,000 mg/L of lead solution on the clayey soil and bentonite amended clayey soil. As it has been observed from the literature that the maximum heavy-metal contaminants concentration in a leachate is 1,000 mg/L [11], this study was carried out at a concentration of 1,000 mg/L of lead solution.

Fig- 2: one dimensional consolidation test

3.2 Determination of Consolidation Characteristics

The test is done in consolidation test apparatus known as consolidometer. In this method, the soil specimens were placed and compacted in a metal ring of diameter 60 mm and thickness 20 mm as per Indian Standard specification (IS 2720-Part 15). The ring did not allow any lateral deformation to the soil. The moisture equilibrated clayey soil and clay-bentonite mixes were then statically compacted to its MDD in the oedometer ring. Porous stone discs were provided at the top and bottom of the sample in order to allow drainage in the vertical direction. The porous stones were kept submerged in water for a sufficient time, and were used in a damp state to avoid loss of moisture from the sample. Then, the entire assembly was placed in a consolidation cell of consolidometer and positioned in the loading frame. It was submerged in deionized (DI) water or 1000 mg/L of lead (heavy-metal) solution. After placement in the consolidation cell, the specimens were allowed to equilibrate under a seating load for a period of at least 24. The sample was then loaded in increments of vertical stress selected as 50, 100, 200, and 400 kPa. Each pressure was maintained for 24 h. Vertical deformation of the specimen was measured by means of a dial gauge. Dial gauge readings are taken after 0.25, 0.5, 1, 2, 4, 8, 15, 30, 60, and 1440 minutes. After the consolidation under the last stress increment got over, the specimen was unloaded in stages.

The coefficient of consolidation (c_v) was determined by Taylor square-root-of-time method at each pressure increment by using the equation,

$$C_v = \frac{D^2 \times T_v}{t_{90}}$$

4. RESULTS AND DISCUSSIONS

The coefficient of consolidation (C_v) indicates the rate at which a saturated sample undergoes one dimensional consolidation when it undergoes an increase in consolidation pressure and was determined by the square-root-of-time method provided by Taylor.

4.1 Coefficient of Consolidation (C_v)

C_v values of clayey soil with and without the presence of lead solution were determined by consolidation. For this, clayey soil was compacted to its MDD in the metal ring. Then it was submerged in deionized (DI) water and 1000 mg/L of lead (heavy-metal) solution. The Variation of C_v values of clayey soil with the presence of 1000 mg/L of lead as shown in chart -1.

From the plots, it was observed that the C_v value of the clayey soil increases with the presence of lead contaminant, because of a reduction in the DDL thickness. The increase in C_v decreases the required time to achieve a desired degree of consolidation. In other words, the rate of the consolidation with the application of consolidation pressure increases because of the presence of lead contaminant in the pore fluid. This produces a relatively quicker settlement of the clay liner material at the waste disposal facility when it interacts with leachate.

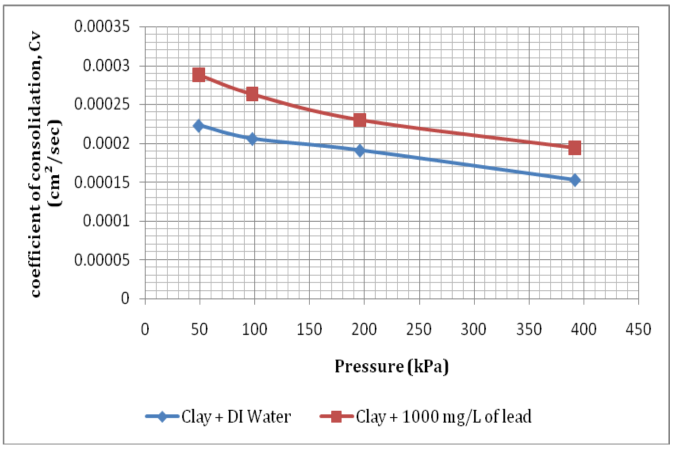

Chart -1: Variation of Cv value of clay with 1000 mg/L of lead

Chart-2 plot the comparison of Cv value of clay and clay bentonite mix (DI Water). Clayey soil is amended with bentonite at 15% by dry weight of clay soil to prepare the sample. The compressibility behaviour of bentonite is depending upon the type of bentonite, nature of pore fluids and exchangeable cations. The interaction between soil particles controls the mechanical effect of the compressibility of bentonite. With an increase in the consolidation pressure, the clay plates move to a closer distance because of a decrease in the DDL thickness, due to this the repulsion between clay plates increases, which prevents further movement of the plates and results in a decrease in the C_v. The plot shows that the C_v decreased with an increase in pressure, indicating a slower rate of consolidation at higher pressure. The study also showed that, C_v value of clay- bentonite mix was more than that of naturally occurring clay. Since the montmorillonite mineral present in bentonite swells when exposed to water, it provides less hydraulic conductivity to bentonite. Since the swelling of bentonite affects the opening and closing of the pore spaces, it is the dominant mechanism that controls the flow of liquid through it.

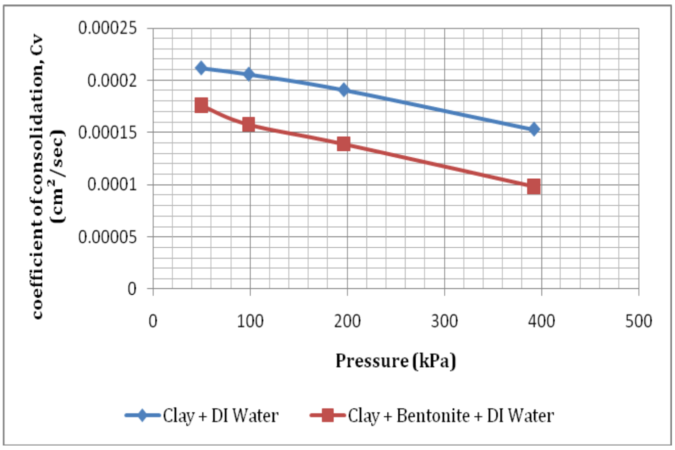

Chart -2: comparison of Cv value of clay and clay-bentonite mix (DI Water)

The variation of C_v of clay-bentonite mix with 1000 mg/L of lead as shown in chart -3. The hydraulic conductivity of bentonite-soil admixture increased significantly with the addition of lead contaminant. The physico-chemical interactions between particles include the interaction between the particles through the diffuse double layers. Many factors such as type and concentration of metal and composition of bentonite could influence the consolidation parameters. Furthermore, the chemical properties of the pore fluid regulate soil performance mainly with low applied load. In general, the change in pH in the presence of heavy metals has a greater effect on the compressibility behavior of the soil than the absence of heavy metals. This is because of the influence of the precipitation of heavy metal. The precipitation processes, which are mostly associated with the lead pollutants, result in the formation of a new substance in the pore water alone or a precipitate attached to the soil solid. The Coefficient of Consolidation (C_v) value of clay-bentonite mix increased significantly with the addition of lead contaminant and decreases with increase in consolidation pressure.

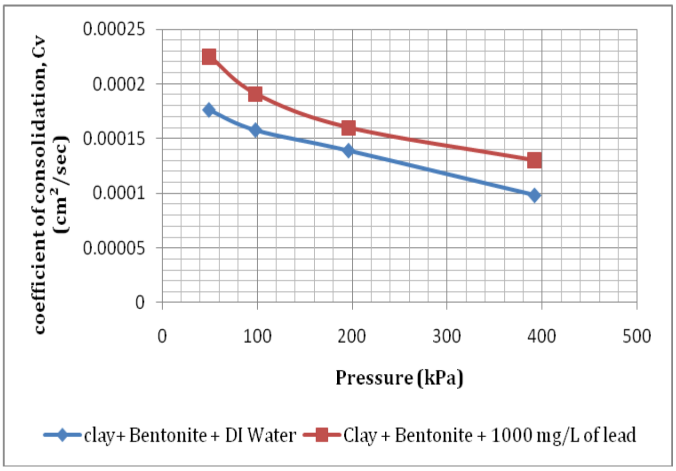

Chart -3: Variation of C_v of clay-bentonite mix with 1000 mg/L of lead

4.2 Time required for 90% consolidation (t_{90})

Chart – 4 plot the variation of t_{90} of clay with 1000 mg/L of lead. The plots show that the t_{90} of the clay sample increases with an increase in the consolidation pressure. The study also showed that, with an increase in pressure, the t_{90} increases; however, it decreases with the presence of lead contaminant. Since the C_v increases with the presence of metal concentration, the time required to achieve a desired degree of consolidation decreases resulting in a reduction in t_{90}. On the contrary, t_{90} increase with the increase in consolidation pressure. The repulsion between clay layers increases, which prevents further movement of the layers and results in a decrease in the C_v and increase in t_{90}.

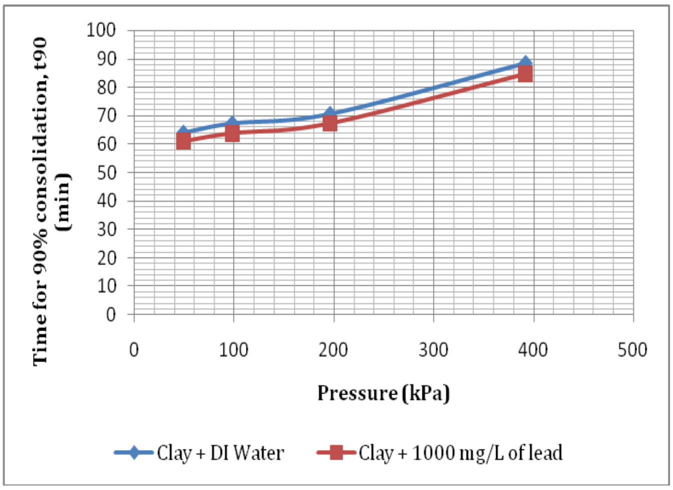

Chart -4: Variation of t_{90} of clay with 1000 mg/L of lead

5. CONCLUSIONS

This investigation was carried out to study the influence of heavy metal contaminant (lead) on the consolidation behavior of clayey soil and bentonite- amended clayey soil. The C_v increases with an increase in heavy metal contaminant concentration because of a reduction in the DDL thickness. The increase in C_v decreases the time required to achieve a desired degree of consolidation. The C_v decreased with an increase in consolidation pressure. The C_v value decreases due to the addition of bentonite, because of its high swelling ability, high contaminant adsorption capacity and low hydraulic conductivity. It acts as a barrier material by preventing and minimising the ingress of pollutant to contaminate the ground water resource. Due to addition of lead contaminant, the percentage increase in the C_v value of clayey soil is 27.7%. Due to addition of bentonite, the percentage decrease in the C_v value of clayey soil is 25.8%. At high pressure, the addition of bentonite and lead has no much significance on the value C_v. The t_{90} of the compacted sample increases with an increase in the consolidation pressure. The t_{90} decreases with an increase in heavy-metal contaminants concentration.

The results showed that the consolidation parameters such as C_v, and t_{90} depend primarily on factors such as the mineralogical composition of the bentonite, types and concentration of heavy metal contaminants present in pore water, and the overburden pressure.

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