Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)

Impact of lead on the swelling, hydraulic and consolidation behaviour of bentonite

Impact de plomb sur le comportement hydraulique et mécanique de la bentonite

A.K. Mishra
Department of Civil Engineering, Indian Institute of Technology, Guwahati, India, anilmishra@iitg.ac.in

ABSTRACT: Bentonite has been widely used at landfill owing to its low permeability and high adsorption properties. However, when the bentonite reacts with the heavy metals, its behaviour changes significantly and render its usefulness as liner material. Presence of heavy metals in the water suppress the diffuse double layer (DDL) thickness and consequently affecting swelling hydraulic and consolidation behaviour of bentonite. Therefore, it is essential to investigate the effect heavy metal, such as lead, of various concentrations on the different behaviour of bentonite. The study aims to investigate the effect of different concentrations (0, 100, 500 1000 and 2000 ppm) of lead on the swelling, hydraulic and consolidation behaviour of bentonite. The experimental results indicated that the free swell, Atterberg limits, swelling pressure, swelling potential, was decreased because of the presence of the various concentrations of lead in the pore water, however, with the rise in the concentration of lead (Pb^{2+}) the permeability increases. It was also observed that the influence of heavy metals on behaviour of the bentonite was more prominent in presence of lead of higher concentration.

KEYWORDS: leachate; bentonite; clay liner; heavy metal, hydraulic conductivity

1 INTRODUCTION

Levels of heavy metals increasing significantly in the environment due to improved living standard and poor waste management and consequently triggering severe pollution problems in the ecosystem. However, several heavy metals are vital in trace quantity for proper functioning of biological process (Häni, 1990). The production of total municipal solid waste (MSW) is being expected to increase to more than 2 billion tons by 2025 (Hoornweg and Bhada 2012). In various countries the widely popular method of discarding of MSW in landfilling (Qian et al. 2002). Leachate produced from the waste within the landfill contains harmful metal ions which can affect the geo-environment. Leachate can cause serious health issues and affect environmental sustainability by contaminating the surrounding environment and groundwater. In an ambient environment, metal ions have a long residence time; therefore, heavy metal may enter into the food chain and may result in bioaccumulation. Liner inhibits the leakage of leachate from landfill to the surrounding atmosphere. For controlling the leaching of the leachate into the environment, layers of compacted bentonite have been used as an ideal barrier material. The pollutant adsorption capacity, significant swelling tendency and low permeability (Dutta and Mishra, 2016, Ray et al. 2020) makes bentonite as an excellent liner material. Bentonite acts as an impervious barrier between waste present in the landfill and groundwater. Bentonite is a highly expansive clay, which is generated from deposition and slow modification of volcanic ash, mainly consist of montmorillonite (Mitchell and Soga 2005). Development of the DDL thickness in presence of water by the mineral montmorillonite, which is present in bentonite, gives the bentonite the swelling properties and consequently lower permeability (Mesri and Olsen, 1971).

The swelling capacity of bentonite mainly depends on various physico-chemical and mineralogical properties (Bolt, 1956), which in turns control its hydraulic and mechanical behaviour. Pore spaces are present in a soil matrix between the clay particles. Due to the swelling of bentonite, these pore spaces gets filled up, and consequently, provide the bentonite with a low permeability value.

Presence of different kind of heavy metals in the leachate suppresses the DDL thickness, consequently affecting the swelling, hydraulic and consolidation properties of bentonite. Therefore, the usefulness of the liner materials also reduced in the long term. However, the extent of effect because of the presence of heavy metal varies with type and its concentration of in the leachate. Hence, it is needful to investigate the impact of heavy metal, such as lead, of various concentrations on the behaviour of bentonite.

The present investigation was performed to explore the impact of lead on the swelling, hydraulic and consolidation behaviour of bentonite. Change in the properties, such as free swell, Atterberg's limits, swelling pressure, swelling potential and permeability and consolidation parameters of bentonite was investigated with the different concentrations of lead solutions.

2 MATERIALS AND METHODS

2.1 *Bentonite*

Bentonite sourced from the Rajasthan state of India was used for the investigation and its various properties are tabulated in Table 1.

Table 1. Properties of Bentonite

Property	Bentonite
Liquid limit (%)	305.0
Plasticity limit (%)	41.0
Free swell (ml/2g)	20.0
Cation exchange capacity (CEC) (meq/100g)	36.2
Specific surface area (SSA) (m^2/g)	340.4
Optimum moisture content (OMC)	33.5 %
Maximum dry density (MDD) (g/cc)	1.30

The free swell and Atterberg limits were obtained by ASTM D 5890 (2006) and ASTM D 4318 (2010), respectively. The SSA was obtained by following the steps as explained by Cerato and Lutenegger (2002). The CEC was measured by following the technique demonstrated by Chapman (1965) and Pratt (1965). The compaction characteristics, i.e. MDD and OMC value of the bentonite was obtained by ASTM D698 (ASTM 2012) method. The hydraulic conductivity, swelling and consolidation parameters were determined from the consolidation test which was performed following the guideline given in ASTM D2435 (ASTM 1996).

2.2 *Contaminant*

Lead is selected for the present investigation as it is present significantly in leachates and may cause an acute hazard to health and the environment. Lead (Pb^{2+}) of various concentration, i.e. 0, 100, 500, 1000 and 2000 ppm were made by mixing various amount of $Pb(NO_3)_2$ with de-ionized (DI) water.

2.3 *Hydraulic conductivity*

Compacted bentonite samples were made first by mixing DI water and the bentonite to raise the initial water content to OMC and then compacting the mixture to MDD. The bentonite samples were statically compressed into a consolidation ring to prepare samples of 6 cm diameter and 1.5 cm thick. After compacting, the samples were positioned in the consolidation apparatus and was applied a pressure of 4.9 kPa and then submerged with various concentrations of lead solution. After the submergence, the samples were permitted for swelling. Subsequently on the end of swelling process, the samples were consolidated progressively by rising the pressure step wise up to 784.8 kPa. During every raise in pressure, the reduction in thickness of the samples were noted and corresponding void ratio was determined.

During each increment of the loading, the coefficient of consolidation (c_v) and coefficient of volume change (m_v) were determined by Taylor's square root method (Taylor, 1948). The hydraulic conductivity was obtained for each step of loading using the Terzaghi's theory of consolidation (Terzaghi, 1943).

2.4 *Determination of swelling potential and swelling pressure*

The swelling pressure and swelling potential of the compacted soil sample at various concentration was determined using the method explained by Sridharan et al. (1986) and Sridharan and Gurtug (2004).

3 RESULTS AND DISCUSSIONS

3.1 *Free swell and liquid limit*

The free swell values of bentonite at different concentration of lead solution is tabulated in Table 2. The values indicate that as the concentration of lead increases the free swell decreases. The swelling was decreased only from 20.0 to 18.5 mL/2g for a rise in concentration from 0 to 100 ppm. An additional rise of concentration up to 2000 ppm, the free swell decreased significantly to 6.0 mL/2g.
The data also indicates that with the enhancement of the concentration from 0 to 100 ppm, the liquid limit reduced from 305.0 to 292.1 %. However, with an additional rise in the concentration up to 2000 ppm, the liquid limit decreased to 204.1 %. This decline in free swell and liquid limit value is caused by the substantial decrease due to an enhancement in concentration is due to the compression in the DDL layer.

Table 2. Free swelling and liquid limit of Bentonite

Lead concentration (ppm)	Bentonite	
	Free swelling (mL/2g)	Liquid limit (%)
0 (DI water)	20.0	305.0
100	18.5	292.1
500	15.0	255.2
1000	9.0	224.2
2000	6.0	204.1

3.2 *Swelling potential and swelling pressure*

The data in Table 3 indicates a drop in the swelling potential and swelling pressure with a rise in concentration. Initially, when the concentration was raised to 100 ppm, the swelling potential dropped from 23.7 to 21.5 %. With an additional enhancement of the concentration up to 2000 ppm, the swelling potential dropped drastically to a value of 16.0%. Identical trend was also seen for the swelling pressure, where it first decreased from 392.6 to 322.8 kPa and then up to 239.9 kPa with an enhancement in the concentration from 0 to 100 and then to 2000 ppm.

Table 3. Swelling potential and Swelling pressure

Lead concentration (ppm)	Swelling potential (%)	Swelling pressure (kPa)
0 (DI water)	23.7	392.6
100	21.5	322.8
500	20.6	290.5
1000	17.9	260.8
2000	16.0	239.9

3.3 *Coefficient of consolidation (c_v)*

The plot in Fig. 1 indicates that at any particular pressure the c_v rises with a rise in concentration demonstrating a higher rate of consolidation. With a rise in the concentration, the DDL thickness of the particles reduces thereby the total repulsive pressure decreases. With the reduction in repulsive pressure, the resistance of the particles of coming closer also decreases. Thereby, the particles were able to come to a denser packing. The difference in the c_v values for various concentration was higher at lower pressure as the interparticle distance is higher. With a rise in the pressure, the interparticle distance decreases and thereby the difference in the c_v also decreases
Figure 1 displays that, by raising the pressure from 98.1 to 784.5 kPa for the sample at 0 concentration, the c_v reduced from 4.9×10^{-5} to 9.8×10^{-6} cm^2/sec. However, the c_v declined from 8.5×10^{-5} to 1.4×10^{-5} cm^2/sec when the specimen was submerged with 2000 ppm of Pb^{2+} solution.

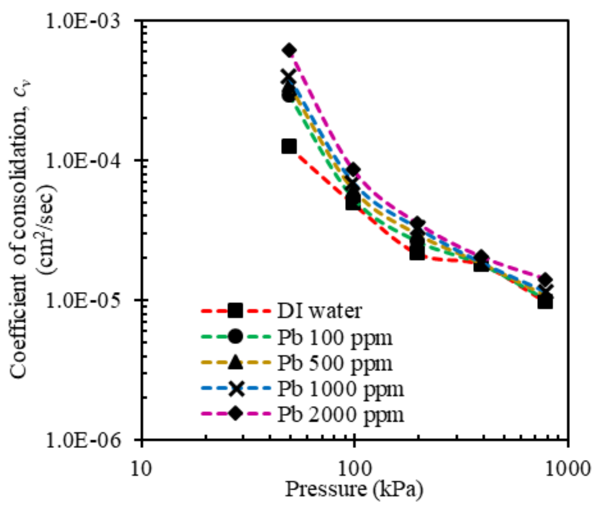

Figure 1. Coefficient of consolidation of bentonite in the presence of lead

3.4 *Compression index*

The effect of Pb^{2+} on the bentonites' compression index (C_c) is shown in Fig. 2. It was noticed that C_c of the samples reduces because of the permeation of Pb^{2+}. The C_c value of the bentonite was dropped by 16.7 % with the enhancement in the concentration level from 0 to 2000 ppm. The more noteworthy reduction in the C_c value for bentonite at higher concentration is attributed to a more considerate lessening in the DDL thickness with the rise in the Pb^{2+} concentration levels, thereby, ensuing in the agglomeration of clay particles (Ray et al. 2019).

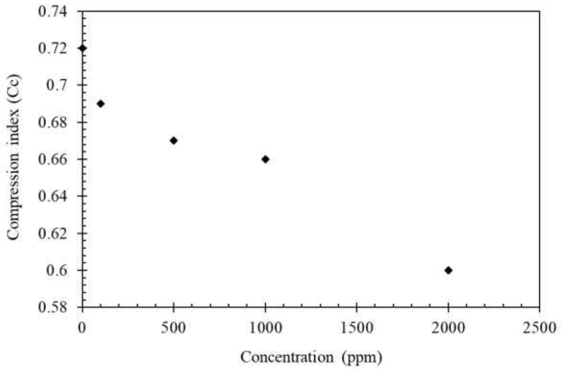

Figure 2. Compression index of bentonite at different concentration

3.5 *Hydraulic conductivity*

Figure 3 indicates that the hydraulic conductivity (*k*) rises with an enhancement in the lead concentration. With an enhancement in the concentration from 0 to 100 ppm the *k* increased very marginally; however, a further enhancement in concentration to 2000 ppm, the *k* raised considerably. This is because the thickness of the DDL decreased with rising lead concentration, causing in opening in the flow path due to a substantial decline in the swelling of the particles.

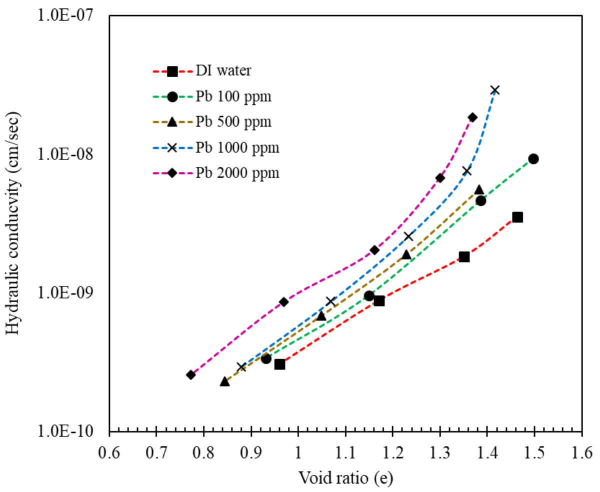

Figure 3. Hydraulic conductivity of bentonite at different concentration

Table 4. Hydraulic conductivity of bentonite at a void ratio of 1.2 at various concentrations.

Concentration (ppm)	Hydraulic conductivity (cm/sec)
0 (DI Water)	1.97×10^{-09}
100	3.95×10^{-09}
500	4.74×10^{-09}
1000	7.48×10^{-09}
2000	1.57×10^{-08}

The table 4 depicts that, the *k* raised from 1.97×10^{-09} to 3.95×10^{-09} cm/sec with the enhancement in the concentration from 0 to 100 ppm; whereas, it raised to 1.57×10^{-08} cm/sec, with a further enhancement in the concentration to 2000 ppm.

4 CONCLUSIONS

The work was performed to study the impact of lead on the swelling, hydraulic and consolidation behaviour of bentonite. The outcome of the study reveals that with the enhancement in lead concentration from 0 to 2000 ppm, the free swell, Atterberg limits, swelling potential and swelling pressure reduced, however permeability increases. This decline due to rise in lead concentration is due to the reduction in DDL thickness. It was also observed that the effect of heavy metals on the behaviour of the bentonite was more prominent in the presence of lead at higher concentration.

5 REFERENCES

ASTM D. 2435 1996. Standard test method for one-dimensional consolidation properties of soils. American Society for Testing and Materials, Philadelphia.

ASTM D. 4318, 2010. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. American Society for Testing and Materials, Philadelphia.

ASTM, D. 5890 2006. Standard test method for swell index of clay mineral component of geosynthetic clay liners. American Society for Testing and Materials, Philadelphia.

ASTM, D. 698 2012. "Standard test method for laboratory compaction characteristics of soil using standard effort (600kN-m/m^3)". American Society of Testing Materials, Philadelphia.

Bolt G.H. 1956. Physico-chemical analysis of the compressibility of pure clays. Geotechnique, 6(2), 86-93.

Cerato A.B. and Lutenegger A.J. 2002. Determination of surface area of fine-grained soils by the ethylene glycol monoethyl ether (EGME) method. Geotechnical Testing Journal, 25(3), 315-321.

Chapman H.D. 1965. Cation-exchange capacity. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties, 9, 891-901.

Dutta J. and Mishra A.K. 2016. Influence of the presence of heavy metals on the behaviour of bentonites. Environmental Earth Sciences, 75(11), 993.

Häni H. 1990. The analysis of inorganic and organic pollutants in soil with special regard to their bioavailability. International journal of environmental analytical chemistry, 39(2), 197-208.

Hoornweg D. and Bhada-Tata P. 2012. What a waste: a global review of solid waste management.

Mesri G. and Olson R.E. 1971. Mechanisms controlling the permeability of clays. Clays and Clay minerals, 19(3), 151-158.

Mitchell J.K. and Soga K. 2005. Fundamentals of soil behavior (Vol. 3). New York: John Wiley & Sons.

Pratt P.F. 1965. Potassium. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties, 9, 1022-1030.

Qian X., Koerner R. M., and Gray D. H. 2002. Geotechnical aspects of landfill design and construction, Prentice Hall, Upper Saddle River, NJ.

Ray S., Mishra A.K. and Kalamdhad A. 2019. Influence of various concentration of lead on consolidation parameters of bentonite. International Journal of Geotechnical Engineering, 1-7.

Ray S., Mishra A.K. and Kalamdhad A.S. 2020. Equilibrium, kinetic and hydraulic study of different Indian bentonites in presence of lead. European Journal of Environmental and Civil Engineering, 1-20.

Sridharan A. and Gurtug Y. 2004. Swelling behaviour of compacted fine-grained soils. Engineering geology, 72(1-2), 9-18.

Sridharan A., Rao A.S. and Sivapullaiah, P.V., 1986. Swelling pressure of clays. Geotechnical Testing Journal, 9(1), 24-33.

Taylor D.W. 1948. Fundamentals of Soil Mechanics. Publisher.

Terzaghi K. 1943. Theoretical soil mechanics. John Wiley & sons. New York, 11-15.