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The Effect of Shrinkage Cracking in Kaolinite Clay Due to Lead Contamination

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Abstract:

The kaolinite clay is low expansive in nature. The properties of kaolinite may affect due to the presence of heavy metal contamination. The mixing up of heavy metals with the soil due to underground or surface water flow in industrial areas is a severe threat to environment. There should be a proper disposal method for this contaminated soil. Clays tend to shrink and collapse under wetting-drying cycles. In this paper, the effect of lead contamination in shrinkage cracking of kaolinite clay is studied. During wetting drying cycles, lead content in the contaminated soil may leach out. It comes in contact with the clay surface. This may change the characteristics of kaolinite clay. Kaolinite clay with varying percentages of lead (0 to 0.1%) is tested for consistency limits and hydraulic conductivity. The results obtained as; with increase in lead concentration the consistency limits and hydraulic conductivity increases. Along with that the crack pattern is studied using digital image processing.

Keywords —**Shrinkage cracking, Wetting-drying cycle, Lead, digital image processing, kaolinite clay.**

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I. INTRODUCTION

The natural crust of soft clay and the cover liner for waste repository or mine tailings dams are exposed to seasonal desiccation and wetting. Clays tend to shrink and collapse under these wetting-drying cycles, and then the developed desiccation cracks can significantly affect the overall hydro-mechanical behaviour of foundations and slopes.

Cracking can adversely affect fine-grained soils. Cracks can also create zones of weakness and stability as well as increases in the compressibility of the soil. Structures that are constructed over fine-grained soils such as foundations and embankments can be affected by mechanical changes caused by cracking. Cracks can also create pathways ways for transport of fluids, which can significantly increase the hydraulic conductivity of the soils. Facilities that are constructed using fine-grained soils such as waste containment facilities and mine tailings dams can be affected by hydraulic changes resulting from cracking. Development of cracks can be due to various processes including desiccation and shrinkage, freezing and thawing, differential settlement, and penetration by plant roots.

In order to quantify the desiccation crack pattern a crack image analysis system (CIAS) based on image processing technique is used. The CIAS can quickly acquire the geometrical parameters of crack network, providing a very effective tool for studying the desiccation cracking behaviour and the involved mechanisms.

 Numerous abandoned industrial sites worldwide have been found to be contaminated with a wide range of heavy metals. These toxic metals such as lead (Pb), zinc (Zn), copper (Cu), and cadmium (Cd), if treated improperly, can pose severe threats to the environment and human health. Considering the fast urbanization and ever-increasing value of the land resources, particularly in the developing countries such as

China and India, it is imperative to develop effective and economical technologies to remediate these heavy metal contaminated industrial sites. In industrial areas the mixing up of heavy metals with the soil due to underground or surface water migration will also result in change in the hydro-mechanical behaviour of clays. Therefore, the effect of heavy metals on the clay's cracking behaviour is a concern in the field of geotechnical engineering.

II. LITERATURE REVIEW

Tang et al. (2010) conducted a research on the temperature dependence of desiccation cracking behaviour of clayey soils. The cracking on soil surface occurs due toloss of water by evaporation and this is temperature-dependent. In this work, experimental tests were conducted on saturated slurry to investigate the desiccation cracking behaviour at three temperatures (22°c, 60°c and 105 °c). The initiation and propagation of desiccation cracks were monitored using a digital camera. Using computer image processing, the surface crack ratio was determined to quantify crack networks at different water contents. The results show that the initiation of desiccation crack increases with temperature rise. After the initiation of a crack, the ratio increases with decreasing water content and then keeps almost constant when the water content becomes lower than the critical water content .

Yesiller et al. (2000) conducted research on desiccation and cracking behaviour of three compacted landfill liner soils. The soils had low plasticity with varying fines content. Surficial dimensions of cracks were determined using the crack intensity factor (cif), which is the ratio of the surface area of cracks to the total surface area of a soil. The maximum cif obtained in the tests was 7% and suctions exceeding 6000 kpa were recorded. It was observed that cracking was affected by the fines content of the soils. The

ciffor wet–dry cycles were greater than the cif for compaction–dry cycles.

Costa et al. (2013) conducted research on desiccation cracking of clay in lab tests. This paper details some of the controlling factors controlling soil desiccation. The desiccation tests were conducted on three materials – clay, potato starch and milled quartz sand. Two controlling factors considered in this experiment are the tensile stress and strain energy development within the material. When the effective layer thickness or the layer thickness itself decreases because of a high desiccation rate, the crack cells sizes decrease, and the relatively high stored energy within this effective layer means that the material may be more conducive to the simultaneous hexagonal form of cracking.

Chertkov et al. (2000) conducted research on using surface crack spacing to predict crack network geometry in swelling soils. Prediction of the geometrical characteristics of steady crack networks in swelling soils is possible using a previously published model based on concepts of multiple cracking and fragmentation. A technique of such estimation is proposed based on the correlation of these parameters with the mean spacing between the shrinkage cracks at the soil surface. Zhanga et al. (2019) conducted research on pore water salinity effect on flocculation and desiccation cracking behaviour of kaolin and bentonite considering working condition cracking behaviour of clays at a local working climate and soils' evolution under seepage boundary is very important for the geological engineering. In coastal regions, pore water salinity is incorporated into above processes. In this study, the properties of typical clays (kaolin and bentonite) in saline environments, including the consistency limits, particle sedimentation and crack pattern, were investigated. The consistency limits of kaolin remain constant regardless of the pore water salinity, while the liquid limits of bentonite noticeably decrease with increasing salinity.

Flocculation of kaolin occurs in both distilled water and nacl solution, whereas the fine particles in bentonite disperse in distilled water but aggregate in saline water. At the end of the evaporation process, the total crack area of bentonite is obviously decreased, and the total crack length increases with pore water salinity, whilst that of kaolin is not influenced.

Zhang et al. (2018) conducted research on effects of tension crack on stability of bentonite-water slurry trenches in clay bentonite-water slurry trenches are utilized not only in underground excavations, but also in geo-environmental protections. Slurry trench can be used to prevent leaks and spills of the contaminant from landfills. This paper presented a procedure for evaluation of the impact of possible tension crack on stability of slurry trench in clay. The procedure is based on variational limiting equilibrium approach to slope stability. A straight extension was made to assess the safety of slurry trenches with cracks. Closed-form solutions were derived for the factor of safety and the potential crack depth for undrained total stress and drained effective stress conditions. Using normalisation presented the derived results in the form of stability chart. These charts provide a convenient tool for selection of the preliminary parameters for the slurry trench and determination of the potential crack depth.

III.MATERIALS

A.Kaolinite clay

Kaolinite is a clay mineral, part of the group of industrial minerals with the chemical composition Al2Si2O5 (OH) 4. It is a layered silicate mineral, with one tetrahedral sheet of silica (SiO4) linked through oxygen atoms to one octahedral sheet of alumina (AlO6) octahedral. Rocks that are rich in kaolinite are known as kaolin or china clay. Kaolinite has a low shrink–swell capacity and a low cation-exchange capacity (1–15 meq/100 g). It is a soft,

earthy, usually white, mineral (dioctahedral phyllosilicate clay), produced by the chemical weathering of aluminium silicate minerals like feldspar. In many parts of the world it is colored pink-orange-red by iron oxide, giving it a distinct rust hue. Lighter concentrations yield white, yellow, or light orange colors. Alternating layers are sometimes found, as at Providence Canyon State Park in Georgia, United States. Commercial grades of kaolin are supplied and transported as dry powder, semi-dry noodle, or liquid slurry. Table shows the properties of kaolinite and fig shows the kaolinite clay.

TABLE I
INITIAL PROPERTIES OF KAOLINITE CLAY

Properties	Value
Specific gravity (is 2720 part3)	2.67
Liquid limit (is 2720 part 5)	34%
Plastic limit (is 2720 part 5)	23%
Shrinkage limit (is 2720 part 6)	21%
Plasticity index (is 2720 part 5)	11%
Optimum moisture content (is 2720 part 7)	32%
Maximum dry density (is 2720 part 7)	1.5g/cc
Soil classification	CL
Coefficient Of Permeability (is 2720 part 17)	4.89×10^{-10} m/s

Fig -1: Kaolinite clay

B. Lead (Ii) Acetate Trihydrate

Lead Acetate Trihydrate is generally immediately available in most volumes. All metallic acetates are inorganic salts containing a metal cation and the

acetate anion, a univalent (-1 charge) polyatomic ion composed of two carbon atoms ionically bound to three hydrogen and two oxygen atoms (Symbol: CH3COO) for a total molecular weight of 379.33 g/mol. Acetates are excellent precursors for production of ultra-high purity compounds, catalysts, and nanoscale materials.

Fig - 2: Lead (Ii) Acetate Trihydrate

IV. METHODOLOGY

Tests conducted throughout this study are;

•Hydrometer analysis (IS: 2720 (Part 4)-1983)

•Atterberg's limit (IS: 2720 (Part 5)-1983)

•Permeability test (IS: 2720 (Part 36)-1983)

The index properties of Kaolinite were determined as per the respective IS Codes.

The Kaolinite clay is collected from English India pvt limited Kochi. Hydrometer analysis was used to obtain the particle size distribution of the samples in accordance with the standard specifications. For the particle size analysis clay contents are percentages of soil fractions smaller than 0.002mm. The clay fraction obtained is CL type. Falling head permeability test were done to find its coefficient of permeability and obtained as 4.89×10^{-10} m/s .Plasticity characteristics liquid limit (wL) is 34%, plastic limit (wP) is 23%, shrinkage limit is 21% and plasticity index (IP) is 11%, were determined in accordance with IS specifications.

Throughout this study lead acetate solutions are prepared as standard solution. Weight of the solute (lead acetate) for preparing various molar concentrations is calculated using the formula;

Weight of solute= (Molarity×Molecular weight of solute×vol of solvent)/1000ml

Molecular weight of solute = 379.33g/mol

The bentonite clay samples which are contaminated with lead of different molar concentrations (0 to 0.1M) were tested. Plasticity characteristics (liquid limit (wL), plastic limit (wP), shrinkage limit and plasticity index (IP)), permeability determined in accordance with IS specifications.

V. RESULTS AND DISCUSSIONS

A.*Variation in liquid limit and plastic limit*

The liquid limit varies from 34% at zero molar lead concentration to 46% at 0.1M concentration. The variation in plastic limit is from 23% to 35%.It is slightly lesser than that of liquid limit.

It is widely accepted that the LL is essentially the maximum absorbed water content around a particle, which correlates to the thickness of the diffuse double layer. The thickness of the diffuse double layer of kaolinite increases by increasing lead concentration, leads to a significantly increase in the LL.
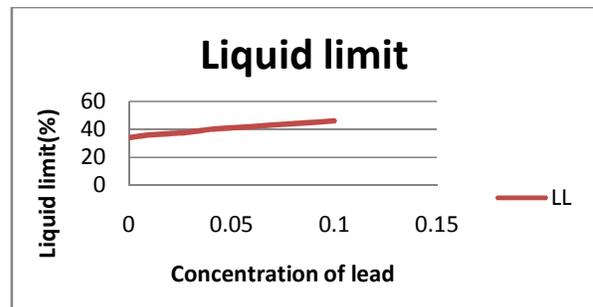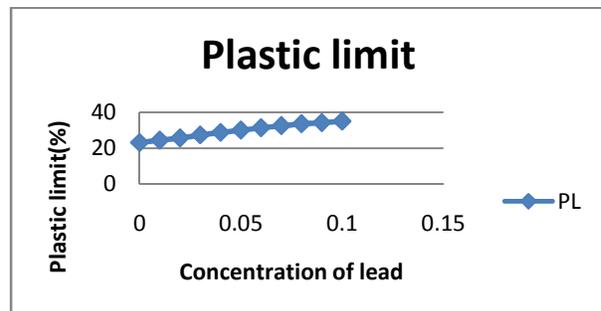
Fig 3: liquid limit v/s conc of lead

Fig 4: plastic limit v/s conc of lead

B. Variation in shrinkage limit

The variation in shrinkage limit is very small when compared with respect to liquid limit and plastic limit. The graphical variation is almost horizontal with X-axis.
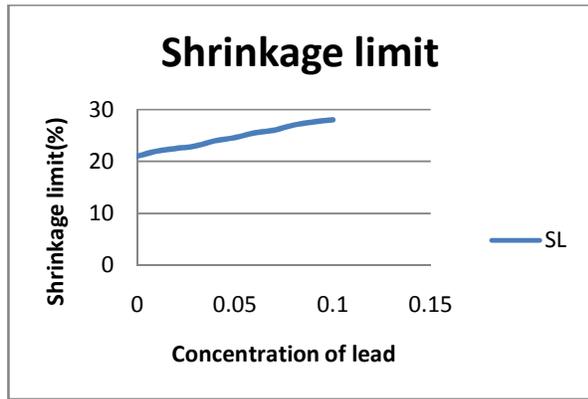

Fig 5: shrinkage limit v/s conc of lead

C. Variation in permeability

The permeability varies from 4.89x10-10m/s to 6.1x10-10m/s with varying concentrations of lead. With increasing lead contamination, particle aggregation in a Kaolinite-water mixture produced larger channels, and thus, more initial micro-cracks develop longer cracks and hence permeability also increases.
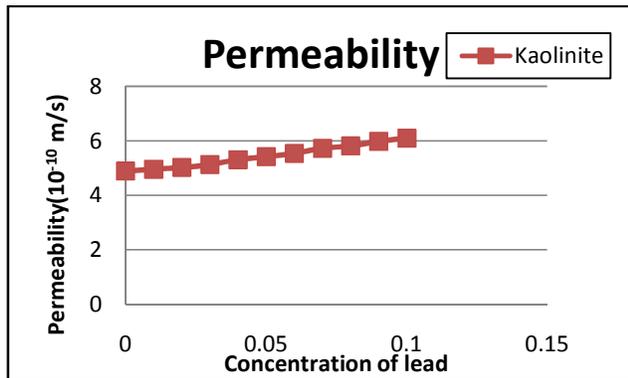

Fig 6: permeability v/s conc of lead

C. Effect of shrinkage cracking

Digital image processing was used for crack study. In this technique the images of the dried sample are taken with a camera. A known distance was included in the digital image along with the sample

in order to calibrate the image in the software. The colour image obtained from the digital camera was converted to a gray scale image. The gray scale image was again converted to a binary image from which the surface crack ratio and value can be calculated. The images of different processing stages are shown in the figure below.
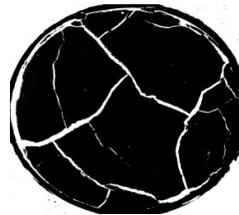

Fig 7: Binary image   Fig 8: Original Image

D. Variation in crack intensity factor

The original image is converted to grey scale and the scale is set. The surface crack area is calculated by threshold process. Crack intensity factor is calculated as the ratio of shrinkage crack area to total surface area. CA varies from 8.968Cm2 to 17.539 Cm2 for varying concentrations of lead.
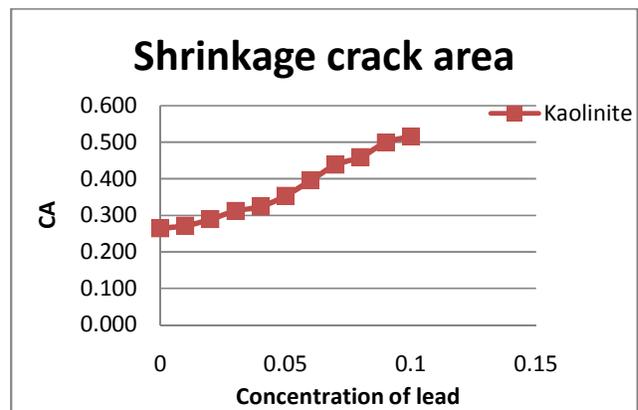

Fig 9: CA v/s conc of lead

VI. CONCLUSION

The liquid limit varies from 34% at zero molar lead concentration to 46% at 0.1M concentration and the plastic limit from 23% to 35%. The permeability varies from 4.89x10-10m/s to 6.1x10-10m/s with varying concentrations of lead.CA varies from $8.968Cm^2$ to $17.539 Cm^2$ for varying concentrations of lead.

VII. REFERENCES

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