

Effect of Various Pore Fluids on Free Swell and Shrinkage Cracking of Clays

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ABSTRACT: The tremendous increase in population and industrialization has increased the concentration of pollutants in soil. Penetration of chemicals into the soil will affect the properties of soil to great extent. In the recent years attention is given to the concentration of acids and alkalis in soil. The sources of acids and alkalis are acid rain, industrial effluents, ground water contamination, leachate from landfills and chemical spillages. The various pore fluids present in the waste materials may percolate into the soil and alter various properties of soil which includes liquid limit, unconfined compressive strength, consolidation behaviour, shrinkage cracking behaviour and swelling behaviour. In the present study investigation is focused on the effect of various pore fluids such as ammonium chloride, sodium chloride, sodium hydroxide and acetic acid on liquid limit variation and swelling behaviour and cracking behavior of a CH clay(bentonite) is studied.

KEYWORDS: Free swell, Pore fluid, Contamination.

I. INTRODUCTION

By definition clays are fine-grained soils that have significant plasticity. They have 50 percent or more by dry weight of particles smaller than the 200 μ sieve and their liquid limit and plasticity index lie on or above the A-Line on a plasticity chart. The crystal structure of clay minerals is the principal factor which determines their physical and chemical properties and their attraction to water. The atomic lattice of clay minerals comprises two structural elements. The first element consist of sheets of octahedrons made up of oxygen atoms or hydroxyl groups with eight coordinated aluminium, iron or magnesium atoms occurring in their interstices at equal distance from oxygen atoms as shown in figure 1.

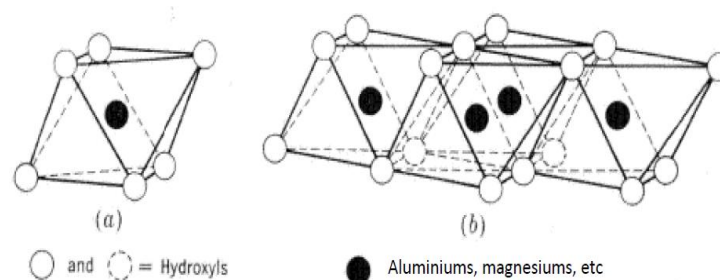


Fig.1.Diagrammatic sketch showing (a) single octahedral unit and (b) the sheet structure of the octahedral units

When aluminium is present, only two thirds of the possible positions are filled to balance the structure which is known as the gibbsite structure and if magnesium is present, all the positions are filled to balance the structure, which is known as brucite structure. Second element comprises of silicon-oxygen tetrahedral, where the silicon atom is equidistant from the four oxygen atoms in each tetrahedron as shown in figure 2. This is necessary to ensure lattice equilibrium.

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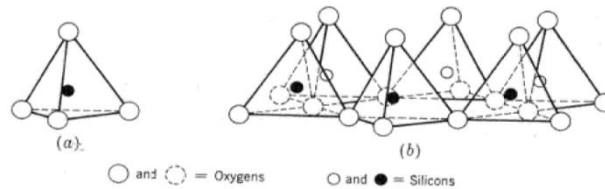


Fig.2. Diagrammatic sketch showing (a) single silica tetrahedron and (b) the sheet structure of silica tetrahedrons arranged hexagonal network

The chemical classification of clay minerals is based on two lattice types. The first type is a layer structure of alternating silicon oxygen tetrahedral and aluminium oxygen octahedral with the ratio of 1:1(eg: Kaolinite). The second structure has a ratio of 2:1(montmorillonite).Kaolinite is made of silicon oxygen and aluminium oxygen. They are joined to form a single electrically unit cell with a structural formula of $(OH)_8Si_4Al_4O_{10}$.The montmorillonite unit cell consist of two external silicon-oxygen sheets and one intermediate oxygen-aluminium sheet. Layers of oxygen atoms surround each unit cell and the adjoining units are held together by Van der Waals bonds, which are easily broken when polar molecules infiltrate interstices. Presence of polar molecules causes substantial swelling of the lattice until individual layers are entirely separated. The degree of inter crystalline swelling in the presence of water also depends upon cation exchange capacity.

Various environmental factors like overburden pressure, temperature, pore fluid, mineral types, dry density etc. control the properties like shrinkage, swelling, cracking and shear strength. As pore fluid changes properties of soil also changes. The present study is intended to find the effect of pore fluid on swelling behaviour and cacking behaviour of CH type clay (Bentonite).

II. MATERIALS AND METHODS

Now a day the use of clayey soils in soil engineering practice is very common. It necessitates a better understanding of their behaviour and their changes in various environments. Clays in which, surface forces or inter particle electrical repulsive and attractive forces are predominant exhibit a wide range of mechanical behaviour on the basis of their changes in physical and physico chemical properties. The soil selected for the present study is bentonite. The properties of used soil and pore fluids are explained below.

Materials

(a)Bentonite

Bentonite is naturally occurring clay with extra ordinary properties such as very high expansion capability by absorbing water (swelling capacity), high ion exchange capacity and very low water permeability. Two types of commercially available bentonites like calcium bentonite and sodium bentonite are commonly used. Calcium bentonite used in the study was purchased from Ashapura Clay Factory, Kinfra. Properties of calcium bentonite are given in table 1.

Table 1.Properties of Calcium Bentonite

PROPERTIES	VALUES
Liquid Limit (%)	245
Plastic Limit (%)	46
Specific Gravity	2.66
Percentage of clay	73
Percentage of silt	18
Percentage of sand	9
Free swell (ml/2g)	18
Unconfined compressive strength (kN/m ²)	15.4
Optimum moisture content(%)	45

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(b) Pore fluids

The pore fluids used in this investigation are sodium hydroxide, sodium chloride, ammonium chloride and acetic acid of varying molarities such as 0.1M, 0.2M, 0.3M and 0.4M. The physical and chemical properties of pore fluids are shown in Table.2.

Table.2 Physical and chemical properties of pore fluids

Type of Liquid	Molecular Formula	Molecular Weight(g/mol)	Dielectric Constant at 20°C	Surface Tension dyne/cm	Boiling Point °C	colour
Sodium Hydroxide	NaOH	40.00	-	-	1660	White, waxy, opaque crystals
Acetic Acid	CH ₃ COOH	60.05	6.2	13.9	118	colourless
Sodium chloride	NaCl	58.44	23	60.66	1413	White solid
Ammonium chloride	NH ₄ Cl	53.491	4.3	-	520	White solid
water	H ₂ O	18.02	80.2	72.75	100.0	colourless

Methods

(a) Free Swell Test

Free swell is the increase in volume of a soil, without any external constraints, on submergence in water. The possibility of damage to structure due to swelling of expansive clays must be identified otherwise it will create serious issues. Free swell of the bentonite was determined as per ASTM D 5890-02 standard. To perform the tests, a 2g sample of dried and finely powdered bentonite is dispersed into a 100 ml graduated cylinder in 0.1g increments over a period of 30 minutes. The sample is then kept for a period of 24 hours and the swell volume is noted. The free swell is expressed in ml/2g of bentonite. Sodium hydroxide, ammonium chloride, sodium chloride and acetic acid solutions of different concentrations (0.1M, 0.2M, 0.3M, and 0.4M) were used in free swell experiments.

(b) Cracking Behaviour

Soil cracking is a natural phenomenon and is frequently observed in many natural and manmade earthen structures. These cracks are a result of an internal energy imbalance in the soil mass caused by non uniform moisture distribution, temperature distribution, or distribution of compaction energy during construction. Shrinkage cracking is the most common cracking found in earth structure. Because of the water loss, soil loses its ability to relieve these tensile forces by plastic flow. These stresses are finally relieved by the formation of shrinkage cracks that break up the surface layer in to pieces of more or less. Cracking behaviour may be found out using Lehig method. The following procedure may be adapted.

- Approximately 50 to 100 g of soil are needed.
- Water content of specimen must be at the full saturation condition. For simplicity the water content of liquid limit can be used.
- Soil water must be mixed thoroughly for at least 5 min. Then spread this wet soil paste uniformly on a clean glass plate. A round shape wet paste sample is formed.
- The maximum height of the wet soil paste must be less than 1/20 in. (0.127 cm). The thinner the wet mud pad, the more distinct cracking pattern will develop.
- Drying process:
- Air dry at room temperature for 24 hrs

III. RESULTS AND DISCUSSIONS

Effect Of Various Pore Fluids On Free Swell Of Clays

(a)Effect Of NaCl On free Swell

The free swell of bentonite was found with different concentrations (0.1M, 0.2M, 0.3M and 0.4M) of Sodium chloride solution are shown in Fig 4.3. The calcium bentonite has a free swell of 18ml/2g in water.

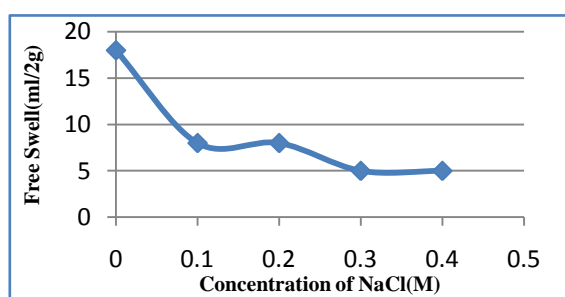


Fig.3.Variation Of Free Swell With Different Concentrations Of NaCl

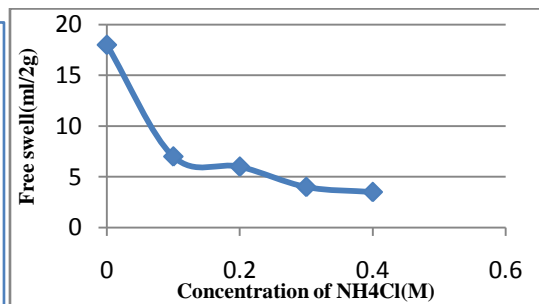


Fig.4. Variation Of Free Swell With Different Concentrations Of NH₄Cl

With increase in concentration of NaCl the free swell values of bentonite get decreased. Decrease in free swell of bentonite is due to reduction in diffuse double layer thickness by Na⁺ ions.

(b) Effect Of NH₄Cl On Free Swell

The free swell of bentonite was found with different concentrations (0.1M, 0.2M, 0.3M and 0.4M) of Ammonium chloride solutions are shown in Fig 4. With the addition of ammonium chloride solutions free swell values reduced for bentonite. Decrease in free swell of bentonite is due to reduction in diffuse double layer thickness by NH⁺ ions.

(c) Effect Of CH₃COOH On Free Swell

The free swell of bentonite was found with different concentrations (0.1M, 0.2M, 0.3M and 0.4M) of Acetic acid solutions are shown in Fig. 5. With increase in concentration of CH₃COOH the free swell values of bentonite get decreased. That means both of the soil showed similar trend in free swell test with acetic acid but in metakaolin the decrease is very less i.e. only 2ml/2g.

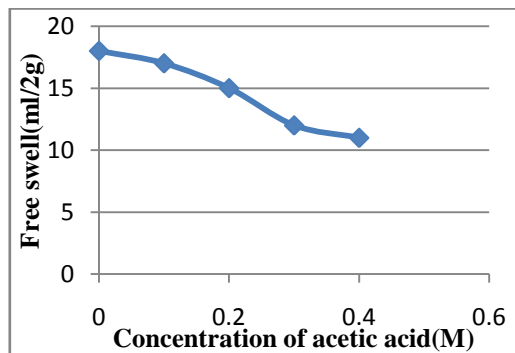


Fig.5.Variation Of Free Swell With Different Concentrations Of CH₃COOH

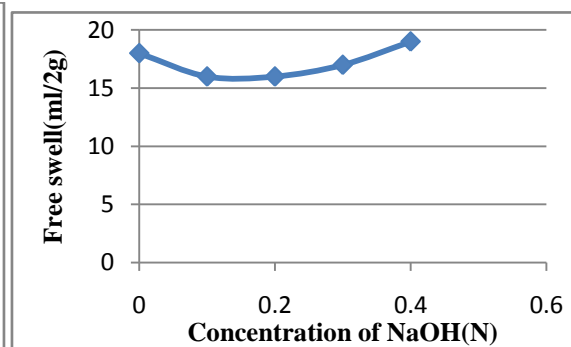


Fig.6. Variation Of Free Swell With Different Concentrations Of NaOH

(d) Effect Of NaOH On Free Swell

The free swell of bentonite and metakaolin found with different concentrations of sodium hydroxide solution are shown in Fig.6. With increase in concentration of NaOH the free swell values of bentonite get increased and this is due to the effect of Na ions which increase the diffuse double layer thickness.

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Effect Of Various Pore Fluids On Cracking Behaviour Of Clays

(a) Effect Of NaCl On Cracking Behaviour

For studying crack pattern and crack width with the addition of sodium chloride, solutions were prepared at 0.1M and 0.4 M. Soil pats were prepared and were allowed to dry. Fig.7. Shows crack width variation with sodium chloride solution (air dry).



(a)Cracking pattern of bentonite with 0.1M NaCl (air dry)



(b) Cracking pattern of bentonite with 0.4M NaCl (air dry)

Fig.7. Cracking pattern for clays with different molarities of NaCl solutions (air dry)

(b) Effect Of NH₄Cl On Cracking Behaviour

For studying crack pattern and crack width with the addition of ammonium chloride, solutions were prepared at 0.1M and 0.4 M. Soil pats were prepared and were allowed to dry. Fig.8.shows crack width variation with ammonium chloride solution (air dry).



(a)Cracking pattern of bentonite with 0.1M NH₄Cl (air dry)



(b) Cracking pattern of bentonite with 0.4M NH₄Cl (air dry)

Fig.8. Cracking pattern for clays with different molarities of NH₄Cl solutions (air dry)

(c) Effect Of CH₃COOH On Cracking Behaviour

For studying crack pattern and crack width with the addition of acetic acid, solutions were prepared at 0.1M and 0.4 M. Soil pats were prepared and were allowed to dry. Fig.9.shows crack width variation with acetic acid solution (air dry).



(a)Cracking pattern of bentonite with 0.1M CH₃COOH (air dry)



(b) Cracking pattern of bentonite with 0.4M CH₃COOH (air dry)

Fig.9. Cracking pattern for clays with different molarities of CH₃COOH solutions (air dry)

(d) Effect Of NaOH On Cracking Behaviour

For studying crack pattern and crack width with the addition of sodium hydroxide solutions were prepared at 0.1N and 0.4 N. Soil pats were prepared and were allowed to dry. Fig.10.shows crack width variation with NaOH solution(air dry).

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(a) Cracking pattern of bentonite with 0.1N NaOH (air dry)



(b) Cracking pattern of bentonite with 0.4N NaOH (air dry)

Fig.9. Cracking pattern for clays with different molarities of NaOH solutions (air dry)

As the concentration of NaOH increased, number of cracks got increased.

IV. CONCLUSIONS

The following are the conclusions derived from the study:

- Pore fluid influences various properties of soil
- Characteristics of pore fluids are very different and sample preparation systems can greatly influence results
- Decrease in free swell of bentonite is due to reduction in diffuse double layer thickness
- Crack width and crack pattern varies with the pore fluid
- Effect of pore fluids should be considered as a serious issue

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