THE IMPACT OF PH AND CONCENTRATIONS OF ION ON THE COHESIVENESS SOIL'S

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ABSTRACT

By altering the electrochemical forces that exist between the solid, liquid, and dissolved phases, adding salt to pore water can change how the soil behaves. The chemistry of the soil's components and the pore fluid chemistry determine how fine-grained soils' geotechnical behaviour changes in response to ionic concentrations and pH. The clay particles have a major role in the geotechnical changes in soil behaviour, and the differences in the varieties of clay are caused by their unique surfaces and net electrical charges. In general, the edges of clay particles are positively charged, whereas the surface is negatively charged. The attraction of cations, which are retained on the particle surface and between the layers, balances the negative charge of the clay particle in order to maintain electrical neutrality. The charged clay surface forms a diffuse double layer with the counter-ions in the pore water. The impact of pH and potassium chloride (KCl) ionic concentrations on the liquid limit of finegrained soil is the main focus of this investigation. Each of the ionic concentrations was created in four distinct pH values (3.5, 5.5, 7.5, and 9.5) in order to perform the fall cone test, which measured the liquid limit in various pore fluid concentrations. Based on the test findings While the liquid limit slightly undulated at lower pH values at ionic concentrations of 0.00001 M, 0.0004 M, and 0.003 M, it was found that the pH values had the least impact at higher ionic concentrations (0.1 M and 1.8 M) of KCL. In general, it was found that the pH values had no discernible effect on the liquid limit of the samples. The buffering effects of the comparatively large solute concentration at 0.1 M and 1.8 M are responsible for this phenomenon. Conversely, when the ionic concentrations of KCL increased, the liquid limit dropped. Raising the ionic concentration causes the diffuse double layer to thin, which weakens the repulsive forces. This raises the effective stress, which causes the clay particles to flocculate, which lowers the liquid limit of the clayey sample.

Keywords: KCI Values, high cohesive strength, industrial advancement, cation exchange capacity, magnesium chloride (MgCl₂)

1. INTRODUCTION:

Fine-grained, low-strength, readily deformable soils with a propensity for particle adhesion are known as cohesive soils. If there are more than 50% of fines (silt and clay-sized particles) by weight, the soil is said to be cohesive. Cohesive soils are pliable and have a high cohesive strength. Three main processes contribute to soil particle cohesion: primary valence bonding and adhesion, cementation, and electrostatic and electromagnetic attraction. The geometric arrangement of soil or mineral particles, which is controlled by interparticle force, is known as soil structure. It is dependent on the soil's genetic, chemical, and mineralogical characteristics as well as previous



stress circumstances. Geotechnical engineering, agriculture, construction, medicine, and materials science all benefit from the study of fine-grained soils. The behaviour of clay, the most prevalent and naturally occurring fine-grained material, is determined by its size, shape, distribution, surface chemistry, surface area, surface charge, and pore fluid chemistry. A large portion of the air, water, and land have recently become contaminated as a result of population increase, rising living standards, and industrial advancement. These issues are brought on by a variety of sources, including open dumps and industrial and chemical waste. The characteristics of ground soil are impacted directly or indirectly by all forms of contamination. Though acid contamination has become a growing global concern, little research has been done to understand the effects of pH, particularly acidic water. A good number of studies have been conducted to understand the influence of pore water chemistry on the strength characteristics of fine-grained soils. It can originate from anthropogenic causes such acid rain, unintentional spills, or municipal waste storage, or from natural processes like the weathering of mudstone (indigenous). Recently, this issue has been acknowledged, and some research has been done to look at how the chemistry of pore fluids affects soil characteristics in relation to pH and ionic concentrations. However, it is still unknown how pore fluid pH and ionic concentrations affect soil strength. Leachate is created when water seeps into the trash during rainy seasons and reacts with it physically, chemically, and biologically. The leachate seeps into the earth, contaminating the groundwater and subsurface. The process of leachate penetration into the subsurface environment often proceeds slowly over a number of years since the solid waste typically remains where it is put. Additionally, liquid wastes damage ground water and subterranean soil by seeping into them. Both treated and untreated industrial effluents are released into the soil, potentially altering its composition. Understanding the impact of industrial effluents becomes crucial as a result. In the unlikely event that soil engineering behaviour improves, industrial waste will undoubtedly contribute value while providing the advantages of safe wastewater disposal. But if the ongoing deterioration of the soil's engineering behaviour continues, depending on the source rock, salts may naturally exist in residual top soils. In coastal areas with salt water, ocean surges can occasionally create flooding, which increases the amount of salt minerals in the soil. Additionally, mining locations have higher concentrations of metallic elements. There have been reports of structural damage and foundation collapse in light industrial structures due to altered soil qualities brought on by different industrial effluents. Sometimes excellent enough soil can get contaminated by industrial wastes, making it too bad to use at all; other times, the soils may not have the geotechnical qualities to be utilised as building materials, which must be stabilised with additions. After that, they must be decontaminated. Density, porosity, structure, the kind of clayey minerals, the history of granulation and tension, and plastic properties are some of the variables that affect the engineering properties of fine-grained soils, especially clayey soils. The kind of minerals present and their concentration in the pore water also affect the engineering properties. This implies that any alteration to these properties will result in an equivalent alteration to the soil's mechanical and physical properties. Engineering characteristics like soil density, shear strength, and plasticity are crucial since they influence the soil's structural performance, especially when it comes to foundations and geotechnical engineering vs civil engineering applications. It is widely accepted in fundamental engineering theory of soil mechanics that there is no chemical interaction between the various phases and that the solid particles and pore water are chemically inert. Nonetheless, it notes that the negatively charged surface of clayey mineral particles indicates the presence of electrochemical interactions between the solid, liquid, and dissolved phases, which affects the mechanical

properties of clayey soil. Furthermore, the kind of anion and cation in the exchange phase, as well as the effect of this interaction on the cation exchange capacity, determine the amount and kind of electro-chemical forces. implies that the bonds between particles within the microstructure, which in turn impacts the soil's engineering qualities, may be influenced by the temperature of the soil and the chemical makeup of the salt. By presenting experimental data on the changes in the liquid limit of our clay sample exposed to pore fluids at various ionic concentrations of KCl and pH, we hope to clarify this issue further. Five distinct KCl concentrations (0.00001 M, 0.0004 M, 0.003 M, 0.1 M, and 1.8 M) were made, with four distinct pH values (3.5, 5.5, 7.5, and 9.5) for each concentration. These numbers reflect the pH that the groundwater would have under typical circumstances; otherwise, the clay minerals would dissolve and the findings would not be able to be reasonably interpreted.

2. LITERATURE REVIEW:

Studies have looked at how the pH of the pore fluid and ionic concentrations affect the soil's engineering qualities, such as its shear strength and classification, preferably with the use of Atterberg limits. In order to provide background information for the tests carried out in the current study and to enable informed comparison and analysis of the test data, the previous review focusses on the investigation of various soils and the effect of salinity on the engineering properties of the soil. It also lists the types of tests carried out in the review along with the results obtained. It performed an extensive investigation into the effects of seawater on the consistency limits and compressibility behavior of clayey soils. Their analysis, which included liquid limit, plastic limit, and shrinkage limit tests, demonstrated that seawater had minimal influence on these geotechnical parameters for soils with liquid limits up to 110%. However, notable variations were observed in the behavior of Na-bentonite samples. assessed the impact of three inorganic salts-potassium chloride (KCl), calcium chloride (CaCl₂), and magnesium chloride (MgCl₂)—on the geotechnical properties of clay used in landfill barrier systems. Their findings revealed a decline in the liquid limit of clay mixtures when salt solutions were introduced. As salt concentration and cation valence increased, interparticle repulsion reduced, thereby decreasing the liquid limit due to the enhanced mobility of particles at lower water contents. examined the consistency limits of clays in the presence of different salt solutions such as NH₄Cl, KCl, CuSO₄, and FeSO₄. They found that salt concentration had contrasting effects based on clay plasticity: low-plasticity (CL) clays showed an increase in liquid limit with rising salt concentration, whereas high-plasticity (CH) clays experienced a reduction. studied the influence of seawater on high-plasticity (CH) clays. Their results indicated that exposure to seawater elevated the liquid limit, plastic limit, and plasticity index by 9.32%, 8%, and 10.91% respectively, compared to tap water. conducted experiments on expansive clays with different mineral compositions and plasticity levels, evaluating their liquid limit in distilled, tap, and seawater. The results highlighted a consistent decline in the liquid limit when seawater was used, with the effect most pronounced in bentonite samples. explored the impact of sodium hydroxide (NaOH) on low-plasticity soils (LL \approx 38%). Their study revealed that increasing NaOH concentration led to a higher liquid limit, attributed to the formation of new swelling compounds from the reaction between alkali and clay minerals. analysed the impact of phosphate ions on the index properties of kaolinite and montmorillonite clays. Phosphate adsorption led to an increase in the liquid limit and surface area for kaolinite due to enhanced flocculation, while Na-montmorillonite experienced a decrease in liquid limit. Ca-montmorillonite showed a complex response, initially decreasing and

later increasing upon phosphate treatment, due to ion exchange dynamics involving divalent and monovalent cations. investigated the influence of various salts (NH₄Cl, KCl, CuSO₄, and FeSO₄) on the Atterberg limits of CL and CH clays. Their results indicated that for CL clays, both liquid and plastic limits increased with salt concentration up to 0.2 M. However, for CH clays, salt concentrations above 0.2 M showed minimal additional impact. The behavior varied depending on the salt type and concentration, with flocculation leading to changes in soil classification (from CL/CH to ML/MH according to USCS). explored how chloride compounds such as KCl, CaCl₂, and MgCl₂ influence soil plasticity. Their study demonstrated a clear trend of decreasing liquid limit, plastic limit, and plasticity index with increasing salt content. examined fine-grained soils using distilled, saline, and semi-saline water. They found that increasing water salinity consistently reduced the Atterberg limits for CL soils. evaluated the effects of three inorganic salts-sodium chloride (NaCl), potassium nitrate (KNO3), and calcium sulfate (CaSO₄)—on the liquid and plastic limits of two subsoils. Using regression analysis, they developed predictive models for LL and PL over time. Their results indicated a decline in both limits due to the salts' impact on cation exchange and pore fluid chemistry. identified a negative correlation between salt concentration and liquid limit, noting that soils with high moisture contents are more susceptible to salinity effects, resulting in decreased liquid limits. conducted Atterberg limit tests on kaolinite-bentonite-sand mixtures exposed to salt water. They observed a substantial decrease in liquid limits as salinity increased. Specifically, a rise in KCl concentration from 0 to 200 g/L caused a 6% reduction in kaolinite's liquid limit. Bentonite samples exhibited even more significant reductions, with up to 70% decrease in liquid limit at high salt concentrations. It assessed the geotechnical behavior of Egyptian clays under varying salinity levels of groundwater. Their findings showed a minor reduction in plasticity index from 26 (pure water) to 24.96 with 80% salt content. It observed a general decline in Atterberg limits for fine-grained soils exposed to saline water compared to tap water. It examined the liquid limit of expansive clays mixed with different water types—distilled, tap, treated wastewater, and seawater. Their results revealed a progressive decrease in liquid limit: from 70% (distilled) to 68% (tap), 61% (treated wastewater), and 55% (seawater), underlining the significant role of water chemistry on soil plasticity behavior.

3. METHODOLOGY:

- To prepare the soil samples for testing, several laboratory apparatuses were employed. These included a lump crusher for breaking down large soil clumps and a set of sieves with aperture sizes ranging from 2 mm to 150 µm to eliminate coarse particles such as stones, pebbles, and debris. Drying ovens operating at temperatures between 120°C and 170°C were used to dry the sieved material. The dried samples were further ground to a fine powder using a mortar. Mass measurements were conducted using a digital weighing balance (Model: CAS SW-1S).
- A systematic experimental program was designed to investigate the influence of potassium chloride (KCl) ionic concentration and pH levels on the Atterberg limits of the clayey soil. The liquid limit was determined using the fall cone apparatus (Model: NL SCIENTIFIC NL 5047 X / 001), in accordance with the British Standard 1377 (1990). This standard defines the liquid limit as the moisture content at which a stainless steel cone weighing 80 ± 0.05 g and having an apex angle of 30 ± 1° penetrates a remolded soil specimen to a depth of 20 mm upon release.

- The liquid limit represents the boundary between the plastic and liquid states of fine-grained soils. At this threshold, the shear strength of the clay is governed by the soil fabric—i.e., the arrangement and interaction of clay particles and aggregates (Mitchell, 1993). In the present study, four different moisture content levels were evaluated for each clay–electrolyte mixture using the cone penetrometer.
- Prior to testing, the clay samples were washed with deionized water until the electrical conductivity (EC) of the effluent dropped below 100 µS/cm, ensuring minimal residual salinity. The initial moisture content was achieved by mixing 60–80 mL of prepared KCl electrolyte solution with 200 g of air-dried clay. The mixture was allowed to hydrate overnight to ensure uniform distribution of moisture and ions. Following the equilibration period, the sample was thoroughly re-mixed and compacted into a standardized metal cup (6.25 cm in diameter and 4.5 cm in height), ensuring that no air pockets remained. The surface was leveled to provide a smooth, even finish.
- Penetration measurements were considered valid within a range of 14 mm to 28 mm. Once the desired penetration was recorded, approximately 15 g of soil was extracted for gravimetric moisture content analysis. Concurrently, the pore-fluid pH was determined using a centrifuge-based extraction method. The remaining soil was then incrementally mixed with additional KCl solution to raise the moisture content and facilitate the next penetration test.
- The complete set of results includes values for gravimetric moisture content (W, %) and corresponding cone penetration depths (mm). The water content associated with 20 mm cone penetration was designated as the liquid limit for each combination of KCl molar concentration and pH. The concentrations of KCl tested were 0.00001 M, 0.0004 M, 0.003 M, 0.1 M, and 1.8 M, each prepared at four distinct pH levels: 3.5, 5.5, 7.5, and 9.5.

Cone Penetration vs Moisture Content at 0.00001 M				
pH Level	Cone Penetration (mm)	Moisture Content W _T (%)		
3.5	16, 19, 23, 26	76, 78.5, 81, 84		
5.5	17, 20.5, 24, 27	76, 79.5, 84, 88.5		
7.5	16, 19.5, 23, 27	76.5, 79, 81.5, 83.5		
9.5	16.5, 20, 23.5, 27	76.5, 78.5, 81, 84		
Cone Penetration vs Moisture Content at 0.0004 M				
3.5	17, 20, 24, 28	76, 79.5, 82.5, 86		
5.5	15, 19, 24, 29	76, 79, 82.5, 85.5		
7.5	14, 18.5, 23, 28	76.5, 78.5, 81, 83.5		
9.5	15, 18.5, 22, 26	77, 79, 80.5, 82.5		
Cone Penetration vs Moisture Content at 0.003 M				
3.5	17, 21, 25, 29	77.5, 80.5, 82.5, 84.5		
5.5	17, 19, 22, 26	76.5, 78.5, 81.5, 84		
7.5	15, 18, 22, 25	75, 77.5, 80.5, 82.5		

4. RESULT AND DISCUSSION:

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9.5	17, 19, 23, 27	76.5, 78, 81, 84.5	
Cone Penetration vs Moisture Content at 0.1 M			
3.5	16, 20, 24, 28	76.5, 79.5, 82.5, 85.5	
5.5	17, 19, 23, 27	77.5, 79.5, 83.5, 85	
7.5	17, 20, 23, 27	72.5, 76.5, 80.5, 85.5	
9.5	14, 17, 21, 27	74.5, 77.5, 81.5, 84	
Cone Penetration vs Moisture Content at 0.4 M			
3.5	17, 20, 23, 27	72, 74, 76, 79	
5.5	16, 19, 22, 27	71, 74, 76, 79	
7.5	16, 18, 21, 26	71.5, 73, 74.5, 77.5	
9.5	16, 19, 22, 27	72, 74, 75.5, 77	







4.1. INTERPRETATION OF SOIL BEHAVIOUR BASED ON MICROSTRUCTURE INTERACTIONS

The behaviour of soil under varying chemical conditions can be explained by the interactions occurring at the microstructural level between clay minerals and water. Water molecules are dipolar, meaning they carry both positive and negative charges. These charges are naturally attracted to the opposite charges present on the surfaces of clay minerals. Specifically, the negatively charged surfaces of clay particles attract the positively charged side of water molecules. Additionally, water molecules are also drawn to the cations located within the diffuse double layer of the clay structure. This mutual attraction between clay minerals and water molecules alters the structure of the double layers and significantly influences soil behaviour.

4.2. EXPERIMENTAL OBSERVATIONS

Figures 1 illustrate the test results. To ensure accuracy, various moisture contents were plotted against corresponding cone penetration values (Figures 1). A line of best fit was drawn through each dataset, and the moisture content corresponding to a cone penetration of 20 mm was identified as the Liquid Limit. The plots

reveal a direct relationship between water content and cone penetration, where higher water content typically results in deeper penetration. While both acidic and basic conditions (pH variations) influence ionic strength, they had minimal impact on the Liquid Limit across different pH levels, especially at lower ionic concentrations (0.00001 M, 0.0004 M, and 0.003 M). However, at higher concentrations (0.1 M and above), the slope of the Liquid Limit line flattens. This suggests that the buffering capacity of the clay, influenced by the increased solute content, moderates changes in the Liquid Limit.

5. CONCLUSION:

- The engineering behavior of fine-grained soils, especially clayey soils, is largely governed by several intrinsic properties, including density, porosity, mineral composition, soil structure, and plasticity characteristics. Any alteration in these parameters can significantly impact the physical and mechanical performance of the soil.
- One of the critical external factors that can modify soil behavior is the presence of salts in the pore water. The introduction of ionic solutions alters the electrochemical interactions among the solid particles, pore fluids, and dissolved ions, thereby influencing the overall soil response.
- This study specifically examines how ionic solution percolation affects the geotechnical properties of clayey soils. While the precise influence of pore fluid chemistry remains a topic of ongoing research and debate, many of the observed geotechnical changes can be explained through the lens of diffuse double layer (DDL) theory.
- As the ion concentration in the pore fluid increases, the thickness of the diffuse double layer surrounding the clay particles is reduced. This thinning of the DDL weakens the repulsive forces between particles, leading to flocculation—a process in which individual clay particles aggregate. Flocculation alters the soil structure, reduces plasticity, and affects fundamental properties such as permeability, shear strength, and compressibility.

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