

Effect of Chemicals on Index Properties of Soil

Purabi Sen ^a, Mahabir Dixit , R Chitra

^a Scientist C, CSMRS, MOWR, Hauz Khas, New Delhi-16

email: purabi_saayon@rediffmail.com,

Abstract— Change in geotechnical behaviour of fine grained soils under the influence of inorganic salts depends on the chemistry of the soil constituents and the pore fluid. The modification of soil behaviour largely depends upon the clay particles which belongs to size 0.002 mm and less and it is unique in nature. The different nature of clay is due to net electrical charge on them. In general, clay particles surface are negatively charged and its edges are positively charged. To preserve electrical neutrality the negative charge of the clay particle is balanced by the attraction of cations which are held between the layers, and on the surface of the particles. The charged clay surface together with the counter-ions in the pore water form diffuse double layer. Furthermore, the double layer is influenced by the valency of the counter-ions and the temperature. Use of salt solution as pore fluid generally causes decrease in liquid limits. The higher the cation valance, higher decrease in liquid limits.

Keywords—Diffuse double layer, Clay particles, Atterberg Limits, Liquid Limit, Plastic limit, Plasticity index, Cation size, Cation valency

INTRODUCTION

Generally, change in geotechnical behaviour of fine grained soils under the influence of inorganic salts depends on the chemistry of the soil constituents and the pore fluid. The source of chemical constituents may be indigenous or this may come from outside by contamination. For residual top soils, which are directly formed from rock, salts may be present in natural condition and depends on the composition of mother rock. And now a days the soil can frequently get contaminated by salts by industrial activities. Sources of contaminants into soil by various operations can be traced within the environment in developing and developed countries. Ocean surges cause occasional flooding in coastal area with salt water. This action would lead to addition of salt minerals into soil. Where mining takes place, metallic elements are present in greater amount. ^[1] Disposal of solid or liquid effluents, waste by products over the land causes alterations of the physical and mechanical properties of the ground. Alteration of soil properties sometimes causes degradation in soil properties. The wastes from chemical industries are found littering both urban and rural soils due to improper management system ^[2]. Modification of soil properties causing foundation failure, structural damage in light industrial buildings on soil contaminated by various industrial effluents have been reported.

Sometimes the soils may be lacking the geotechnical properties for soil to be used as construction materials, which are to be stabilised using additives, sometimes good enough soil can get contaminated by industrial wastes which become severely affected to be used at all. Then these need decontamination.

In the present paper, study has been done to understand how the various chemical salts affect Atterberg limits of soil.

Mechanisms behind the Modification in Physical and Engineering Properties of Soil

The modification of soil behaviour largely depends upon the clay particles which belongs to size 0.002 mm and less and it is unique in nature. Clay with a large quantity of water behaves like a viscous liquid, with less water it can be moulded and when dried it looks like a solid. On the other hand sand, silt or rock dust are very difficult to mould. The different nature of clay is due to net electrical charge on them. In general, clay particles surface are negatively charged and its edges are positively charged (Fig. 1). Due to the surface charge, it would adsorb or attract cations (+ve charged) and dipolar molecules like water towards it. As a result, a layer of adsorbed water exists adjacent to clay surface, usually a negative charge on their faces and a positive charge on their ends. ^[3]



Fig. 1 Typically charged clay particle

Diffuse double layer

To preserve electrical neutrality the negative charge of the clay particle is balanced by the attraction of cations which are held between the layers, and on the surface of the particles (Fig.2), while electrostatically attracted the concentration of these cations or counter-ions diminishes with increasing distance from the clay particle surface. The charged clay surface together with the counter-ions in the pore water, form the so-called diffuse double layer.^{[4],[5]} Furthermore, the double layer is influenced by the valency of the counter-ions and the temperature.

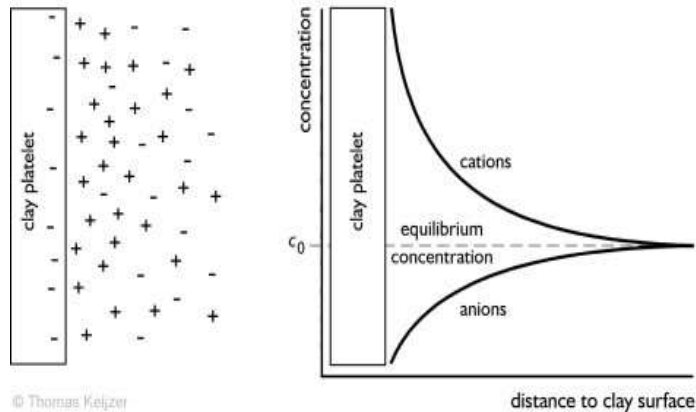


Fig. 2 Distribution of cations and anions adjacent to a clay platelet according to the diffuse double layer theory

The influence of pore fluid chemistry on the engineering behaviour of clay soil in many respects is still unclear and is even controversial in some cases. However, modification in all the engineering properties and behaviours have been reported and explained in most cases in the light of change in thickness in diffuse double layer with the addition of salt in soil. Changes in fine grained soil behaviour due to contaminants can be explained by changes in diffuse double layer theory and fabric changes. According to Gouy-Chapman theory by increasing the ion concentration, the thickness of diffuse double layer decreases which leads to flocculation of the clay particles^[6].

To understand the mechanisms behind the modification in physical and engineering properties of soil, one have to understand the structure of clay particles and source of negative charges.

Structure of Clay Particles and source of negative charges:

Clay particles due to their small size, coupled with plate-like shapes, contribute to very high external surface areas that are complemented in some cases with even more extensive internal surface areas. These surfaces characteristically carry negative and/or positive charges that influence the attraction and repulsion of the particles toward each other and that attract swarms of ions of the opposite charge along with numerous water molecules (Fig 3).

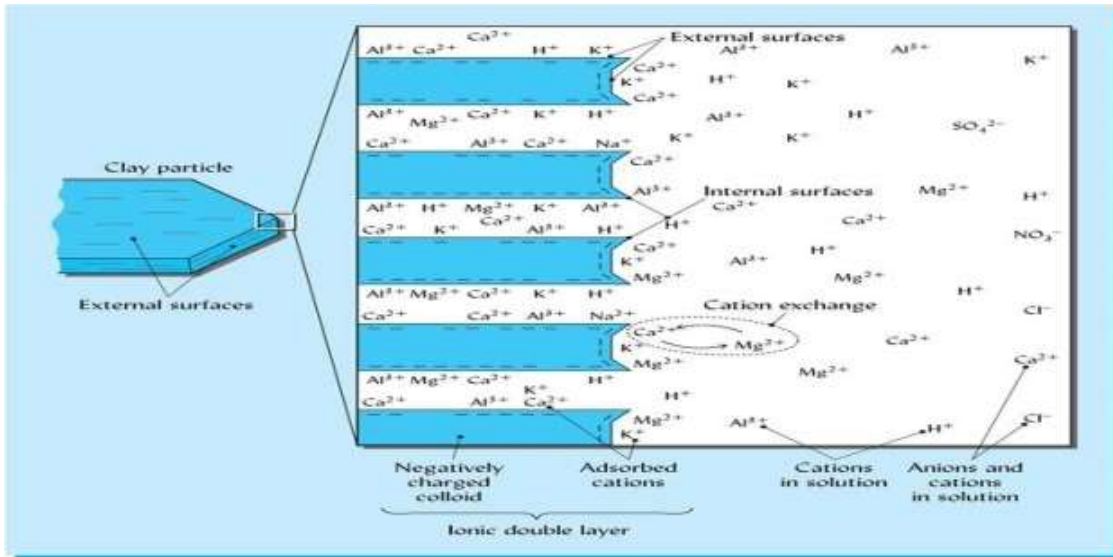


Fig. 3 Representation of a clay crystal, its complement of adsorbed cations, and ions in the surrounding soil solution.

More Simplified sheet structure of clay particle can be shown below: (Fig 4)

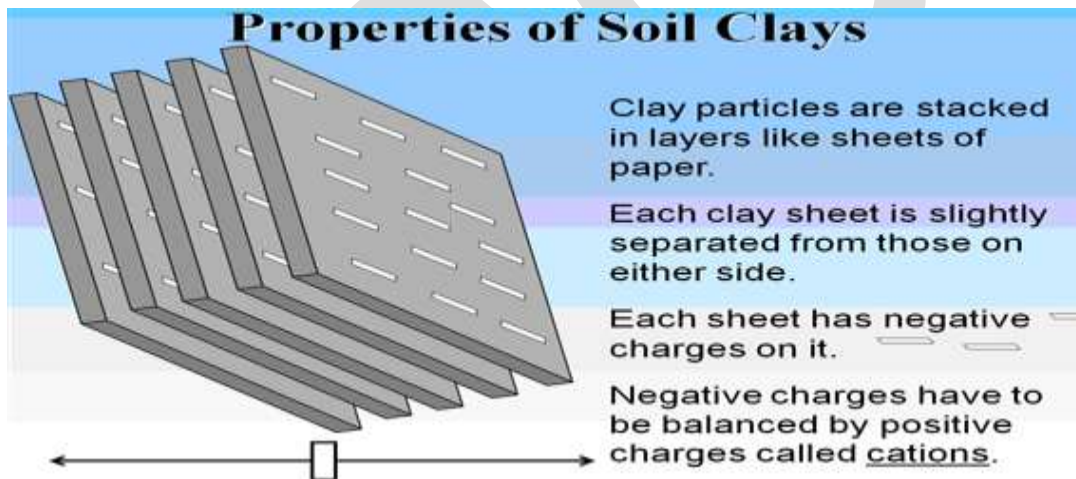


Fig. 4 Simplified sheet structure of clay particles

Source of Negative Charges and Isomorphous Substitution

Now why the clay particles are charged particles and where from the charges are coming. To get an explanation, one has to know about isomorphous substitution in clay particle, which is a common phenomenon in most of clay particles.

In nature, ions having nearly the same radius as a silicon atom (e.g. Aluminium) can fit in the tetrahedral sheet through a process called isomorphous substitution. If the substituting ion has a lower valence than silicon, an unsatisfied negative charge within the crystal results. This is the primary source of the negative charge on the crystal.^[14] Similar isomorphous substitution can take place in the octahedral sheet with aluminium being replaced by a similar-sized lower-valent cation (e.g. magnesium) likewise giving rise to a negative charge. Isomorphous Substitution - internal charge not satisfied because of ionic substitution of Al^{3+} for Si^{4+} or Mg^{2+} for Al^{3+} (Fig.5).

In vermiculite the replacement of Si^{4+} with Al^{3+} in 25% of tetrahedrals creates 1 negative site for each substitution.

In smectite Mg^{2+} replaces Al^{3+} in Octahedral layers about 1/4 of the time and creates negative sites. These negative charges can then attract cations from the soil solution.

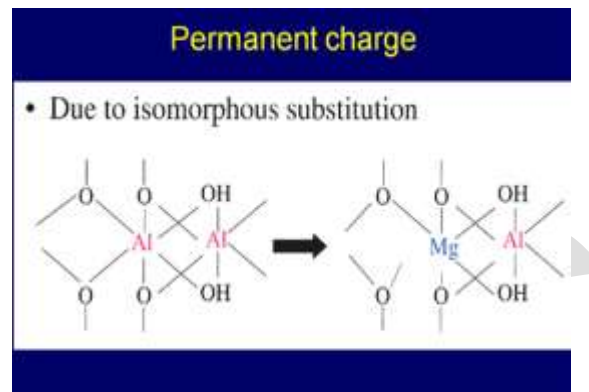


Fig. 5 Source of Negative Charges and Isomorphous Substitution

Atterberg Limits

In the form of dry powder, clay particles exist as packets, each packet containing numerous particles. The packet is electrically inert since the particles within it satisfy each other's charges. When given access to water, the packet disintegrates into particles and they begin to interact with each other giving clay its property of plasticity. The amount of water present in clay play a very significant role in determining its behaviour. With enough water in clay it behaves like a liquid, with removal of water it starts solidifying. The water contents at which the consistency changes from one state to the next are called consistency limits or Atterberg limits (Fig 7) Consistency varies with the water content of the soil. The consistency of a soil can range from (dry) solid to semi-solid to plastic to liquid (wet)^[3].

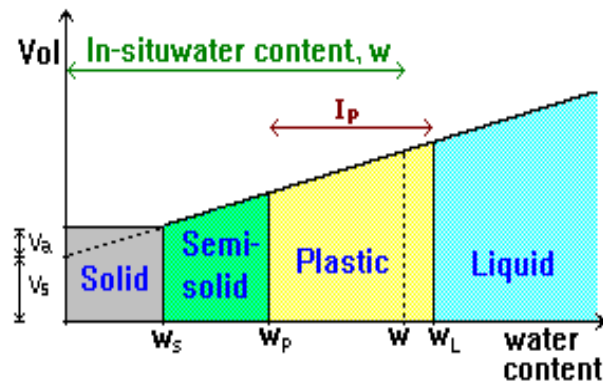


Fig. 6 Consistency limits and plasticity graph

Liquid limit (w_L) - change of consistency from plastic to liquid

Plastic limit (w_p) - change of consistency from brittle/crumblly to plastic

The consistency of most soils in the ground will be plastic or semi-solid. Soil strength and stiffness behaviour are related to the range of plastic consistency. The range of water content over which a soil has a plastic consistency is termed the **Plasticity Index (I_p or PI)**.

$$I_p = \text{liquid limit}(w_L) - \text{plastic limit}(w_p)$$

Classification and Soil Behaviour

The size of particles along with Atterberg Limits can enable the classification of the soil. The purpose of classification is to get a qualitative idea about how the soil would behave from an engineering view point. Such a preview is presented in Table 1.

Table 1- Classification and Soil Behaviour

Sl No	Soil Type	Engineering Behaviour of Soil
1	Cobbles	On account of their sizes they usually lend stability to slopes as well as foundations
2	Gravel and Sand	Have similar behaviour. High permeability behaviour; gravels more resistant to erosion. Well graded mixes are more stable and less permeable. Presence of water in voids is of little consequence.
3.	Silt	Relatively less pervious, erodable, unstable. Presence of water increases potential for instability.
4.	Clay	Marked by its sticky nature. Has very low permeability and therefore difficult to drain, moderately resistant to erosion. Highly compressible. Properties influenced by mineralogy – Marked influence of presence of water.

Influence of salts on Atterberg Limits

According to Sridharan and Jaideva (1982) thickness of double layer is a function of dielectric constant of pore fluid, electrolytic concentration and cationic valency. The electric double layer suppressed when following things occur:

- (1) A decrease in dielectric constant of pore fluid
- (2) An increase in electrolyte concentration
- (3) An increase in cationic valency

Correspondingly, a decrease in Liquid Limit will occur in all the above conditions. Sometimes hydrated cationic radius affects the LL, although valency being same.

Table 2 shows the influence of cation size, valency and hydrated cationic radius for adsorbed cations on LL. Clay used was Bentonite type ^[7]

Table 2- Influence of cation size, valency and hydrated cationic radius on Limits (Shridaran et al, 1986)

Adsorbed Cation	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Hydrated cationic radius ^{A⁰}
Lithium (Li ⁺)	2.61	675	49.1	7.30-10.10
Sodium(Na ⁺)	2.81	495	49.2	5.60-7.90
Ammonium (NH ₄ ⁺)	2.59	223	55.8	5.37
Potassium(K ⁺)	2.72	233	57.8	3.80-5.32
Magnesium (Mg ⁺⁺)	2.65	129	49.9	10.80
Calcium(Ca ⁺⁺)	2.65	125	40.6	9.50
Barium(Ba ⁺⁺)	2.73	108	45.8	8.80
Aluminium (Al ⁺⁺⁺)	2.43	108	60.5	-
Iron(Fe ⁺⁺⁺)	2.70	120	63.5	-

Table summarizing the effect of salt, electrolyte concentration and cationic valency, hydrated cationic radius on liquid limits of clays has been reported in the literature which can be presented as follows: Table 2

Table 2 - Effect of salts on liquid limits

Clay type	Electrolytic salt solution used	Concentration of electrolyte solution	Liquid Limit (%)	Work referred by
Na- Montmorillonite	Water	-	950	Yong and Warkentin (1975)
Na- Montmorillonite	NaCl	0.1N	780	Yong and Warkentin (1975)
Na- Montmorillonite	NaCl	1.0 N	350	Yong and Warkentin (1975)
Ca- Montmorillonite	Water	-	360	Yong and Warkentin (1975)
Ca- Montmorillonite	CaCl ₂	1.0 N	310	Yong and Warkentin (1975)
Bentonite	Water	-	332	Sridharan and Prakash(1999)
Bentonite	NaCl	0.5 N	94	Sridharan and Prakash(1999)
Black Cotton soil (Montmorillonitic)	Water	-	92	Sridharan and Prakash(1999)
Black Cotton soil (Montmorillonitic)	NaCl	0.5 N	85	Sridharan and Prakash(1999)
Na- Montmorillonite	-	-	700	White (1949)
Ca- Montmorillonite	-	-	177	White (1949)
Na- Bentonite	-	-	410	Rao et. al (1993)
Bentonite	Sea Water equilibrated	-	142	Rao et. al (1993)
Li ⁺ - Bentonite	-	-	675	Sridharan, Rao and Murthy(1986)
Na ⁺ - Bentonite			495	Sridharan, Rao and Murthy(1986)
NH ₄ ⁺ - Bentonite			223	Sridharan, Rao and Murthy(1986)
K ⁺ - Bentonite			233	Sridharan, Rao and Murthy(1986)
Mg ⁺⁺ - Bentonite			129	Sridharan, Rao and Murthy(1986)
Ca ⁺⁺ - Bentonite			125	Sridharan, Rao and Murthy(1986)
Ba ⁺⁺ - Bentonite			108	Sridharan, Rao and Murthy(1986)
Al ⁺⁺⁺ - Bentonite			108	Sridharan, Rao and Murthy(1986)

Studies on effect of salts on soils

Effect of three inorganic salts NaCl, CaCl₂ and MgCl₂ on consistency limits of mixture of cohesive fine grained soil and bentonite in various proportions has been studied by Nader Shariatmadari, et al (2011)^[6]. The samples were prepared in 2 proportions of 100:10 and 100:20 (100 is the total weight and 10 and 20 are the weight of bentonite). The used pore fluids were DI water, and NaCl, CaCl₂ and MgCl₂ with various concentrations of 0.01N, 0.1N, 1.0 N and 2.0 N. The soil mixtures were exposed to salt solutions and then placed in plastic bags for 24 hours. The result indicates that using salt solutions as pore fluids decreases the limit of the mixtures. Furthermore by increasing salt concentration the liquid limit decreases. Also it could be concluded that with increasing cation valance the decrease in liquid limit will be higher. Increasing salt concentration and the cation valance decreases the inter-particle repulsion which results in particles moving more freely in lower water contents, thus the liquid limit of the mixtures decreases.

Investigation was done by Sivapullaiah et.al, (2005)^[8] to see the effect of NaOH solution on some geotechnical properties of soil with low plasticity (LL 38%). Their results have shown that the liquid limits of soil increases as the as NaOH solution concentration increases. The reason behind that is the formation of a new swelling compound created by reaction of alkali solution with clay.

Studies were conducted on the effects of phosphate ions (PO₄⁻³) on index properties by Sreepada Rao (1982)^[9]. Anion adsorption was caused by treating kaolinite and montmorillonite clays with phosphate and acetates at low pHs. Phosphate adsorption increases the liquid limit, of kaolinite and liquid limit of Na-montmorillonite decreased on phosphate adsorption. In Ca-montmorillonite, initially

these values decreased with treatment, but subsequently increased. The treatment appreciably changed the physico-chemical properties of both kaolinite and montmorillonite clays, Phosphoric acid increases stable aggregation leading to higher porosities and water holding capacities but lower bulk densities. Phosphate adsorption increases the liquid limit, the surface area and the free swell volumes of kaolinite significantly because of flocculation of clay particles. Because of aggregation, the liquid limit of Na-montmorillonite decreased on phosphate adsorption. In Ca-montmorillonite, initially these values decreased with treatment, but subsequently increased because of the exchange of divalent calcium by monovalent hydrogen.

Effect of four salt solutions including NH_4Cl , KCl , CuSO_4 and FeSO_4 on consistency limits of CL clay and CH clay was studied by Arsan and Yetimoglu (2008)^[10]. The conclusions were as follows:

- For CL clay, the liquid limits and plastic limits increased with increase of salt concentrations up to 0.2M. The salt solutions at a concentration greater than 0.2M seemed to damage the clay fabric: thus the clay behaved as an non plastic soil and the plastic limit could not be obtained.
- All the salt solutions with a concentration up to approximately 0.2M significantly reduced the liquid limits of CH class clay. For NH_4Cl and KCl concentrations greater than around 0.2M, the liquid limit of CH clay remained more or less constant. However, for FeSO_4 and CuSO_4 metallic salts the liquid limit of CH clay tended to increase at concentration higher than 0.2M.
- For CH clay plastic limit decreased at low salt concentrations (between 0.0001 and 0.001M) and then increased with increase in salt concentration between 0.001 and 0.2M. For concentration value higher than 0.2M, the plastic limit was not significantly affected by salt solutions and plastic limit value approached the raw clay sample.
- Both CL and CH clays flocculated and formed clusters as the clay class tended to be changed. For the conditions investigated, CL and CH class clays were transformed into ML and MH class soils respectively according to Unified Soil Classification System (USCS).

Investigation was done to see the effect of different chloride compounds such as NaCl , CaCl_2 and MgCl_2 on various geotechnical properties by Tamadher T Abood et. al. (2007)^[11]. According to them liquid limit, plastic limit and plasticity index decreases with increase of salt content.

Studies was conducted to show the effect of saline water on geotechnical properties of fine grained soil Rassoul Ajalloian et. al., (2013)^[12]. They used three types of water, distilled, saline and half saline water. Chemical analysis values of these three types of waters used for the study is presented in table 4

Table 4 - Effect of saline water on Atterberg limits - Chemical analysis values

Water type	Ca^{2+}	Mg^{2+}	Na^+	K^+	TDS (ppm)
Distilled water	0.82	0.4	3	0.08	4.3
Half saline water	92	42	1739	4.6	1877.6
Saline water	678	648	95652	42	97020

According to their study Atterberg limits decreased as the water salinity increases for CL soil.

In another study Ayininuola, G.M, and Agbede, O.A (2013)^[13] focused on the influence of 3 inorganic salts viz. Sodium Chloride (NaCl), Potassium Nitrate, (KNO_3) and Calcium Sulphate (CaSO_4) in various concentrations on liquid limits and plastic limits of 2 sub soils. The limits were monitored before and after contamination. The soil cation exchange capacity (CEC), exchangeable cations and exchangeable anions were also determined. A set of equations for predicting LL and PL at different level of chemical interaction with time was developed using multiple regression analysis model. The results showed that both NaCl and KNO_3 brought about reduction in LL and PL while CaSO_4 addition led to increment in LL and PL. The predicting equations revealed that there is high tendency for the contaminated soils to regain their uncontaminated LL and PL values with time.

CONCLUSION

Changes in fine grained soil behaviour due to contaminants can be explained by changes in diffuse double layer theory and fabric changes. Although the influence of pore fluid chemistry on the engineering behaviour of clay soil in many respects is still unclear and

is even controversial in some cases, but in general, it can be explained in light of changes in diffuse double layer. By increasing the ion concentration, the thickness of diffuse double layer decreases which leads to flocculation of the clay particles.

Use of salt solution as pore fluid generally causes decrease in liquid limits. The higher the cation valance, higher decrease in liquid limits.

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