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Effect of Chemicals on Engineering Properties of Soil

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Abstract: ***Geotechnical behaviour of fine grained soils is controlled by constituent of soil, type of pore fluid, presence of salts etc. The clay particles having effective size less than 0.002 mm havenegative charges at surface and positive charges at edges.The charged clay surface together with the counter–ions in the pore water form diffuse double layer.The entire system tries to attain equilibrium under weak Vander wall forces.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. Salt solutions generally increase the maximum dry density and decrease the optimum moisture content. Increase in unconfined compressive strength is observed with addition of salt in lower concentrations. Permeability generally increased with the addition of salt. When treated with salts in most cases it has been reported that Compression index Cc, Swelling index Cs, and coefficient of compressibility (a_v) decreased, whereas coefficient of consolidation (C_v) increased as the water salinity increased. In the present paper the effect of presence of salts as pore fluid on engineering properties of soil as reported in literature has been highlighted.***

Keywords: Diffuse double layer, Clay particles, Atterberg Limits, Soil Compaction, Consolidation, Permeability, Shear strength

I. 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 external such as contamination. For residual top soils, salts may be present in natural condition depending upon source rock. Ocean surges cause occasional flooding in coastal area with salt water lead to addition of salt minerals into soil.Metallic elements are present in greater amount in mining area[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.

A. 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].

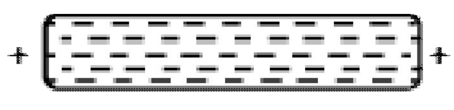

Fig. 1 typically charged clay particle

1) 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

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counter–ions in the pore water, form the diffuse double layer. [4], [5] Furthermore, the double layer is influenced by the valency of the counter–ions and the temperature.

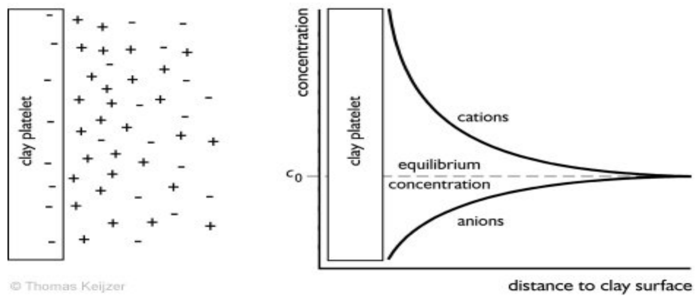

Fig. 2 Distribution of cations and anions adjacent to a clay platelet according to the diffuse double layer theory (Keijzer, 2000).

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 thestructure of clay particles and source of negative charges.

2) 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 charges.(Fig.3)

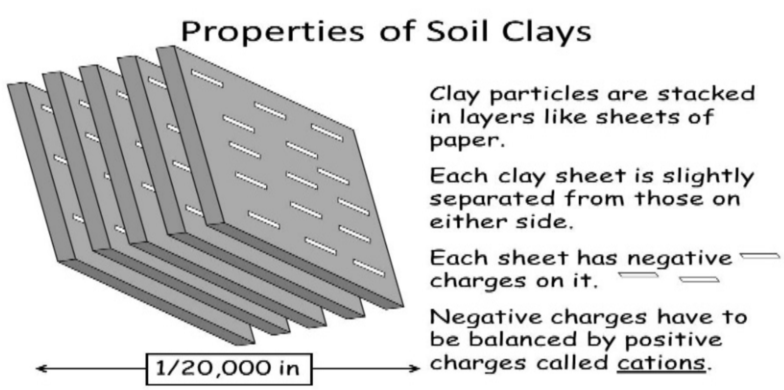

Fig. 3 Sheet structure of clay particles

3) Source of Negative Charges and Isomorphous Substitution

Isomorphous substitution is a common phenomenon in most of clay particles. In nature, ions having nearly the same radius as a silicon atom (e.g. aluminium) and 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.4).In spectate 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.

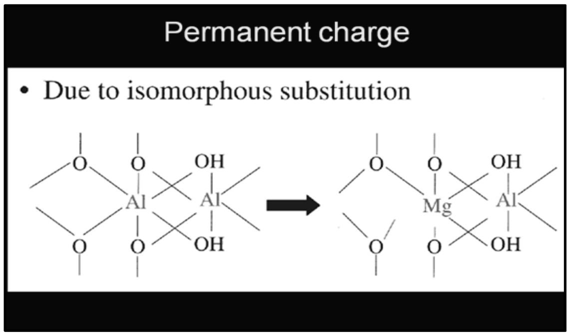

Fig. 4Source of Negative Charges and Isomorphous Substitution

II. SOIL COMPACTION

Soil compaction improves strength characteristics of soil and consequently increases bearing capacity of foundations constructed on it. Compaction is the process by which the bulk density of an aggregate of matter is increased by driving out air. For any soil, for a given amount of compactive effort, the density obtained depends on the moisture content. At high moisture contents, the maximum dry density is achieved when the soil is compacted to nearly saturation, where (almost) all the air is driven out. At low moisture contents, the soil particles interfere with each other; addition of some moisture will allow greater bulk densities, with a peak density where this effect begins to be counteracted by the saturation of the soil.Typical moisture-density relationship from standard compaction test is shown below (Fig 5)

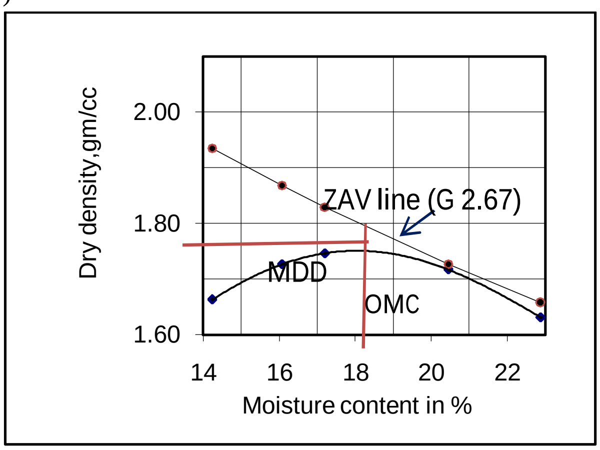

Fig. 5Typical moisture-density relationship from standard compaction test(Mohanpura Project, MP, India)

A. *Effect of salt on Compaction Parameter*

Salt solution increases the maximum dry density and decreases optimum moisture content of the mixtures. This behaviour has been explained in light of diffuse double layer. At low moisture content, before compaction, the soil structure tends to change from face to edge type flocculation to face to face type flocculation with the increase of salt concentration (Lambe, 1958). Consequently, under the dynamic compaction, the clay particles become more orientedand the compacted dry unit weight increases. Higher cation valance leads to increase in maximum dry density and decrease in optimum moisture content as well. The decrease of diffuse double layer's thickness is the reason of this trend.

A large no of studies have been reported in literature showing modification in soil properties in respect of compaction parameters when salts are added.

1) The effect of salinity on the compaction test results was studied by Emami, (2008), Mansour st. al. (2008))[7] and Alainachi and Alobaidy, (2010)[8]. Their test results show that optimum moisture content decreases and maximum dry unit weight of soil increases as the salinity of water increases. The reason of these changes has been attributed to the reduction of double layer thickness and increasing attractive force between particles as pore fluid concentration increases.
2) The effect of certain industrial effluents studied in detail viz. textile effluent, tannery effluent and battery effluent on compaction characteristics of expansive soil by Dr. Narsima Rao et. al.)[9].

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a) When soil is mixed with textile effluent, the dry density decreases and optimum pore fluid increases. This could be attributed to ion exchange at the surface of the clay particle. The chloride in the additives reacted with the lower valance metallic ions in the clay microstructure and causes decrease in double layer thickness. The decrease in double layer thickness causes increase in attractive forces and decrease in repulsive forces leading flocculated structures. Hence dry density decreases. Due to retaining of water within the voids of flocculated structure water holding capacity of soil increases hence optimum moisture content also increases.

b) When the soil is mixed with tannery effluent the dry density increases and optimum pore fluid decreases. This is attributed due to adsorption of Chromium ions (CrO_4) on the clay particles present in tannery effluent. Due to its higher valance adsorption of Chromium decreases the double layer thickness. The reduction of double layer thickness brings the particle closer and hence maximum dry density increases. Therefore using same amount of compaction energy, the particles pack better together and dry density increases. Consequent on particles becoming closure and decreased water holding capacity the optimum water content decreases.

c) When the soil is mixed with battery effluent the dry density decreases and optimum pore fluid increases. This is attributed due to adsorption of sulphate (SO_4) on the clay particles present in battery effluent. The adsorption of divalent negative sulphate ions causes the entire clay particles to be negatively charged. This on the other hand causes increase the activity of clay mineral for adsorption of water which has considerable volume and this leads to increase in optimum moisture content. The increase in double layer thickness may cause increase in repulsive forces and dispersion of clay particles. Hence offers more resistance to pack better together leading to decrease in maximum dry density.

3) Effect of three salts NaCl, $CaCl_2$, $MgCl_2$ on compaction parameter of mixture of cohesive fine grained soil and bentonite were done in another study by Nadar Shariatmadari et. al.)[6]. Salt solution increases the maximum dry density and decreases optimum moisture content of the mixtures. Higher cation valance leads to higher increase in maximum dry density and higher decrease in optimum moisture content as well. The decrease of diffuse double layer's thickness is the source of this trend.

III. CONSOLIDATION

Consolidation is a process by which soils decrease in volume and it is the process by which soil particles are packed more closely together over a period of time under the application of continued pressure. It is accompanied by drainage of water from the pore spaces between soil particles. Typical phases of consolidation has been presented and deformation versus time plot has been presented in Fig. 6

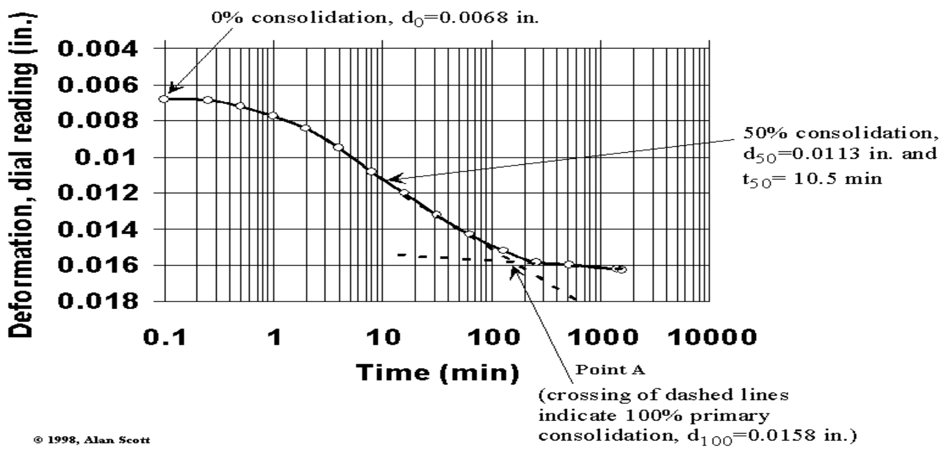

Fig.6 Phases of consolidation curve and analysis of log-time/settlement curve

This test indicates soil compressibility amount that is one of the important properties of the soil. Volume changes in soils are important because of their consequences in terms of settlement due to compression. In addition, changes in volume lead to changes in strength and deformation properties, which in turn influence stability. Compressibility of pure clays can be accounted for quantitatively by the consideration of double-layer repulsive forces. These forces between particles are due to the presence of exchangeable ions. It has been established that electrical double layer theory of Guoy-Chapman can be effectively used to describe the compressibility behaviour.The important terms are Coefficient of Compressibility (a_v), Coefficient of Volume Compressibility (m_v), Coefficient of Consolidation (Cv), Compression Index (Cc) and Swelling Index (Cs)

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A. *Effect of Salt on Consolidation Parameters*

Compressibility of pure clays can be accounted for quantitatively by the consideration of double-layer repulsive forces. These forces between particles are due to the presence of exchangeable ions. It has been established that electrical double layer theory of Guoy-Chapman can be effectively used to describe the compressibility behaviour.

When treated with salts in most cases it has been reported that Compression index Cc, Swelling index Cs, and coefficient of compressibility (av)decreased, whereas coefficient of consolidation (Cv) increased as the water salinity increased. The reason of such tendency might be due to the reduction in diffuse double layer thickness.

Some important works reported in literature which are representative of effect of salt on consolidation parameters can be described below.

1) The test results performed by Yukselen-Aksoy et. al. (2008)[11] show seawater has limited effect on the compressibility of clayey soils with liquid limits less than 110%. In clayey soils with liquid limits more than 110% (bentonite) the seawater effect becomes significant.
2) Effect of monovalent, divalent and trivalent cations on the test results of consolidationhave studied by Rao and Mathew, (1995)[12] . This study has indicated the replacement of monovalent cations by higher valency cations can change the particle arrangement from dispersion to flocculation due to reduction in double layer thickness.
3) The effect of 3 inorganic salts solutions viz. NaCl, $CaCl_2$ and$MgCl_2$ (0.1N and 1.0N solutions) on consolidation parameters for a mixture of low plasticity soil sample and bentonite(10% and 20%) was studiedby Sariatmadari et. al, (2011))[6]. . It has been observed that by increasing salt concentrations the compression index (Cc) decreases, however the effect of cation valance is not pronounced.
4) Study of the effect of saline water on geotechnical properties of fine grained soilwas done by Rassoul Ajalloian et. al., (2013)[10]. The one dimensional consolidation test was performed for determination of Compression index(Cc) , Swelling index (Cs), coefficient of volume compressibility (mv), coefficient of consolidation (Cv) and coefficient of compressibility(av) using distilled, half saline and saline water. Test results showed that Compression index Cc, Swelling index Cs, and coefficient of compressibility (av)decreased, whereas coefficient of consolidation (Cv) increased as the water salinity increased. The reason of such tendency might be due to the reduction in diffuse double layer thickness.
5) According to P.Sivapullaiah[13]., the consolidation characteristics of montmorillonite depend upon the size of the cation present in the clay-water system. Variations in pore water electrolyte concentration have little effect on the void ratio-effective stress relationships for the Ca-montmorillonite in water, apparently because double-layer effects are smaller than predicted by classical theory and because of the formation of permanent domains. Even in the case of Na-montmorillonite there is evidence of domain formation during swelling at low values of effective stress though their consolidation curves are in qualitative confirmation of double-layer theory. The compressibility order found for bentonite is,$Li^+ > Na^+ > K^+ > Ca^{++} > Ba^{++}$ in accordance with the characteristics of these ions. However, special notice should be taken of the particular position occupied by the K-bentonite. This different behavior is due to particle fixation of potassium in a non-exchangeable manner (on drying the sample) and becoming colloidally inactive.

IV. PERMEABILITY

Permeability is defined as the property of a porous material which permits the passage or seepage of water through its interconnecting voids. In the two phase soil liquid system, that constitutes saturated soil, the liquid, usually exists in the pore of the soil.(Fig 7) The pores are inter connected and remains in highly intricate and complex collection of irregular tubes. When water in these tubes is subjected to a potential difference, water flows from zones of high potential to low potential zones. The ease with which water flows through soil is quantitatively termed as permeability of soil.

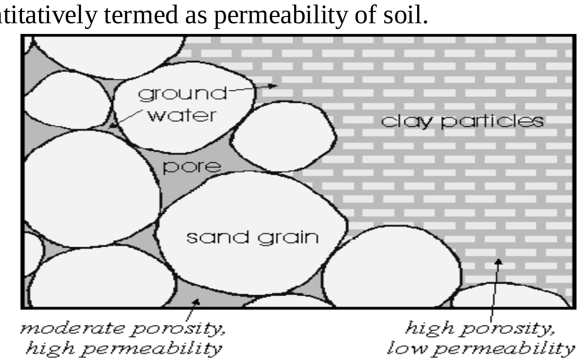

Fig. 7 Two phase soil liquid system- showing liquid exists in the pore of the soil

Permeability is a function of void ratio, soil fabric and effective stress, properties of pore fluid, etc. The law of flow of water through soil was first studied by Darcy (1856) who demonstrated experimentally that for laminar flow conditions in a saturated soil, the rate of flow or discharge per unit time proportional to the hydraulic gradient. (Fig 8)

$$q = k \frac{h1-h2}{L} A$$

A = total cross sectional area of soil mass, perpendicular to the direction of flow
k = Darcy's coefficient of permeability
L = Length of soil sample, $h_1 - h_2$ = differential head of water = Δh
$\frac{h1-h2}{L}$ = Hydraulic gradient
K is defined as coefficient of permeability, when average velocity of flow that will occur through the total cross sectional area under unit hydraulic gradient. Coefficient of permeability is usually expressed as cm/sec.

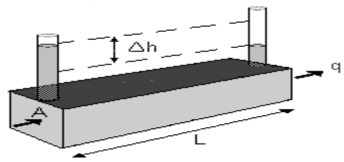

Fig. 8 Permeability

A. Effect of inorganic salt on permeability

It has been observed that permeability or hydraulic conductivity increases by adding salt to the pore fluid and increasing its concentration. The reason could be attributed to the decrease in thickness of diffuse double layer, resulting flocculation of clay particles. Increasing the cation valance also increases hydraulic conductivity.

1) Some important observationswerereported byP.Sivapullaiah **(**2009)[14].The variables which influence the permeability of soils apart from molding water content, compaction method and compactive effort are: i) associated exchangeable cations; ii) adsorbed anions, and iii) nature of permeating fluid. The effects can be summarized as:
a) Complex changes in the permeability of clay soil occur with exchangeable cation type, adsorbed anions and the nature of pore fluid. An attempt is made to generalize these changes.
b) Increase in the electrolyte concentration of pore fluid increases the permeability of liners. At low and relatively low electrolyte concentrations, the permeability increases with increase in the concentration. At high electrolyte concentrations, the type of cation or anion of the electrolyte plays less important role.
c) Acidic solutions generally decrease the permeability of clays initially due to plugging of pores by precipitates formed by reactions between clays and acids. But the long-term effects increase the permeability. The clay becomes saturated with aluminium ion and/or degradation of clay by reactions with acids takes place. Clay saturated with water is impervious to immiscible organic solvents.
d) The effect of mixtures of organic fluid and water on the permeability is negligible until the organic liquid content of the fluid is about 70%.
e) The permeability increases with decrease in the dielectric constant of the pore medium.
f) In the presence of organic fluids of low dielectric constant or electrolyte solutions of high concentration (like brine solution), the clay may shrink and crack causing hydraulic fracturing. But if the confining stress is high this phenomenon may not occur.
g) Abnormal increase in the permeability of montmorillonite clays occurs in the presence of potassium salts due to potassium linkages between clay liners. Thus the behaviour of polluted soil, on the absence of strong interaction can be explained based on changes in double layer development and fabric changes.

2) The effect of three inorganic salts, NaCl, $CaCl_2$ and$MgCl_2$ (0.1N and 1.0N solutions) on hydraulic conductivity for a mixture of low plasticity soil sample and bentonite (10% and 20%) was studied by Sariatmadari. N et.al.)[6]. It was observed that hydraulic conductivity increases by adding salt to the pore fluid and increasing its concentration. The reason could be attributed to the decrease in thickness of diffuse double layer, resulting flocculation of clay particles. Increasing the cation valance also increases hydraulic conductivity.

3) Investigation done byAyininuola, G.M.et.al,)[15] on the effect of two inorganic salt, sodium chloride (NaCl) and calcium sulphate ($CaSO_4$) on soil permeability. The soils were treated with different concentrations of these salt solutions. The coefficient of permeability was found to increase in case of NaCl salt with increase of time and concentration and coefficient of permeability reduced with increasing $CaSO_4$ concentration. This is due to attraction of Ca^{+2} divalent cation to absorbed layers

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of soil to produce strong bond which constitute resistance to passage of water in soil. On the other hand increase in coefficient of permeability observed for NaCl treated soils was due to weak bond produced when monovalent cation like Na^+ is attracted to absorbed layer.

4) Many researchers focused on the investigation of hydraulic conductivity of higher activity clays such as bentonite or geosynthetic clay liners (GCL). Gleason et.al, (1997))[16] examined the different concentration of $CaCl_2$ on the hydraulic conductivity of Na and Ca bentonite.
5) Jo et al, (2001))[17] investigated hydraulic conductivity and swelling of non pre hydrated GCLs permeated with single species salt solutions such as lithium chloride (LiCl), sodium chloride (NaCl), potassium chloride(KCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), zinc chloride ($ZnCl_2$), copper chloride ($CuCl_2$), and lanthanum chloride ($LaCl_3$).
6) Shakelford et al (2000))[18] studied the hydraulic conductivity of GCLs permeated with non standard liquids such as sodium chloride (NaCl), zinc chloride ($ZnCl_2$), calcium chloride ($CaCl_2$).
7) Lee et al (2005)[19] used calcium chloride ($CaCl_2$) as the testing liquid for the determination of hydraulic conductivity of GCLs.
8) hydraulic conductivity of bentonite clay or GCLs increased when the concentration of salt solutions was increased

V. SHEAR STRENGTH

Determination of strength characteristics has always been one of the most important factors for geotechnical engineers. Extensive studies have been done in this field.

Number of cases have been reported in the literature about contamination of soil and severe damage in engineering properties. On the other hand in many situations, soil in its natural state do not possess adequate geotechnical properties to be used as foundation layers and road service layers. In order to meet the requirements of technical specifications of construction industry, studying of soil stabilisation is more emphasised. It has been reported that sometimes some industrial effluents improve the soil properties and they can be used as soil stabilizers.

A. *Effect of salts on shear parameters*

1) Investigation done byAbood. T, et. al,(2007)[20], on the effect of adding different chloride compounds such as NaCl, $CaCl_2$ and $MgCl_2$ on shear parameters of silty clay soil. They used 2%, 4% and 8% salts. It has been seen that increase in salt contents leads to an increase in unconfined compressive strength. The addition of salt to the soil causes an increase in the ion concentration pore water with concomitant reduction in the double layer thickness and this in turn, causes a reduction in the particle-particle repulsion and increase in the attraction resulting in the increase in cohesion.Maximum shear strength was found in case of soil treated with $CaCl_2$. The addition of $CaCl_2$ cause hardening and more strength is gained as compared to soil specimens containing other salts additives.
2) Naima Rao, A.V. et.al)[9] investigated the effect of certain industrial effluents on expansive soil and studied undrained shear strength characteristics. The soil was of SC group and differential free swell index was 255%.

a) The industrial effluents used were textile effluent (P^H 9.83, Chloride: 380 mg/lit), tannery effluent (P^H 3.15, Chromium: 250 mg/lit, Chloride: 200mg/lit, Sulphate: 52.8 mg/lit) and Battery effluent (P^H 8.45, Sulphate: 250mg/lit, Chloride: 30mg/lit, Lead Sulphate: 63.08 mg/lit, Total Lead: 75.42mg/lit).
b) In case oftextile effluent there was an increase in unconfined compressive strength. This could be attributed to covalent linkage between clay particles and dyes present in textile effluent. This chemical bonding may be responsible for increase of undrained cohesion between soil particles.
c) In case of tannery effluent, a reduction in UCS value was observed. This could be attributed to absorption of Chromium ions present in the effluent. Due to higher valence Chromium ions decrease the double layer thickness, which in turn reduces the viscous resistance for the same water content under undrained condition.
d) In case of battery effluent, a reduction in UCS value was observed. This could be attributed due to absorption of sulphates on the clay surface causing increase in net negative charges of the clay particles which in turn increases thickness of diffused layer around the clay particles enhancing inter particle repulsion and decrease in undrained shear strength.

3) Rassoul Ajalloian et. al., (2013)[10] studied the effect of saline water on geotechnical properties of fine grained soil. They observed that salinity exert very little effect on shear strength parameters. The values of cohesion and friction angle with distilled, half saline and saline water were 0.078, 0.108, and 0.107 kg/cm^2 and 14.8, 15.8 and 15.2 degrees respectively. However cohesion and friction angle have increased with saline and half saline water. The reason for low change may be the

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low clay content in soil and the low increase of these of these parameters with water salinity can be due to increasing attractive force between particles and establishing bond between them.

4) Aninteresting study was done by Naeini, S.A et.al,(2011)[21] showing effect of inorganic salt solutions on shear parameters of soils having different plasticity. Three different salt solutions (2%, 5%, and 10% NaCl solutions) were used in this study and deionised water was indicated as 0% salt solution. The strengths were determined by direct shear test and laboratory vane shear test.It was observed that addition of salt solution sharply increases the undrained shear resistance of sample prepared with NaCl solution up to 2%, which may be due to changes in chemical structure of clay and then it started decreasing (up to 10%). This may be due to salt flocculation which decreases attractive forces. It has been also seen that undrained shear resistance increase nonlinearly with increase of plasticity index. Comparison of direct shear and vane shear suggested that as the plasticity of soil increases undrained shear resistance obtained by vane shear test may give overestimated results.

5) Shirsavkar (2010)[22] have been made experimental investigations to study the suitability of molasses to improve some properties of soil. He observed that the value of CBR is found to increase by addition of molasses.

6) Kamon Masashi (2001)[23] reported that the durability of pavement is improved when stabilised with ferrum lime aluminium sludge.

7) Ekem Kalkan(2006)[24] investigated and concluded that cement-red mud waste can be successfully used for the stabilisation of clay liners in geotechnical application.

8) Sridharan & Rao(1979)[25]conducted triaxial tests on Ca- and Na- kaolinites and montmorillonites. Friction angels of 28.4°and 24.4° for Ca- and Na- kaolinites and 21.7° and 11.2° for Ca- and Na- montmorillonites were reported. Zero cohesion intercepts were obtained for all the cases. Thus it is seen that both kaolinite and montmorillonites given higher friction angles when saturated with calcium.

VI. CONCLUSIONS

After detailed literature studies of the works of previous researchers on the topic, the conclusions drawn can be summarized as follows

A. Due to chemical contamination, which is often unavoidable now a days, alteration of soil properties commonly occurs and this may lead to severe foundation failure, structural damage etc.

B. Understanding of the underlying mechanisms behind the modification in physical and engineering properties of soil under the influence of chemical constituents or chemical salts is necessary. 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. Yet in most cases changes in fine grained soil behaviour due to contaminants can be explained by diffuse double layer theory and fabric changes.

C. Salt solutions generally increase the maximum dry density and decrease the optimum moisture content. Higher valance cations lead to higher increase in maximum dry density and higher decrease in the optimum moisture content.

D. Increase in unconfined compressive strength can be observed with addition of salt in lower concentrations. The addition of salt to the soil causes an increase in the ion concentration pore water with concomitant reduction in the double layer thickness and this in turn, causes a reduction in the particle-particle repulsion and increase in the attraction resulting in the increase in cohesion. Sometimes more strength can be gained when calcium salts are used which may exert extra hardening effect.

E. When treated with salts in most cases it has been reported that Compression index Cc, Swelling index Cs, and coefficient of compressibility (a) decreased, whereas coefficient of consolidation (C_u) increased as the water salinity increased. The reason of such tendency might be due to the reduction in diffuse double layer thickness.

F. Permeability can be increased with the addition of salt. By increasing the ion concentration, the thickness of diffuse double layer decreases which leads to flocculation of the clay particles, creating large pore channels through which flow can occur. Sometimes calcium salts can exert resistance to permeability.

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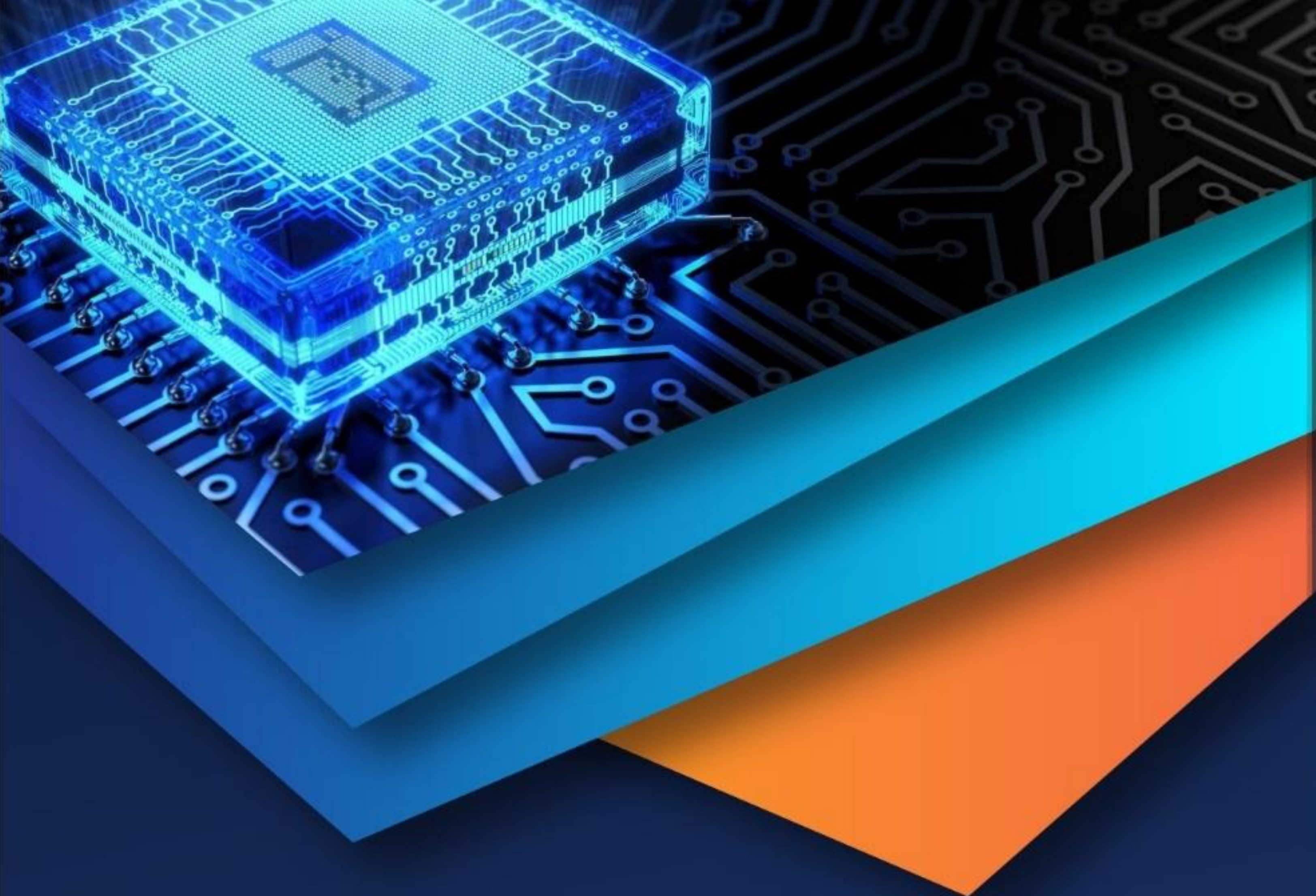

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