# Effects Of Salt Solutions and Sea Water on the Geotechnical Properties of Soil – A Review

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***Abstract*— in coastal areas, Sea water percolates into ground water and affect the various characteristics of ground water such as increase in Total Dissolved Solids content and Salinity in the groundwater. This leads to a further treatment of groundwater. In this study, Bentonite Soil mixture is used as Barrier between Sea water and Groundwater and to know the effect of Seawater on Bentonite Soil mixture characteristics such as atterberg limit, swelling index, Hydraulic conductivity and Compaction characteristics. Bentonite is absorbent Aluminium Phyllosilicate essentially impure clay consisting mostly of Montomorillonite. Various investigations were made on changes in properties of Bentonite soil mixture over seawater. From this study indicated sea water and different type of salt water could have a considerable effect on the geotechnical properties of the mixtures.**

***Keywords—Bentonite, salt solution, sea water, Atterberg limit, Swelling index, hydraulic conductivity***

## I. INTRODUCTION

Coastal zones contain some of the most densely populated areas in the world as they generally present the best conditions for productivity. However, these regions face many hydrological problems like flooding due to cyclones and wave surge, and drinking fresh water scarcity due to problem of salt water intrusion. Saltwater intrusion reduces freshwater storage in coastal aquifers and can result in the abandonment of freshwater supply wells when concentrations of dissolved ions exceed drinking-water standards. The degree of saltwater intrusion varies widely among localities and hydro geologic settings. We are studied about bentonite and soil mixture properties on the intrusion of sea water and salt water.

## II. EFFECT OF SALT SOLUTION ON GEOTECHNICAL PROPERTIES

### *A. Effect of Atterbergs limit*

[1] Has studied the Effect of three inorganic salts, NaCl, CaCl2 and MgCl2 on some geotechnical properties of a common used clay soil in impermeable bottom barrier in Kahrizak landfill. Also the effect of bentonite content by adding different percentage of this special clay mineral, 10 and 20 percent, on these properties was investigated. Laboratory tests like liquid limit the results indicate that using salt solutions as pore fluids decreases the liquid limit of the mixtures. Furthermore by increasing salt concentration in both mixtures, the liquid limit decreases. Also it could be concluded that with increasing cation valance the decrease in the liquid limit will be higher especially in the case of mixtures with 20% bentonite. Increasing the salt concentration and the cation valence decreases the inter-particle repulsion which results in particles moving more freely in lower water contents, thus the liquid limit of the mixtures decreases

[2] Has studied the influence of Nacl and Cacl2 at various concentrations on compressibility of mixtures of basalt soil and bentonite. In this study it concluded that the compressibility of the soil mixture was reduced with increasing salt concentration of the pore fluid.

[15] Has studied the effects of 4 different salt solutions on the consistency limits of clays were experimentally investigated. The salt solutions used as leachate compounds were ammonium chloride (NH4Cl), potassium chloride (KCl), copper(II) sulfate (CuSO4), and iron(II) sulfate (FeSO4). Consistency limit tests were conducted on low plasticity (CL-class) and high plasticity (CH-class) commercial clays using both distilled water and these salt solutions. The experimental results indicated that the liquid limit increased when the salt concentration for the CL clay was increased. Moreover, the liquid limit was found to decrease when the salt concentration for the CH clay was increased. The plastic limit of the CL clay increased as the salt concentration increased to a certain value. However, the plastic limit of CH clay decreased at low salt concentrations and increased at high salt concentrations.

Table 1 Attenberg limit of salt solution presences

| Reference | Type of soil | Type of salt solution | Attenberg limit |
|---|---|---|---|
| [1] | bentonite and clay mineral | NaCl, CaCl2 and MgCl2 | Increasing the salt concentration decreases the liquid limit |
| [15] | low plasticity and high plasticity commercial clays | NH4Cl,KCl,CuSO4, and FeSO4 | 1. Liquid limit decrease when the salt concentration for the CH clay was increased. 2. The plastic limit of the CL clay increased as the salt concentration increased to a certain value. 3. Plastic limit of CH clay decreased at low salt concentrations and increased at high salt concentrations. |

*B. Effect on hydraulic conductivity*

[3] Has studied that the hydraulic conductivity of na bentonite powder and bentonite sand mixtures(10 and 20% of bentonite by dry weight) have been measured with distilled water and various salt solutions like Na, K, Cs, Mg, Ca and AI chloride solutions at 0.01, 0.1and 1 mol/l concentration. The hydraulic conductivity of a bentonite sand mixture to aqueous solutions can be predicted from the hydraulic conductivity of the bentonite in the appropriate solution and the porosity and tortuosity of the sand matrix the hydraulic conductivity of a mixture decreases as wt% clay decreases, hydraulic conductivity of each mixture increases as the clay-void ratio increases.

[1] Has investigated the effect of three different inorganic salt solutions (as permeant liquids) on the hydraulic conductivity of two types of clay-bentonite mixtures. The three different inorganic salt solutions used were: sodium chloride (NaCl), calcium chloride (CaCl2) and Magnesium chloride (MgCl2). Bentonite clay in two proportions of 10% and 20% by weight were added to a clay soil with low plasticity. The hydraulic conductivity of the samples increases by adding the salt to the pore fluid and increasing its concentration. Increasing the cation valance also increases the Hydraulic conductivity.

[2] Has tested the impact of distilled water and Calcium chloride in a modified Bentonite on hydraulic conductivity. In this study a 'Multi swellable' bentonite (MSB) has been obtained by treating standard sodium bentonite with propylene carbonate. The hydraulic conductivity increased from 1.1610_11 m/s in Distilled Water to 7.0610_11 m/s in 5 mm CaCl2. The increase in hydraulic conductivity was also attributed to the invasion of pore space by Ca2+ cations.

[5] Has studied the Effect of bentonite quality on the hydraulic conductivity of soil-bentonite mixtures was evaluated in the presence of various concentrations of NaCl and CaCl2 solutions. Result for the hydraulic conductivity (k) showed that the effects of salt concentration on k of the mixtures depend on the type of bentonite present in the mixture. Mixture with a lower quality of bentonite which is characterized by a lower value of ESP

[9] Has studied the influence of water salinity on the hydraulic conductivities of compacted bentonites with several dry Densities. The results showed that the hydraulic conductivity increases with increasing salinity only when the dry density of bentonite is relatively low. The degree of increase becomes more remarkable at a lower dry density of bentonite. For bentonite with the density of 1.0 Mg/m3 and 1.2 Mg/m3, the hydraulic conductivity of the 0.4 M NaCl solution increases up to about 7 times and 3 times, respectively higher than that of freshwater. However, for the bentonite with a dry density higher than 1.4 Mg/m3, the salinity has an insignificant effect on the hydraulic conductivity, and the hydraulic conductivity is nearly constant within the salinity range of 0.04 to 0.4 M NaCl. The pre-saturation of the bentonite specimen with freshwater has no significant influence on the hydraulic conductivity.

[2] Has studied the effect of Nacl on hydraulic properties of Bentonite and Bentonite – palygorskite mixture. The purpose of this work is to investigate the properties of Na bentonite and bentonite–palygorskite filler material for GCL in saline solutions in the range between 0.5% and 10% (0.09 and 1.8 M) NaCl concentration. The investigation has been carried out to evaluate and study the chemical and geotechnical properties of Na-bentonite and bentonite–palygorskite mixture. The observations suggest that the resistance of Na-bentonite to chlorides is increased by adding 40% palygorskite Hydraulic conductivity was determined for water and for 10% NaCl (1.80 M) solution. The results show that Na-bentonite palygorskite mixture serves as an effective absorber of both water and saline solutions up to a concentration of 10% (1.80 M) of NaCl without increasing the hydraulic conductivity.

[11] Has studied the influence of Nacl and Cacl2 at various concentrations on permeability of mixtures of basalt soil and bentonite. In this study it concluded that comparison of hydraulic conductivity (k) for different salt solutions shows that the divalent cations have more effect than monovalent cation. Comparison of different salt concentrations for a particular salt on a particular soil mixture show that the k decreases with decreasing salt concentration. This decrease can be attributed to an increase in diffuse double layer thickness. A change in salt concentration from 0 (Deionized water) to 0.01 mol/L did not produce any significant effect on the k for the basalt soil-bentonite mixture of proportion 100:20, but a further increase in salt concentration had a pronounced effect on k.

Table 2 Hydraulic Conductivity of Salt solution presences

| Reference | Type of soil | Type of salt solution | Hydraulic conductivity |
|---|---|---|---|
| [1] | bentonite and clay mineral | NaCl, CaCl2 and MgCl2 | Increasing the cation valance also increases the hydraulic conductivity |
| [11] | basalt soil and bentonite | Nacl and Cacl2 | hydraulic conductivity decreases with decreasing salt concentration |
| [3] | Na bentonite & bentonite sand mixtures | Na, K, Cs, Mg, Ca, AI and Cl solutions | Hydraulic conductivity decreases as wt% clay decreases |
| [2] | 'Multisw ellable' bentonite | distilled water and Calcium chloride | The hydraulic conductivity increased from 1.1610_11 m/s in DistilledWater to |

| | | | |
|---|---|---|---|
| | | | 7.0610_11 m/s in 5 mm CaCl2. |
| [5] | soil-bentonite | Nacl and cacl2 solution | the hydraulic conductivity of salt concentration depend on the type of bentonite present in the mixture |
| [9] | bentonite | NaCl solution | NaCl solution increasing the hydraulic conductivity increases |
| [7] | Na bentonite and bentonite – palygorskite | Various NaCl concentration | Na-bentonite palygorskite mixture serves as an effective absorber of both water and saline solutions up to a concentration of 10% (1.80 M) of NaCl without increasing the hydraulic conductivity. |

*C. Swelling pressure*

[3] Has studied that the swelling behavior of Na-bentonite powder and bentonite-sand mixtures (10 and 20% of bentonite by dry weight) have been measured with distilled water and various salt solutions It was found that in dilute solutions, the bentonite in mixtures subjected to small confining stresses swells sufficiently to separate the sand particles and reach a clay void ratio similar to that achieved by bentonite alone. At high stresses, or in strong solutions, the bentonite in a mixture has insufficient swelling capacity to force the sand particles apart and swelling is limited by the sand pore volume.

[1] Has investigated the effect of three different inorganic salt solutions (as permeant liquids) on the free swelling, consolidation characteristics of two types of clay-bentonite mixtures. The three different inorganic salt solutions used were: sodium chloride (NaCl), calcium chloride (CaCl2) and Magnesium chloride (MgCl2). Bentonite clay in two proportions of 10% and 20% by weight were added to a clay soil with low plasticity. The result shows by increasing the salt concentration and cation valance the swelling volume decreases.

[5] Has studied the Effect of bentonite quality on the free swelling of soil-bentonite mixtures was evaluated in the presence of various concentrations of NaCl and CaCl2 solutions. The results showed that the bentonite with a higher exchangeable sodium percentage (ESP) undergoes a large reduction in the free swelling due the addition of the salt solution compare to the bentonite with a lower ESP. salt affects significantly the k of the mixture containing a higher quality of bentonite which is characterized by a higher ESP,

Table 3 Free swell pressure of Salt solution presences

| Reference | Type of soil | Type of salt solution | Free swell pressure |
|---|---|---|---|
| [1] | bentonite and clay mineral | NaCl, CaCl2 and MgCl2 | Increasing the salt concentration and cation valance the swelling volume decreases. |
| [3] | na bentonite powder and bentonite sand mixtures | Na, K, Cs, Mg, Ca , AI and Cl solutions at 0.01, 0.1and 1 mol/l concentration. | At high stresses, or in strong solutions, the bentonite in a mixture has insufficient swelling capacity to force the sand particles apart and swelling is limited by the sand pore volume. |
| [5] | soil-bentonite | Nacl and cacl2 solution | a large reduction in the free swelling due the addition of the salt solution compare to the bentonite with a lower ESP |

*D. Effect of compaction characteristic.*

[1] Has studied the Effect of three inorganic salts, NaCl, CaCl2 and MgCl2 on some compaction characteristic of a common used clay soil in impermeable bottom barrier in Kahrizak landfill from the result Salt solution increases the maximum dry density and decreases the optimum water content of mixtures. Higher cation valance leads to higher increase in the maximum dry density and higher decrease in optimum water content as well. The decrease of the diffuse double layer's thickness is the source of this trend.

[5] Has studied the Effect of bentonite quality on compressibility behavior of soil-bentonite mixtures was evaluated in the presence of various concentrations of NaCl and CaCl2 solutions. The results showed that the bentonite with a higher exchangeable sodium percentage (ESP). The plot between ESP of bentonite and the compression index (Cc) of the soil-bentonite mixtures showed that Cc increased with the increase in the ESP. However, the effect of the ESP on the Cc diminished with the increase in the salt concentration and at 1 N of both NaCl and CaCl2, irrespective of the ESP value of the bentonite, almost an equal Cc was observed for all the four mixtures.

Table 4 Compaction characters of salt solution presences

| Reference | Type of soil | Type of salt solution | Compaction characters |
|---|---|---|---|
| [1] | the effect of bentonite content by adding different percentage of this special clay mineral | NaCl, CaCl2 and MgCl2 | Salt solution increases the maximum dry density and decrease the optimum water content of mixtures. Higher cation valance leads to higher increase in the maximum dry density and higher decrease in optimum water content as well |

## III. EFFECT ON SOIL PROPERTIES IN SEA WATER

### *A. Effect on atterberg limit*

[4] Has studied the Seawater effect on consistency limits and compressibility characteristics of clays. In this study consistency limits including liquid, plastic and shrinkage limits, sediment volume and compressibility characteristics of ten soils were tested using distilled water and natural seawater from the Aegean Sea. The results indicate that the effect of seawater is negligible on the tested consistency limits and compressibility characteristics of soils when they have liquid limits up to 110%. The seawater effect is most noticed on the consistency limits and compressibility of Na-bentonites. They also compared the results with previous research. All reported data were normalized by dividing the index values obtained using seawater by those obtained using distilled water. The comparison of data indicate that the compiled data and present study data are in good agreement, i.e. when the normalized values are plotted as function of liquid limit, all index properties plot along the unity line until the liquid limit of soils is about 110%; then, the normalized index values decrease almost linearly with liquid limit.

[8] Has studied effect of sea water on some geo technical properties of clayey soil. In this study soil which falls under CH group as per I.S classification is used and geotechnical properties were discussed The variation of liquid limit, plastic limit and plasticity index with tap water and sea water, it is observed that the liquid limit, plastic
Limit and plasticity index values of the contaminated soil increases when the result of tap water is compared with the result of sea water. Liquid limit Increase 9.32% Plastic limit Increase 8% Plasticity index Increase 10.91%

[10] Has studied the seawater influence on the behavior of the expansive clays. in this study the rate of change in liquid limit of clayey soils when exposed to natural seawater with respect to distilled water. The four clayey soil samples were gathered with different mineralogy and plasticity characteristics and tested to determine liquid limit in the presence of distilled water, tap water and seawater. The results showed that The liquid limit decrease in presence of seawater; values of all liquid limits in seawater are lower than those in tap water. This difference can be seen more clearly for the bentonite sample.

Table 5 Attenberg limit of Sea water presences

| Reference | Type of soil | Sea water compared | Attenberg limit |
|---|---|---|---|
| [4] | Na-bentonite and clay | Distilled water | |
| [8] | Clayey soil | Tap water | the liquid limit, plastic limit and plasticity index values of the contaminated soil increases when the result of tap water is compared with the result of sea water |
| [10] | Four Expansive clay soil | Distilled water and tap water | The liquid limit decrease in presence of seawater; values of all liquid limits in seawater are lower than those in tap water. This difference can be seen more clearly for the bentonite sample |

### *B. Swelling pressure*

[8] Has studied effect of sea water on some geo technical properties of clayey soil. In this study soil which falls under CH group as per I.S classification is used and geotechnical properties were discussed the free swell index with tap water and sea water
It is observed that the free swell index increased 6.67% in sea water

[10] Has studied the seawater influence on the behavior of the expansive clays. In this study the rate of change in swelling behavior of clayey soils when exposed to natural seawater with respect to distilled water. The four clayey soil samples were gathered with different mineralogy and plasticity characteristics and tested to swelling characteristics in the presence of distilled water, tap water and seawater. The results The differential free swell percent is lower than that in tap water and distilled water for swelling soils (LL > 150...200 %), indicating reduction in swelling potential in seawater, The difference in free swell percent between distilled water and seawater is remarkable, between 0% to

200%; zero is for non-swelling soils and 200% is for bentonite

Table 1.6 Free swell index of Sea water presences

| Reference | Type of soil | Sea water compared | Free swell index |
|---|---|---|---|
| [8] | Clayey soil | Tap water | the free swell index increased 6.67% in sea water |
| [10] | Four Expansive clay soil | Distilled water and tap water | The differential free swell percent is lower than that in tap water and distilled water for swelling soils (LL > 150...200 %), indicating reduction in swelling potential in seawater, The difference in free swell percent between distilled water and seawater is remarkable, between 0% to 200%; zero is for non-swelling soils and 200% is for bentonite; |

*C .Effect of compaction characteristic.*

[8] Has studied effect of sea water on some geo technical properties of clayey soil. In this study soil which falls under CH group as per I.S classification is used and geotechnical properties were discussed compaction characteristic like OMC, Dry density and UCC, OMC increased 30 % Dry density increased 7.58% UCC 20% increased sea water compared with tap water.

Table 1.7 compaction characters of sea water presences

| Reference | Type of soil | Sea water compared | Compaction characteristic |
|---|---|---|---|
| [8] | Clayey soil | Tap water | OMC, Dry density and UCC, increased 30 % Dry density increased 7.58% UCC 20% increased sea water compared with tap water |

## IV. CONCLUSION

A study has been conducted to investigate the effect of sea water and different inorganic salt solutions (as permeant liquids) on the compaction characteristics, liquid limit, free swelling, consolidation characteristics and hydraulic conductivity of different types of clay-bentonite mixtures. . Sea water and Salt solution increases the maximum dry density and decrease the optimum water content of mixtures. Higher cation valance leads to higher increase in the maximum dry density and higher decrease in optimum water content, By increasing the sea water and salt concentration the swelling volume decreases By increasing the sea water and salt decreases the liquid limit of the mixtures. Higher cation valance and salt concentration cause higher decrease in liquid limit by increases the sea water and salt water concentration, the compression index decreases the hydraulic conductivity of the samples increases by adding the salt water and sea water concentration increases.

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