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Effect of Some Chloride Salts on Swelling Properties of Expansive Soil

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Abstract: Chemical stabilization has been increasingly adopted for improving the properties of expansive soils in recent years. The use of chloride salts to stabilize expansive clays has been investigated by many researchers. In this regard an attempt has been made to evaluate the influence of adding three chloride salts ($AlCl_3$, $FeCl_2$, NH_4Cl) to an expansive clay of high swelling potential on its swelling properties. Laboratory tests conducted on natural and treated soils include Atterberg's limits, free swell, swell potential, and swell pressure tests. Various amounts of each salt (0%, 5%, 10%, and 15%) were added to the soil to study their effect on plasticity and swelling characteristics. Comparing the results obtained for the natural and treated soils, the increase in the percentage of the salt decreased the liquid limit and plasticity index of the soil. The reduction in the plasticity index values of the treated soil with addition of 15% salt is more than 78% of the virgin soil. A significant decrease in the free swell index, swell potential and swell pressure of the treated soil was experienced. The tests results indicated that among the three chloride salts tested, ammonium chloride showed promising results. It can be concluded that the chloride salts studied had shown great potential to improve swelling properties of expansive soils.

Keywords*: Aluminum; ammonium; ferric; chloride; expansive soil.*

1. INTRODUCTION

Expansive soils have been encountered in arid and semiarid regions in the world. In Sudan it is one of the major regional soil deposits which cover over one-third of the country land area and is predominantly located along Nile river and its branches [1]. Expansive soil deposits are problematic to civil engineers due to its cyclic volumetric change with seasonal moisture fluctuation accompanied by the loss of strength with increase in moisture content [2]. Because of swell-shrink behavior of expansive clay, there is considerable damage to structures founded on it.

The undesirable characteristics and performance of expansive soil can be altered and improved with chemical additives like lime, cement, fly ash, inorganic salts, chemical compounds etc. Cement and lime are most commonly used for the stabilization of expansive soils to ensure high strength [3]. As high strength may not always be required, cheaper additives such as chlorides and gypsum have been used to stabilize soils [4], [5].

The chloride salts could be an effective alternative to conventional lime treatment due to its ready dissolvability and can supply adequate cations for exchange reactions. However, the use of water soluble chemicals is considered feasible to improve expansive soil by diffusion technique [6]. In practice an efficient and cost effective method with minimum time is always preferred in soil stabilization.

This paper highlights on certain chloride salts which have been investigated by many researchers as reported in available literature. The objective of present study is to determine the effect of addition of chloride salts such as aluminum chloride, ferric and ammonium chlorides ($AlCl_3$, $FeCl_3$, NH_4Cl) on expansive soil in term of change in index properties and swelling characteristics.

The Clay soils having montmorillonite minerals show high plasticity index and high affinity to water [2]. Absorption and expulsion of water lead to volume change which is a very crucial matter and has strong potential for research. There are many techniques available to reduce the effect of volume change of expansive soil due to change in water content within the soil mass. Soil stabilization by mixing various chemical additives has been proved to be effective alternative solution to overcome the undesirable swell-shrink behaviour. The stabilization agents can improve the soil properties and alter the performance of expansive soil when structures are founded on them [7].

Ferric chloride and aluminum chloride have been found to be promising water proofers for heavy clays stabilized by phosphoric acid, and it has been postulated that the ferric and aluminum ions reduced swelling of the montmorillonite minerals in the soil by replacing the interlayer metallic cations [8]. Ferric chloride stabilization gained prominence for modification of marine clays due to the availability of ferric chloride and its adaptability. In fact, Ferric chloride is sparingly soluble (about 1.2 g/litre at 21°C) in water and free calcium ions available for substantial cation-exchange reactions [9].

Chemical stabilizers can broadly be divided into three groups; traditional stabilizers such as hydrated lime, Portland cement, and fly ash; non-traditional stabilizers comprised of salts, organic materials, enzymes, biological binders and polymers; and by-product stabilizers include steel slag, cement kiln dust, lime kiln dust etc [10].

Traditional stabilizers undergo pozzolanic reactions and cation exchange to modify and/or stabilize the soil. In case of by-product stabilizers also pozzolanic reactions and cation exchange are the primary stabilization mechanisms. The mechanism of stabilization for non-traditional stabilizers varies greatly among the stabilizers [10].

Expansive soil characteristics can be altered and soil performance can also be improved with chemical admixtures. The selection and success of the used additives depends on economy consideration, soil condition, level of modification required and availability of material and instrumentation required for particular techniques.

During last three decades, many researchers have conducted chemical stabilization with various additives which have positive impact on soil performance. There are many researches had been used chloride salts as stabilizing materials for modification and they have positive impacts on expansive soils.

Many studies are available in the literature on stabilization of soils using various chloride compounds. They considered the index properties, swelling characteristics and shear strength in investigating the effect of chloride salts as stabilizers. Some examples of these researched are reviewed in this section.

Abood *et al*. [6] studied the effect of adding three chloride salts (NaCl, $MgCl_2$, $CaCl_2$) on the properties of silty clay soil. Their findings showed that the addition of each salt decreased the liquid limit and increased the plastic limit and accordingly reduced the plasticity index of the soil. The maximum dry density and the compressive strength increased while the optimum moisture content decreased with the increased in salt percentage.

Radhakrishnan *et al*. [11] tested the swelling properties of expansive subgrade soil treated with Magnesium Chloride ($MgCl_2$), Aluminum Chloride ($AlCl_3$) mixed with fly ash in varying percentages. Their findings showed that the treatment of the expansive soil with $AlCl_3$ and flyash at 1% and 10% respectively is the optimum amount of the stabilizer and very effective in reducing the differential free swell, the swell pressure and swell potential of the soil considered.

Kolaventi *et al.* [12] studied the efficiency of sodium chloride (NaCl) and calcium chloride ($CaCl_2$) salts as stabilizing agents for black cotton soil. They added various amount of each salt (2%, 4%, 6% and 8%) to the soil and found that the properties of the soil are improved by the addition of sodium chloride & calcium chloride at 8%. By comparing the results given by the two salts, they found that calcium chloride gives better results than sodium chloride. Comparing the cost, Sodium Chloride (Nacl) is cheaper than Calcium Chloride ($Cacl_2$). Therefore, it is more economical to use Sodium Chloride (Nacl) for stabilizing large areas.

Ramadas *et al.* [13] studied the effect of various percentages of calcium chloride (0.5 %, 1.0%, 1.5% and 2%) on the engineering properties of three expansive soils. Their results showed great reduction in swelling and significant increasing in strength properties of these soils. Belabbaci *et al.* [14] studied the effect of potassium chloride (KCl) and magnesium chloride ($MgCl_2$) solution on increasing the mechanical strength and bearing capacity of clay and it was found that addition of salts increased strength and reduced swelling and soil absorption capacity.

Kesava *et al*. [15] carried out a study to investigate the efficiency of strong electrolyte like potassium chloride (KCl), calcium chloride ($CaCl_2$) and ferric chloride ($FeCl_3$) as stabilizing agents. They found considerable reduction in swell-shrink tendency. They observed that calcium chloride had given better results than ferric and potassium chlorides.

Rao and Subba Rao [16] recommended 5% of Ferric chloride ($FeCl_3$) solution to treat the caustic soda contaminated ground of an industrial building in Bangalore. Scholen [17] studied the effect of ammonium chloride to stabilize expansive soil. When ammonium chloride is added to the expansive soil, it removes ionized water and draws the lattice together, but the ammonium ions reduce the capillarity in the soil requiring more thorough mixing of the soil.

Cokca [18] conducted Oedometer free swell tests on the fly ash mixed with expansive soil and confirmed that the plasticity index, activity and swelling potential of the samples decreased with the increasing percent stabilizer and curing time and the optimum content of fly ash in decreasing the swell potential was found to be 20%.

The previous experiences reviewed had proven that chloride salts have positive impacts on the engineering properties of high swelling clays. Their findings confirmed that the effect of added chloride salt not only depends upon the soil property but also on the added salt quantity.

2. MATERIALS AND METHODS

The laboratory testing program was undertaken to achieve the objective of the study. Tests were conducted on natural and treated soils using three different chloride salts to investigate their influence on swelling properties.

2.1 Materials Used

In this study, the materials used in the experimental investigation are expansive soil and three chloride salts, Aluminum chloride, ferric chloride, and ammonium chloride.

a) Expansive soil

The expansive soil used in this study was obtained from Almanshia in Khartoum. The soil is dark grey stiff clay of high plasticity. The basic soil properties were determined as given in Table 1. The soil has high swell potential.

Table 1. Properties of the tested soil

Property	Value
Specific gravity (G_s)	2.74
Liquid limit (LL), %	63
Plastic limit (PL), %	18
Plasticity index (PI), %	45
Sand (S), %	8
Silt (M), %	30
Clay (C), %	62
Free swell index (FSI), %	150
Swell potential, %	5.5
Swell pressure, KN/m^2	124
Soil classification	CH

Table 2: The properties of Aluminium chloride sample

Property	Value
Molar Mass, g/mole	133.3
Appearance	pale yellow solid
Minimum Assay, %	98
Maximum limits of Impurities, %	
Sulphate (SO_4)	0.01%
Iron (Fe)	0.05%
Specific gravity	2.48

b) Alumimum chloride

Aluminum chloride ($AlCl_3$) is a salt of white colour and when contaminated with iron trichloride becomes yellow. This salt has low melting and boiling points. It is mainly produced and consumed in the production of Aluminum metal, but large amounts are also used in other areas of chemical industry. It is an inorganic compound that cracks at mild temperature and reversibly changing from a polymer to a monomer. The properties of $AlCl_3$ used in testing are given in Table 2.

c) Ferric chloride

Ferric chloride ($FeCl_3$) is an orange to brown-black solid. It is completely soluble in water. Ferric chloride is noncombustible. Ferric chloride is corrosive to aluminum and most metals when it is wet. Pick up and remove spilled solid before adding water. From earlier studies it was found that FeCl3 was quite effective in minimizing swelling of expansive soils. So $FeCl_3$ – ferric chloride was adopted for this study. When dissolved in water, ferric chloride undergoes hydrolysis and gives heat in an exothermic reaction. The resulting brown, acidic, and corrosive solution is used as a flocculent in sewage treatment and drinking water production. Its boiling point is 280°C.

d) Ammonium chloride

Ammonium chloride (NH_4Cl) is a white crystalline salt that is highly soluble in water. Solutions of ammonium chloride are mildly acidic. Nushadir salt is a name of ammonium chloride. The mineral is commonly formed on burning coal dumps from condensation of coal-derived gases. It is also found around some types of volcanic vents. It is mainly used as fertilizer and a flavoring agent in some types of liquorices. Its boiling point is 520 °C.

2.2 Sample Preparation and Test Procedure

The soil was initially air dried, sieved through sieve number 4 (4.75mm). The soil samples were oven dried at 105-110 °C for 24 hours. The samples were subdivided and each sub-sample was mixed with each salt at various amounts. The three salts of aluminum, ferric and ammonium Chlorides were each dissolved in water, left for one day. The salts used at different concentrations.

The soil was mixed with each salt at four different contents (0%, 5%, 10%, and 15%). Each salt percent was mixed with soil and then subjected to testing. Laboratory tests like Atterberg's limits, free swell, and Odometer tests were performed. All tests were conducted according to BS [19]. A brief description of each test is presented in the following sections:

Atterberg's limits tests: the tests conducted include the liquid limit and plastic limit tests. The soil was mixed with the salt solutions of different concentrations then placed in plastic bags to remain for 24 hours. The liquid limit was determined by Cassagrande apparatus.

Free swell test: The free swell of the natural and treated soil was evaluated. First, samples were dried at 105±5°C; then approximately 40 grams of dried clay were added to salt solution in a 2000 ml cylinder. The salt added at different concentration according to salt content (5%, 10%, and 15%). The samples were left to settle for 24 hours.

Oedometer tests: in the Oedometer cell, the swell under loading was performed to determine the swell percent at a certain load and swell pressure. The sample of natural and treated soils were compacted at maximum dry density and optimum moisture content and prepared in the Oedomter ring. In the Oedometer cell, two filter papers were placed between the soil sample and the upper and lower porous stones to distribute the water evenly. The cell was then placed in the load frame of testing machine. The cell dial gauge reading was set to zero and the specimen was inundated by adding distilled water. The cell readings were recorded at 1, 2, 4, 8, 16, 64, 128 and 1440 minutes. All readings were stopped when negligible increase in cell gauges was observed. The soil samples were tested under different surcharge loads. The swell percent variation with the surcharge loads was drawn to determine the swell pressure (i.e. the surcharge pressure at zero swell). The swell percent at a certain load and swelling pressure were computed using Excel spreadsheet.

3. RESULTS AND DISCUSSION

Laboratory tests were conducted on samples prepared by adding different percentages of aluminum chloride, ferric chloride, and ammonium chloride to the expansive soil. Atterberg's limits, and swelling tests were performed to investigate the effect of adding various percentages of the three salts to the soil on measured soil properties. The tests results are presented in Table 3.

Table 3: Summary of tests results for the natural and treated soils

Properties	$ALCl_3$				$FeCl_3$				NH_4Cl			
	0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Liquid limit, %	63	42	30	28	63	47	39	35	63	39	32	32
Plastic limit, %	18	22	25	28	18	21	23	25	18	19	21	25
Plasticity index, %	45	20	5	0	45	26	16	10	45	20	11	7
Free swell, %	150	80	80	50	150	50	40	30	150	50	17	7
Swell Potential, %	5.5	5.1	4.3	3.0	5.5	4.5	2.5	1.8	5.5	4.5	0.4	0.1
Swell Pressure, kPa	124	87	64	46	124	116	78	75	124	34	20	12

3.1 Effect on Atterberg's Limits

The influence of each salt ($AlCl_3$, $FeCl_3$, NH_4Cl) with varying percentages 0, 5, 10, and 15 on liquid limit and plastic limit are clearly shown in **Fig. 1 and 2**. From these figures, there is significant decrease in liquid limit and increase in plastic limit with the addition of $AlCl_3$, $FeCl_3$, and NH_4Cl to the soil. The decrease in liquid limit and the increase in plastic limit cause a net reduction in plasticity index. It is observed that, the reductions in the plasticity index values of treated soil with addition of 15% $AlCl_3$, $FeCl_3$, and NH_4Cl are 100%, 78%, and 84% respectively. This result could be attributed to the depressed double layer thickness due to cation exchange by aluminum, ferric, and ammonium ions [20].

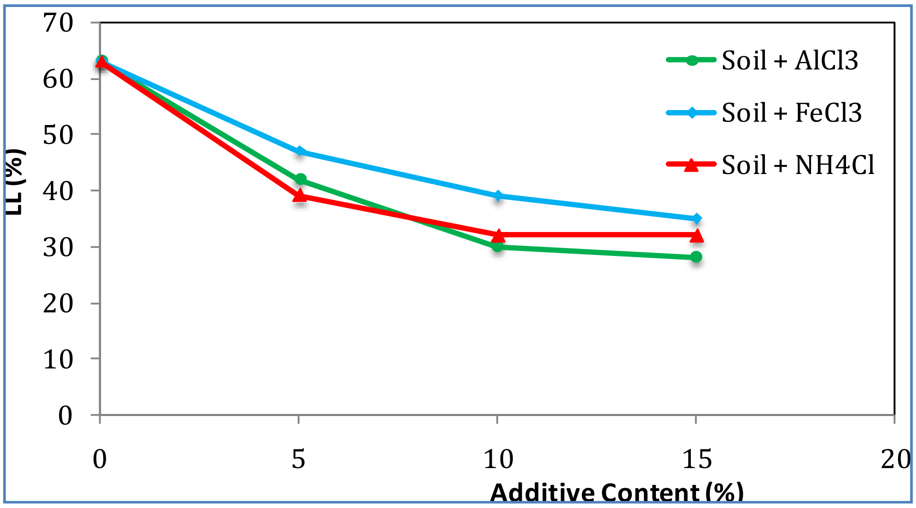

Fig. 1. Influence of $AlCl_3$, $FeCl_3$, and NH_4Cl on liquid limit

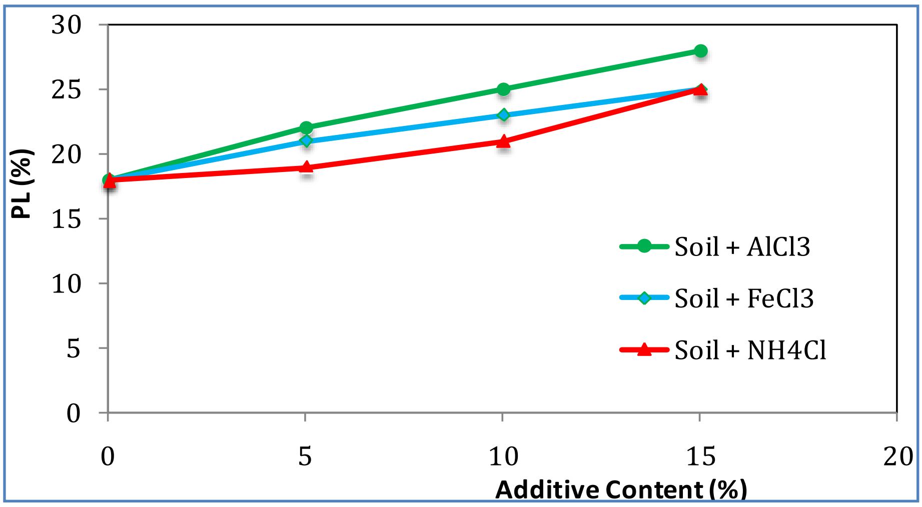

Fig. 2. Influence of $AlCl_3$, $FeCl_3$, and NH_4Cl on plastic limit

3.2 Effect on Free Swell Index

The free swell index (FSI) of the treated clay with addition of 0%, 5%, 10%, and 15% of each chloride salt ($AlCl_3$, $FeCl_3$, NH_4Cl) is presented in **Fig 3**. In this figure, it is observed that the FSI value of the treated soil rapidly decreased with addition of 5% salt, beyond this percentage the FSI value marginally decreased with added salt. The reduction in FSI values of treated soil with 5% of each salt is from 47% to 67% compared with the expansive clay. At 15% $AlCl_3$, $FeCl_3$ and NH_4Cl, the reductions in FSI are 67%, 80%, and 95% respectively. These reductions may be due to the fact that at higher salt content, cation concentration increases which resulted in depressed double layer thickness due to cation exchange reaction. This result could be supported by the double layer thickness is depressed with cation exchange with aluminum, ferric and ammonium ions and with increased electrolyte concentration [20].

3.3 Effect on Swell Potential

The influence of $AlCl_3$, $FeCl_3$, and NH_4Cl with varying percentages 0, 5, 10, and 15 on swell potential is shown in **Fig. 4**. It is noticed from this figure that there is a significant decrease in swell potential with increase in the percentage of each salt. The major reduction in swell potential observed at 10% salt content. The swell potential values at 15% $AlCl_3$, $FeCl_3$, and NH_4Cl reduced by 45%, 67%, and 98% respectively. Higher reduction in swell potential values occurred in addition of NH_4Cl compared to $FeCl_3$ and $AlCl_3$. This result could be supported by the fact that the double layer thickness is greatly depressed with ammonium ions than with ferric and aluminium ions due to increase in electrolyte concentration [20].

3.4 Effect on Swell Pressure

Fig. 5 shows the variation of swell pressure of treated expansive clay with addition of different percentages of the

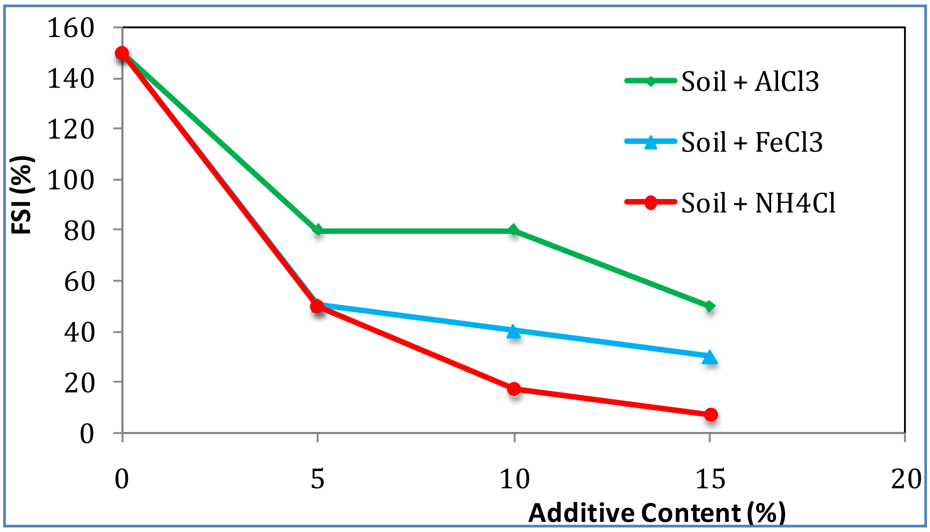

Fig. 3. Variation of free swell index of stabilized soil with $AlCl_3$, $FeCl_3$, and NH_4Cl

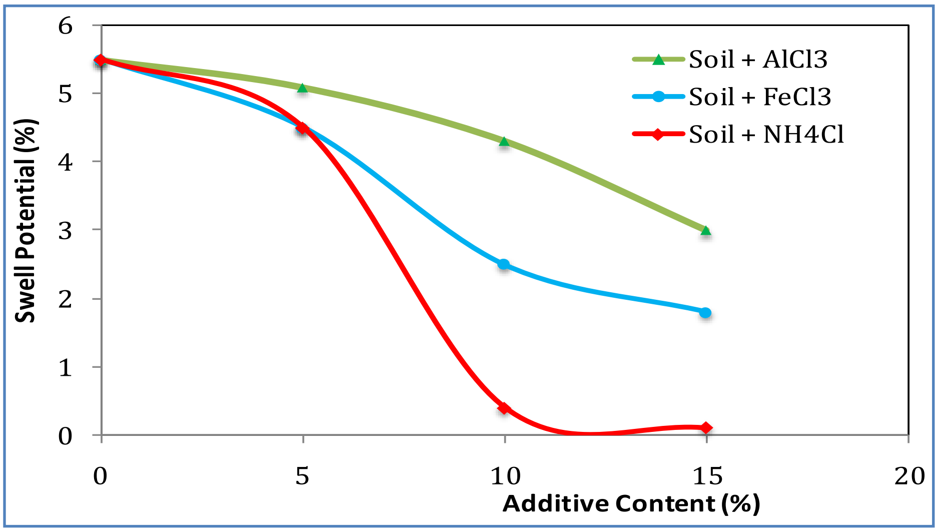

Fig. 4. Effect of $AlCl_3$, $FeCl_3$, and NH_4Cl on swell potential

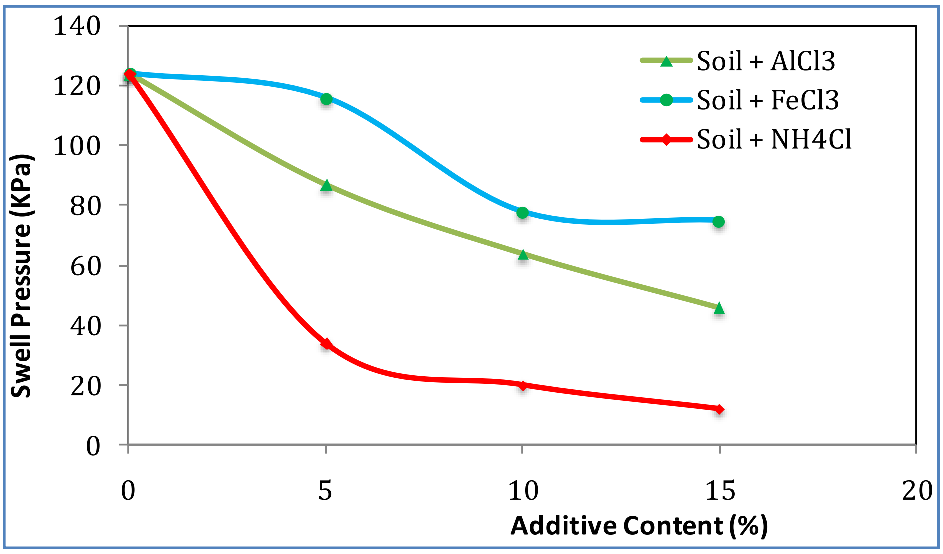

Fig. 5. Variation of swell pressure with various $AlCl_3$, $FeCl_3$, and NH_4Cl contents

three chloride salts tested. It can be seen that the swell pressure decreased with increasing amount of each salt added to the soil. Addition of 15% $AlCl_3$, $FeCl_3$, and NH_4Cl to expansive clay decreased the swell pressure values by 63%, 40%, and 90% respectively, when compared with the initial values. The reduction in swell pressure values of treated soil

with addition of 5% NH_4Cl is almost 70% of virgin soil. This result indicated that NH_4Cl shows significant reduction in swell pressure values than $FeCl_3$ and $AlCl_3$ when added to expansive clay.

Finally, from the above discussion, it is clear that there is considerable improvement in the plasticity and swelling properties of expansive soil treated with $AlCl_3$, $FeCl_3$, and NH_4Cl.

4. CONCLUSIONS

This study was conducted to investigate the effects of three chloride salts ($AlCl_3$, $FeCl_3$, NH_4Cl) on the swelling properties of expansive clay soil from Sudan. Based on the present laboratory study, the following conclusions are drawn:

- The engineering properties of the soil tested showed that the soil is classified as high plastic clay (CH) of high expansiveness, PI is 45%; free swell index is 150%; swell potential is 5.5%; and swelling pressure is 124 kN/m^2.
- The addition of each chloride salt ($AlCl_3$, $FeCl_3$, NH_4Cl) to the expansive clay decreased the liquid limit and the plasticity index of the treated soil. The reduction in the plasticity index values of the treated soil with addition of 15% salt is more than 78% of the initial value.
- A significant decrease in the swelling characteristics of the stabilized expansive clay with addition of NH_4Cl. The maximum reduction in swelling properties observed when NH_4Cl salt added to the soil, while the minimum reduction occurred in addition of $AlCl_3$ salt. When 5% of NH_4Cl added to the soil, the free swell index and swell pressure values greatly reduced by almost 70% of the initial values. The swell potential has major reduction, more than 90% with addition of 10% NH_4Cl to the soil.
- In comparing the three salts ($AlCl_3$, $FeCl_3$, NH_4Cl) for their efficiency in improving swelling properties of expansive clay, the findings indicated that among the three chloride compounds tested ammonium chloride showed encouraging results in terms of plasticity and swelling properties. This may be due to its ready solubility in water and supplying adequate ammonium ions for exchange reactions.

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