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ORIGINAL PAPER

Enhancing the Swelling Characteristics and Shear Strength of Expansive Soil Using Ferric Chloride Solution

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Abstract
Expansive soil has high tendency to swell and shrink with the change in moisture content. This phenomenon can cause excessive total and differential movements of overlying structures. Population growth has led to rapid urbanization that requires expansion of civil engineering infrastructures and the associated services. In Egypt, these types of soils are extensively found in many areas and it is virtually impossible to avoid construction on such soil. Recently, chemical stabilization became one of the most popular soil treatment techniques as they have the ability to dissolve easily in water. In this study, X-ray diffraction analysis, free swell index, modified Proctor compaction, consistency limits and swelling pressure of bentonite as a tested expansive soil were determined. Solid ferric chloride ($FeCl_3$) is an inorganic highly ionizable material that can produce active trivalent iron compound (Fe^{3+}) when mixed with water. In this study, the optimum percentage for ferric chloride solution was found to be 1%. At that percentage of ferric chloride solution, the free swell index and the swelling pressure for the expansive soil were reduced by 62% and 43%, respectively. Also, at 15% ferric chloride solution, the expansive soil plasticity index was reduced by 35%. Ferric chloride solution is a novel material that has not been used before in improving the behavior of expansive soil. This study demonstrates the effectiveness of the proposed method in stabilizing and improving the properties of expansive soil.

Keywords Expansive soil · Bentonite · Ferric chloride · Free swell index · Swelling pressure

Introduction

Soil stabilization is known to be an effective approach to enhance the engineering properties of expansive soils. Nowadays, engineers are interested in finding an economic solution to stabilize expansive soils before construction. Expansive soils are sensitive to additional moisture that can result from precipitation, flooding and leaking pipelines. Excessive soil movement can cause uplift pressures on buildings, which can lead to considerable damage to light structures and distresses in floor slabs leading to insurance claims of millions of dollars yearly to repair homes impacted by expansive soils [1].

The effects of two types of nanocarbons (NCs); carbon nanotubes (CNTs) and carbon nanofibers (CNFs), on the swelling properties of expansive soil were investigated [2]. Waanders et al. [3] studied the effect of adding different percentages of both sodium hydroxide (NaOH) and sodium carbonate (Na_2CO_3) on the behavior of the bentonite. It was found that the maximum swelling index was reached by adding 7.5% and 6.5% NaOH and Na_2CO_3, respectively. The influence of adding 3% and 5% of crushed polyethylene terephthalate bottles on improving the shear strength parameters of bentonite was also evaluated [4]. In addition, the effectiveness of slag and Portland cement additives in stabilizing expansive soils was investigated [5].

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The results showed that adding these stabilizers improved the strength of soils by a factor that ranges from 4 to 10 and decreased the swelling potential to less than 1%. The effect of adding lime to improve the geotechnical properties of expansive soil was studied [6].

Sakr et al. investigated the effect of using micro-metakaolin [7], micro-silica fume [8, 9] and nanoclay [10] on improving the swelling behavior of the expansive soil. El-mashad [11] studied the effect of adding chemical additives such as sodium chloride, lime, sodium carbonate and ammonium chloride to the expansive soil. Several investigators reported an improvement in the geotechnical properties of expansive soils using different additives such as egg shell powder mixed with corn cob ash [12] and with plastic wastes [13], vinyl copolymers [14], coconut husk ash [15], pumice mixed with lime [16], lime mixed with volcanic ash [17], hydroxy-aluminum (Al_{13}) [18] and a concentrated liquid ionic stabilizer [19].

Swelling of bentonite soil mainly occur due to the conversions of dry solid bentonite particles into negatively charged colloidal particles when moistened with water. The expansion of that soil is due to the repulsion between that charged particles. Ferric chloride is an electrolyte when ionized gives a positively charged ferric ions (Fe^{3+}), which can be attracted to the colloidal particles and neutralize its charge leading to colloidal particles coagulation [20].

The main goal of this study is to investigate the potential benefits of using ferric chloride solution ($FeCl_3$) as a stabilizing technique to improve the geotechnical properties of expansive soils and to reduce its swelling potential. Characterization tests were performed before and after the addition of $FeCl_3$ such as X-ray diffraction pattern (XRD), consistency limits, compaction tests, free swell index, swelling pressure and shear strength tests.

Materials

Soil

The bentonite used in this study represents a type of expansive soil in a homogeneous phase. This bentonite was obtained from "Bentonite and Derivatives Company" in Borg Al-Arab, Alexandria, Egypt. The physical, chemical, geotechnical properties and the mineralogical composition of the used expansive soil are summarized in Table 1. The hydrometer analysis of this bentonite indicated that the sample consists of 64% clay and 36% silt. Also, X-ray diffraction pattern (XRD) was conducted on the expansive soil at the central laboratory—Tanta University, Egypt. XRD of the

Table 1 Properties of the used bentonite

	Property	Value
Physical and chemical properties	Specific gravity, G_s	2.6
	SiO_2 (%)	61.0
	Al_2O_3 (%)	14.6
	Fe_2O_3 (%)	2.1
	TiO_2, SO_2, Cl, BaO (%)	<0.5
	CaO, K_2O (%)	0.8
	MgO (%)	2.2
	Na_2O (%)	2.0
	Loss on ignition, LOI (%)	10.0
Geotechnical properties	Free swell index, SI (%)	501.9
	Swelling pressure, Sp (kPa)	410.0
	Unit weight, γ (kN/m^3)	10.7
	Liquid limit, L.L. (%)	331.0
	Plastic limit, P.L. (%)	36.0
	Plasticity index, P.I. (%)	295.0
	Maximum dry unit weight, $\gamma_{dry\ max}$ (kN/m^3)	14.7
	Optimum moisture content, O.M.C. (%)	21.2
	Undrained shear strength, c_u (kPa)	9.9
	Friction angle, φ (°)	26.9
Mineralogical composition	Kaolinite (%)	16
	Quartz (%)	40
	Smectite (%)	40
	Others (%)	4

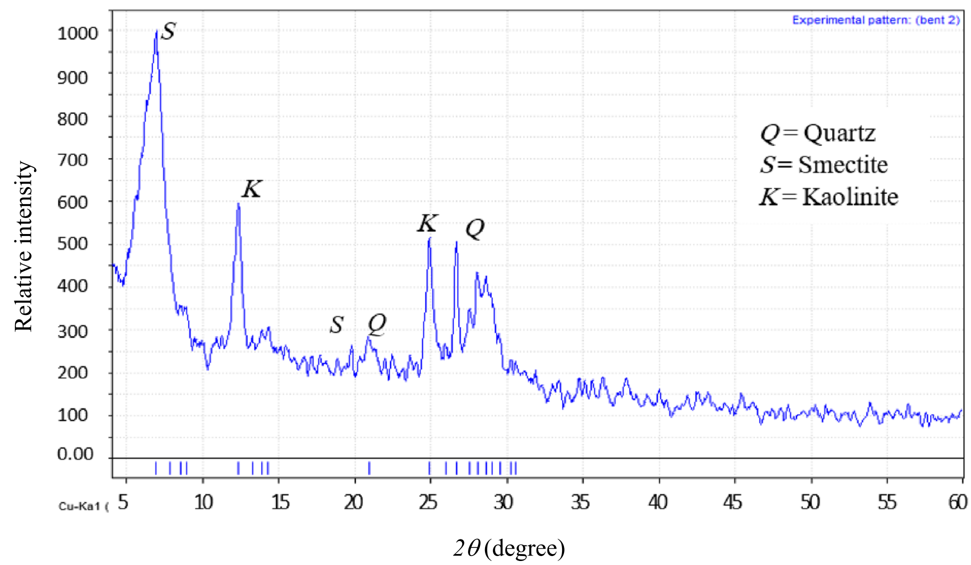

Fig. 1 X-ray diffraction pattern of the expansive soil sample

used bentonite is depicted in Fig. 1. Kaolinite component peaks mainly exist at 2Theta of 12.3° and 24.9°. Quartz component peak exists at 2Theta value equals 27° and smectite (montmorillonite) component peak exists at 2Theta of 5.9°. As a result, a tangent line was drawn at those peaks, to calculate the areas under them. According to the calculated areas, each component percentage could be obtained. The mineralogical composition of tested expansive soil consists of 16%, 40% and 40% of kaolinite, quartz and smectite, respectively. The calculated d-spacing (Å) for the characteristic peaks located at 2Theta values 5.9, 12.3, 21.1, 24.9, and 27° using Bragg equation ($\lambda = 1.540$ Å) were found to be 12.1, 7.05, 4.0, 3.2, and 2.89 Å, respectively.

Ferric Chloride Solution

Ferric chloride solution is an inorganic compound with a composition of $FeCl_3$. It is a + 3 oxidation state iron compound. It has a colorless to light brown aqueous solution with a faint hydrochloric acid odor. Ferric chloride was obtained from "Al-Gomhoria Company for Chemicals", Al Mansoura, Egypt.

Samples Preparation

The preparation of the soil mixture is an important step to get a homogeneous mixture ready for the tested samples. The main principle is to prepare a reconstituted soil with a certain additive content, and then compact it to a certain dry unit weight in the cell of an Oedometer or in a direct shear box using a certain energy as per Benkadja and Belouahri [21]. Following the guidelines of the ECP 202-part 2 [22], the compaction tool used in this study is composed of a disc fixed to a rod with a load of 136 g slides alongside of the rod, falls from 150 mm height and comes to strike the disc to compact the materials. In this study, we used a compaction energy (Ec) equals 8 J or 20 blows/layer matching values verified by Benkadja and Belouahri [21]. This compaction energy gives a maximum dry unit weight of 75–80% of maximum dry unit weight which is consistent with the results given by Sakr et al. [23], Rabah [24] and Nazir [25]. Therefore, to prepare the expansive soil–ferric chloride solution mixture: first, the samples were oven dried at 105 °C [11], weighed according to the maximum dry unit weight of the soil and the chosen percentage of additive, and then mixed for 10 min to each portion to ensure a homogeneous sample. Then, the weighed amount of soil is compacted in two layers using the same energy (20 blows/layer). The tested sample is leveled inside the Oedometer cell or in the direct shear box maintaining leveled surface.

Experimental Program

In this study, the effect of adding 1%, 3%, 5%, 10% and 15% of ferric chloride solution ($FeCl_3$) to the expansive soil on X-ray diffraction and different geotechnical and engineering properties of the expansive soil is experimentally investigated. In total, 38 tests were performed on the expansive soil before and after treatment using different percentages of ferric chloride solution.

X-ray diffraction analysis was investigated on ferric chloride treated and untreated expansive soil sample to determine the degree of crystalline or amorphous nature of the tested sample. The analyses were performed by A Philips PANalytical X'pert PRO diffractometer. X-ray patterns data were taken via thin powder sample which is placed onto an oriented monocrystalline quartz plate for exposure to a Cu

Kα X-ray source ($\lambda = 1.5406$ Å) and radiation source operating at the voltage of 40 kV and a current of 40 mA with Ni-filtered radiation. The samples were analyzed at room temperature over a range of 10°–60° 2θ with a step size of 0.02°.

Consistency limit tests were performed on the expansive soil only without treatment (control sample) and on the soil mixed with $FeCl_3$ (treated samples) according to the ECP 202-part 2 [22]. Then, samples were mixed with different amounts of water and their corresponding dry unit weight were determined using the modified Proctor test apparatus according to the ASTM, D1557 [26]. To investigate the swelling activity of the expansive soil, free swell index tests were performed according ECP 202-part 5 [27]. The soil samples were oven dried at 105 °C and 30 ml of water were placed in a 100 ml graduated cylinder. Pre-sieved soil was progressively added to the water in 1 g increments. After the 10 g was added, water was poured to fill the cylinder up to 100 ml and to rinse any unmixed particles. The final volume of the expansive soil was measured after reaching the full expanded volume. The free swell index is calculated as:

$$\mathrm{SI} = \frac{V_f - V_i}{V_i} \times 100, \tag{1}$$

where SI is the free swell index (%), V_f is the final volume (cm^3) and V_i is the initial volume (cm^3).

Then, swelling tests were performed in a standard one-dimensional Oedometer apparatus according to the ECP 202-part 5 [27]. The oven-dried soil samples were compacted as described earlier in a fixed stainless steel Oedometer ring with 50 mm internal diameter and 20 mm height. Three samples were tested under vertical pressures of 100 kPa, 200 kPa and 300 kPa. Each pressure increment was applied to the dry sample and sustained until the vertical movement has stopped. Water was then added to the cell and the swelling of the sample was recorded with time [11]. The results of the final swelling ratio under each pressure increment are discussed in the next section. The swelling ratio is expressed as a percentage of the total swell to the initial sample's height.

$$\mathrm{SR} = \frac{H_f - H_i}{H_i} \times 100, \tag{2}$$

where SR = swelling ratio (%), H_f = final height (cm) and H_i = initial height (cm).

To investigate the relationship between the swelling characteristics and the percentage of the added ferric chloride solution, the relationship between the swelling pressures and the time elapsed since water addition to the prepared mix was studied. The elapsed time that corresponds to insignificant change in swelling pressure is recorded. Figure 2 shows that the swelling pressure consistently increases for the case of expansive soil without additives throughout the first week. After 8 days, the change in swelling pressure is found to be almost negligible as the rate of swelling pressure remains approximately constant. Therefore, the test duration for the rest of the tests was set at 8 days. This is consistent with the results reported by different investigators [11, 28].

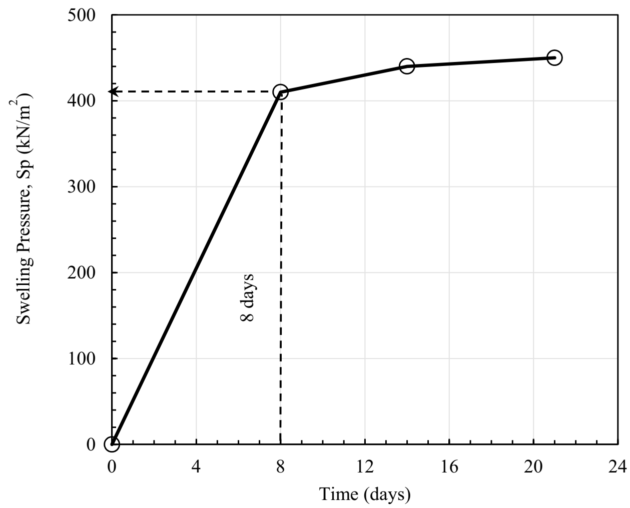

Fig. 2 Swelling pressure versus time

For the direct shear test, the oven-dried soil samples were compacted in a shear box with an internal dimensions of 60 × 60 mm^2 and a height of 25 mm. Three samples were tested for each $FeCl_3$ percentage under stress increments of 25 kPa, 50 kPa and 100 kPa with a rate of shear displacement of 0.0005 mm/min. This slow rate was chosen to allow for pore pressure dissipation for tests involving soaked samples as per the ECP 202-part 2 [22]. This chosen loading rate is consistent with that reported by Sinha [29]. For the case of unsoaked samples, each stress increment was applied to the tested sample and the corresponding shear strength was recorded when the horizontal displacement has reached 15% of the sample's side length as per the ECP 202-part 2 [22]. Similar procedures were adopted for each prepared sample such that the oven-dried sample is compacted as described above and the next stress increment was applied. The components of the shear strength were determined in both the unsoaked and soaked states.

Results and Discussion

To study the impact of adding ferric chloride solution to the expansive soil on the improvement of swelling and shear strength characteristics of such soil, different tests such as XRD pattern before and after treatment, modified Proctor test, Atterberg limit tests, free swell index tests, swelling pressure tests and direct shear box tests were conducted. The obtained results were analyzed and presented in this section.

X-ray Diffraction Analysis

Adding ferric chloride solution to the expansive soil transformed the expansive soil from crystalline material to amorphous material with no peaks and the smectite peak which is responsible for the swelling activity of the soil disappeared. This proves that the swelling ability of soil has been significantly reduced. This could be explained with the fact that the treatment by ferric chloride solution makes the expansive soil a material with zero iso-electric charge as the ferric chloride which has a trivalent charge neutralizes the expansive soil charges. Therefore, treating the expansive soil with ferric chloride solution does not only reduce the swelling behavior of soil but also enhances its structure.

Consistency Limits

Consistency limits are important tools for classifying, describing and identifying different types of soil, and they are generally used for the initial evaluation of the soil properties. The obtained values of liquid limit, plastic limit and plasticity index for the soil treated with different percentages of ferric chloride solution are presented in Fig. 3. As can be seen from this figure, adding ferric chloride solution to the expansive soil reduces its liquid limit and increases its plastic limit resulting in a gradual decrease in the values of the plasticity index of the expansive soil. At 1% and 15% ferric chloride solution, the plasticity index was reduced by around 15% and 35%, respectively. The decrease in the plasticity index with the addition of $FeCl_3$ may be attributed to the more diffusible velocity of Fe^{3+} and Cl^- compared with polar H_2O group. It is known that montmorillonite is a highly hydrophilic solid due to the presence of rich surface active sites which tend to sorb polar molecules such as water. In the presence of ferric and chloride ions based on the small sizes of Fe^{3+} and Cl^- and their higher volume change, they compete with water for active sites. This combined with the decrease in the expansive soil tendency to sorb water.

Compaction Parameters

Figure 4 shows the relationship between the dry unit weight and the water content for the expansive soil samples after adding ferric chloride solution. While, Fig. 5 presents the effect of ferric chloride solution on the maximum dry unit weight and the optimum moisture content of the expansive soil. Adding 10% ferric chloride solution to the expansive soil, increases its dry unit weight by around 3%. Then, the maximum dry unit weight is reduced. On the other hand, at adding 1% ferric chloride solution to the expansive soil, its optimum moisture content decreased by around 2% then, the optimum moisture content increased. This demonstrates the relationship between the positively charged ferric ions present in the additive, which is attracted to the negatively charged particles of the expansive soil. At lower concentration of ferric chloride solution (less than 10%), the ferric ions are attracted to the negatively charged soil particles causing the soil particles to move closer to each other. However, at higher concentration of ferric chloride solution (more than 10%), the positively charged ferric ions increases creating a state where the positively charged ions become more than the negatively charged soil particles. So,

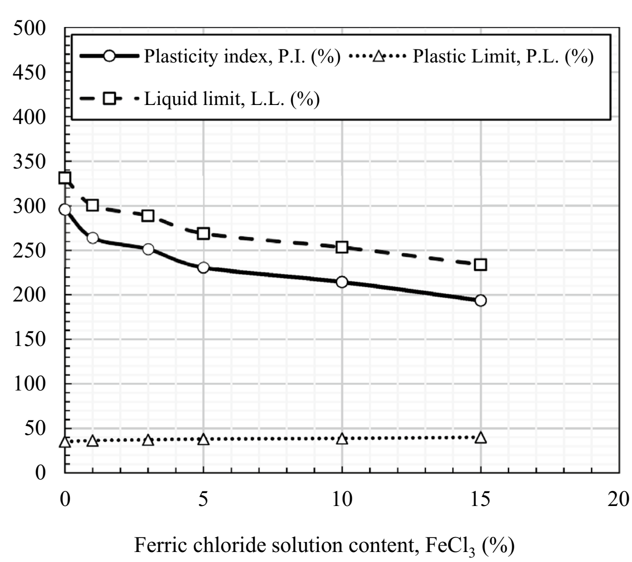

Fig. 3 The effect of ferric chloride solution on the consistency limits of the expansive soil

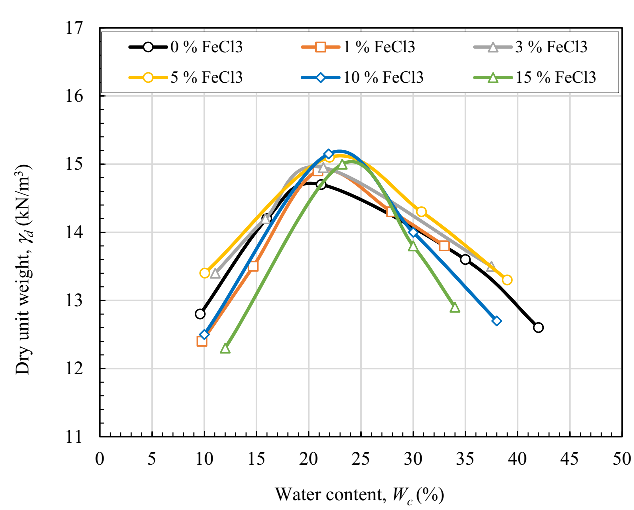

Fig. 4 The relationship between dry unit weight and water content for different percentages of ferric chloride solution

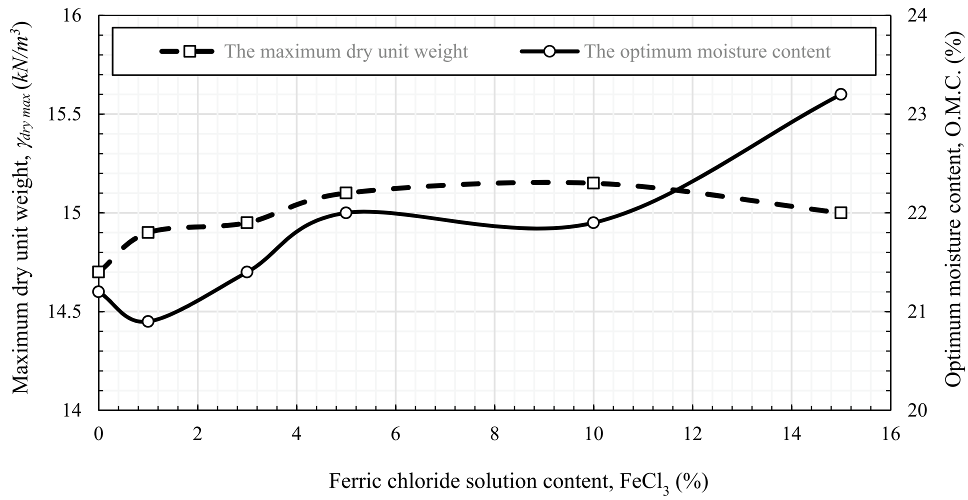

Fig. 5 Ferric chloride solution effect on the compaction parameters

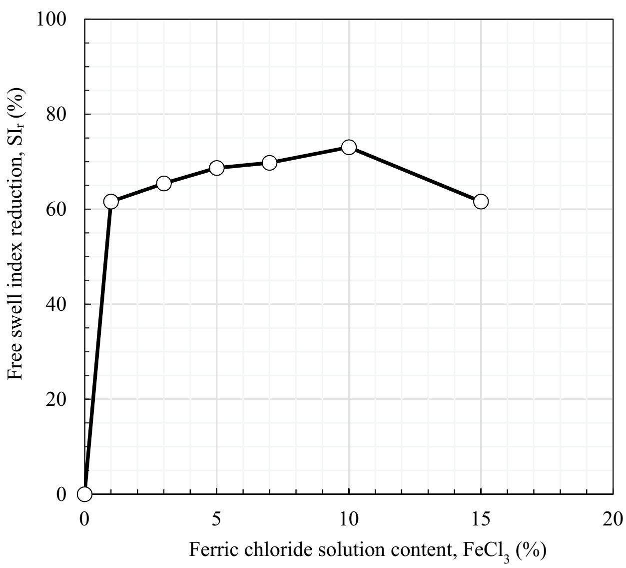

Fig. 6 The effect of adding ferric chloride soluion on the free swell index

a repulsion force between the positively charged particles is created leading to the expansion of the soil layers again. From this it can be concluded that, there is a point between these two states which is called iso-electric point where the concentration of ferric chloride solution becomes enough to neutralize the expansive soil.

Swelling Properties

(a) Free swell index:

The free swell index (SI) of the expansive soil decreases with the increase in ferric chloride solution content up to 10%. Then, the free swell index increases with increasing the ferric chloride solution till 15%. The reduction in the free swell index (SI_r) is the ratio between rate of decrease in the free swell index due to the usage of ferric chloride solution ($FeCl_3$) addition and the free swell index for the untreated soils. Figure 6 shows the effect of adding ferric chloride solution on the free swell index reduction of the expansive soil. This relationship can be expressed as:

$$\text{Free swell index reduction (\%)} = \frac{[\text{SI(untreated)} - \text{SI(treated)}]}{\text{SI (untreated)}}, \quad (3)$$

where SI is the free swell index of the expansive soil in (%).

From Fig. 6, it can be concluded that for 1%, 10% and 15% ferric chloride solution ($FeCl_3$), the free swell index decreased by about 62%, 73% and 62%, respectively, as compared to the untreated sample. The optimum content for $FeCl_3$ is 1% as increasing $FeCl_3$ content than that value, results in insignificant decrease in the free swell index. Therefore, treating the soil with only 1% $FeCl_3$ seems to be more economical compared to 10% $FeCl_3$ content. The swelling process after mixing the expansive soil with water can be related to the creation of the negatively charged colloidal particles and the repulsion occurring between these particles. With the addition of ferric chloride solution, the positively charged Fe^{3+} ions will be attracted to the negatively charged expansive soil particles and neutralize it at the so called iso-electric point. At that iso-electric point, attraction between the positively charged Fe^{3+} ions and the negatively charged expansive soil particles leads to reducing the expansive soil free swell index as the expansive soil affinity for moisture is reduced. This also leads to a more stable soil with smaller diffuse double layer. After the iso-electric point, the free swell index of the expansive soil increases again due to the increase in the amount of Fe^{3+} inside the mixture leading to creating a repulsion force between the positively charged particles. Therefore, the diffuse double layer thickness increases again and the expansive soil affinity for moisture increases.

(b) Swelling pressure:

The swelling pressure of the expansive soil treated with different percentages of ferric chloride solution was obtained using a standard one-dimensional Oedometer apparatus according to the ECP 202-part 5 [27]. The Oedometer test results for different ferric chloride solution contents are shown in Fig. 7. The gradual addition of ferric chloride solution ($FeCl_3$) to the expansive soil samples reduces the swelling pressure (Sp) of the expansive soil up to ferric chloride solution content of 10%. Then, the swelling pressure increases with the increase in ferric chloride solution up to 15%. Swelling pressure reduction (Sp_r) can be defined as the ratio between the rate of decrease in swelling pressure due to the usage of ferric chloride solution ($FeCl_3$) and the swelling pressure for untreated soil. Figure 8 shows the relationship between the reduction in swelling pressure of the expansive soil and the ferric chloride solution content added to the expansive soil. This relationship can be stated as follows:

$$\text{Swelling pressure reduction (\%)} = \frac{[\text{Sp(untreated)} - \text{Sp(treated)}]}{\text{Sp(untreated)}}, \quad (4)$$

where Sp is the swelling pressure in kPa.

For 1%, 10% and 15% ferric chloride solution ($FeCl_3$), the swelling pressure decreased by about 43%, 49% and 27%, respectively, as compared to the untreated sample. The optimum $FeCl_3$ content can be considered as 1% as mentioned earlier. This demonstrates that ferric chloride solution has a great effect on the potential severity of swelling, since it reduces the swelling pressure with a high degree at a very low percentage of ferric chloride solution.

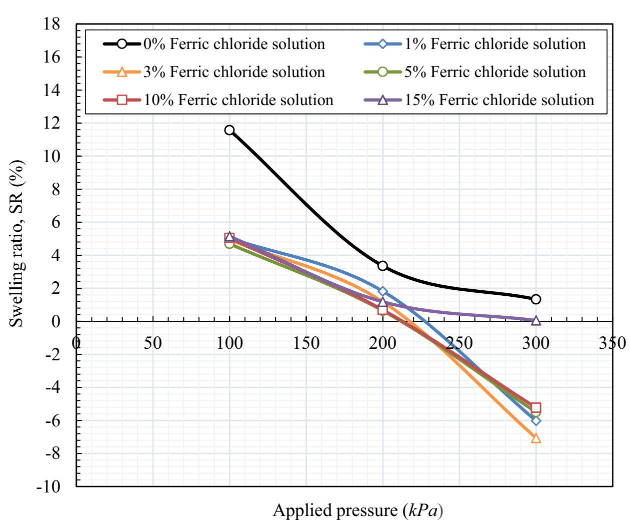

Fig. 7 Relationship between the swelling ratio and the applied loads in the Oedometer test

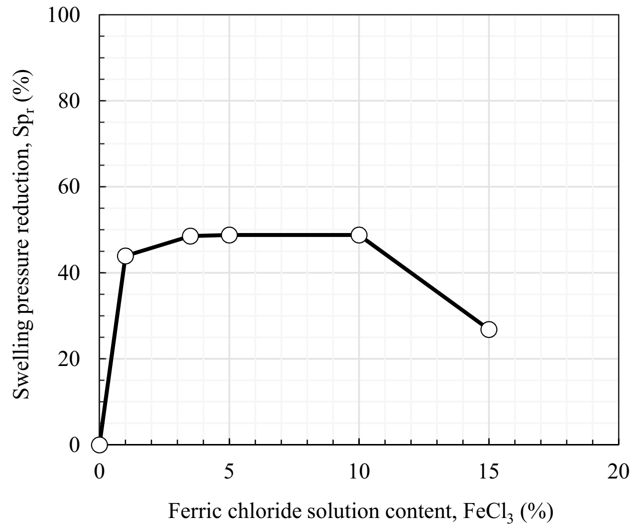

Fig. 8 The effect of adding ferric chloride soluion on the swelling pressure

Shear Strength

The cohesion and friction angle for the tested expansive soil are determined using linear Mohr–Coulomb failure envelop obtained from the direct shear test in both the unsoaked and the soaked states as shown in Table 2. As can be seen in this table for the unsoaked state, both the angle of internal friction and the undrained cohesion increase after adding ferric chloride solution. At 1% ferric chloride solution, the angle of internal friction and the undrained cohesion increased by 13% and 36%, respectively. After that, the angle of internal friction and the undrained cohesion decreased gradually with the increase in the ferric chloride solution as they reached 9% and 26% at 3% ferric chloride solution, respectively. As for the soaked state, the angle of internal friction and the cohesion initially increase with the increase of the content of ferric chloride solution and then gradually decrease. At 1% ferric chloride solution, the angle of internal friction and the undrained cohesion increased by 10% and 6%, respectively but at 3% ferric chloride solution, the angle of internal friction and the undrained cohesion increase is gradually reduced by 3%

Table 2 Shear strength parameters for ferric chloride solution–soil mixtures in both the unsoaked and the soaked states

	Unsoaked state			Soaked state		
$FeCl_3$ content (g/100 ml)	0	1	3	0	1	3
Cohesion, c_u (kPa)	9.9	13.5	12.5	21.3	22.5	21.4
$\frac{c\ \text{treated}}{c\ \text{untreated}}(\%)$	–	136.4	126.3	–	105.6	100.5
Friction angle, φ (°)	26.9	30.4	29.4	31.62	34.9	32.4
$\frac{\varphi\ \text{treated}}{\varphi\ \text{untreated}}(\%)$	–	112.8	109.2	–	110.3	102.6
Shear strength, τ (kPa) at 25 kN/m^2	22.9	28.1	26.6	36.7	39.9	37.2
$\frac{\tau\ \text{treated}}{\tau\ \text{untreated}}(\%)$	–	123.9	117.4	–	108.8	101.4
Shear strength, τ (kPa) at 50 kN/m^2	36.1	42.6	40.6	52.1	57.4	53
$\frac{\tau\ \text{treated}}{\tau\ \text{untreated}}(\%)$	–	120.4	114.8	–	110.1	101.7
Shear strength, τ (kPa) at 100 kN/m^2	62.2	71.7	68.8	82.9	92.2	84.6

and 0.5%, respectively. Subsequently, the shear strength was assessed as:

$$\tau = c_u + \sigma \tan(\varphi). \quad (5)$$

The values of the shear strength after treating the expansive soil with different percentages of ferric chloride solution are also given in Table 2. As can be seen in this table, at 1% ferric chloride solution, the soil shear strength increased by 24% in the unsoaked state and by 11% in the soaked state.

The increase in the values of the shear strength parameters initially confirms the hypothesis that the presence of Fe^{3+} neutralizes the negatively charged expansive soil. This eliminates the swelling activity of the expansive soil at the so called the iso-electric point. In this study, the iso-electric point is 1% ferric chloride solution as there is no much enhancement in the expansive soil characteristics from this point up to 10% of ferric chloride addition. After that (adding more than 10% $FeCl_3$), the volume of the mixture increases again because of the repulsion force between the positively charged ferric ions as discussed earlier.

Conclusions

In this study, ferric chloride solution was used to stabilize expansive soil. Free swell index, modified Proctor compaction, swelling pressure, consistency limits and direct shear tests were performed to investigate the swelling activity and shear strength characteristics of the stabilized expansive soil. The microstructure of the treated soil was also studied using X-ray diffraction analysis.

Some conclusion can be summarized as follows:

- The optimum percentage of ferric chloride solution used to treat expansive soils is found to be approximately 1%.
- The X-ray diffraction analysis for the soil treated with ferric chloride solution indicated that adding ferric chloride solution to the expansive soil transformed the soil from crystalline to amorphous material with no peaks and the smectite peak responsible for the swelling activity of soil disappeared.
- The free swell index and the swelling pressure of the expansive soil treated with ferric chloride solution decreased by 62% and 43%, respectively.
- At 1% and 15% ferric chloride solution, the plasticity index decreased by around 15% and 35%, respectively.
- Adding 1% ferric chloride solution to the expansive soil, increases its dry unit weight by about 2% and decreases its optimum moisture content by about 2%.
- The shear strength of the tested expansive soil was also enhanced by ferric chloride solution addition at its optimum percentage; for the unsoaked state, the angle of internal friction and the undrained cohesion increase by 13% and 36%, respectively. While, for the soaked state, the angle of internal friction and the undrained cohesion increased by 10% and 6%, respectively. Also, the Young's modulus value increased 1.3 times its value for the untreated soil sample at 3% ferric chloride solution in the soaked state.
- Finally, given all the above results, ferric chloride solution can be considered as an effective and economical, additive to improve the characteristics of swelling soils in arid environment.

Author Contributions MAS: principal investigator (P. I.), work coordinator, data analysis, paper writing curation, and final review. WRA: data curation and analysis, visualization, reviewing and editing. MAM: reviewing and editing. AFH: reviewing and editing the chemical analysis. HAG (corresponding Author): co-principal investigator (Co-P. I.), conceptualization, methodology, visualization, investigation, writing and editing.

Data Availability All data that support the findings of this study are available from the co-author upon request.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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