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Static and Dynamic Bahavior of Dry Saline Soil

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Abstract

In this paper, two samples of dry natural saline soil were studied and physical and chemical tests were conducted. The first sample was from Diyala Governorate, Al-Khalis District, and was taken at a depth of 1 meter. This sample had a sodium chloride salt concentration of 54%. The second sample was prepared in the soil laboratory at the College of Engineering, University of Diyala, by mixing the first sample in known weight ratios with clean, salt-free sand to obtain a second soil sample with a sodium chloride salt concentration of 32%. After that, the container in which the laboratory tests were carried out was prepared and made locally with dimensions of 50 cm × 50 cm × 55 cm and was painted yellow. The behavior of the two samples was studied under static and dynamic loading. Through the latter, we knew the dynamic response parameters, represented by speed, acceleration, displacement amplitude, and settlement, all with respect to time. It was found that the behavior of the soil with a sodium chloride salt concentration of 54% was much weaker compared to the behavior of the soil with a sodium chloride salt concentration of 32%. The weakness is represented by an approximate percentage of about 50%. In the static state, the bearing capacity decreased from (48 to 32) kilopascals for the two percentages of 32% and 54%, respectively. However, it was also found that increasing the salt content in the soil leads to increased vibration amplitude, decreased damping, and faster sedimentation, especially at frequencies of 15 Hz and 20 Hz. These effects are attributed to the weak internal structure of the salt bonds between soil particles, which weaken rapidly under cyclic loading. At the end of the study, it was found that reducing the salt content of the soil in the laboratory by mixing it with clean, dry sand in known weight ratios significantly improved the soil properties and dynamic behavior. The results of this study have contributed to a better understanding of the behavior of dry sabkha soils for the design of better and safer foundations in areas where saline soils predominate.

Keywords: Saline Soil, Dynamic loading, Vibration, Foundation settlement, Dry Condition

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1. Introduction

Saline soil (collapsible soil), locally called sabkha, is found in various regions around the world, such as South Africa, China, Iraq, Kuwait, and others. From a geotechnical perspective, sabkha soil poses a significant and potential hazard to structures or projects built on it once it becomes wet [1,2].

In its natural dry state, saline soil gives a strong impression of being a solid soil with high surface shear strength. When saturated, however, it exhibits the opposite; it is a collapsible soil with low shear strength [3]. Capillary pressure and soil heating improved the moisture content and, in some soils, increased the salinity of the water. For this reason, the water content is a key component of saline soils, and it increases the rate of accumulation of this type of salt when the water evaporates [4].

The molecular structure of soil changes as voids form between soil particles. This phenomenon involves the earth's ability to support structures and the reorganization of soil particles. The causes include sudden and unexpected sinking and an accelerated rate of shear strength loss in the soil, leading to structural problems for buildings and infrastructure. For standard buildings, raft foundations are recommended to prevent these problems, although they are costly [4]. The structural instability of saline soils and their sensitivity to deep hydration are among the main challenges they face. The concept of collapse upon wetting is characterized by the disintegration of salt bonds, leading to a sudden breakdown of grain cohesion and a rapid loss of strength in large, irregular deposits [1, 5, 6]. Abdel-Jawad and Al-Amoudi (1995) presented an original research study in this area, demonstrating that salt leaching damages cement bonds, leading to failure, increased permeability and penetration, and decreased durability. The study by Abdel-Gawad and Al-Amoudi provides a theoretical basis for explaining this behavior, as it parallels what happens in other collapsible soils.

Most engineering structures are subject to dynamic or cycling loads in addition to static loads due to traffic, vibrating machinery, or earthquakes [8, 9, 10]. The way the soil reacts to these loads is one of the most vital components of safe engineering design. The dynamic behavior of various soil types has been carefully investigated, and relationships between the loss of damping properties and the shear modulus during loading cycles have been established. Studies by Roy and

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Chaudhary on sandy soils challenged conventional theory by showing that conventional calculation methods could underestimate the damping ratio by 40% to 70% and by finding the reduction in damping ratio after a shear stress exceeds 1% [7]. Another study showed that most of the accumulated plastic deformation occurs within the first 100 loading cycles, along with other studies that focused on the accumulation of deformations [8]. Studies have shown a decrease in the dynamic strength and dynamic elastic modulus of soils with decreasing salt, moisture, and freeze-thaw cycles [9].

In fact, Wang et al. found a nonlinear relationship. Compared to non-saline soils, the dynamic strength of clayey soils increased at a low salt level of 1% (from 192 kPa to 213 kPa) and decreased significantly with increasing salt content by 3% and 5% (to 144 and 95 kPa, respectively) [10]. Soluble salts affect soil texture, structure, and elasticity; sodium salts cause soil dispersion, while calcium salts promote clumping and stability [11]. Highly saline soil means poor soil with low permeability, in addition to a significant impact on plant growth or even its complete absenc [12] . From an engineering perspective, many experimental studies have demonstrated and documented that soil with a high salt concentration is a soil with weak shear resistance and bearing capacity compared to soils that do not contain salts [13]. Sodium chloride, in particular, is a highly soluble salt that reduces the maximum density and CBR values [14].

2. Methodology

2.1 The soil used

A sample of naturally saline soil was collected at a depth of 1 meter below the ground surface in the Al-Khalis district of Diyala Governorate. A chemical test was conducted to determine the salt concentration, specifically the sodium chloride concentration, which is one of the most dangerous salts in soil due to its high solubility, which causes soil collapse. The sodium chloride concentration is 54%. The soil sample was air dried for several days and then sieved with a No. 4 sieve with a 4.75 mm aperture to remove coarse particles. In addition, a second sample was prepared by mixing the natural saline soil of the above-known percentage with sandy soil completely free of salts in known mixing proportions. A second sample was obtained with a salt percentage of 32% sodium chloride.

2.2 Characteristics of Soil

The term "natural saline soil" is given to the first soil sample with a natural saline concentration of 54%, while the term "sandy saline soil" is given to the second soil sample with a sandy saline concentration of 32%, considering that this concentration results from mixing sand completely free of salts. Table (1) show Chemical test for soil used. Table (2) shows the characteristics of natural saline soil and sandy saline soil.

Table 1 Chemical test for soil used

Soil Composition	**Value (%)**
Dissolved salts	70
Sodium chioride (NaCl)	54
Sulphate content	0.9
Gypsum content	0.7
Organic material	0.08
Chloride content	1.3
PH	8.1

Table 2 characteristics of natural saline soil and sandy saline soil

Standards	**For Percent salt 54%**	**For Percent salt 32%**	**Properties**
ASTM D 422 and ASTM D 2487 (2006)	0.17	0.077	Effective size, D10 (mm)
	0.52	0.28	D30 (mm)
	0.95	0.73	D50 (mm)
	1.3	1	D60 (mm)
	7	13	Coefficient of uniformity, Cu
	1.3	1	Coefficient of curvature, Cc
	SP	SP	Classification (USCS)
ASTM D 854 (2006)	2.71	2.67	Specific Gravity, Gs
ASTM D 3040-04(2006)	32º	35º	Angle of Internal Friction (Ø)
ASTM D 4253 - (2006)	16.9	17.6	γd (max.) (kN /m^3)
ASTM D 4254 - (2006)	13.7	15	γd (min.) (kN /m^3)
ASTM D 4254 - (2006)	0.93	0.82	Maximum void ratio, e_{max}
ASTM D 4254 - (2006)	0.62	0.53	Minimum void ratio, e_{min}
ASTM D 4254 - (2006)	15.5	16.27	γd (kN/m^3)Dry unit weight,
ASTM D 4254 – (2006)	50%	50%	Relative density, Dr.%

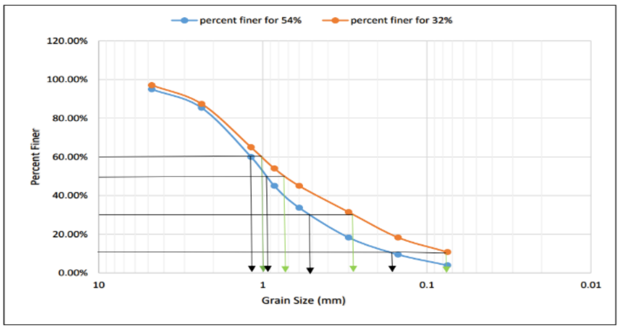

Fig 1 Curve for natural saline soil grain size distribution and sandy saline soil grain size distribution

2.3 Box model and steel frame

The steel model, it was 50 cm at length, 50 cm in width and 55 cm in height, was created locally. The overall thickness of the steel box plates is 4 mm. As shown in the Figure 2, a container of 143 cm in length and 67 cm in height is set inside the foot.

Fig 2 Steel model

2.4 Footing mode and vibration source

A mechanical oscillator provides the vibration source for vertical vibration measurement. The mechanical oscillator is set on a foundation measuring (100 × 100 × 4) mm. The mechanical oscillator's accelerating steel discs are 60 mm in diameter and 4 mm thick. A small eccentricity mass (me) is set on a disc that rotates with a rotational axis (an eccentricity) of (20) mm, shown in Figure 3. In this research, just one type of eccentric arrangement with a value of 55 grams.

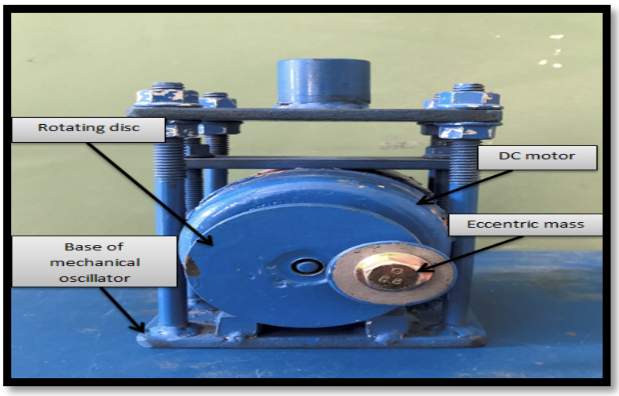

Fig 3 Vibration response evaluation device

2.5 Density Control

All layers of natural saline soil and sandy saline soil in the experiment share a constant relative density. Therefore, the rainwater technique is applied to prepare the soil. The rate of sand precipitation and the volume of runoff indicate the feasibility of producing soil in this test and the possibility of obtaining homogeneous soil deposits with the required density. At a drop height of 65 cm, the study requires a relative density of 50%. At a drop height of 65 cm, the testing container is filled in 10 cm layers, each 10 cm of the container's height. A lifting roller is used to raise the soil cone by 10 cm after the first layer is filled, in order to fill the second layer and maintain the drop height. As shown in Figure 4, this results in a relative density of 50%.

Fig 4 The raining technique

2.6 Instruments for Assessing Vibration Reaction

Experiments are conducted to determine the dynamic responsiveness of the Footing using vibration meters that measure acceleration, velocity, and displacement amplitude. It is connected to a single-channel, digital vibration meter (HG 6360) Model with an accuracy of 0.001-4.0 mm. It can be connected to a computer to view the dynamic response, depending on the preset function A vibration meter is used to Measure the vibration response, as shown in Figure 5.

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Fig 5 Vibration sensor devices and accessories are available

2.7 Limitations of the acceleration recording system

The oscilloscope used in this study provides operational acceleration readings during testing; however, it does not store a full, high-resolution acceleration record (raw waveform) in the instrument's base. The instrument records only discrete acceleration values at relatively large time intervals, preventing the reconstruction of the instantaneous sinusoidal input signal or the production of a frequency-field representation (fast Fourier transform spectrum) similar to the standard formats commonly used in robust motion databases, such as those of the United States Geological Survey (USGS). Despite this limitation, the excitation frequency was independently verified using a digital rotary tachometer (DT-2234C+), as shown in Figures 6 and 7, respectively, confirming that the applied load was perfectly harmonic at 10 Hz, 15 Hz, and 20 Hz. Therefore, the acceleration values presented in the results represent the operational input amplitudes associated with these controlled harmonic excitations.

Fig 6. Digital tachometer

Fig 7 Frequency of machine hacking

2.8 Prototype Testing Procedures

The tests are conducted under dry conditions and in two states: static and dynamic, according to the following steps:

1. To prevent wave reflection inside the container during the dynamic state, the container is lined internally with rubber. Four layers of saline soil are placed inside the container in both states, each layer weighing approximately 42.6 kg, for a total container weight of 170 kg, as in shown Figure 8.
2. The saline soil, with a relative density of 50%, considered medium density, is placed in the container using the rain technique as shown in Figure 4. The vertical distance between each layer is set at 65 cm.
3. A mechanical base is placed in the center of the container on the surface of the saline soil. A base fixed to the center of the weight carrier is used to place the dead loads on the machine's base. The motor weighs approximately five kilograms. In the static test, the procedure is the same as for the dynamic test; the only difference is that the motor is not running, and instead of using a LVDT as shown in Figure 8, a dial cage is used. This cage is fixed to the motor's surface, and the model is loaded with weights in eight stages of 10 kg each. The settlement is then calculated, and the failure criterion, according to (Terzaghi, 1943), is adopted as 10% of the base width, which equates to a failure criterion of 10 mm.
4. In the dynamic test, a vibration meter is used to measure settlement, displacement, velocity, and acceleration, and a digital speedometer is used to monitor the frequency. An electronic gauge is installed to measure the stability of the base.
5. The test begins as soon as the machine's base is positioned to rotate in the center of the container. The machine is run for thirty minutes, and readings, including displacement, acceleration, and velocity, are recorded every two minutes.
6. In the dynamic test, three frequencies (10, 15, and 20 Hz) are used. Static and dynamic tests are performed on two soil samples, totaling eight tests, which will be presented in the results section.

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Fig 8 The container with specimen, the steel footing model and the fixed LVDT

3. Results

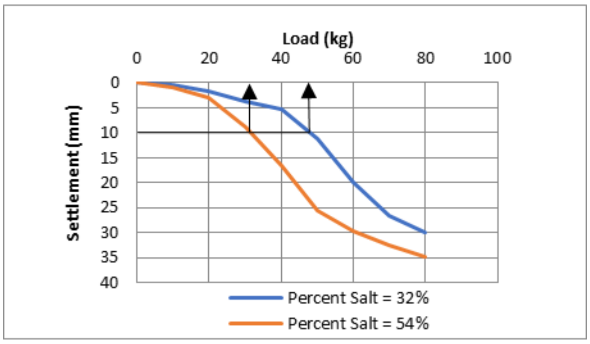


Fig 9. Relation between load and settlement for S-1 soil with salt NaCl= 54% and S-2 soil with salt NaCl=32% and with depth 0.4B in dry static load condition

S-1 (NaCl =32%) is Qult = 48 kg

S-2 (NaCl = 54%) is Qult = 32 kg

Foundation plate area: 10 × 10 cm (0.01 m²).

Table 3 Ultimate and Allowable Bearing Capacity for Soils with Different Salt Content (F.S = 2.5)

Salt Content (NaCl %)	Qult (kPa)	Qallowable (kPa)	Fallowable (N)	Equivalent Mass (kg)
32%	48	18.8	188	19
54%	32	12.8	128	13

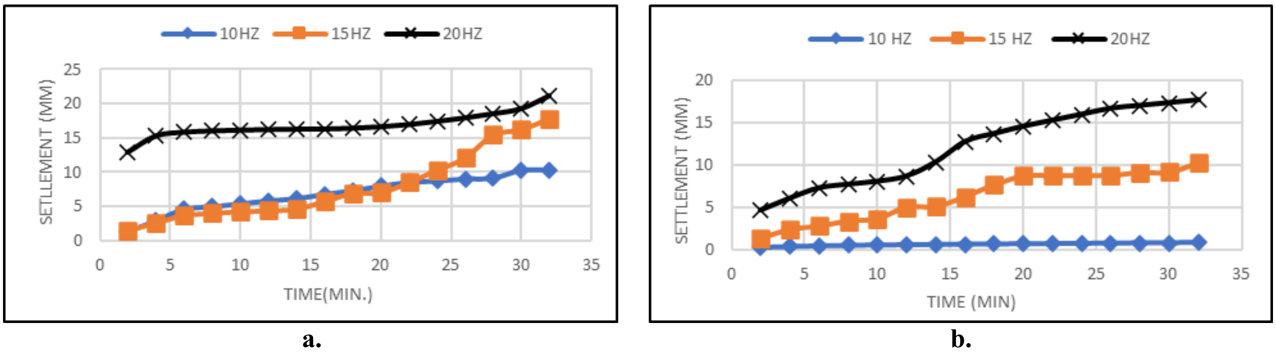


Fig 10 Relation between settlement with time for three frequencies values: a. with S-1 content salt NaCl= 54%. b. with S-2 content salt NaCl= 32%

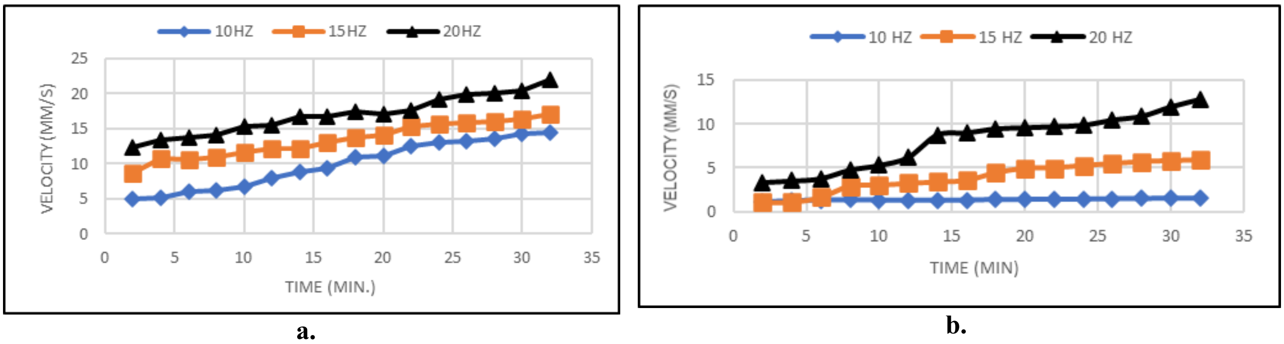
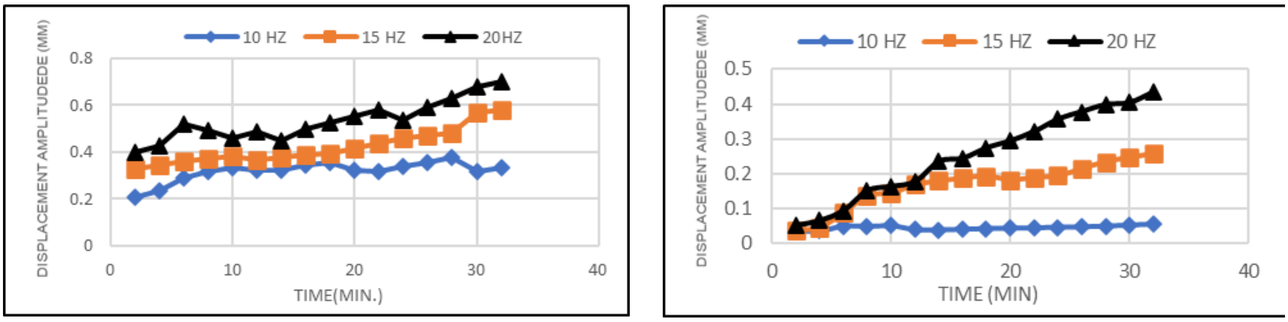


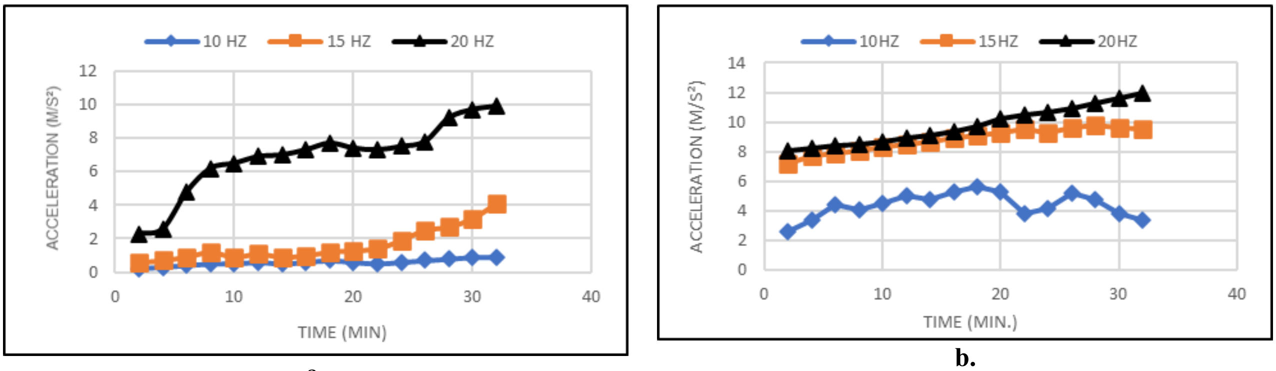
Fig 11 Relation between velocity variations with time for three frequencies values: a. with content salt NaCl= 54%.

b. with S-2 content salt NaCl= 32%



a. b.

Fig 12 Relation between displacement amplitude variations with time for three frequencies values: a. with S-1 content salt NaCl=54%. b. with S-2 content salt NaCl= 32%



a. b.

Fig 13 Relation between acceleration variations with time for three frequencies values: a. with S-1 content salt NaCl= 54%. b. with S-2 content salt NaCl= %32

4. Discussion

Laboratory results from tests of naturally occurring saline soils in their dry state at two different sodium chloride concentrations (54% and 32%, respectively) showed that the salt in the dry state imparts a false apparent strength to the soil. This strength collapses as soon as the soil is subjected to static or dynamic stress. The reason for this sudden collapse is attributed to the breakdown or disintegration of the salt bonds within the soil. Our laboratory tests also logically revealed that a decrease in the sodium chloride concentration improved the soil's behavior by approximately 50%.

4.1 Static Behavior

The results of laboratory tests on dry, natural saline soil in its static state are summarized in Table 3 and Figure 7. The bearing capacity of the saline soil decreased from 48 kPa to 32 kPa for sodium chloride concentrations of 54% and 32%, respectively. This decrease is attributed to the breakdown of salt bonds under shear stress, leading to a loss of elasticity, as observed in the results of researchers Elsawy, Lacourt, Alnuaim, et al. [1, 5]. Furthermore, the void content decreased from 0.93 to 0.82, and the specific gravity decreased from 15.5 to 16.27 kN/m³ for sodium chloride concentrations of 54% and 32%, respectively. Soil with a higher salt concentration has a lower compaction density, resulting in less strength and homogeneity under loads, unlike soil with a lower salt concentration.

4.2 Dynamic Behavior

The results of laboratory tests on dry, natural saline soil in the dynamic state are summarized in Figures 9, 10, 11, and 12. These figures show the relationships between displacement, velocity, acceleration, and settlement, all with respect to time. It was found that displacement, acceleration, and velocity were highest in saline soil with a sodium chloride concentration of 54%. This is attributed to the weakening and breakdown of salt bonds. Settlement occurred within approximately the first 12 minutes of dynamic loading, which is consistent with studies of Roy and Chaudhry [7] and Kay et al. [8] that showed soil settlement and deformation occur within the first 100 cycles of dynamic loading. Furthermore, we observed a non-linear relationship between salinity and dynamic loading Wang et al. [10]. Therefore, saline soil with a sodium chloride concentration of 32% is considered more cohesive, stable, and safer than saline soil with a sodium chloride concentration of 32%.

5. Conclusion

1. Under dynamic loading, soil with a sodium chloride concentration of 54% exhibits significantly greater velocity, acceleration, displacement, and settlement compared to soil with a sodium chloride concentration of 32%. This is because the salt forms bonds and possesses a

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fictitious strength that collapses upon exposure to any load, whether static or dynamic.

2. The bearing capacity of saline soil with a sodium chloride concentration of 54% in the static state is halved compared to soil with a sodium chloride concentration of 32%.

3. Most of the settlement occurs within the first 12 minutes of dynamic loading due to the breakdown of salt bonds, which act as cementitious bonds under normal conditions without any load.

4. In the static state, as shown in Table 3, the bearing capacity decreases with increasing soil salinity.

5. We can conclude that saline soil with a salt concentration of 32% is a stable and safe soil, and replacing saline soil with clean sand is a good treatment process to make it safer, more cohesive, and more stable.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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