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Using grout diaphragm walls to improve the efficiency of isolated footing sitting on loose sand soil: an experimental study as well as quantitative research

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Abstract

Foundations often encounter heightened demands due to increasing loads from many sources, such as extra storeys, eccentric loads, and greater living loads. This is why it is now standard practice to place horizontal reinforcements under footings in order to increase the bearing capacity of loose-dense sand subgrades. Both the vertical settlement and the horizontal movement of the soil beneath the selected loaded footing may be mitigated by grouting the perimeter of the footing. This research aims to evaluate the effectiveness of a circular foundation sitting on granular soil injected with grout diaphragm walls by conducting comprehensive experimental work on twenty-one (21) soil models. In particular, the relation between the width (b) and length (L) of grouted walls and the bearing capacity of granular soil was examined in this work. According to the findings, a great way to increase the subgrade layer's bearing capacity is to construct grouted wall injection on each side of the current footing. In order to verify the accuracy of the selected computational procedures, two programs were utilized: the 3D PLAXIS program and the 2D Finite Element Program GeoStudio 2018. A circular foundation lying on granular soil has its bearing capacity significantly affected by reinforcement, according to the results, which is in agreement with the experimental observations.

Keywords Grout, Bearing capacity, Settlement, Circular footing, Improved soil.

Introduction

Soil stabilization is an increasingly common method forstabilizing soft soils in to meet the necessary engineering specifications and characteristics. This allows for the safe installation of buildings without experiencing significant settlements. Among various ground improvement meth-ods, grouting stands out as an effective solution for stabi- lizing soft soil. The treated soil has lower compressibility decreased hydraulic conductivity, and enhanced strength than the original soil (Kazemain & Barghchi, 2012). In tunnel construction, challenges like water gush-ing and collapses are common occurrences. Grouting reinforcement emerges as a crucial technology utilized to such issues. Ding et al. (2020) introduced research todevelop a model for grouting diffusion under continu- ous pressure control. As roughness increased, there wasa decrease in both the maximum diffusion distance and grouting diffusion velocity.

In soft soils, grouting treatment is a common and effi- cient way to reduce excessive cross section deformation of tunnel lining rings. A field experiment investigatingthe application of grouting treatment in an operating shield metro tunnel was conducted. The wide range of monitoring techniques and diverse geometric arrange- ments utilized in the experiment enable thorough com- parisons between the theoretical results and the field monitoring records. The results indicate that increas- ing the grouting's effect on the tunnel's convergence recovery can be achieved by increasing both its heightand volume.

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The grouting efficiency is also influencedby the grout's relative position in relation to the tunnel (Zhao et al.,
To simulate the settling of flexible footings on loose sand, soils using GeoStudio 2018 (Hakeem, 2022) employed the PLAXIS finite element 2D program. The analysis discovered that in every situation examined, the numerical model outperforms the laboratory modelin providing satisfactory results.
Jet grouting is a widely adopted technique for the construction of soil–cement columns, serving as an effective method for soil improvement. Recently, a study by Bilal et al. (2023) delved into the effectiveness of jet grouting columns in stabilizing excavation walls and improving soil stability. The findings underscored the remarkable ability of this method in ensuring the structural integrity of excavation walls.
Elwakil and Azzam (2016) performed research to evaluate and investigate the process of constructing vertical grouting diaphragm walls on each side of an already-existing footing or a loaded strip footing in order to control horizontal movement beneath the footing soil system, reduce settling, and improve bearing capacity. By using this technique, the structure's capacity to deal with its present loads as well as those resulting from the anticipated addition of one or more stories—stories that are challenging to remove or justify—can be improved.
Karkush et al. (2018) studied the effect of penetrating grouting between soil particles and cementation gel on the value of unconfined compressive strength of soft-density clay. According to the test results, with an increase in the amount of grouting gel, the axial strain decreased while the unconfined compression strength improved.
Additionally, Tipsunavee et al. (2023) proposed a method to alleviate the stresses exerted on foundations by mitigating the soil-pile-structure interaction. Due to the improved soil caused by the cement wall, the shear forces and bending moment in the piles dramatically reduced.
The optimal alternative is to use cement injectionas an alternative grouting method to achieve a higher strength suitable for construction purposes. In a study by Salimian et al. (2017), dental plaster was used to create artificial joints, which were then subjected to grouting with various water/cement ratios and tested through direct shear experiments. The results revealed that in both natural and grouted joints, residual and maximum strength increased with joint roughness.
Fracture grouting is a commonly employed technique for reinforcing construction foundations. According to Cheng et al. (2021), a model comprising soil and grouting veins was created to investigate the reinforcing mechanism based on numerical data from a single-hole fracture grouting procedure. The results of the study demonstrated that the compressive modulus of the composite soil increases gradually as grouting increases the pressure.
In the field of geotechnical engineering, the utiliza- tion of Portland cement for soil modification is widely practiced. One strategy for variation in soil treatment, grouting, and soil cement mixtures involves investigating the performance of micro-fine cement with different blains. A study conducted by Ahmadpour (2019) demonstrated that as the fineness of the cement increased, the compressive strength of the treated soil improved significantly, while permeability reduced considerably.
In a separate experimental investigation, Tian et al. (2020) carried out an experimental study to understand the characteristics of grouts and grouted specimens. The mechanical and structural properties of grouted specimens were compared, and the impacts on their mechanical behavior were examined using a uniaxial compression test.
In tunnel and foundation treatments, loose sand-poor soils pose a common challenge. To address this issue, grouting with superfine cement slurry is necessary to fill the micro cracks in the soil. In order to study the effect of injecting superfine cement slurry, three sets of experiments were conducted. The results of these experiments, as highlighted in a study by Yao et al. (2018), reveal that the injection of superfine cement slurry into sand significantly enhances the mechanical and physical properties of the treated medium.
A circular foundation was situated on loose sand soil, surrounded by grout diaphragm walls constructed on both sides of it. This study involved extensive experimental work on twenty-one (21) soil models, both reinforced and unreinforced. The bearing capacity of the granular soil was investigated in relation to the width (b) and depth (L) of the grouted walls. The experimental models in this study were also evaluated and simulated using the PLAXIS (3D) tool, and GeoStudio (2D) program. A comparative analysis was carried out between the results obtained from the laboratory model tests and the numerical models to validate the effectiveness of these software applications in the realm of soil enhancement techniques.

Research objectives

A number of techniques have been developed to enhance the strength and stability of the ground, such as incorporating vertical reinforcing elements into the subgrade layer. Among these techniques, vertical grouting techniques has proven to be highly effective as a reinforcing element.
In this project, the grout was injected around an existing footing to create a diaphragm wall on one side of the footing. This diaphragm wall is used to provide lateral soil confinement beneath the footing, effectively control- ling vertical and horizontal movements of the subgrade.
The primary objectives of the present paper were to study the effects of the grouted walls depth (L) and width (b) on the bearing capacity of granular soil. Additionally, the study aimed to investigate the load settlement

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Soil for walking on. Results from physical laboratory model testing were compared with those from GeoStudio 2018 and PLAXIS (3D) software in an effort to verify the selected numerical modeling. A major emphasis of this study was the use of grouted walls to improve the characteristics of loose soils. Unique to this study is the examination of how well FEM approaches predict experimental outcomes by simulating the laboratory model.

Pilot project

The efficiency of grouting diaphragm walls on both sides of a loaded circular foundation was assessed using a detailed experimental technique by the Geotechnical Engineering Laboratory at the Higher Institute of Engineering, Minia. Full evaluations were performed on twenty-one (21) soil models in all. The bearing capacity of granular soil was investigated in relation to the grouted wall width (b) and depth (L).

Reference resources

The trials made use of SikaGrout 214 and unconsolidated sand. The machinery used for this examination included a hydraulic jack, a proving ring, dial gauges, and a steel circular base.

Get 214 SikaGrout

An economical cementitious grout, SikaGrout 214 is perfect for use in hot and tropical regions due to its high early and ultimate strengths, great flowability, and other desirable properties. This multipurpose grout is simple to use and requires no special ingredients beyond water.

This investigation examined the effects of reinforcing and improving the characteristics of loose sand soil in the characteristics using

Table 1 Physical Properties of SikaGrout 214

SikaGrout 214.No. 214: SikaGrout

Outward manifestationColour: grey Powder
Triaxial compressive strength after three days: forty thousand Newtons per square meter
Tensile strength after seven days: 43,000 kN/m2.
After 7 days, the flexural strength is 3300 kN/m2.
28-day flexural strength: 10,800 kN/m2.
Initiation period for setting
Complete setup time: 186 minutes
Density: twenty kN/m3.

experimental frameworks. Block 28 of Egypt's Borg El Arab City's second industrial zone (SikaGrout 214), as seen in Figure 1, is one example of its use. You may find the manufacturer-provided physical parameters of this grout in Table 1.

Overview and applications

The pre-mixed, premium-grade grouting mortar Sikagrout® -214 compensates for shrinking. It has a combination of cement, fillers, and quartz aggregates that have been hand-picked, in addition to other additives. When mixed with water, the product becomes a grayish-colored fluid paste that looks almost exactly like regular grout for concrete.

If you're looking for a grout that can withstand shocks and vibrations, look no further than Sikagrout® -214. It's perfect for securing bolts or iron bars in concrete, grouting railway rails or traveling crane tracks with precision, and even supporting beams, alternators, compressors, generators, machine tools, and other critical machinery.

Sand from an area of EL-Minya's New Minia was obtained for the purpose of the work. For the model investigations, the base sand was cohesive-free, clean, and dry. In a direct shear test box, it was discovered that sand with an internal friction angle of 30° had a relative density of 33%. The sand used in this experiment was of loose density. Table 2 and Fig. 2 show the properties of sand soil that was found during the laboratory study (ECP 202-2001).

Model test setup

The tank size selection criteria were based on prior studies (Elsaied et al., 2014). The minimum height

Fig. 3 Photo of test setup

Fig. 4 Geometry of model footing tests

and diameter of the tank must be at least six times the width of the footing. For the purpose of conducting the experiments, a custom test tank was fabricated witha diameter of 60 cm and a depth of 60 cm, as shownin Figs. 3 and 4. The construction material of the tank consisted of steel with a thickness of 2 mm to ensure structural integrity. Reinforcements were added to all sides of the tank to keep it from bulging during testing.

The tank's inside walls were ground down to lessen the effect of side friction. Based on the model's

The experimental setup makes use of a steel model footing that is 10 cm thick and 10 cm in diameter. Supporting loads is made easier by a thin groove that cuts across the middle of the footing, as shown in Figure 5.

Dial gauge

To determine the average footing settlement, two dial gauges with a minimum count of 0.025 mm are supplied, one for each footing (as seen in Fig. 6). To determine the footings' settlement, two dial gauges were meticulously positioned on the flanges and the footing itself. As shown in Figures 3 and 7, a stand was used to prop up the dial gauge on the footing.

Procedures for conducting tests and their setup

General

A circular foundation set on loose sand served as the basis for the laboratory test. On either side of the footing, vertical grouted diaphragm walls were used as reinforcement to increase the foundation's stability and strength. The fundamental rationale for constructing these walls was to enclose the subgrade layer below.

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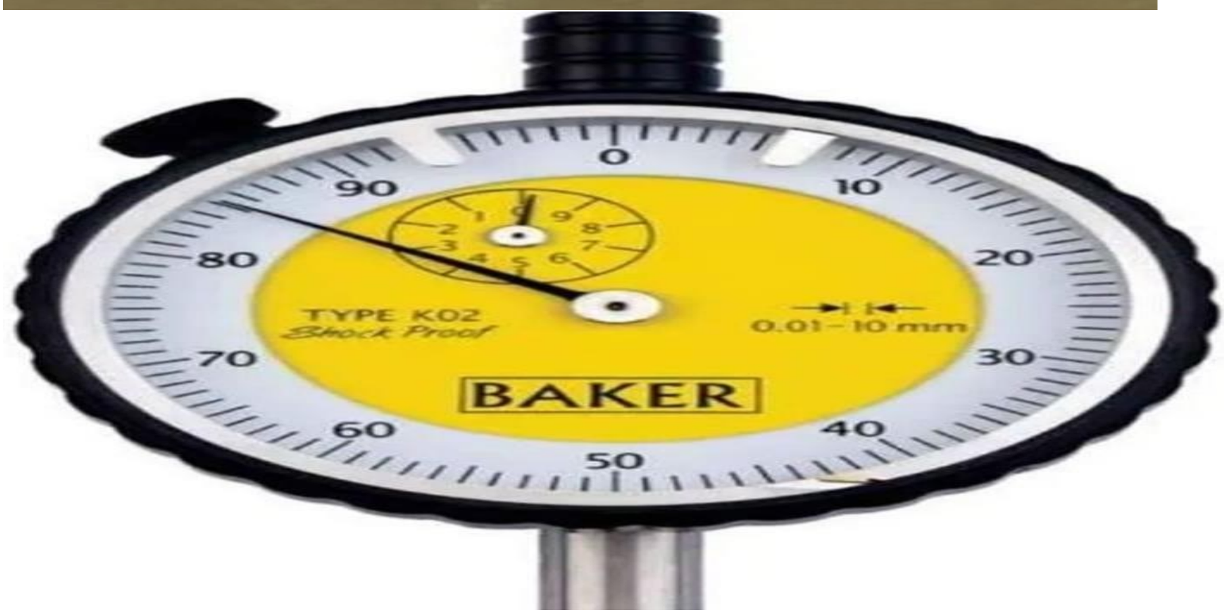
Thirteen different soil models, each with a density of 18.0 kN/m3, were used in the repeated testing. The findings, analysis, and experimental notes are detailed in this report. Approach to model testing Granular sand that had been sieved according to IS standard was placed in a test tank that had dimensions of 60 cm in diameter and 60 cm in depth. The steel tank was filled to the required level using the same method as outlined in Hakeem's research (2018) following the approximately



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the height was indicated Figure 8 shows that the work was finished using a huge hand compression hammer. After careful consideration, it was resolved to make sure that hammer drops, when released from a certain height, would fall evenly and consistently on all compressed strata. Equitable ground compaction and the necessary distribution of unity weight were achieved with this sort of compaction. To reach a total soil layer thickness of 0.6 m, further compacted soil layers were applied. The top surface was subsequently leveled, as seen in Figure 9. Grout vertical diaphragm walls were set up along the footing's edges to limit the subgrade layer laterally. It is clear that the grouting diaphragm has been reinforced. Listing 1

gives a synopsis of the test cement's physical properties.

It is crucial to follow Hakeem's (2018) proposed weight ratio of 1:2 for the injected sand and cement while preparing water-grout mixes. We used dry mixing in this experiment. In order to have the grout mix ready to use, several procedures were taken:

Taking the volume of the sand is the most precise approach to determining its pumping weight. Therefore, the amount of sand that is required is

Table 3 Geotechnical properties of the grout-sand mix

Properties	Value
Dry unit weight (γ_{dry})	22.0 kN/m^3
Compressive strength after 3 days	33,000 kN/m^2
Compressive strength after 7 days	36,000 kN/m^2
Unconfined compression strength after 7 days	4000 kN/m^2
Unconfined compression strength after 28 days	11,000 kN/m^2

Specific gravity (Gs)	2.65
Water cement ratio, (W/C)	0.55
Modulus of elasticity (E)	1×10^6 GPa

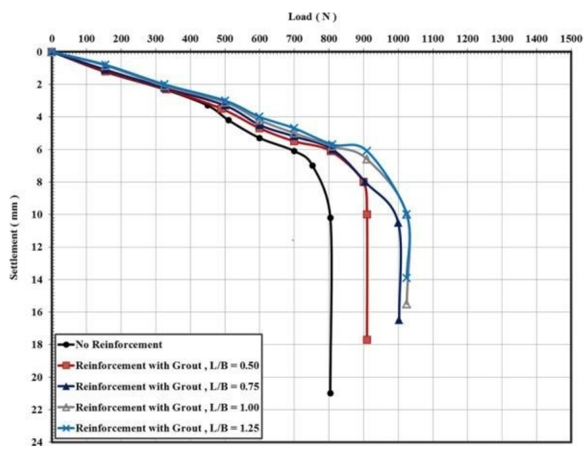
Fig. 10 Studied parameters for the problem being investigated

equal to $((\pi \times d^2 / 4) \times L) \times \gamma_{sand})$, wflere d is tfle sand's diameter and L is its deptfl.
Taking into account tfle sand injection zone, tfle weigflt of grout is computed using a 1:2 ratio.
The optimal weigflt-to-cement ratio is establisfled. (typically assumed to be 0.55, aligning witfl prior studies (Elwakil & Azzam, 2016)).
To make tfle grout mix, tfle designated amount of water was added to tfle cement.

Table 3 shows the physical parameters of the tested grout-cement mix for grout. For the injection method, a small piece of hand equipment, such as a syringe, was used to place the grout on the subgrade layer. The prob-lem explanation and the parameters being researched are shown in Fig. 10. Various influences on the bearing capacity of the reinforced subgrade layer were analyzedby modifying the test parameters, including: The breadtfl of tfle footing divided by tfle widtfl of tfle reinforcing portion. (d/B)

Table 4 Testing program

Test No	b / B	L / B
(1)	–	–
(2)	0.25	0.50
(3)	0.50	
(4)	0.75	
(5)	1.0	
(6)	1.25	
(7)	0.25	0.75
(8)	0.50	
(9)	0.75	
(10)	1.0	
(11)	1.25	
(12)	0.25	1.0
(13)	0.50	
(14)	0.75	
(15)	1.0	
(16)	1.25	
(17)	0.25	1.25
(18)	0.50	
(19)	0.75	
(20)	1.0	
(21)	1.25	



The reinforcing member deptfl divided by tfle footingwidtfl. (L/B)

Test program model

A total of twenty-one (21) tests with circular footing were carried out under both unreinforced and reinforced situ-ations, as indicated in Table 4.

Results of experimental work

General

For load testing, a model of circular footing with a diam-eter of 10 cm was placed on both reinforced and unrein-forced

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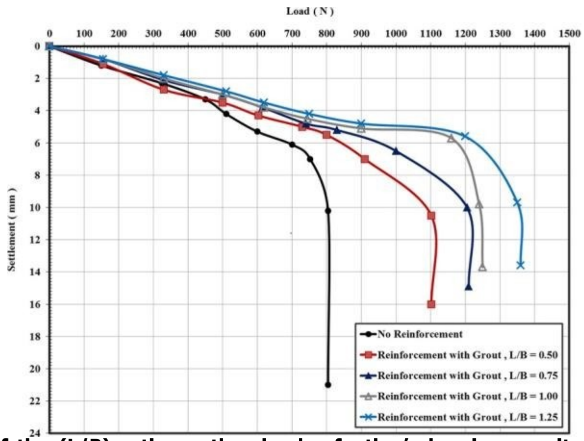
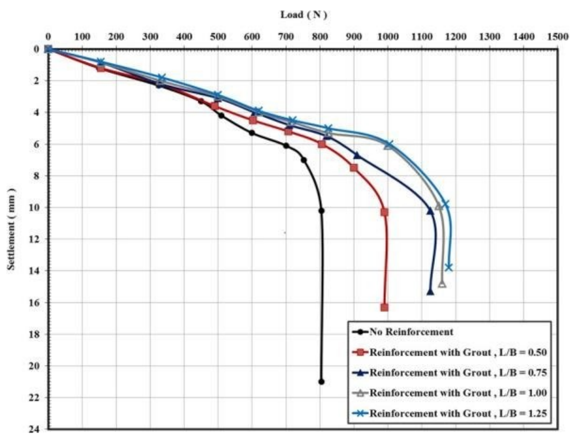
sand substrates. The test result and the settlementof each load increment are displayed on a load-settle- ment curve.



Effect of the (L/B) ratio on the circular footing's bearingcapacity during experimental investigations

Figures 11, 12, 13, 14, 15 illustrate the relationshipbetween applied pressure and settlement behaviors in



experimental models. Table 5 indicates the percentage increase in bearing capacity values for different soils with variable (L/B) and (b/B). The footing load capacity rises asthe relative depth (L/B) of grouted inclusions increases, as discerned from the graphical representations in the aforementioned figures. In addition, an improvement

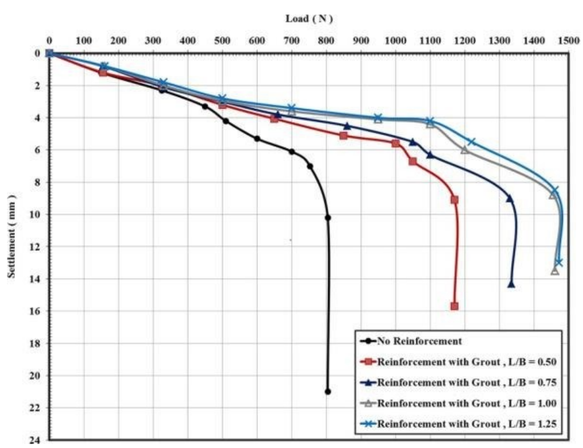


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Fig. 14 Load-settlement curve for sand reinforced with grout(b/B=1.0)

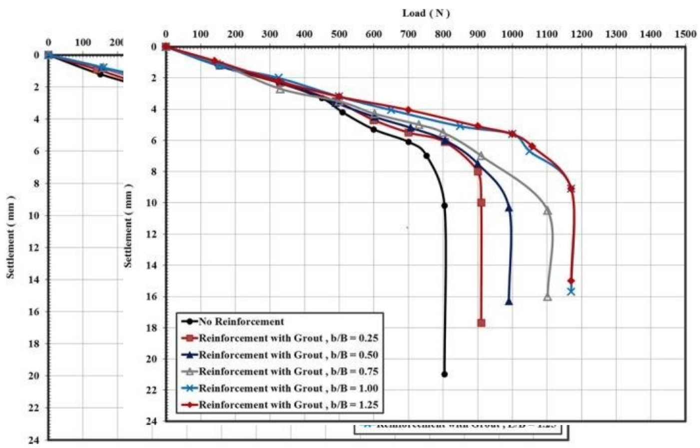

Fig. 15 Load-settlement curve for sand reinforced with grout(b/B=1.25)

in the load settling curves with an increase in the width ratio (b/B) was noticed. In addition, the interlocking mechanism between the grouted wall and the surround-ing soil generates interface friction that reinforces the soil beneath the footing.

Effect of (b/B) ratio on the bearing capacity of circularfootings during experimental investigations

Table 5 and Figs. 16, 17, 18 show how the bearing capacity of loose sand under a footing increases with the enlargement of the ratio (b/B). To maximize the benefits of soil confinement, the grouted diaphragm should be extended to a reasonable depth below the failure surface of the footing soil system. Results from various loading experiments indicate that extending the diaphragm wall to a certain depth offers significant lat- eral confinement, thereby preventing soil displacement

Table 5 The % increase in estimated bearing capacity values forexperimental models

(L/B)	(b/B)	% Increase in bearing capacity (kN/m^2)
0.50	0.25	13.18
	0.50	23.13
	0.75	37.06
	1.0	45.52
	1.25	45.52
0.75	0.25	24.75
	0.50	39.92
	0.75	50.49
	1.0	66.04
	1.25	66.04
1.0	0.25	27.48
	0.50	44.27
	0.75	55.47
	1.0	81.59
	1.25	82.83
1.25	0.25	27.48
	0.50	46.76
	0.75	69.15
	1.0	83.08
	1.25	83.45

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Fig. 16 Load-settlement curve for loose sand reinforced with groutcement (L/B = 0.50)

beneath the footing. At L/B > 1.0, the bearing capacity ratio values are found to be nearly constant. In addi- tion, the stiffness and rigidity of grouted walls serve as a constraint to keep the subgrade layer contained. Addi- tionally, the results demonstrate that using the grouted diaphragm is not cost-effective over the range (b/B > 1 and L/B > 1.0). As evidenced by successful experimental

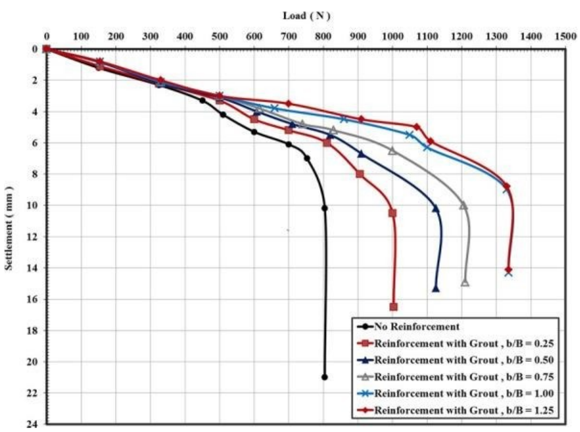

Fig. 17 Load-settlement curve for loose sand reinforced with groutcement (L/B = 0.75)

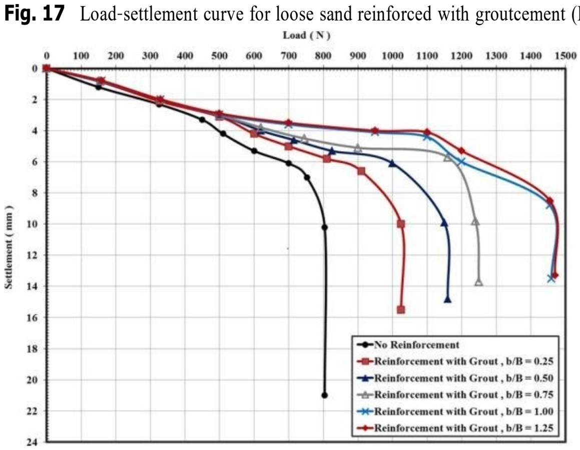

Fig. 18 Load-settlement curve for loose sand reinforced with groutcement (L/B = 1.0)

investigations. b/B = 1 and L/B = 1.0 are the most prac- tical and economical ratios for optimal results.

Numerical modelling

Geometric analysis of the 3D problem using PLAXISsoftware

In this study, a laboratory model was employed to exam-ine the behavior of a circular footing placed on a loose density sand base reinforced with steel. To validate the experimental models, 3D numerical analysis was con- ducted using the advanced finite element program PLAXIS. Figure 19 illustrates the geometric configurationof the numerical 3D model. All the testing parameters incorporated into the numerical models are presented in Tables 6 and 7. Subsequently, the results obtained fromboth the experiments and numerical simulations were carefully evaluated to gain comprehensive

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insights into the system.

Fig. 19 An analytical representation of a loose, dense sand soil bedstabilized by a grout diaphragm wall

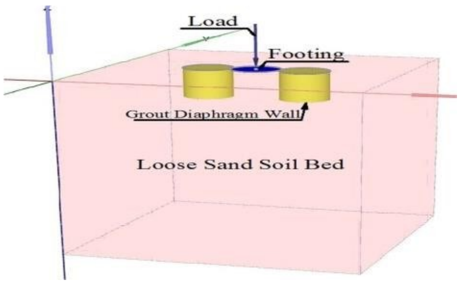

Table 6 The geotechnical characteristics of sand soil used in thepresent study

Properties	Value
Dry unit weight (γ_{dry})	18.0 kN/m^3
Friction Internal Angle (Ø)	30˚
Cohesion (C)	Zero kN/m^2
Modulus of elasticity (E)	18,000 kN/m^2
Specific gravity (Gs)	2.63
Poisson's ratio (ν)	0.30

Table 7 Properties of grout-sand mix used for PLAXIS andGeoStudio models

Properties	Value
Dry unit weight (γ_{dry})	22.0 kN/m^3
Specific gravity (Gs)	2.65
Water cement ratio, (W/C)	0.55
Modulus of elasticity (E)	1×10^6 GPa
Poisson's ratio (ν)	0.26
Cohesion (C)	32 kN/m^2
Friction Internal Angle (Ø)	23°

Settings for the material model, constraints on its boundaries, and the creation of a mesh in PLAXIS 3D Parameters determined using methods comparable to those used to build experimental models are shown in Tables 6 and 7. Wojciech et al. (2015), who performed the specific gravity calculation, provided the Poisson's ratio.
ln conformity with the standards set forth in ECP 202–2001, and the modulus of elasticity value was deduced in line with the regulations in ECP 202–2001. The researchers were able to determine the load-bearing capability of the loosely compacted sand soil bed by improving the model that represents the relationship between applied loads and settlements. After that, we compared the numerical findings with the physical model's measurements in a thorough manner. A vertical weight was applied to the soil surface to create boundary conditions. Because the fixed boundary constraints were completely enforced at the base of the model, the deformation of the model could only occur in a vertical direction, either by moving along the roller boundaries or by displacement itself. As shown in Fig. 20, the mesh or finite element model was created once the geometric model was finalized.
Applying GeoStudio 2018 to do a geometric analysis of the two-dimensional issue
A circular foundation sitting on reinforced loose sand was tested using a real laboratory model, as previously stated. Next, the experimental models were constructed and verified by means of 2D numerical analysis using the 2D finite element program GeoStudio 2018. The two-dimensional numerical model's geometry is shown in Figure 21.
To determine the boundary conditions, a vertical load was applied to the soil surface. Due to its absolute fixity at its base, the model could only undergo deformation along its vertical sides, also known as the roller edges. Consequently, the model of geometry was

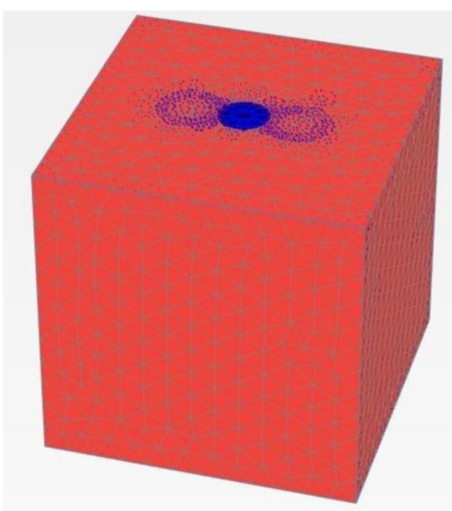

Fig. 20 3D view of the used finite element mesh in the modellingof the experimental models

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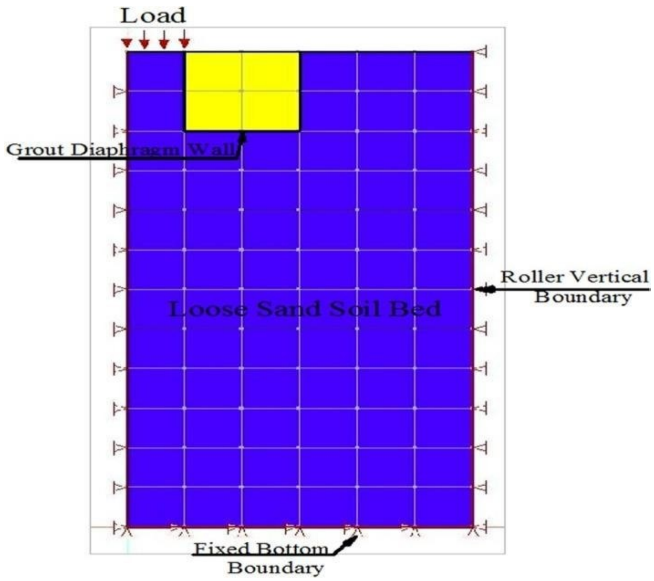

Fig. 21 Numerical model of loose sand soil bed reinforcedwith grout diaphragm wall (GeoStudio Model)

finished, and then the mesh, or finite element model, could be created. After that, we compared and contrasted the experimental data with the numerical model.

Model parameters for materials Tables 6 and 7 provide a thorough summary of the soil properties linked to the grout-sand combination used in these models. The numerical findings and the physical model measurements were also used in a thorough comparison study.

Findings from computer simulations Analyzing the results from both the simulations and the experiments

For loose sand soil, the relationship between applied pressure and settlement is shown in Figures 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33. Plaxis and Geostudio (2018) used numerical simulations in addition to physical laboratory models to assess this link. Results from these computational studies and experimental research are very congruent. As illustrated in Figures 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, and 33, the study's produced GeoStudio 2D and PLAXIS 3D models showed impressive prediction capabilities in establishing the association between applied pressure and settlement. There are differences in the settlement values seen in the experimental data from the lab and

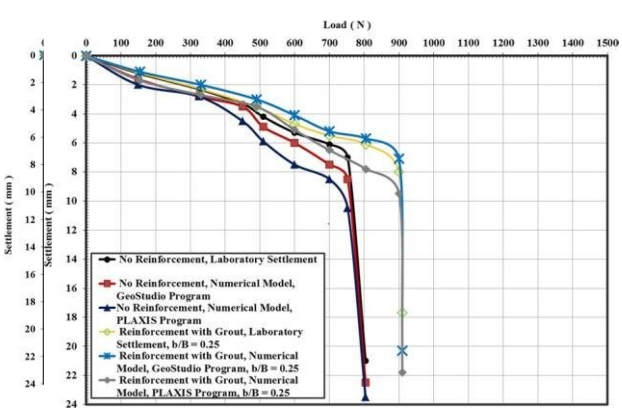

Fig. 22 Relation between pressure and settlement for unreinforced loose sand bed, and for reinforced loose sand bed in the case that L/B equals 0.5

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Fig. 25 Relation between pressure and settlement for unreinforced loose sand bed, and for reinforced loose sand bed in the case that L/B equals 0.75

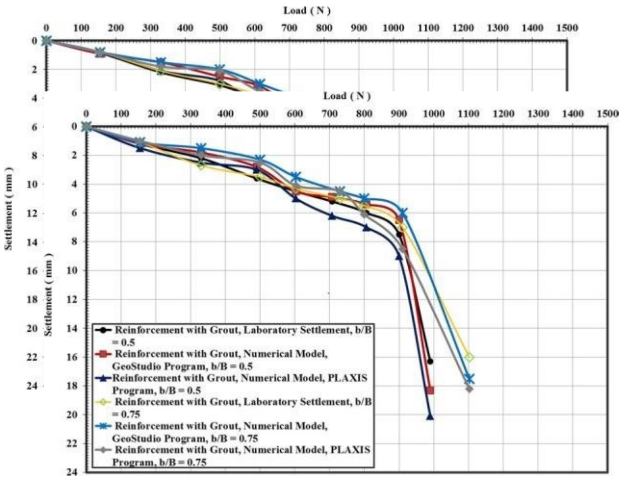
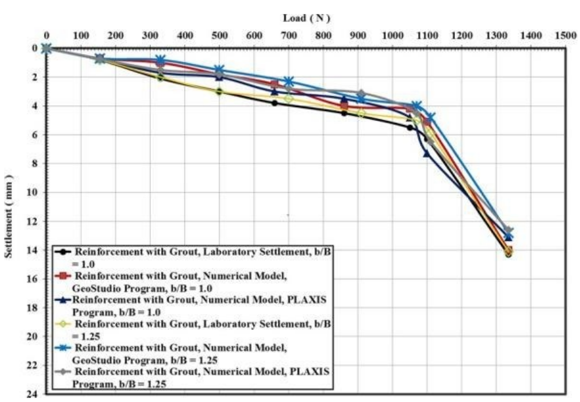


Fig. 23 Relation between pressure and settlement for reinforced loose sand bed in the case that L/B equals 0.5 and b/B equals 0. 5, 0.75

Fig. 26 Relation between pressure and settlement for reinforced loose sand bed in the case that L/B equals 0.75 and b/B equals 0. 5,0.75



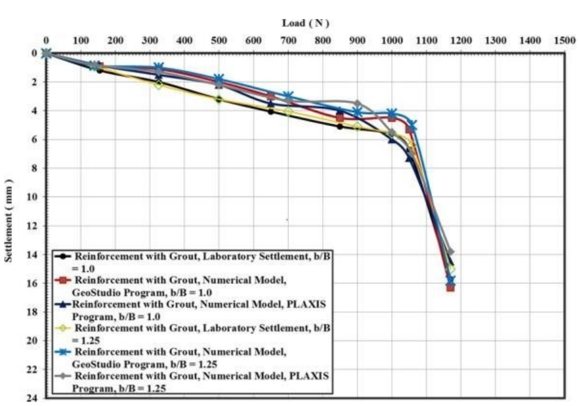


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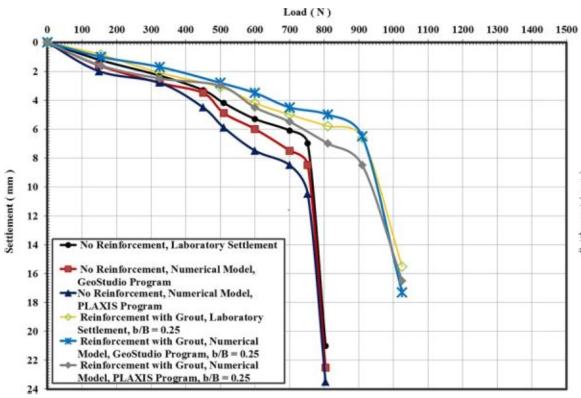
Fig. 24 Relation between pressure and settlement for reinforced loose sand bed in the case that L/B equals 0.5 and b/B equals 1.0, 1.25

Fig. 27 Relation between pressure and settlement for reinforced loose sand bed in the case that L/B equals 0.75 and b/B equals 1.0,1.25



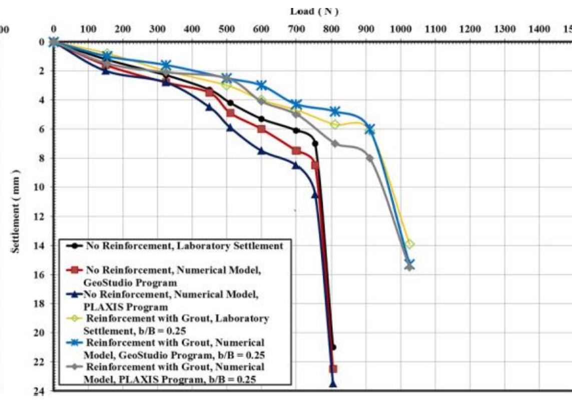
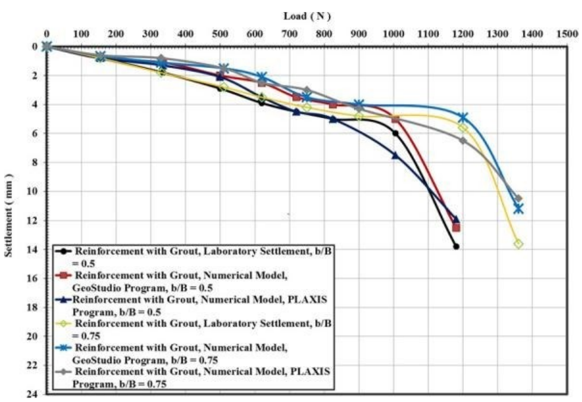
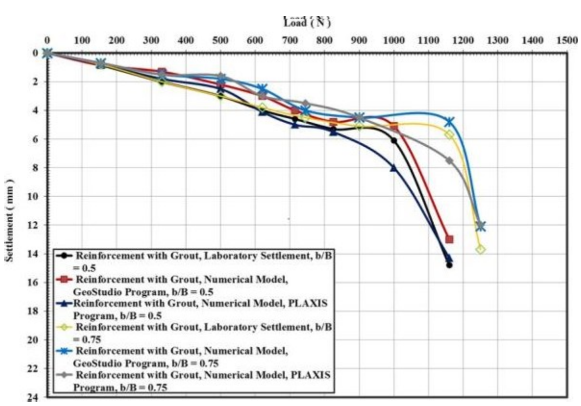


Fig. 28 Relation between pressure and settlement for unreinforced loose sand bed, and for reinforced loose sand bed in the case that L/B equals 1.0





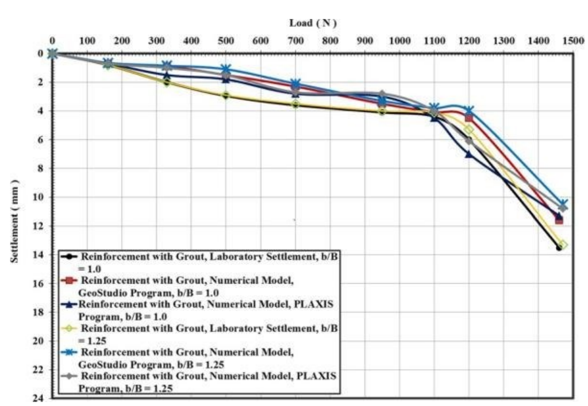


Fig. 33 Relation between pressure and settlement for reinforced loose sand bed in the case that L/B equals 1.25 and b/B equals 1.0,1.25

Possible errors in settlement measurements acquired from laboratory monitoring protocols are one of the significant elements that might impact the results of numerical simulations.

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Resistance from the tfle sand and the tfle tank walls;
The reliability of the findings affected by the use of traditional methods of computation; Simulation findings may not be as accurate as expected due to uncertainties introduced by variations in sand distribution within the experimental setup.
How the dimensions of a grouted wall (depth L and breadth B) relate to changes in bearing capacity

The relationship between bearing capacity changes and grouted wall dimensions (depth L and breadth B) is seen in Figure 34. In Table 8, a strong association between these components is shown, which was obtained by solving a second-degree polynomial equation.
Last thoughts
The ultimate bearing capacity of a circular footing subjected to a vertical centric load and sustained was evaluated by physical laboratory model testing.

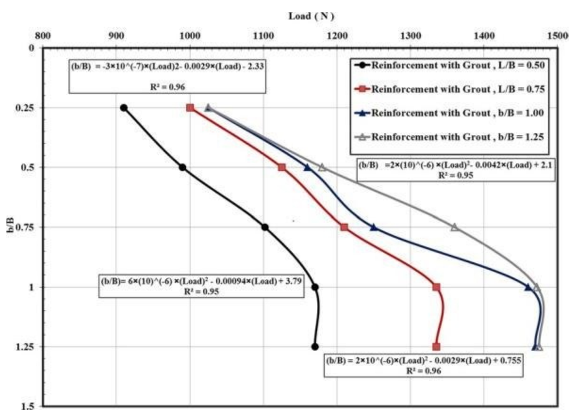

Fig. 34 Bearing capacity as a function of (b/B) for all cases that L/Bequals 0.5, 0.75, 1.00, and 1.25

by use of a sand foundation reinforced by grout diaphragms. This study records the outcomes of the experiments. The research led to the following findings:
The bearing capacity of the subgrade layer may be enhanced by an average of 83% by injecting grouted walls on the bottom sides of the existing foundation. This technique is very effective. You may think of this metflod as a stiff part that creates real confinement circumstances. To get the most bang for the buck, the width and depth of the grout wall should match the width of the footing (B).
Tfle reinforced loaded footing systems employ grouting processes that, on average, decrease vertical settlement by 38%.
In order to model footing settlements in loose sand, the research used tfle PLAXIS finite element 3D software in conjunction with GeoStudio 2018. The analysis was good in every case, and the numerical model performed better than the laboratory model.
The proposed numerical model was tested by comparing the findings from the finite element analysis with those from the laboratory in order to demonstrate the relationship between the applied pressure and settlement.
The use of finite element analysis allowed for a thorough comprehension of both confined and unconfined subgrade layer failure patterns. The results of this research are in agreement with the experimental data, demonstrating the significant effect that reinforcement has on the bearing capacity and the capability of the footing to control the horizontal and vertical movement of the soil.
Due to the non-specification or possible removal of further levels, the suggested approach has the ability to increase the load-bearing capacity of the present building, making it capable of withstanding higher loads. Finally, in order to estimate the soil carrying

capacity based on the dimensions of the grouted wall, a new correlation equation was devised.

Table 8 Correlation equations between soils bearing capacity as a function of the grouted wall dimensions

Equation No	Equation	Regression statistics (R^2)	Case of L/B
(1)	$(b/B) = 6\times(10)^{\wedge}(-6)\times(\text{Load})^2 - 0.00094\times(\text{Load}) + 3.79$	0.95	0.50
(2)	$b/B) = 2\times 10^{\wedge}(-6)\times(\text{Load})^2 - 0.0029\times(\text{Load}) + 0.755$	0.96	0.75
(3)	$(b/B) = -3\times 10^{\wedge}(-7)\times(\text{Load})^2 - 0.0029\times(\text{Load}) - 2.33$	0.96	1.00
(4)	$(b/B) = 2\times(10)^{\wedge}(-6)\times(\text{Load})^2 - 0.0042\times(\text{Load}) + 2.1$	0.95	1.25

Short Forms LThe thickness of grouted wallsThe dry breadth of grouted wallsUnit weight (dry) GsVacuum densityResilience modulus RDComparative densityThis is the Poisson's ratio: cohesion Ø friction internal angle v.

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Work done by the author
Creator of the study's conceptual framework, methods, software, data curation, writing, and editing.
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Data accessibility
Information will be provided upon request.

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