sciendo

Civil and Environmental Engineering
Vol. 20, Issue 2, 742-753, DOI: 10.2478/cee-2024-0056

ASSESSMENT OF THE NUMERICAL BEHAVIOR OF REMOLDED AND UNDISTURBED CLAYEY SOIL

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Abstract

The simulation of soil behavior using finite element analysis depends mainly on the input parameters considered in analysis, moreover, in the case of clayey soil, most of the experimental studies for small models are performed on remolded samples because of difficulty of providing undisturbed soils. This leads to unreal results for numerical analysis as the validation process of numerical results is performed on remolded sample.

It was conducted experimental work on remolded clay including load-settlement tests of model footing at three states on undrained cohesion (cu), and then performed unconfined compression tests at the same undrained cohesion. After that, performing numerical modeling of the model footing from the data of unconfined compression tests.

It was observed that the value of the modulus of elasticity in clay from unconfined test considering the initial tangent is low for remolded state compared to the findings of the previous research.

Moreover, great care must be taken in selecting the elasticity modulus in performing the numerical analysis of the clayey soil, however, for undisturbed clay it is greater than remolded, the difference in the value is up to two times for stiff clay in the case of large scale footing, while it was reaches about four times.

Keywords:

Undisturbed;
Remolded;
Finite element;
Hardening model;
Clayey soil.

1 Introduction

In geotechnical engineering, the need to use finite element models for analyzing or designing situations where practical full scale models cannot be made, so small models are used. Moreover, in the case of clayey soil, most of the experimental model studies are performed on remolded samples because of difficulty of providing undisturbed soils. As the validation process of the numerical results with experimental data is performed on remolded sample this leads to unreal results for in modeling other case studies.

After conducting an investigation of the previous studies, there are many studies that indicate the difference between the behavior of remolded and undisturbed clays.

It is known that the behavior of undisturbed clays (natural) is different from remolded clays, although the two types have the same shear strength, the stress yield of consolidation for undisturbed clays is higher than for reconstituted clays because of the formed soil structure during sedimentation and post-depositional processes [1].

The difference in the structure of the clay will directly affect the mechanical response under external load in addition to the stress-strain behavior of soil.

Generally, natural clays have a compression curve of the relationship between void ratio versus vertical effective stress lying above that of remolded clays due to the effect of structure of clay [2-8].

Klai carried out a laboratory experimental investigation on undisturbed and remolded specimens of soft clayey soil. The laboratory tests include oedometer and triaxial tests, it was observed that the properties of reconstituted soft clays are sometimes different from those of undisturbed samples [9].

Zhang, et al. performed static triaxial tests of consolidated drained and consolidated undrained of undisturbed and remolded samples of loess soil, from the results of tests ,it was observed the stress-strain relation for undisturbed soil is a strain softening while it was a weak strain hardening curve for remolded sample. It was found the structure of soil influences the stress-strain response of the soil [10].

Hence, the difference in behavior between undisturbed and remolded clay is not well understood, the problem is noticeable, especially since most of the research in cohesive soils is performed on remolded samples because of the difficulty of providing undisturbed soils. This gives unreal results for numerical analysis because the validation process of numerical analysis is conducted on remolded soils.

2 Methodology

For achieving the aim of the research, regarding the remolded soil condition, experimental work will be conducted on remolded clayey soil. The experimental tests include load-settlement tests of small-scale model footing at three states on undrained cohesion (cu) and then performed unconfined tests at the same undrained cohesion. The purpose is to perform numerical modelling of the model footing from the data of unconfined tests. In the case of undisturbed soil, it was considered an experimental loading test of footing conducted on undisturbed natural clay, and then performed a validation of the numerical analysis. After that, the results will be evaluated for the two cases of soil.

2.1 Soil Used

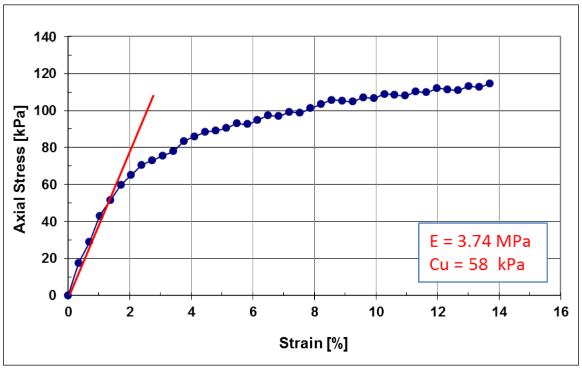
In this study, the soil used was borrowed from Baghdad city, the soil is silty clay with a brown color, the physical properties in addition to the Atterberg limits can be seen in Table (1), the soil can be classified as low plasticity clay as stated by the unified system of soil classification (CL).

Table 1: The soil properties.

Property of soil	Index Value	Specification
Liquid limit (L.L)	50	ASTM-D4318-2010
Plastic limit (P.L)	27	ASTM-D4318-2010
Plasticity index (P.I)	23	ASTM-D4318-2010
Specific gravity (G_s)	2.71	ASTM-D854-2010
Gravel (coarser than 4.75 mm)	0 %	ASTM-D422-2010
Sand (4.75mm to 0.075mm)	4 %	ASTM-D422-2010
Silt (0.075 mm to 0.005mm)	45 %	ASTM-D422-2010
Clay (finer than 0.005 mm)	51 %	ASTM-D422-2010
Soil Classification	CL	USCS

2.2 Laboratory unconfined compression tests

The unconfined test is conducted according to (ASTM D 2166). The diameter of sample is (36 mm) with a height of (76 mm). The objective of conducting this test for obtain the stress-strain response of the specimen, and then the results were considered as input parameters for a finite element modeling of the load-settlement of model footing. The stress-strain of unconfined tests are demonstrated in Figures (1, 2, and 3), however, it was considered the initial tangent to find the elasticity modulus. It was observed that the value of the modulus of elastic is low compared with previous studies, this is also mentioned in the results of Waheed and Asmael [15].



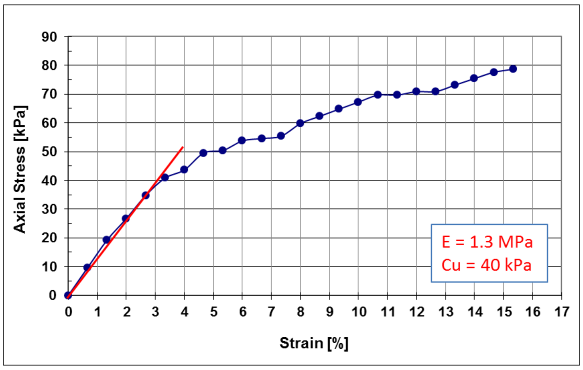


Fig. 1: Unconfined test 1. Fig. 2: Unconfined test 2.

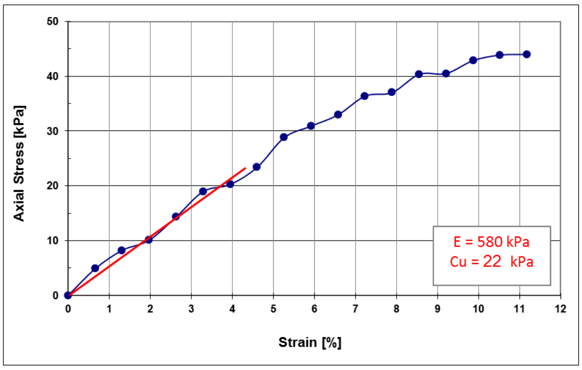


Fig. 3: Unconfined test 3.

2.3 Loading tests of model footing in remolded clay

The experimental work includes a load-settlement test of small-scale model footing at three states on undrained cohesion (20, 40, and 60 kPa). To find the water content to get these cohesion states. Several tests are conducted to obtain the relationship between shear strength and water content. The soil is ground mechanically in the laboratory and then the water content is adjusted according required undrained cohesion. The obtained wet clay is gently tamped in layers inside a tank to get rid of any entrapped air.

A square foundation was used of (210 mm) width with thickness (3 mm). The assembly of loading device includes of a mainframe and a steel container. The container length is (800 mm) and (800 mm) in width, where the depth is (600 mm). The mainframe includes a horizontal beam and two vertical columns. The vertical load is applied on footing through a level, as shown in Fig. (4). The settlement of footing during loading is measured through two dial gauges. The load-settlement curve of the three tests can be seen in Fig. (5).

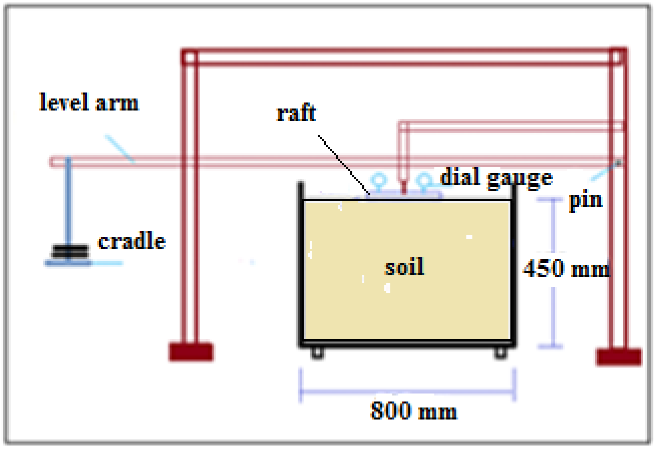


Fig. 4: The assembly of loading test.

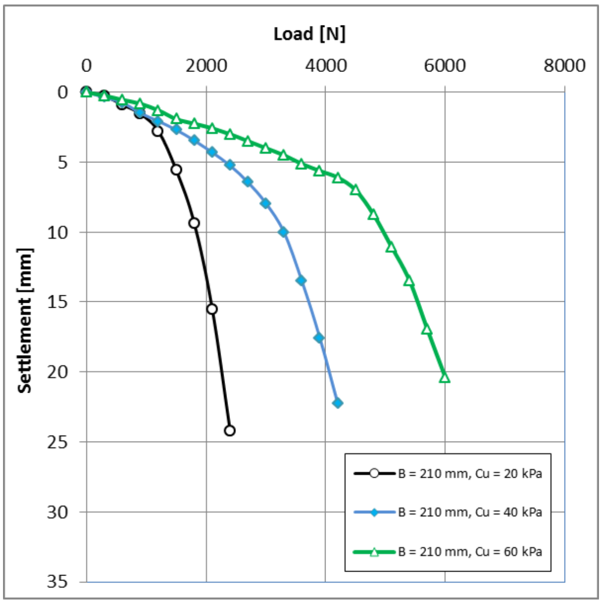


Fig. 5: Load-settlement curve of the three model footings.

2.4 Modeling of model footing in remolded clay

For the purpose of modeling the load-settlement of model footing using the results of unconfined tests for the three cases of soil cohesion (20, 40, and 60 kPa), the Plaxis software is considered to simulate a numerical model. Plaxis is finite element software and is a useful tool used for simulating, analysis, and design in geotechnical engineering [16 - 19]. The Hardening model is considered in the analysis; the main benefit of using this model for the simulation of soil behavior is the ability to adopt the path of stress and their effect on the stiffness of soil [20]. The representation of the behavior of clayey soil using this model gives better results than the other models and gives a more realistic response [16]. The inputs considered in modeling are given in Table (2), the geometry of the footing (for case 2) is shown in Fig. (6) while the vertical displacement under loading can be demonstrated in Fig. (7).

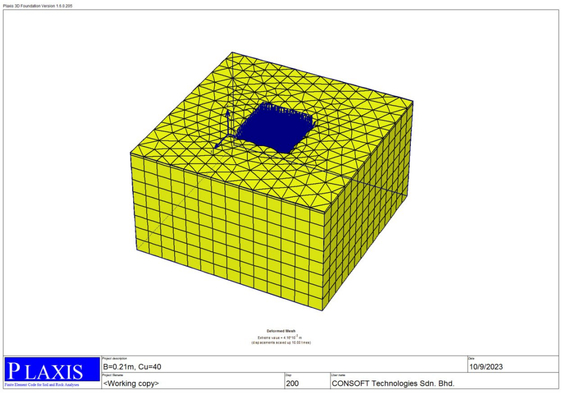


Fig. 6: The geometry of the footing (B=0.21 m, c_u= 40 kPa).

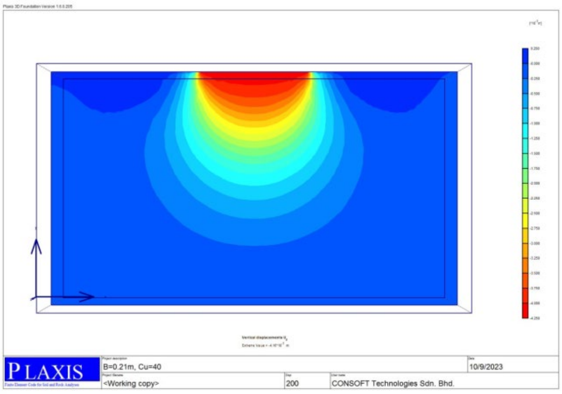


Fig. 7: Vertical displacement of the footing under load (B=0.21 m, c_u= 40 kPa).

It can be seen in Figs. (8, 9 and 10) that although the elasticity modulus considered in the numerical analysis is relatively small, the results of simulation is overestimation for modeling the load-settlement test in the three cases of undrained cohesion (20, 40, and 60 kPa) and this may be attributed to the small size of footing that may cause a reduction if the stresses within the soil at the plane of failure.

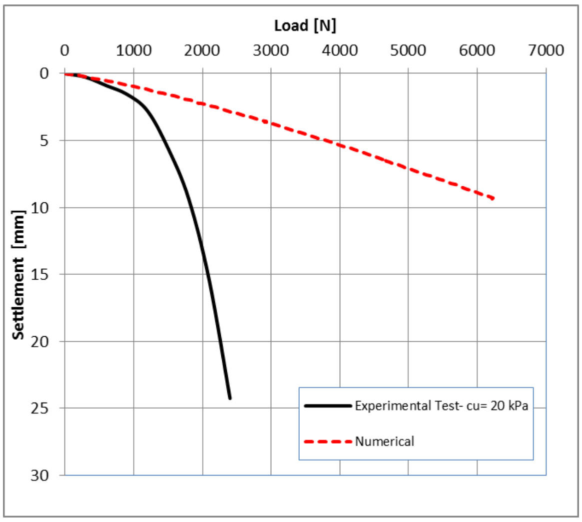


Fig. 8: Load-settlement curve – c_u = 20 kPa.

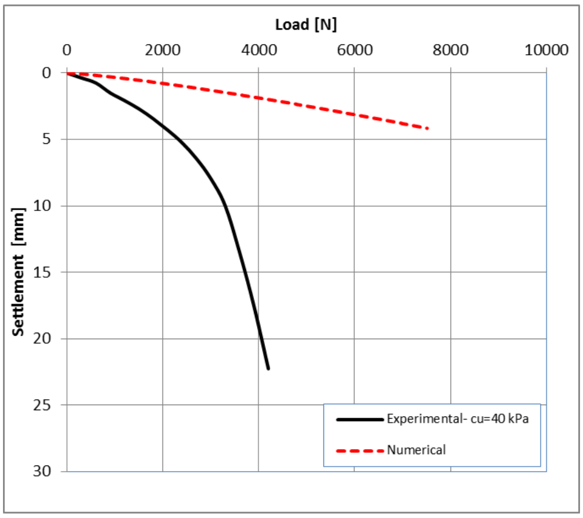


Fig. 9: Load-settlement curve – c_u = 40 kPa.

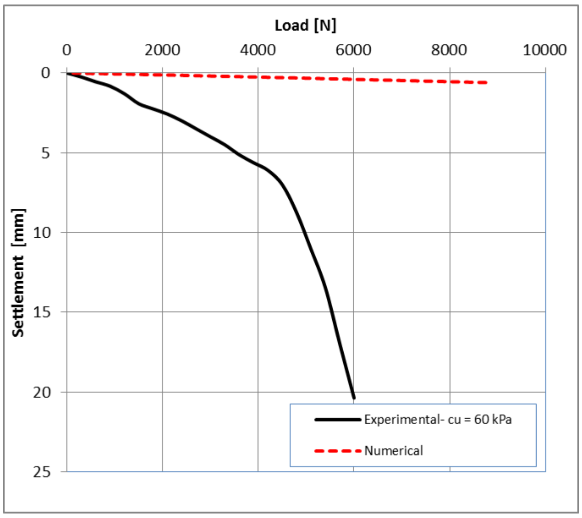


Fig. 10: Load-settlement curve – c_u = 60 kPa.

Table 2: The soil properties considered in the finite element analysis for the three cases.

Description	Symbol	Unit	Case 1	Case 2	Case 3
Type of model behavior	-	-	Drained	Drained	Drained
Modulus of elasticity	E^{ref}_{50}	[MPa]	0.58	1.3	3.74
Oedometer modulus (Auto. calculate)	E^{ref}_{oed}	[MPa]	1.74	3.9	11.2
Unloading modulus (Default = 3 E^{ref}_{50})	E^{ref}_{ur}	[MPa]	1.74	3.9	11.2
Cohesion	c_u	[kPa]	20	40	60
Angle of Friction	Ø	[º]	8	8	10
Poisson's Ratio	v	-	0.45	0.4	0.4
Exponential Power	m	-	1	1	1

2.5 Modeling of raft for remolded clay

For the purpose of studying a large size of footing, a square raft of (10 m) width was adopted using the same input parameters for the three states of soil cohesion (20, 40, and 60 kPa), as given in Table (2). For comparison purposes, the numerical results for raft width (B=10 m) are drawn with experimental results conducted in this study for footing width (B=0.21 m). The relationships of bearing stress (q) against a settlement ratio (S/B) are shown in Figs. (11,13 and 15), while the relation of a bearing ratio (q/c_u) with the settlement ratio is demonstrated in Figures (12,14 and 16) for the soil cohesion (20, 40, and 60 kPa) respectively, so that the settlement ratio represents the settlement of footing (S) to raft width (B) and the stress ratio is a ratio of bearing stress (q) to the cohesion (c_u) and represents the (N_c) factor in bearing capacity formula for shallow footing in clay . It was observed for experimental results of (B=0.21m) that the average stress ratio of the three cases at (10%) footing width is about (2.4), so this magnitude is lower than the range of the (N_c) factor that is between (5.7 to 6.18) for saturated clay at (φ = 0) (Bowles, 1996) [21] . In the settlement ratio of about (2-3 %) for the cohesion of clay (20 and 40 kPa) there was a good agreement between the results while there was over prediction for (60 kPa) cohesion.

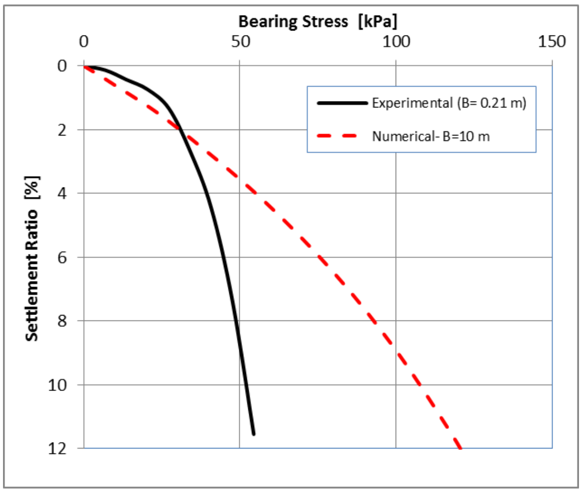


Fig. 11: Bearing stress -settlement ratio curve , c_u = 20 kPa.

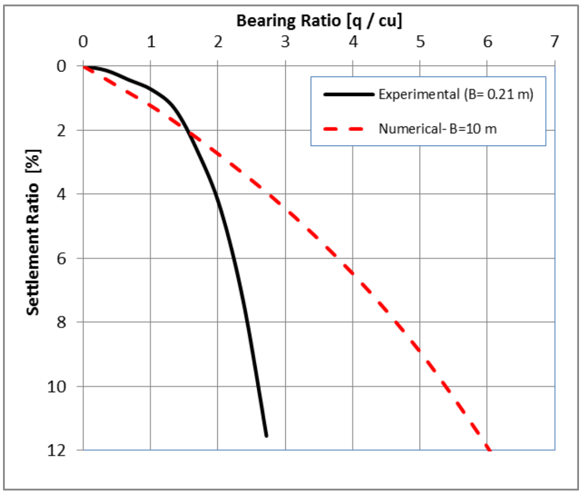


Fig. 12: Bearing ratio - settlement ratio curve, c_u = 20 kPa.

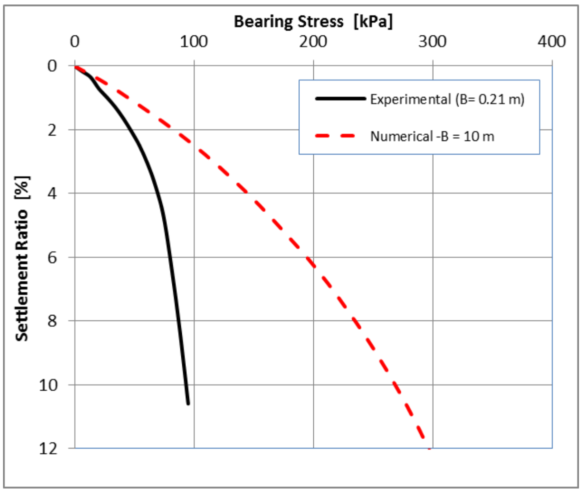


Fig. 13: Bearing stress -settlement ratio curve, c_u = 40 kPa.

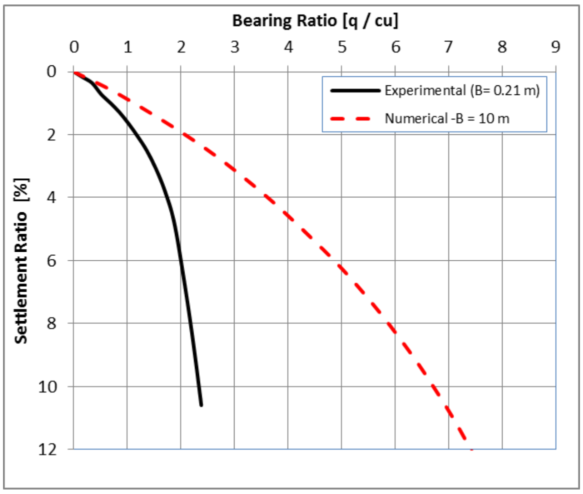


Fig. 14: Bearing ratio - settlement ratio curve, c_u = 40 kPa.

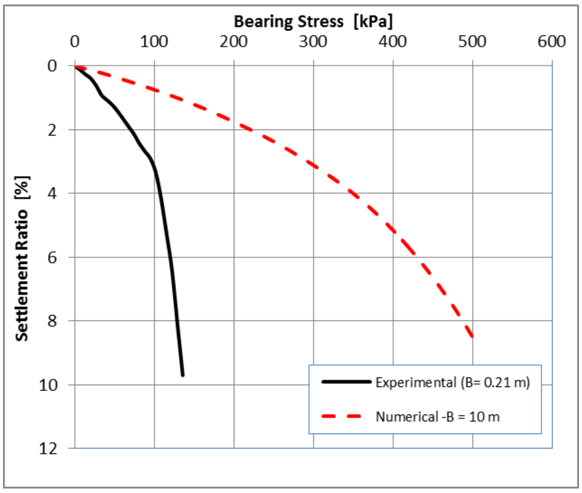


Fig. 15: Bearing stress -settlement ratio curve , c_u = 60 kPa.

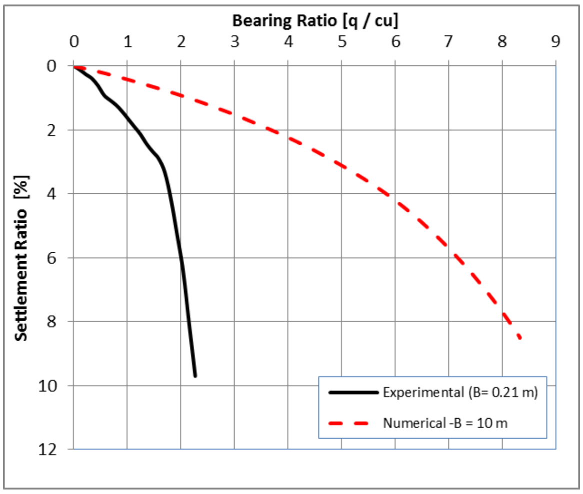


Fig. 16: Bearing ratio - settlement ratio curve, c_u = 60 kPa.

2.6 Modeling of raft for undisturbed clay

In order to investigate the numerical analysis for undisturbed soils and perform validation, it was considered a case study from the experimental work of undisturbed clay conducted by Ornek et al. [22]. The site of work in Turkey at the Metropolitan Municipality of Adana, where the load-settlement test was performed with a footing diameter of (0.9 m). From the results of the site investigation performed, it was observed that there were three layers of soil, as can be seen in Fig. (17), the first top layer of thickness (0.8 m) was extracted before test. The loading test was conducted at the second layer (6.2 m) thick, it was a silty clay of high plasticity. While the thickness of the third layer is (3.5 m), it was a low plasticity silty clay with sand. Fig. (18) shows the properties of soil profiles with depth, and it was observed the average of undrained cohesion (c_u) for the second layer of about (70 kPa). The values of input parameters considered in the validation are shown in Table (3). In order to simulate a case study, a footing of (0.8 m) width of square shape is considered equivalent to (0.9 m) circular shape of footing with (0.9 m) diameter according to the recommendation of Lee and Salgado [23].

The footing geometry and the vertical displacement distribution of finite element analysis using Plaxis program of (10 m) width footing are demonstrated in Figs. (19) and (20).

It was observed from Fig. (21) that there was a good agreement between numerical and experimental results. The results of the bearing stress -settlement ratio curve of the experimental case study and a numerical of the two cases, (0.8 m) and (10 m) raft width can be seen in Fig. (22), from this Figure it was observed that increasing foundation width from (0.8 m) to (10 m) does not have a noticeable effect on the foundation capacity at a specific value of the settlement ratio, this in agreement with the authors finding [24,25]. From Fig. (23), it can be demonstrated that at settlement ratio (3%) the bearing capacity factor (N_c) is within the approved range in clayey soil.

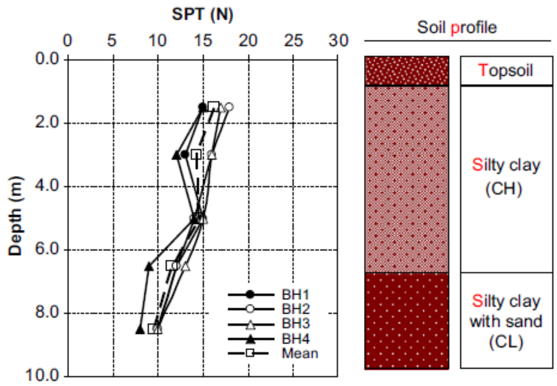


Fig. 17: The soil profile of site [22].

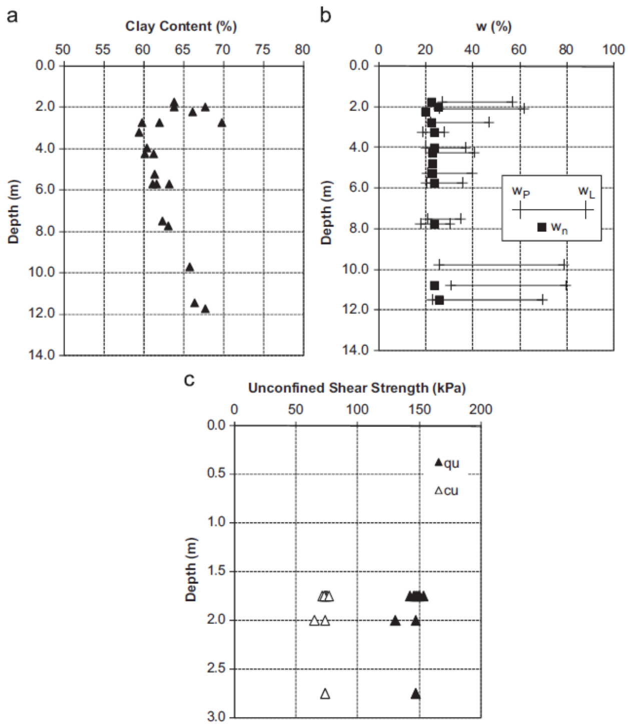


Fig. 18: The distribution of soil characteristics with depth, a) content of clay, b) moisture content, and c) shear strength [22].

Table 3: The soil properties considered for the validation of undisturbed clay.

Description	Symbol	Unit	Value
Type of model behavior	-	-	Drained
Modulus of elasticity	E^{ref}_{50}	MPa	8.4
Oedometer modulus (Auto. calculate)	E^{ref}_{oed}	MPa	24.7
Unloading modulus (Default = 3 E^{ref}_{50})	E^{ref}_{ur}	MPa	25.2
Cohesion	c_u	kPa	70
Angle of Friction	Ø	o	9
Poisson's Ratio	v	-	0.35
Exponential Power	m	-	1

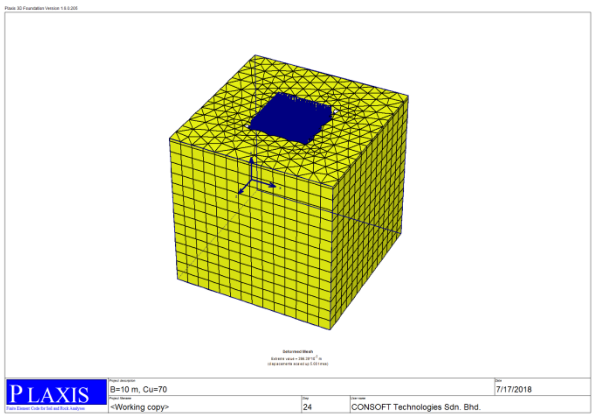


Fig. 19: The geometry of (10 m) width footing of numerical model.

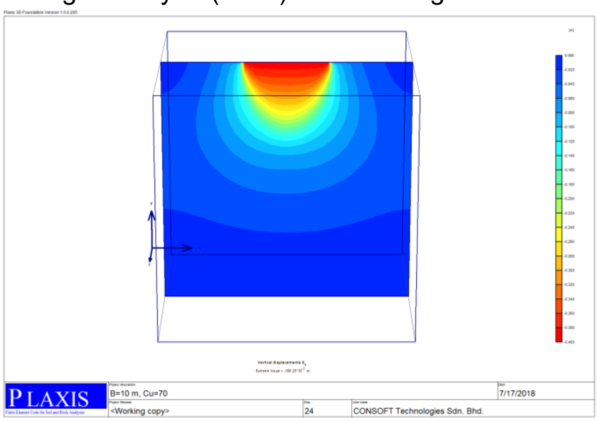


Fig. 20: The vertical displacement under loading of (10 m) width footing of the numerical model.

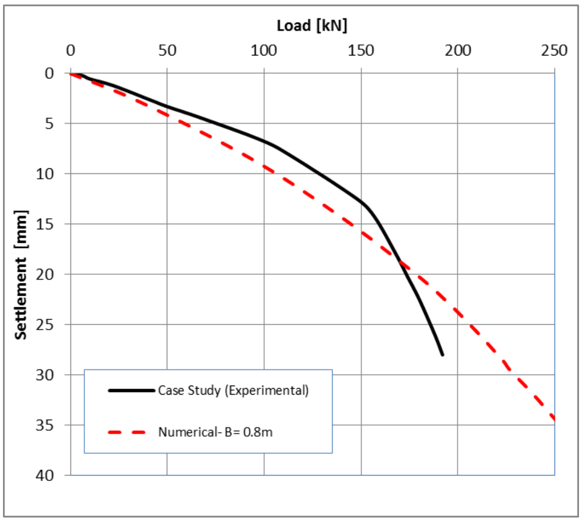


Fig. 21: The load-settlement result of numerical and experimental results of undisturbed clay.

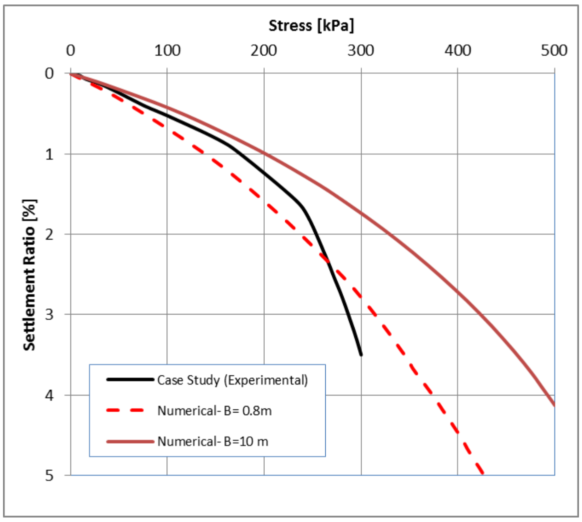


Fig. 22: Bearing stress -settlement ratio curve of numerical and experimental results of undisturbed clay.

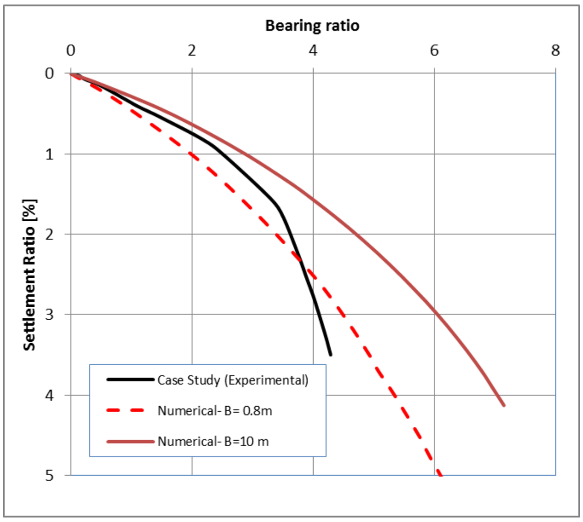


Fig. 23: Bearing ratio -settlement ratio curve of numerical and experimental results of undisturbed clay.

For the purpose of evaluating the values of elasticity modulus (Es) used in the numerical simulation according to the state of clay samples (remolded and undisturbed) , the relation between the elasticity modulus and cohesion of clay considered the numerical analysis of the two cases of clay is given in Table (4). It was observed that the value of the modulus of elastic for remolded clay is low compared to the findings of the previous research, moreover, the elasticity modulus of the undisturbed clay is higher than the case of remolded clay, so the variation in the value is up to about two times for stiff clay in case of large scale footing, while it was reaches about four times in case of performing the validation on small scale footing.

Table 4: Summary of results of the numerical simulation of the remolded and undisturbed clay.

Case No.	State of clay	Soil Cohesion [kPa]	Elasticity Modulus [MPa]	Ratio of Elasticity Modulus to Cohesion [E/ c_u]
1	Remoulded	20	0.58	29
2	Remoulded	40	1.3	32.5
3	Remoulded	60	3.74	62
4	Undisturbed	70	8.4	120

3 Conclusion

In this paper, experimental and numerical analysis is conducted using a finite element program, from the results obtained from this research the following conclusion can be drawn:

1) The finite element simulation of the load-settlement response of shallow foundations rested on clayey soil considering Hardening soil model gives a good result for both small and large-size.

2) The value of the modulus of elasticity in clay from unconfined test considering the initial tangent is low for remolded state compared to the findings of the previous research, so that for soft state is (30 cu), and for medium stiff clay it is about (60 cu) , and reach about (120 cu) for undisturbed state.

3) The finite element simulation of the experimental load-settlement relationship is overestimation for model footing in remolded clay while considering the initial tangent of elasticity modulus from the unconfined test for the three cases of undrained cohesion (20, 40 and 60 kPa) .

4) According to experimental results of small size footing, the bearing capacity factor (Nc) of the three cases of undrained cohesion (20 , 40 and 60 kPa) at (10%) footing width is about (2.4), where this value is lower than the proposed value that is between (5.7 to 6.18) for clay of fully saturated case.

5) Great care must be taken in selecting the elasticity modulus of the undisturbed clay in performing the numerical validation, however, it is greater than for remolded state, so the variation in the value is up to two times for stiff clay in the case of large scale footing, while it was reaches about four times in case on small scale footing.

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