BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

Advances in Geological and Geotechnical Engineering Research
https://ojs.bilpublishing.com/index.php/agger

ARTICLE

Bearing Capacity of Defective Reinforced Concrete Pile in Sand-model Study

A. M. Nasr[1] **W. R. Azzam**[1] **K. E. Ebeed**[2*]

1. Geotechnical Engineering, Faculty of Engineering, Tanta University, Tanta, Egypt
2. Faculty of Engineering, Tanta University, Tanta, Egypt

ARTICLE INFO

Article history
Received: 20 June 2022
Revised: 06 August 2022
Accepted: 11 August 2022
Published Online: 16 August 2022

Keywords:
Structural defect
Geotechnical defect
Debris
Necking and soft layer

ABSTRACT

Concrete piles that were poorly constructed or analyzed in their soil analyses may have structural or geotechnical defects. To examine such defects, an experimental study was conducted to investigate how a defective reinforced concrete pile behaved. These piles were installed and subjected to a compression axial load in the sand that had relative densities of 30%, 60%, and 80%. The tests were performed using four concrete model piles: one intact pile and the other three piles had a structural defect (necking) at three different positions of the pile at (0.25 L from the top, center, and 0.25 L bottom). Geotechnical defect (soft layer or debris) was studied using Styrofoam layer at various vertical distances under the pile toe with Y/D = (0, 0.5, 1 and 1.5) D. The test results showed that the bearing capacity of the structural defect was the most in the case of a neck at 0.25 L from the bottom, followed by a neck at the center, and finally a neck at 0.25 L from the top. In the case of a geotechnical defect, the bearing capacity of the pile decreased with the decrease of the vertical distance between the soft layer and the pile toe.

1. Introduction

Pile foundations were used when the soil had a low shear strength and bearing capability. In such cases, piles were used to shift the load to deep, strong strata. A point to be noted is that there were two main types of piles: end load bearing piles and friction piles. Such piles were classified by their load transmission method. The reduction in a pile's cross-sectional area (necking), as one of the structural defects, can occur during the casting process of the pile due to local concrete failures, fractured zones, weakened zones, damaged zones in the pile, and geotechnical defects as debris or soft layer under the pile toe. An important point to be noted is that poor designs or poor geotechnical studies were the main causes of geotechnical defects. Moreover, the load-bearing capabilities were lower than expected at the lateral friction and the base load [1]. Furthermore, there were structural defects because of pile execution mistakes, as it was usual for a pile's strength and size to deviate from the design expectations. Another point to be noted is that

*Corresponding Author:
K. E. Ebeed,
Faculty of Engineering, Tanta University, Tanta, Egypt;
Email: khaled135245@f-eng.tanta.edu.eg

DOI: https://doi.org/10.30564/agger.v4i3.4808

these defects frequently showed up as a rapid reduction in a pile's cross-sectional area, known as necking, and at weakened zones due to local concrete failures [2]. Another important point to be noted is that the results of a German study on defective piles showed that 15% of analyzed piles had abnormal PIT (pile integrity test) indicators, and 5% of those piles were labelled defective and potentially intervention-required. Additionally, 30% of these piles had issues with the quality of the concrete, 21% of them had insufficient lengths, 14% of them had "necking", and 35% of them had structural cracks [3]. The behavior of the reinforced concrete piles when they had discontinuities, improper end bearings, poor concreting, and clay necking was studied [4]. Moreover, investigation was done into how voids and necking defects affected the compression bearing capacity of sand at various pile positions [5]. A model for local failure surrounding the pile was simulated in order to define the effect zone that should be utilized to estimate the bearing capacity of the piles from the data of the CPT [6]. In addition, the mechanism of a strip footing failure and its ultimate bearing capacity that was loaded vertically above a soft pocket on a geogrid-reinforced and unreinforced sand slope were examined [7]. The effect of the debris at the pile tip on the axially loaded bored piles was fully investigated. Model scale laboratory tests at various scales were conducted, including single pile without raft, single pile with raft, and pile groups with 2, 3, and 4 piles [8].

Accordingly, it was found that, all investigated models of the piles used the steel model pile with a defect at a given zone at the pile or at the concrete pile in sand. Therefore in this research, reinforced concrete model pile was adopted to simulate the real behavior of a defective pile. Such a study was not thoroughly investigated before in the sand.

Moreover, in the current study, the influence of the defects on the stress characteristics and the load carrying capacity of a single defective reinforced concrete pile foundation was examined. Furthermore, the effect of the geotechnical defect (the debris or the soft layer) and the structural defect (necking) in different positions of the pile foundations bearing capacity were investigated. A point to be noted is that the medium used for the analysis was a poorly graduated sand. In addition, the sand density was varied to see how its effect on the pile foundation bearing capabilities.

2. Experimental Facility and Model

2.1 Loading Frame and Test Tank

The pile load tests were conducted in a steel tank made specifically for the purpose, which had a wall thickness of 4 mm, a depth of 1100 mm, and a plan size of 800 mm by 800 mm. The bottom steel beams were welded with the test tank. The loading frame was made up of two columns, fixed with two horizontal steel beams. A manually driven hydraulic jack was used to progressively apply the axial compression stresses to a number of model piles. The loads were observed using a load cell. Moreover, the applied compression load settlement was recorded with a digital data log reader. Furthermore, steel flat plate was placed in the center of the test tank's width to attach the dial gauges' magnetic bases. Two dial gauges were fixed equidistant from the pile axis. When each increment of loading became steady, dial gauge readings were recorded for both dial gauges. The axial displacement of the pile in response to the applied compression load was determined as the average value of the displacement obtained from both dial gauges. The experimental set up is shown in Figure 1.

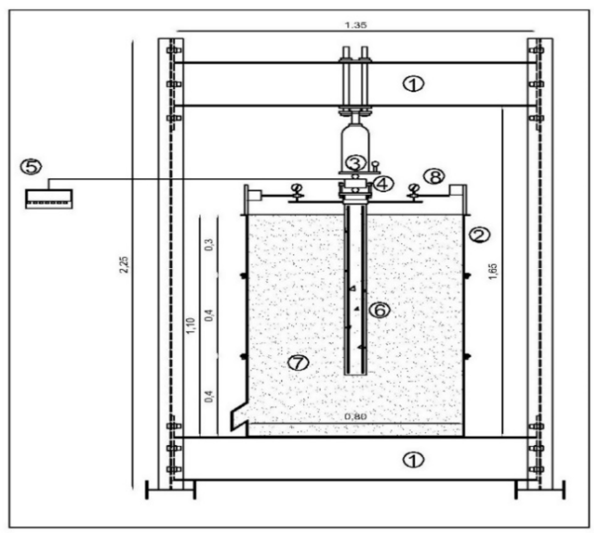

Figure 1. Layout of experimental setup**.**

1-Loading frame, 2-Test tank, 3-Hydraulic jack, 4-Load cell, 5-Read out unite, 6-Model pile, 7-Sand and 8-Dial gauges

2.2 Sand Used

Dry, commercially available sand was used in the current studies. The sand used in this experiment was poorly graded, according to the Unified Soil Classification System (SP). The usage of sand and the round grains helped to reduce the friction between the soil and the test tank walls. Table 1 shows the physical characteristics of the utilized sand. Sand beds were placed in 50 mm thick layers by using the predetermined weight [9]. To create situation of sand relative densities, the predetermined weight of each additional sand layer put was employed and compacted to the desired thickness, previously identified by lines drawn on the internal sides of steel test tank. The sand relative density, achieved during the tests, was monitored by collecting samples in small cans at the time of filling. Moreover, the volume was placed at different locations in the test tank, and the sand density was determined [9]. The relative densities of the sand obtained with cans were found to be within the range of Dr= 30% ± 0.56% in loose sand, Dr= 60% ± 0.9% in medium dense sand and Dr= 80% ± 1.22% in dense sand.

Table 1. The physical properties of the sand used.

Properties	Value
Maximum unit weight, $\gamma_{max.}$ (kN/m^3)	19.58
O.M.C (%)	8.20
Minimum unit weight, $\gamma_{min.}$ (kN/m^3)	15.51
Specific gravity (G_s)	2.64
The effective grain size, D_{10} (mm)	0.16
D_{30} (mm)	0.27
Mean grain size, D_{50} (mm)	0.56
D_{60} (mm)	0.63
Uniformity coefficient, C_u	3.94
Coefficient of curvature, C_c	0.72
Classification, USCS	SP
Maximum angle of internal friction, φ (degree)	42.5
Minimum angle of internal friction, φ (degree)	30
Maximum void ratio, $e_{max.}$	0.702
Minimum void ratio, $e_{min.}$	0.348
Dense sand properties	
Unit weight, γ (kN/m^3)	18.77
Relative density, D_r (%)	80
Angle of internal friction, φ (degree)	39.5
Medium dense sand properties	
Unit weight, γ (kN/m^3)	17.9
Relative density, D_r (%)	60
Angle of internal friction, φ (degree)	35.4
Loose sand properties	
Unit weight, γ (kN/m^3)	16.77
Relative density, D_r (%)	30
Angle of internal friction, φ (degree)	32.1

2.3 Model Piles

Model piles were four reinforced concrete piles cast using PVC pipe as a model. The piles were divided into three defective ones, and a one with no defect with diameter of 80 mm and height of 900 mm. An important point to be noted is that the maximum nominal size of the aggregate shall not be more than 1/5 of the lowest dimension in the concrete component. In addition, the size shall not exceed 3/4 the pure distance between the reinforcing steel bars [10]. As a result, all of the model concrete piles were made of coarse aggregate sizes, which were not larger than 10 mm. The ratio of longitudinal steel cross-sectional area to cross-sectional area of the pile should not be less than 1.5 percent or more than 8% [11]. The piles were reinforced with four 6 mm steel bars at a ratio of 2.25. The pile defect was a neck at 0.25 L from the top, center and 0.25 L from the bottom. Furthermore, the dimension of the neck was equal to the desired defect, which was formed by heating the PVC pipe mold to create a 0.5D necking appearance [12], as seen in Figures 2 and 3. The minimum cement content of the pile shall be 400 kg/m^3 [13]. Therefore, the mixing ratio used was (400 kg/m^3 of cement and 0.8 m^3 of aggregate and 0.4 m^3 of sand). A series of compression strength tests were conducted on samples at ages 3, 7. Moreover, the tests took 28 days to be prepared and tested on cubes with dimension of 100 × 100 × 100 mm. The results of the tests are summarized in Table 2.

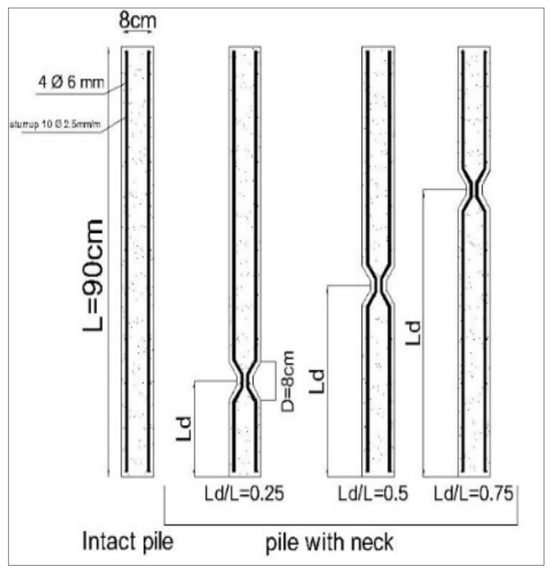

Figure 2. The details of defective and intact piles.

Figure 3. Model piles with different positions of neck.

2.4 Model of a Soft Pocket

Since Styrofoam is made up of 98% air, which makes it light and buoyant, a Styrofoam layer was used as a soft pocket in the current study. Styrofoam was placed beneath the pile's center and parallel to the tank's width. The dimensions of Styrofoam were square, and the side length was 240 mm and 50 mm thickness in all the tests. As seen in Figure 4, Styrofoam is a white polystyrene foam. The manufacturer provided the parameters, as shown in Table 3. The position of the soft pocket according to the bottom of the pile is illustrated in Figure 5.

Figure 4. The model of a soft pocket (Styrofoam layer).

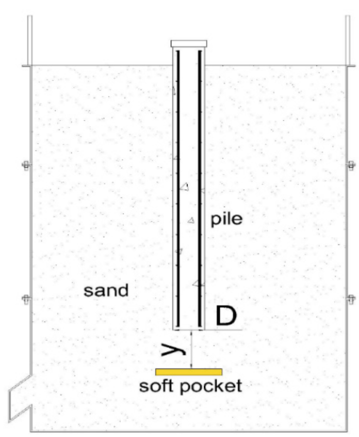

Figure 5. The details of the position of the soft pocket.

Table 2. The compressive and the shear strength results of the used concrete.

Test type	Cube 1	Cube 1	Cube 1	Mean Strength
Compression Strength after 3 days (MPa)	20.2	19.6	20.8	20.2
Compression Strength after 7 days (MPa)	26.5	25.5	27.1	26.4
Compression Strength after 8 days (MPa)	30.2	29.5	32	30.6

Table 3. Properties of Styrofoam.

Property	Value
Thermal Resistance per inch (50 mm)	5.0 (.88)
Compressive Strength, ASTM D1621, psi (kPa), min.	30 (207)
Surface Burning Characteristics, ASTM E84 for both foam core and finished product	Class A
Flame Spread	25
Smoke Developed	<450
Elasticity Modulus (E) kN/m^2	0.1200
Density (kN/m^3)	0.063

3. Installation Steps

After placing the sand at the desired relative density to the bottom level of the pile, the model precast pile was placed vertically on the sand surface using a special guide attached to the test tank edge. Then, the sand was put to the tank top level. Finally, the axial compression loading tests were performed via a hydraulic jack. The load was applied incrementally until the vertical settlement exceeded 50% of the used pile diameter, or reaching failure. Figure 6 summarizes installation steps of the test material.

4. Testing Program

Twelve model pile load tests were carried out in the sand to study the effect of the existence of necking and soft pocket on the capacity of the piles in the sand. Table 4 summarizes the experimental testing program.

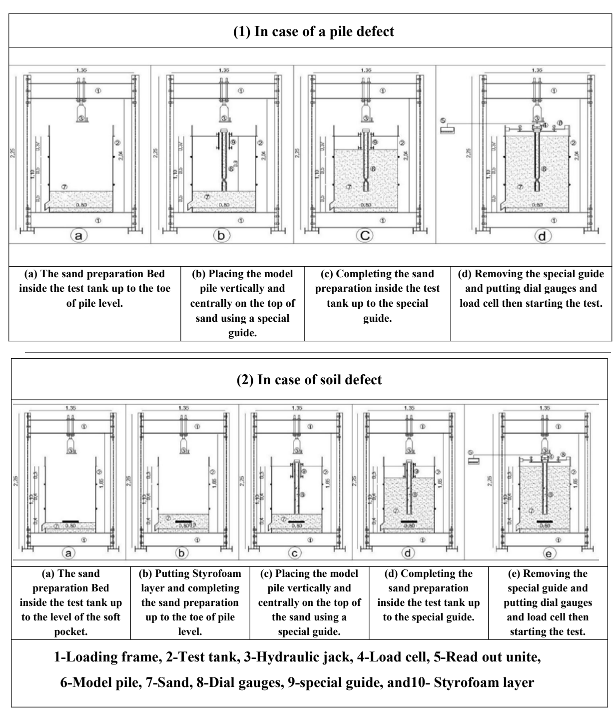

Figure 6. Installation steps for the defective sand and the pile.

Table 4. Experimental testing program.

series		Variable parameters				No. of tests
		Kind of defect		Relative density (Dr%)	Defective position	
Group(A)	S1	Pile defect	sound	30	-	1
	S2		necking	30	Ld /L=0.25	1
	S3		necking	30	Ld /L=0.5	1
	S4		necking	30	Ld /L=0.75	1
Group(B)	S5		sound	60	-	1
	S6		necking	60	Ld /L=0.25	1
	S7		necking	60	Ld /L=0.5	1
	S8		necking	60	Ld /L=0.75	1
Group(C)	S9		sound	80	-	1
	S10		necking	80	Ld /L=0.25	1
	S11		necking	80	Ld /L=0.5	1
	S12		necking	80	Ld /L=0.75	1
Group(D)	S13	Soil defect	Soft pocket	30	Y/D=0	1
	S14		Soft pocket	30	Y/D=0.5	1
	S15		Soft pocket	30	Y/D=1	1
	S16		Soft pocket	30	Y/D=1.5	1
Group(E)	S17		Soft pocket	60	Y/D=0	1
	S18		Soft pocket	60	Y/D=0.5	1
	S19		Soft pocket	60	Y/D=1	1
	S20		Soft pocket	60	Y/D=1.5	1
Group(F)	S21		Soft pocket	80	Y/D=0	1
	S22		Soft pocket	80	Y/D=0.5	1
	S23		Soft pocket	80	Y/D=1	1
	S2		Soft pocket	80	Y/D=1.5	1
Total number of series						**24**

L:total length of pile, Ld: the length from defect to pile toe, Y: distance from soft pocket to pile toe and D: pile diameter

5. Results and Discussion

5.1 Definition of Failure Load

The ultimate axial capacity of a pile was obtained from the load-displacement curves. The pile displacement, S (mm) is expressed in a non-dimensional form in terms of the pile diameter, D (mm) as a percentage ratio, S/D (%). In this study, the ultimate axial capacity of the model pipe pile was obtained from the load-displacement curve, as the load corresponding to the total axial movement equals to 10% of the pile diameter [5,14,15].

5.2 Load-Displacement Relationship

Twenty-four tests were conducted using four different pile models with different positions of defected piles with lengths equal to 800 mm and 80 mm in diameter L/D=10. Such tests were performed in order to examine the behavior of the defective reinforced concrete piles in the sand [4-12]. Moreover, the geotechnical and structural defects were discussed that a structural defect was a neck with diameter 0.5D, and its position was at 0.25 L from bottom, the pile with neck at center and the pile with neck at 0.25 L from top [4]. The geotechnical defect was a soft pocket under the pile in a different position from the pile toe, with Y/D = (0, 0.5, 1 and 1.5).

A-structural defect

The load-displacement curves were obtained and presented in Figures 7 to 9 for a pile with structural defect at different relative density. Figure 7 shows typical axial compression load versus relative displacement, S/D (%) for sound pile and different defective model piles in loose sand (Dr= 30%), in case of sound pile. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 4%, then they are non-linear in stages of the axial loading up to relative displacement equal to 12.5%, but afterwards they are linear. In case of pile with neck at 0.25 L from bottom. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 7.5%, then they are non-linear in stages of the axial loading up to relative displacement equal to 22%, but afterwards they are linear. In case of pile with neck at center. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 5%, then they are non-linear in stages of the axial loading up to relative displacement equal to 20%, but afterwards they are linear. And in case of pile with neck at 0.25 L from top. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 10%, then they are non-linear in stages of the axial loading up to relative displacement equal to 20%, but afterwards they are linear. It is also indicated that, Moreover, it is noted that at the relative displacement, S/D equals10%, the ultimate capacities (Qult.) were found to be (1259.5N, 1139N, 1070N and 1026.5N) for the sound pile, the pile with neck at 0.25 L from bottom, the pile with neck at center and the pile with neck at 0.25 L from top. Figure 8 shows typical axial compression load versus relative displacement, S/D (%) for the sound pile and different defective model piles in medium sand (Dr= 60%). In case of sound pile. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 5%, then they are non-linear in stages of the axial loading up to relative displacement equal to 20%, but afterwards they are linear. In case of pile with neck at 0.25 L from bottom. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 5%, then they are non-linear in stages of the axial loading up to relative displacement equal to 15%, but afterwards they are linear. In case of pile with neck at center. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 5%, then they are non-linear in stages of the axial loading up to relative displacement equal to 25%, but afterwards they are linear. And in case of pile with neck at 0.25 L from top. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 5%, then they are non-linear in stages of the axial loading up to relative displacement equal to 15%, but afterwards they are linear. Another point to be noted is that, at the relative displacement, S/D equals10%, the ultimate capacities (Qult.) were found to be (2714.33N,2524.48N, 2386.83N and 2196.8N) for the sound pile, the pile with neck at 0.25 L from bottom, the pile with neck at center and the pile with neck at 0.25 L from top . Figure 9 shows typical axial compression load versus relative displacement, S/D (%) for the sound pile and different defective model piles in the dense sand (Dr= 80%). In case of sound pile. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 3%, then they are non-linear in stages of the axial loading up to relative displacement equal to 5%, but afterwards they are linear. In case of pile with neck at 0.25 L from bottom. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 3%, then they are non-linear in stages of the axial loading up to relative displacement equal to 6%, but afterwards they are linear. In case of pile with neck at center. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 3%, then they are non-linear in stages of the axial loading up to relative displacement equal to 12%, but afterwards they are linear. And in case of pile with neck at 0.25 L from top. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 3%, then they are non-linear in stages of the axial loading up to relative displacement equal to 20%, but afterwards they are linear. Furthermore, it is noted that, at relative displacement, S/D equals 10%, the ultimate capacities (Qult.) were found to be (4830N, 4260N, 4060N and 3680N) for the sound pile, the pile with neck at 0.25 L from bottom, the pile with neck at center and the pile with neck at 0.25 L from top. An important point to be noted is that the existing of such a neck can distinctly modify the load displacement response. Load capacity was gradually reduced with larger settlement relative to the location of necking. Bearing capacity decrease as necking depth decrease.

B-geotechnical defect

The load-displacement curves were obtained and presented in Figures 10 to 12 for a pile with geotechnical defect at different relative density. A typical pile constructed on a soft pocket that is positioned differently in loose sand (Dr=30%) is shown in Figure 10 as an axial compression load versus relative displacement, S/D. In case of Y/D=0. It is clear that, non-linear relationship in the early stages of the loading up to relative displacement of about 3%, afterwards they are linear. In case of Y/D=1/2. It is clear that, non-linear relationship in the early stages of the loading up to relative displacement of about 5%, afterwards they are linear. In case of Y/D=1. It is clear that, non-linear relationship in the early stages of the loading up to relative displacement of about 7.5%, afterwards they are linear. In case of Y/D=3/2. It is clear that, non-linear relationship in the early stages of the loading up to relative displacement of about 15%, afterwards they are linear. It should be noted that the maximum capacities (Qult.) for Y/D =(0, 0.5, 1, and 1.5) at relative displacement, S/D equals 10% were obtained 490N, 598N, 684N, and 875N. A typical pile constructed on a soft pocket that is positioned differently in medium sand (Dr=60 percent) is shown in Figure 11 as an axial compression load versus relative displacement, S/D. In case of Y/D=0. It is clear that, non-linear relationship in the early stages of the loading up to relative displacement of about 4%, afterwards they are linear. In case of Y/D=1/2. It is clear that, non-linear relationship in the early stages of the loading up to relative displacement of about 10%, afterwards they are linear. In case of Y/D=1, it is clear that, non-linear relationship in the early stages of the loading up to relative displacement of about 8%, afterwards they are linear. In case of Y/D=3/2. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 2%, then they are non-linear in stages of the axial loading up to relative displacement equal to 6%, afterwards they are linear. It should be noted that the maximum capacities (Qult.) for Y/D =(0, 0.5, 1, and 1.5) at relative displacement, S/D equals 10% were obtained 1405 N, 1676 N, 1876 N, and 2292 N. Typical axial compression load versus relative displacement, S/D (percent), for a pile based on a soft pocket with a different position in dense sand (Dr=80 percent), is shown in Figure 12 in case of Y/D=0. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 1%, then they are non-linear in stages of the axial loading up to relative displacement equal to 2%, afterwards they are linear. In case of Y/D=1/2. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 2%, then they are non-linear in stages of the axial loading up to relative displacement equal to 8%, afterwards they are linear, in case of Y/D=1. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 3%, then they are non-linear in stages of the axial loading up to relative displacement equal to 10%, afterwards they are linear. In case of Y/D=3/2. It is clear that, linear relationship in the early stages of the loading up to relative displacement of about 3%, then they are non-linear in stages of the axial loading up to relative displacement equal to 5%, afterwards they are linear. It should be noted that the maximum capacities (Qult.) for Y/D=(0, 0.5, 1, and 1.5) were found to be (2394N, 2930N, 3225N, and 3725 N) at relative displacement S/D equals 10%. It is evident that piles capacity in dense sand are more resistant than those erected in medium- and loose-grained sand. And the axial pile capacity has been observably shown to be greatly affected by the position of geotechnical defect according to pile toe.

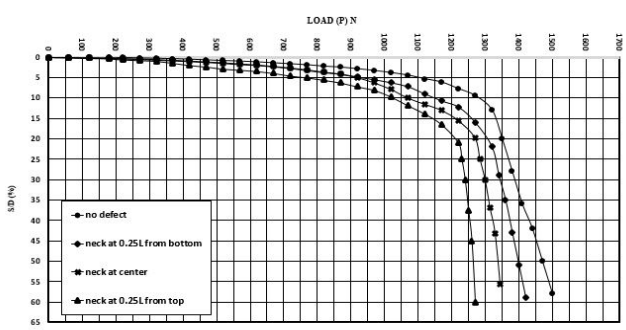

Figure 7. Relationship between axial compression load and relative displacement, S/D (%) for the sound pile and different defective model piles in the loose sand (Dr= 30%).

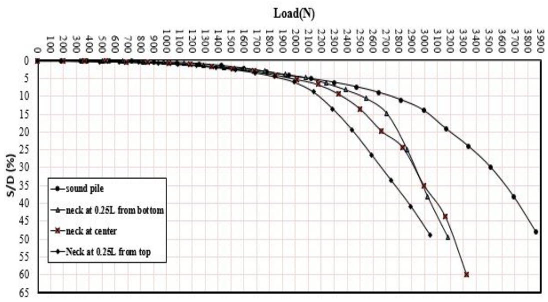

Figure 8. Relationship between axial compression load and relative displacement, S/D (%) for the sound pile and different defective model piles in the medium dense sand (Dr= 60%).

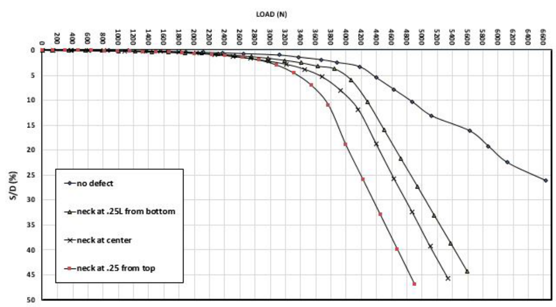

Figure 9. Relationship between axial compression load and relative displacement, S/D (%) for the sound pile and different defective model piles in the dense sand (Dr= 80%).

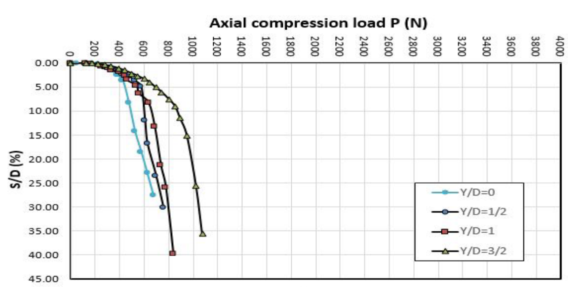

Figure 10. Relationship between axial compression load and relative displacement, S/D (%) for a pile based on soft pocket with different positions (Dr=30%).

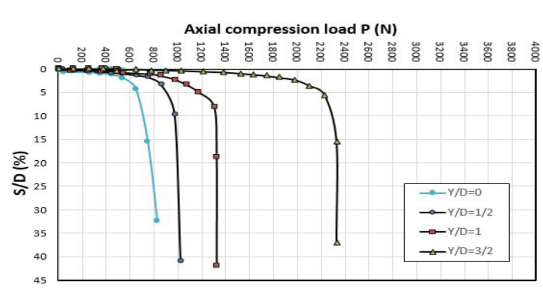

Figure 11. Relationship between axial compression load and relative displacement, S/D (%) for a pile based on soft pocket with different positions (Dr= 60%).

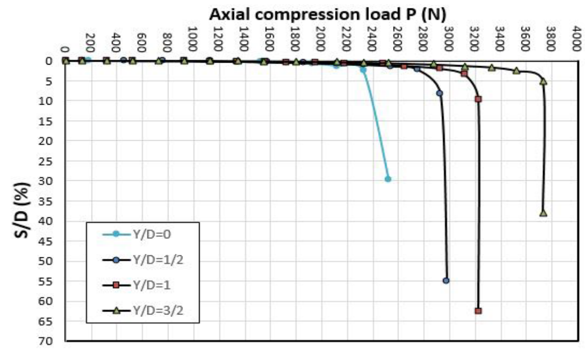

Figure 12. Relationship between axial compression load and relative displacement, S/D (%) for a pile based on soft pocket with different positions (Dr= 80%).

5.3 Effect of Structural Defect (Necking)

The influence of the existence of necking in a pile and the ultimate axial load reduction factor = [(B.C of sound pile – B.C of defective pile)/B.C of sound pile] for different model piles were studied and presented in Figure 13. This figure indicated the relation of the load reduction factor for model piles with different positions of necking in different relative density. In the loose sand (Dr=30%) reduction factors were found to be (9.57%, 15.05% and 18.5%) for the pile with a neck at 0.25 L from the pile toe, the pile with a neck at center and the pile with a neck at 0.25 L from the pile toe in the medium sand (Dr=60%), and the reduction factors were found to be (6.99%, 12.07% and 19.07%) for the pile with a neck at 0.25 L from pile toe, the pile with a neck at the center and the pile with a neck at 0.25 L from the pile toe. Furthermore, in the medium dense sand (Dr=80%), the reduction factors were found to be (11.8%, 15.94% and 23.81%) for the pile with a neck at 0.25 L from the pile toe, the pile with a neck at the center and the pile with a neck at 0.25 L from the pile toe. According to this figure, one the one hand, it was clear that the ultimate axial load reduction factor pile was greater when the neck was present at the top of the pile, followed by the neck in the middle, and finally by the neck at the bottom of the pile. It can be concluded that, our results agreed with results [5,16,17]. According to Al-Mosawe and Al-Shakarchi, the decrease in the bearing capacity was (21%). Furthermore, the decrease in the bearing capacity was found to be (14%) and (10%) when the defect was at (L/2) and (2L/3), respectively. And this is agreed with or conclusion in that, the influence of necking in reducing the load carrying capacity of the pile was more when the neck was present near the top of the pile. The existence of necking made a loss of the side friction resistance. The axial load distribution of the pile was maximum on the top and then it decreased with depth. Therefore, the presence of necking on the top of the pile was more effective on the reduction load bearing capacity, and on the presence of necking at the bottom of the pile, respectively. On the other hand, this figure also indicated that, the values of the reduction factors were more in the dense sand due to increase in soil friction angle.

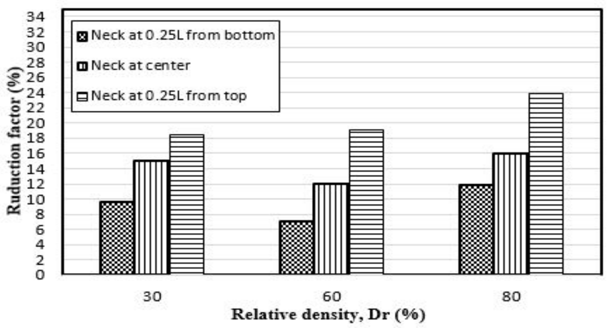

Figure 13. Relationship between axial compression load reduction factor (%) and relative displacement (Dr), in different positions of necking.

5.4 Effect of Geotechnical Defect (Soft Pocket)

To study the effect of the existence of the soft pocket, Figure 14 indicates the reduction factor = [(B.C of the sound pile – B.C of the pile with geotechnical defect)/ B.C of the sound pile] for different positions of the soft pocket. This figure indicates the relation of the load reduction factor for the model piles with different positions of the soft pocket in different relative densities. In the loose sand (Dr= 30%), reduction factors were found to be (61.1%, 52.52%, 45.69% and 30.53%) for the pile with a soft pocket at (Y/D=0, Y/D=1/2, Y/D=1 and Y/D=3/2) respectively. In addition, in the medium dense sand (Dr=60%), reduction factors were found to be (48.24%, 38.25%, 30.89% and 15.56%) for the pile with a soft pocket at (Y/D=0, Y/D=1/2, Y/D=1 and Y/D=3/2) respectively. Furthermore, in the medium dense sand (Dr=80%), reduction factors were found to be (50.43%, 39.34%, 33.23% and 23.81%) for the pile with a soft pocket at (Y/D=0, Y/D=1/2, Y/D=1 and Y/D=3/2) respectively. An important point to be noted is that the ultimate axial load reduction factor a pile was greater when Y/D=0, followed by Y/D=1/2, Y/D=1 and finally by Y/D=3/2 from the bottom of the pile. However, this figure also shows that the reduction factor values were higher in the loose sand. It can be concluded that the effect of geotechnical defect decrease whenever the distance between the geotechnical defect and pile toe increase agreed with [7]. According to Eslami and Fellenius, the failure zone includes a depth below the pile toe ranging from 1.1 b to 1.5 b, and a horizontal extent ranging from 2 b to 4 b. Therefore, the greater the distance between the defect and the body of the effect, the less its effect is until it reaches a small degree value it exits out of failure zone.

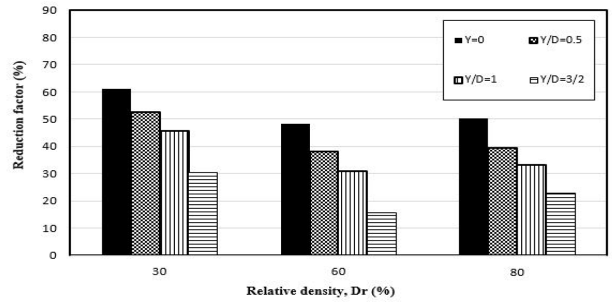

Figure 14. Relationship between axial compression load reduction factor (%) and relative displacement (Dr), in different positions of the soft pocket.

Influence of Sand Relative Density

Figures 15 and 16 show the effect of the sand relative density (Dr) on the ultimate axial pile load in the case of a structural defect and a geotechnical defect. This figure shows the relation between the ultimate axial load of sound and defective piles and different sand relative densities in different positions of defect. According to this figure, it is noticed that, in case of a structural defect, the ultimate axial load of different model piles increases with the increase of sand relative density. It was noticed that ultimate axial load of the model piles in the medium dense sand increased by (1.16, 1.22, 1.23, and 1.14) and in case of dense sand increased by (3.83, 3.74, 3.79, and 3.58), respectively for the sound pile, the pile with a neck at 0.25 L from the pile bottom, the pile with a neck at the center, and the pile with a neck at 0.25 L from the pile top respectively in comparison to the ultimate axial load of model piles in the loose sand. On the one hand, it was noticed that the influence of the sand relative density was most in case of the sound pile followed by the pile with a neck at 0.25 L from bottom, the pile with a neck at the center, and finally the least in the pile with a neck at 0.25 L from the top it can be concluded that bearing capacity increase with increase of relative density as a result of increase of soil friction angle and the surface area of pile. On the other hand, in the case of the geotechnical defect, the ultimate axial load of different model piles increased with the increase of the sand relative density [16,17]. The ultimate axial load of the model piles in the medium dense sand were increased by (2.87, 2.8, 2.74 and 2.62) and in case of dense sand were increased by (4.89, 4.90, 4.71 and 4.26) compared with the ultimate axial load of the model piles in the loose sand for the pile with a soft pocket at (Y/D=0, Y/D=1/2, Y/D=1 and Y/D =3/2) respectively**.** A point to be noted is that the influence of the sand relative density was most in case of Y/D=0 followed by Y/D=1/2, Y/D=1, and finally the least when Y/D =3/2).

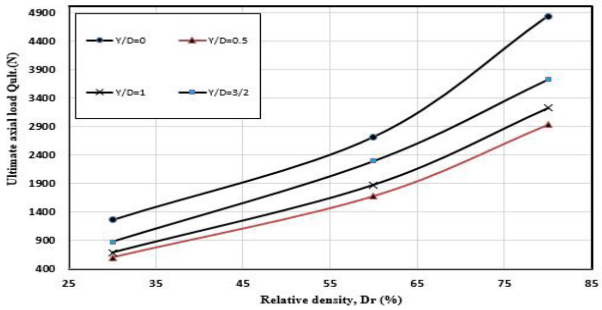

Figure 15. Relationship between ultimate axial Qult (N) load and relative dense, Dr (%)in different position of necking.

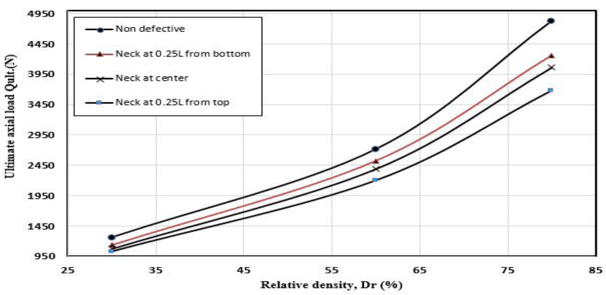

Figure 16. Relationship between ultimate axial Qult (N) load and relative dense, Dr (%) in different position of soft pocket.

6. Conclusions

The results showed that the structural and the geotechnical defect of a pile had a great effect on the reduction of the pile load capacity and on increasing the settlement. Such defects can be summarized as follows:

A. Structural defect:

The results clearly show that the existence of necking reduced the load carrying capacity of the pile.

Based on the experimental results, the influence of necking in reducing the load carrying capacity of the pile was most when the neck was present at the top of the pile followed by a neck at the center and a neck at the bottom of the pile.

The results of the study also show the load carrying capacity of the pile increased with the increase of relative density due to the increase of the pile skin friction force and the end bearing.

The results indicate that the influence of sand relative density was most in the case of the sound pile followed by the pile with a neck at 0.25 L from the bottom, the pile with a neck at the center, and finally the least in the pile with a neck at 0.25 L from the top.

B. Geotechnical defect:

The existence of the soft pocket reduced the load carrying capacity of the pile.

The influence of the soft pocket in reducing the load carrying capacity of the pile was greater when Y/D=0, followed by Y/D=1/2, Y/D=1 and finally Y/D =3/2 from the bottom of the pile.

The load carrying capacity of the pile increased with the increase of the relative density due to the increase in the pile skin friction force and the end bearing.

The influence of the sand relative density in increasing the relative density was most in case of Y/D=0 followed by Y/D=1/2, Y/D=1, and finally the least when Y/D =3/2).

Conflict of Interest

There is no conflict of interest.

References

[1] Poulos, H.G., 2005. Pile behavior—Consequences of geological and construction imperfections. Journal of Geotechnical and Geoenvironmental Engineering. 131(5), 538-563.
DOI: https://doi.org/10.1061/(ASCE)1090-0241(2005)131:5(538)

[2] Poulos, H.G., 1999. Behaviour of pile groups with defective piles. International Conference on Soil Mechanics and Foundation Engineering. pp. 871-876.

[3] Klingmüller, O., Kirsch, F., 2004. A Quality and Safety Issue for Cast-in-Place Piles-25 Years of Experience with Low-Strain Integrity Testing in Germany: From Scientific Peculiarity to Day-to-Day Practice. Current Practices and Future Trends in Deep Foundations. pp. 202-221.
DOI: https://doi.org/10.1061/40743(142)12

[4] Sakr, M., 2000. "Load Transfer Characteristics of Model Defective Piles in Clay" 8ASEC. pp. 1037-1051.

[5] Al-Mosawe, M., Al-Shakarchi, Y., 2021. Behavior of Defective Cast in Place Piles. Journal of Engineering. 27(4).
DOI: https://doi.org/10.31026/j.eng.2021.04.08

[6] Eslami, A., Fellenius, B.H., 1997. Pile capacity by direct CPT and CPTu methods applied to 102 case histories. Canadian Geotechnical Journal. 34(6), 886-904.
DOI: https://doi.org/10.1139/t97-056

[7] Elsawwaf, M.A.E., Azzam, W.R., Kassem, E.M.,

2021. An Experimental Study of the Behavior of a Strip Footing Adjacent to Reinforced Sand Slope Above a Soft Pocket. GEOMATE Journal. 21(87), 118-127.
DOI: https://doi.org/10.21660/2021.87.j2369

[8] Xu, M., Ni, P., Ding, X., et al., 2019. Physical and numerical modelling of axially loaded bored piles with debris at the pile tip. Computers and Geotechnics. 114, 103146.
DOI: https://doi.org/10.1016/j.compgeo.2019.103146

[9] Azzam, W.R., Al Mesmary, M., 2010. The behavior of single tension pile subjected to surcharge loading. Ned University Journal of Research. 7(1), 1-12.

[10] ECP (Egyptian Code of Practice), 2007. Egyptian code for design and construction of reinforced concrete structures. ECP 203-2007, Housing and Building Research Centre, Cairo.

[11] American Concrete Institute, 2000. Design, Manufacture, and Installation of Concrete Piles (ACI 543R-00), American Concrete Institute, Michigan, USA.

[12] Rao, S., Nasr, A., 2010. Behavior of vertical piles embedded in reinforced sand under pullout oblique loads. International Journal of Geotechnical Engineering. 4(2), 217-230.
DOI: https://doi.org/10.3328/IJGE.2010.04.02.217-230

[13] IS 2911 Part 1/Sec 1, 2010. Indian standard design and construction of pile foundations-code of practice: concrete piles.

[14] Terzaghi, K., Peck, R.B., Mesri, G., 1996. Soil mechanics in engineering practice. John Wiley & Sons.

[15] Meyerhof, G.G., 1976. Bearing capacity and settlement of pile foundations. Journal of the Geotechnical Engineering Division. 102(3), 197-228.
DOI: https://doi.org/10.1061/AJGEB6.0000243

[16] Krishnamurthy, P., Hariswaran, S., 2017. Numerical Studies on the Load Carrying Capacity of Defective Pile. Indian Geotechnical Conference.

[17] Sarvesh, E.A., Hariswaran, S., Premalatha, K. Influence of presence of defective pile in the load carrying capacity of pile group. Indian Geotechnical Conference.