University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 4 Volume 27 April 2021

Civil and Architectural Engineering

Behavior of Defective Cast in Place Piles

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ABSTRACT

This paper deals with testing defected model piles in the soil in order to study their behavior. In this respect, the results of model pile tests are discussed either geotechnically or structurally according to the type of failure.

Two parameters were studied in order to evaluate the general behavior of defective piles. These parameters include the defect location and the defect type for floating and end bearing pile. The results of the experimental work indicated that the critical case for floating pile is seen to be when the defect of (5%) at the first third of the pile length at which the decrease in the bearing capacity is about (21%), while the decrease in the bearing capacity is found to be (14%) and (10%), when the defect is at the middle and the lower third of the pile length, respectively. The decrease in the bearing capacity for floating pile is found to be (31%) and (21%) for void and neck defect, respectively, while the decrease in the bearing capacity for end bearing pile is found to be (43%) and (52%) for void and neck defect, respectively.

Keywords: defective pile, geotechnical failure ,structural failure, experimental work.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2021.04.08

Article received: 21/9/2020
Article accepted: 1/11/2020
Article published:1/4/2021

تصرف الركائزالمتضررة المصبوبة موقعيا

الاستاذ الدكتور يوسف الشكرجي	ألاستاذ الدكتور آمال السعيدي	الاستاذ الدكتور موسى الموسوي
كلية الهندسة-جامعة بغداد	كلية الهندسة-جامعة بغداد	كلية الهندسة-جامعة بغداد

الخلاصة

يتناول هذا البحث فحوصات لنماذج ركائز كونكريتية متضررة بهدف دراسة تصرفها داخل التربة. في هذا المجال نوقشت نتائج الفحوصات حسب طريقة فشلها أما انشائيا أو جيوتكنيكيا . تم دراسة عاملين لغرض تقدير التصرف العام للركائز المتضررة. العاملان هما موقع ونوع الضرر لكلا من نوعي الركائز السائبة وركائز التحمل الطرفي. بينت النتائج أن الحالة الحرجة للركائز السائبة ولنسبة ضرر (5 %) تكون في الثلث الاول من طول الركيزة ونسبة النقصان في قابلية تحملها (21 %) بينما نسبة النقصان في قابلية التحمل وجدت (14%)و (10%)عندما يكون موقع الضرر في منتصف والثلث الاخير من طول الركيزة، على التوالي. كما وجد أن نسبة النقصان في قابلية التحمل للركائز السائبة (31 %) و (21 %) عندما يكون نوع الضرر فراغ أو تجويف داخل مادة الركيزة وتخصر بالركيزة، على التوالي. بينما نسبة النقصان في قابلية التحمل للركائز ذات التحمل الطرفي (43 %) و (52 %) عندما يكون الضرر تجويف أو فراغ داخل مادة الركيزة وتخصر بالركيزة، على التوالي .

الكلمات الرئيسية: الركائز المتضررة ،الفشل الجيوتكنيكي ، الفشل الانشائي ، عمل تجريبي .

INTRODUCTION:

The defects in the cast-in-situ piles are often the consequence of faulty concreting. use of deleterious concrete materials, improper mix design, faulty concrete placement, and subsequent ground disturbances due to the construction of adjoining piles may combine to produce a poor quality pile **(Mohan, 1981) .** The effect of construction process on the pile can affect the pile performance and causes pile defects, These defects can also be classified into natural sources, inadequate ground investigation, construction causes, pile loading tests,and loading during operation **(Poulos,2005 ; El Wakil, and Kassim , 2010)**

Most defects in bored piles are not apparent at the completion of pile construction and this adds to the difficulties of prescribing any corrective action **(Al-Mosawe and Al-Obaydi, 2002).** During the last years progress was made towards ensuring the integrity of bored piles, and it seems probable popularity of this type of pile **(Davis, 1982; Sliwinsks, and Fleming, 1983).**

The common defects of piles are cold joints, zone of segregated or contaminated concrete, trapping of bentonite mud necking, and cavities **(Johnson and Kavanagh, 1968 ; Winterkorn and Fang, 1975; Thorburn and Thorburn, 1977; Fleming et al., 1985; Tomlinson, 1994)** . The first two types of defects result from interruptions in the concrete placement or premature extracting of the tremie pipe either partially or completely above the concrete-slurry interface. Mud trappings are caused by concrete of low workability and impediment to the flow of concrete due to closely spaced bars. Discontinuities or partial separation in the piles at the bottom edge of temporary casing can be caused by accidental lifting of low workability concrete or concrete without controlled setting during casing extraction. If the concrete in the casing is too stiff and has considerable frictional resistance against the casing, a column of concrete can be pulled up with casing.

Various studies have been conducted on the subject of defective piles. In general, however, these studies are mainly of theoretical, numerical or associated with experiments on reduced-scale models studies, for example the studies of Makarchian and Poulos (1994), Xu (2000), Novak et al. (2005), Cunha et al. (2010), and Freitas Neto et al. (2013, 2020).

The objective of this study is to identify the effects of different types and location of defects on a concrete pile behavior for both geotechnical and structural failure .

2. TESTING APPARATUS:

The testing apparatus of model piles comprises of three main parts: the model pile, the sand container and the loading system. The detailed description of each part is explained in the following paragraphs.

2.1. The Model Pile:

The model pile used in this study was made of concrete with a circular cross section, 55 mm diameter, with 300 mm length

A water balance was used to keep the pile axis vertical during the preparation of the test. The centring bar consisted of a small clamp, having two holes with screws used to fix the pile to the centring bar, and to fix the model pile in the required position.

2.2. The Sand Container:

The sand container is a steel box of dimensions (600×600×700 mm depth), made of steel plate of 3 mm thickness, stiffened with 3 lines of 25 mm angle sections, provided with 280×220 mm hatch for sand refilling as shown in Plate (1). The base was stiffened with additional 3 mm steel plates and 25 mm steel angle frame and stiffeners, in order to prevent concentration of the load exerted from the piston on a small area. In order to keep the pile model vertical in position and quite in centre of the box, a special guide with a diameter of 70 mm, fixed on the box walls was installed. The guide is provided with two screw bolts to adjust the pile model in place as shown in Plate (2). The internal faces of the box were covered with polyethylene sheets, in order to reduce the slight friction which might be developed between the box surface and soil.

Plate1.The Sand Container.

Plate 2. Special Guide to Adjust the Pile Model in Place.

2.3. The Loading System:

A conventional compression machine with digital control system was used to conduct the axial loading on piles.

The load on the pile was measured using proving rings of 5 and 100 kN capacity proving rings, while the vertical deflection of the pile was measured using dial gauge (0.01 mm/division) as shown in Plate (3).

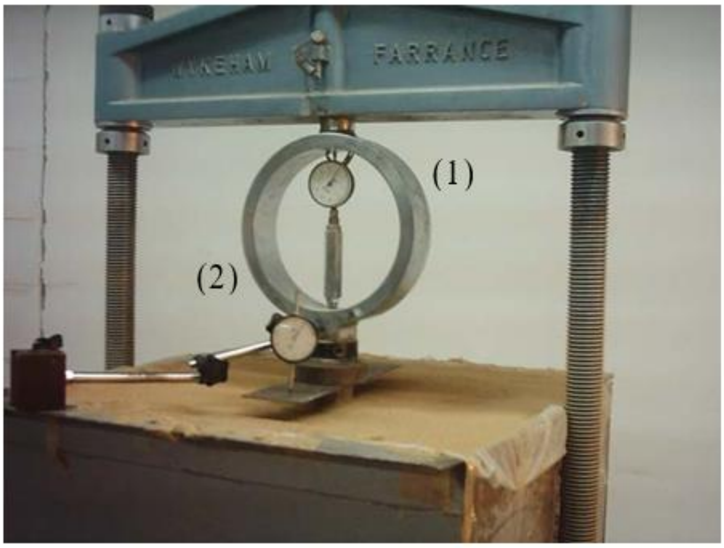

Plate 3. Arrangement of the Proving Ring and Dial Gauge During Axial Loading Tests, (1) Proving Ring, (2) Dial Gauge.

3. SAND PROPERTIES:

The sand used in this study, is well graded Al-Ekhaither sand. In order to remove as much dust as possible the sand was washed with running water. Then the sand is air dried. The sand passing sieve No.10 (B.S.) was used.

The tests are performed with dense sand corresponding to a dry unit weight of approximately 17.50 kN/m^3. The maximum and minimum dry unit weights of the sand are determined according to the ASTM (4253-00) and ASTM (4254-00), respectively. The results of maximum and minimum dry unit weight of sand are 18.4 kN/m^3 and 15.2 kN/m^3, respectively.

The specific gravity test is performed according to the British standard B.S.(1377: 1975). The specific gravity of the used sand is 2.67.

The grain size are analyzed according to the ASTM (D422-63). According to the grain size distribution curve shown in **Fig.1** the sand is classified as poorly graded sand with a coefficient of uniformity less than 6 and coefficient of curvature (C_c = 1.16).

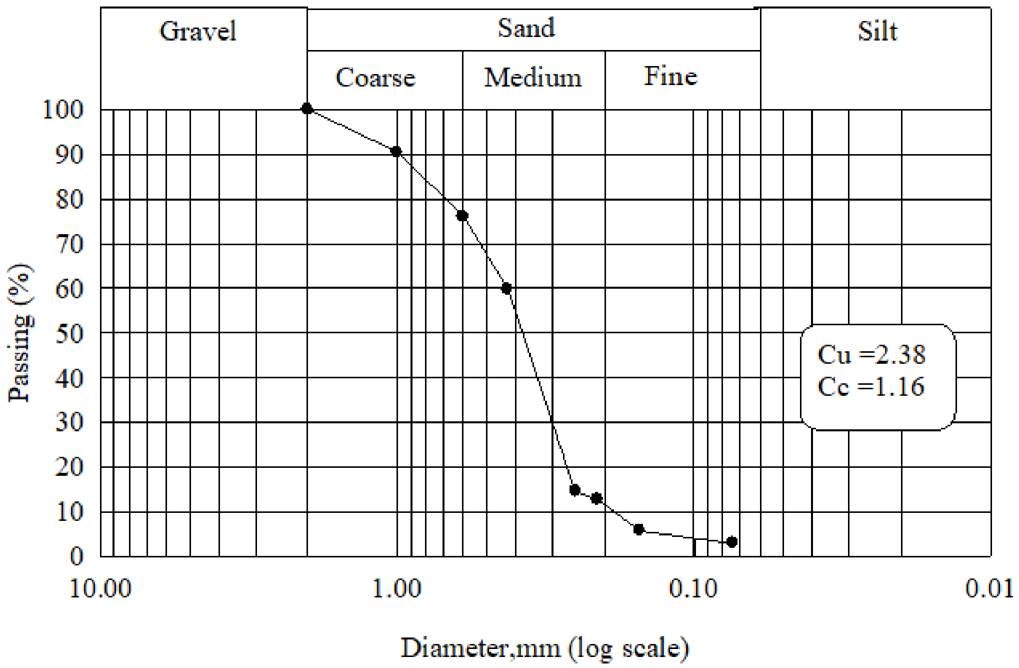

Figure 1. Grain Size Distribution Curve for the Tested Sand.

Laboratory tests were carried out on the sand to get some other properties and their values are listed in **Table 1.**

Table 1. Sand Properties.

Specific Gravity	Gs = 2.67
Void Ratio and Dry Unit Weight	e_{max} = 0.72, γ_{dmin} = 15.2 kN/m^3
	e_{min} = 0.42, γ_{dmax} = 18.4 kN/m^3
	e_{used} = 0.50, γ_{dused} = 17.5 kN/m^3
Relative Density	D_r = 75%
Angle of Internal Friction	ϕ = 38°

The Value of (∅) was obtained from the results of triaxial compression test (uu test) in accordance with ASTM D2850-95.

4. TESTING PROGRAM:

The details of the testing program is shown in **Table 2.**

Table 2. The Testing Program.

Variables studied	Type of pile	Location of defect	Defect ratio	Length of pile (mm)	Type of defect	Embedment ratio
(I) Floating Pile						
(1) Influence of the external defect location	Defected	L/3	5%	300	Neck	1.0
	Defected	L/2	5%	300	Neck	1.0
	Defected	2L/3	5%	300	Neck	1.0
	Sound	–	–	300	–	1.0
(2) Influence of external defect type	Defected	L/3	5%	300	Neck	1.0
	Defected	L/3	5%	300	External void	1.0
	Sound	–	–	300	–	1.0
(II) End Bearing Pile						
(1) Influence of the defect location						
(a) External	Defected	L/3	5%	300	Neck	1.0
	Defected	L/2	5%	300	Neck	1.0
	Defected	2L/3	5%	300	Neck	1.0
	Sound	–	–	300	–	1.0
(b) Internal	Defected	L/3	5%	300	Void	1.0
	Defected	L/2	5%	300	Void	1.0
	Defected	2L/3	5%	300	Void	1.0
	Sound	–	–	300	–	1.0
(2) Influence of defect type	Defected	L/3	5%	300	Neck	1.0
	Defected	L/3	5%	300	Void	1.0
	Sound	–	–	300	–	1.0

Note: - L is the length of pile.
- All diameters of pile (55) mm.
- Defected ratio, is the defected volume compared to the total volume of the pile.
- Embedment ratio, is the embedded pile length to the total length of the pile.

5. TESTING PROCEDURE:

5.1 Placement of Sand:

To get dense sand with relative density of 75%, accumulated weight of the sand for a specified volume was taken. The sand was poured in layers, 100 mm for each layer until the desired height of sand was reached. A vibrator was used to compact the layer. The thickness of each layer after compaction was 100mm.

5.2 Placement of the Models:

The sand was poured in layers, 100 mm each, until reaching the bottom level of the model pile. After installing the model in its vertical position by the guide and the screw bolts that are attached, in such a way to ensure its central position and verticality, which was checked by the water balance. Resuming sand was then poured with a similar procedure to the designed level with special care to avoid disturbing the pile. After that the guide was removed carefully and the sand surface was levelled. Finally, the proving ring was fixed on top of the model, and the dial gauge was fixed in its position as shown in Plate (3).

5.3 Model Pile Test:

The results of all tests described in the testing program, **Table 2.** on the model piles are presented. In this respect, the results of model pile tests will be discussed through two directions. The first includes the non-destructive test, in which the failure is a geotechnical one (the failure load is taken as the load corresponding to a settlement equal to (0.1) times the diameter of the pile **(Terzaghi and Peck, 1967)**, and the end condition of the pile is floating.

The second includes the destructive tests, where the load tests is running on the model to cause structural damage in which the pile condition is considered end bearing.

6. RESULTS AND DISCUSSION:

6.1 Variables Studied in Non-Destructive Testing (Geotechnical Failure):

6.1.1. Influence of the external defect location:

Fig 2. presents the load-settlement relations for a sound pile and a number of defective piles. The location of the defect is at L/3, L/2 and 2L/3, respectively, (where L is the pile length). A (5%) neck defect is considered in the study. It can be noticed that uniform relations are obtained for the whole cases. This may be attributed to the uniform defects made in the piles. The critical case is seen to be when the defect is at the first third of the pile length at which the bearing capacity decreased to about (21%) while the decrease in bearing capacity is found to be (14%) and (10%) when the defect is at (L/2) and (2L/3), respectively.

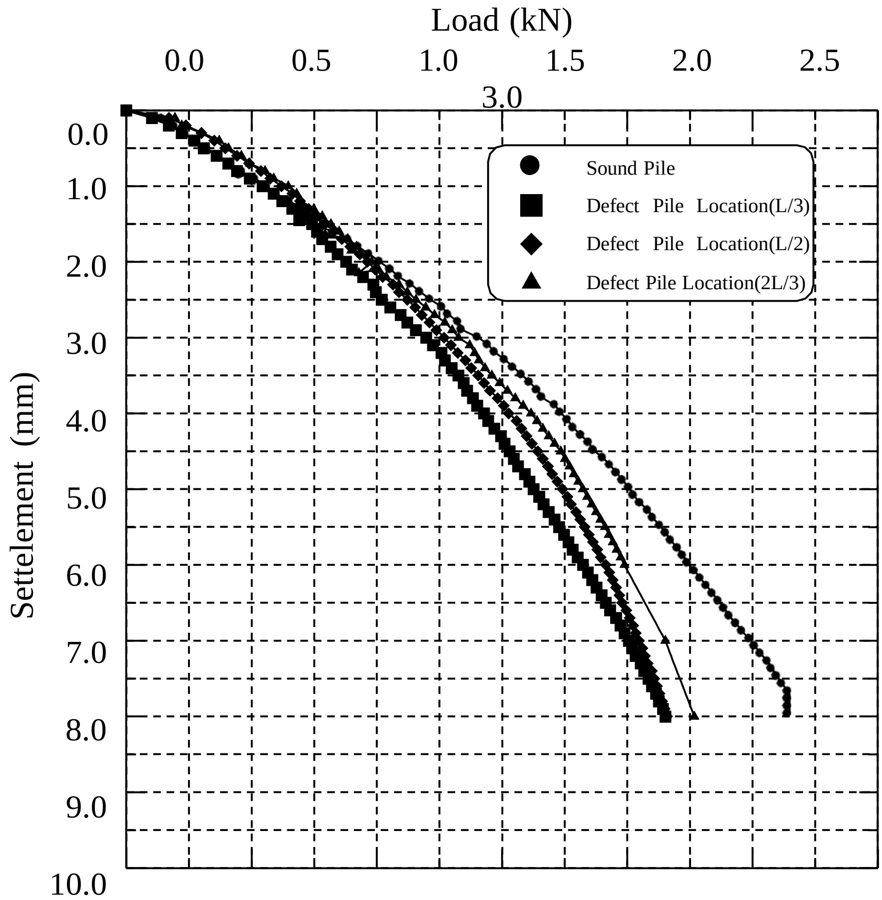

Figure 2. Location Effect for Floating Pile.

Fig. 3 shows a relationship between the load ratio (P/P_u) (where P is the pile head load and P_u is the ultimate load) and settlement. It can be seen that when the load is normalized for the different cases, the load-settlement curves show approximately a unique relation. This means that sound and defective piles show the same settlement at the same stress level.

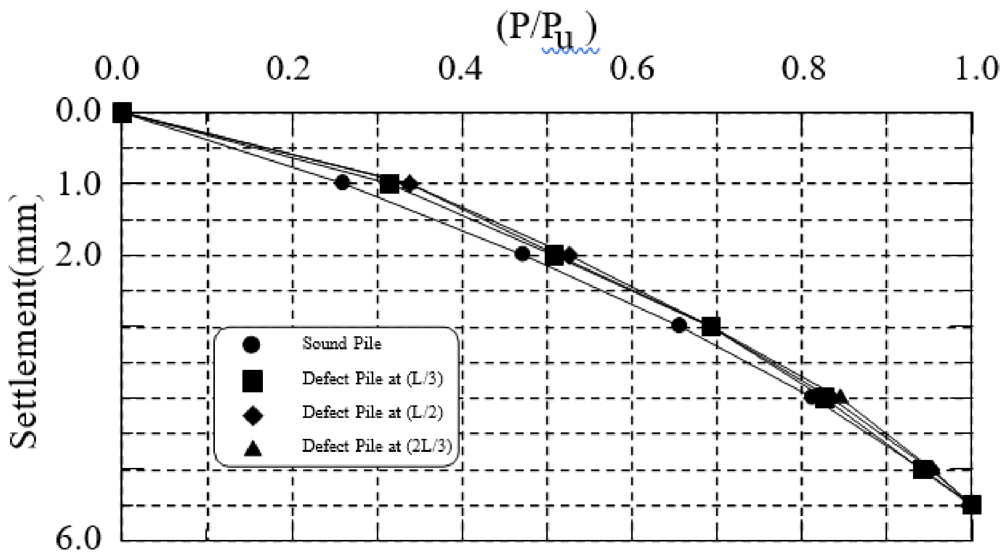

Figure 3. The Relation Between (P/P_u) for Floating Pile and Settlement.

Fig. 4 shows a relationship between the load ratio (P_d/P_s) (where P_d and P_s are the load on the defective and sound piles, respectively) and settlement for different defect locations. It can be noticed that the measured settlement of defective
pile decreases as its load capacity approaches that of sound pile (P_d/P_s 1).

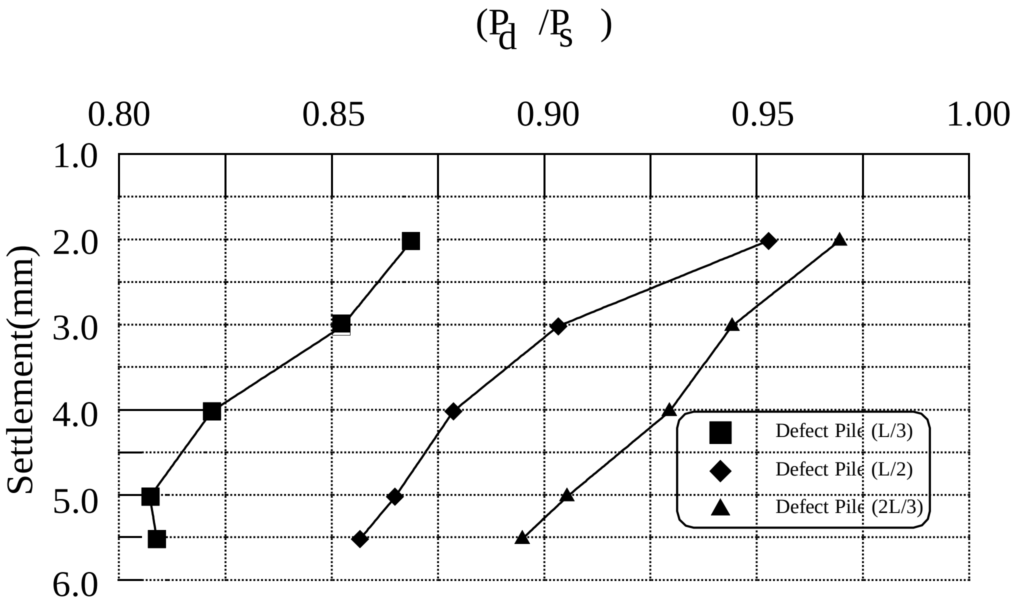

Figure 4. The Relation Between (P_d /P_s) for Floating Pile and Settlement.

Fig.5 shows the variation of the load reduction factor ($r = (1 - P_{ud}/P_{us}) \times 100$, where P_{ud} and P_{us} are the ultimate loads for defective and sound piles, respectively) with the location of defect along the pile. One could notice that the load reduction factor increases when the defect moves downward the pile.

The load reduction factor, r, decreased to about 10% when the location of the defect moves from L/3 to 2L/3.

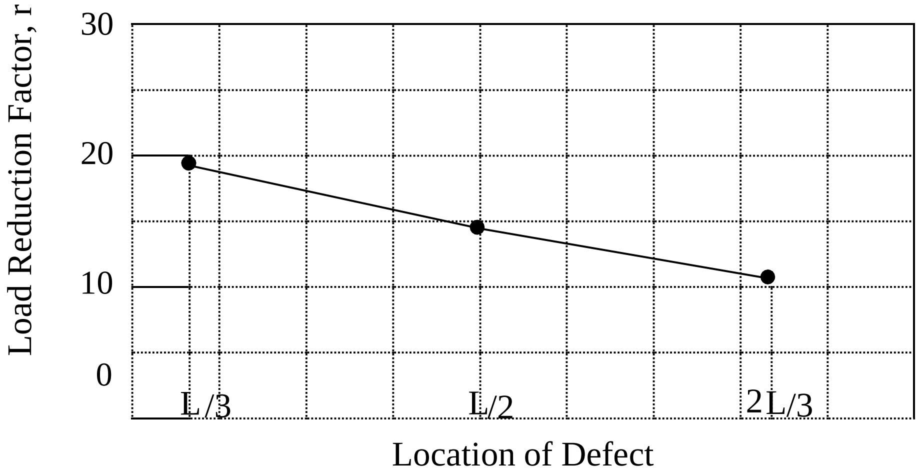

Figure 5. The Relation Between Load Reduction Factor (r) and Location of Defect.

6.1.2. Influence of Defect Type:

Fig.6 shows the effect of two types of defect on the load-settlement characteristics of floating piles. These are made through necking or by making an external void in the pile of the same ratio of the neck defect.

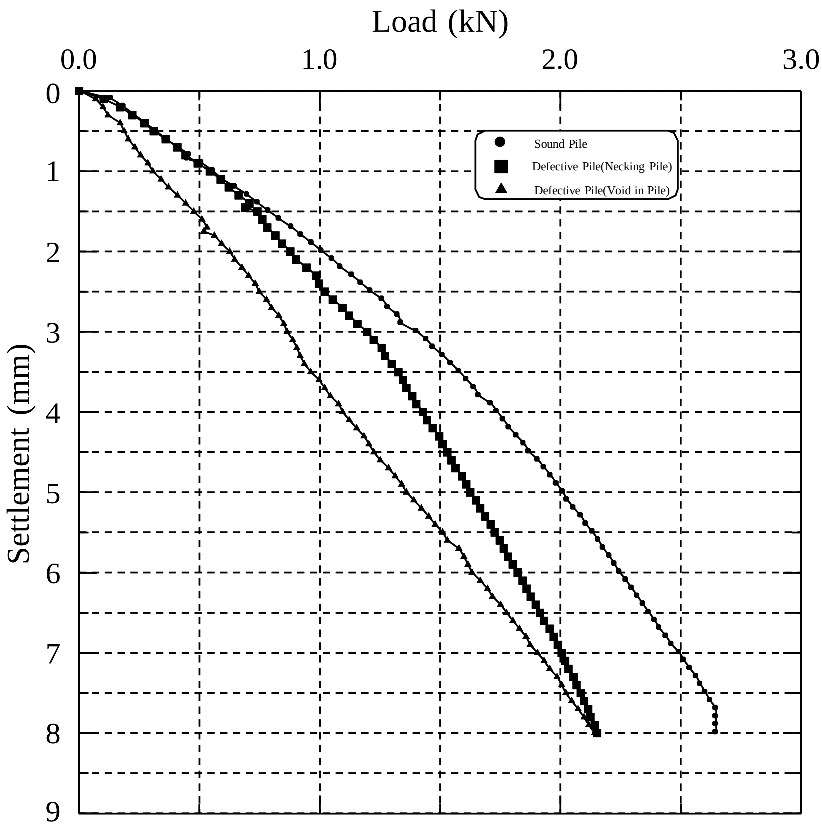

Figure 6. Effect of the Defect Type for Floating Pile.

From the test results it appears that at a constant external defect ratio (5%), the bearing capacity of the pile containing a void defect was less than that of necking type. This is because of the higher defect surface provided in the void type than that of the necking one, which causes reduction in friction, i.e., the necked pile looses some of its skin friction capacity, and hence the ultimate bearing capacity. The decrease in the bearing capacity found to be (31 %) and (21 %) for void and neck defect, respectively.

6.2 Variables Studied in Destructive Testing (Structural Failure):

6.2.1. Influence of the defect location:

Figs (7) and (8) present the effect of defect location on the settlement characteristics of both cases; piles with internal defect (void) and external defect (neck).

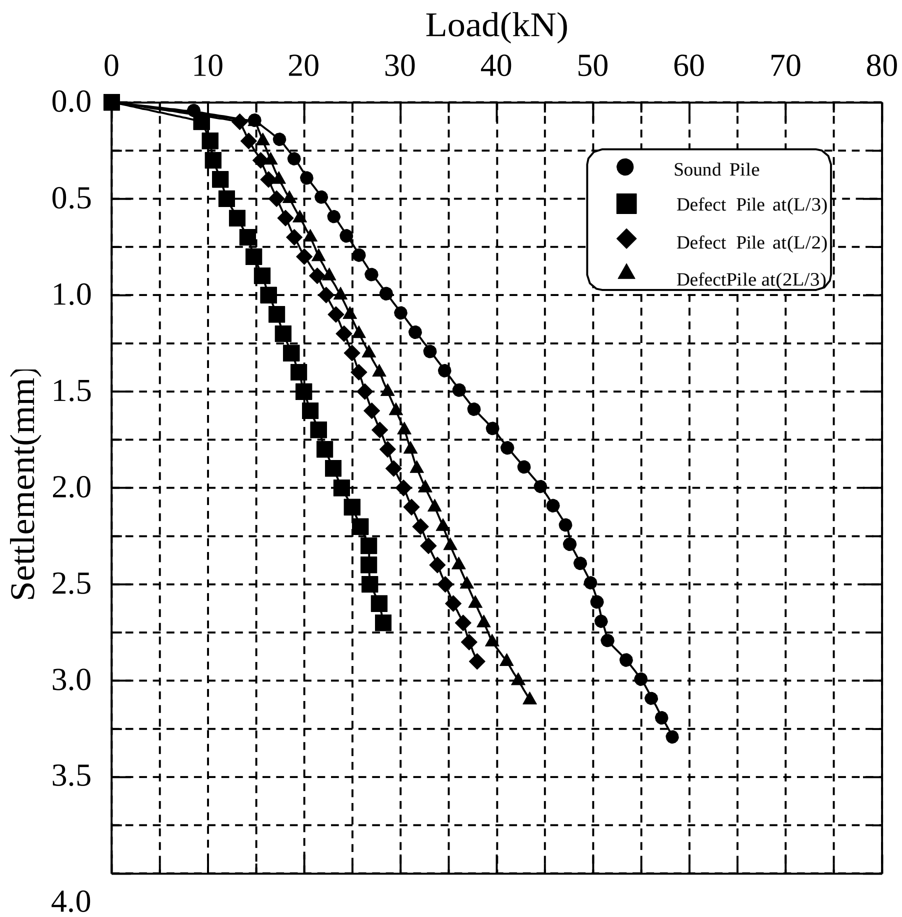

Figure 7. Effect of Defect Location for End Bearing Pile (External Defect).

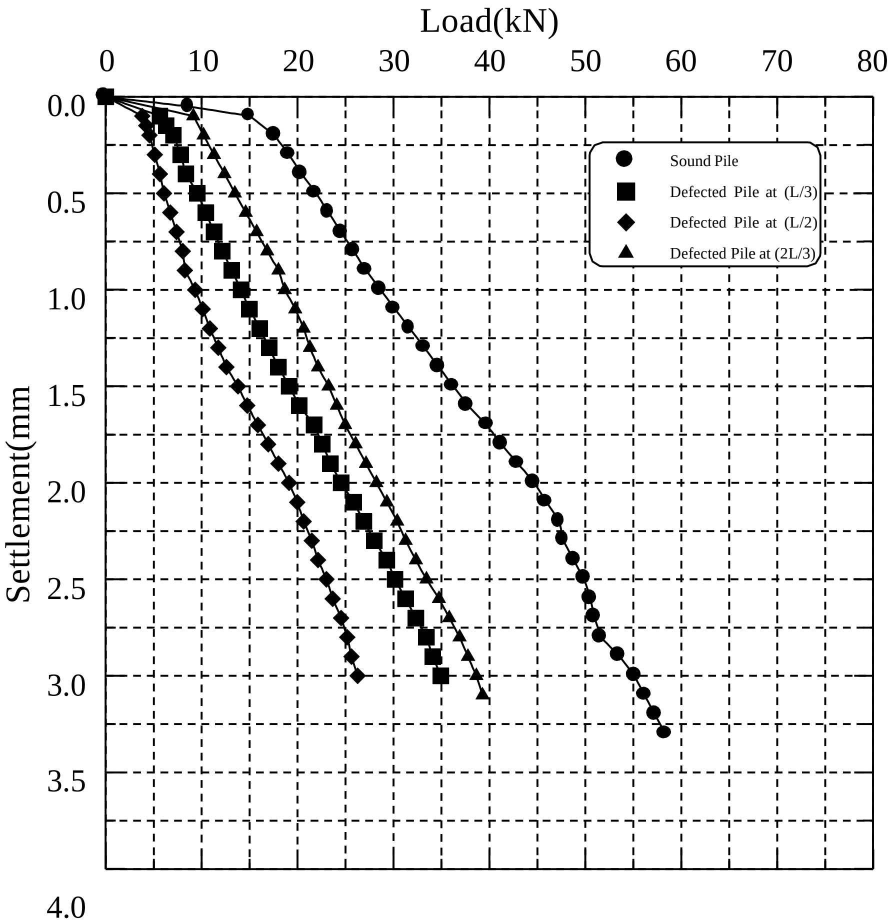

Figure 8. Effect of Defect Location for End Bearing Pile (Internal Defect).

Fig.7 shows the load-settlement relationships of different piles. The position of defect is varied from (1/3) to (2/3) of the pile length. It can be seen that the ultimate bearing capacity of the pile decreases by a pronounced manner when the pile is defected.

The critical position of the defect is found to be at the first third of the pile length at which the bearing capacity is decreased by about (52 %) while the decrease in bearing capacity is found to be (35 %) and (26 %) when the defect is at (L/2) and (2L/3) respectively.

For piles with internal defect, **Fig.8**, the critical position of the defect is at the mid length of the pile where the bearing capacity decreases by about (55 %) compared with sound piles, while the decrease in bearing capacity is found to be (40 %) and (33%) when the defect is at (L/3) and (2L/3) respectively.

Fig.9 shows that the normalized local capacity (r) load reduction factor ($r = (1 - P_{ud}/P_{us}) \times 100$, where P_{ud} and P_{us} are the ultimate load on defective and sound pile, respectively) decreases when the location of external defect moves downward the pile.

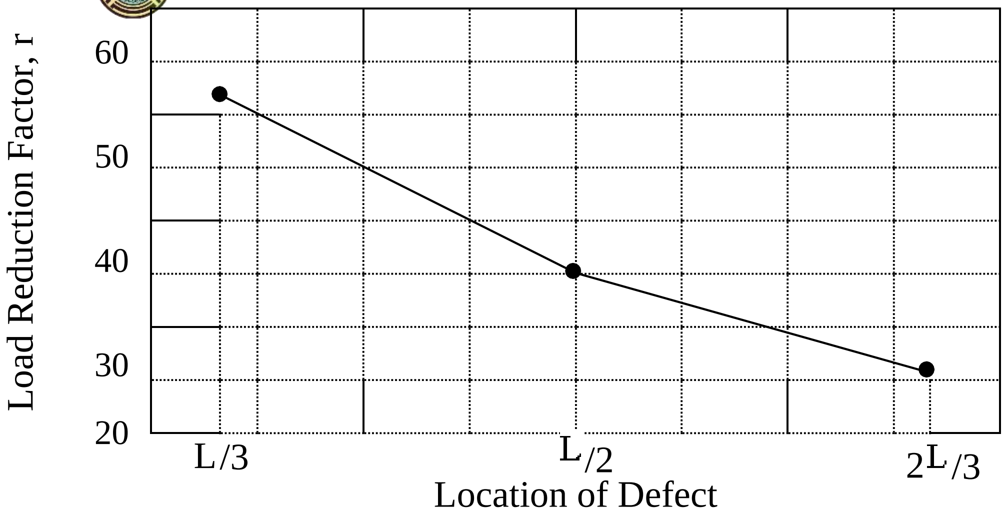

Figure 9. The Relation Between Load Reduction Factor (r) and Location of Defect for End Bearing Pile.

6.2.2. Influence of Defect Type:

At a constant defect ratio, the test results show that the bearing capacity of the neck defect was less than that of void defect **Fig.10.** The decrease in the bearing capacity is found to be (43%) and (52%) for void and neck defect, respectively.

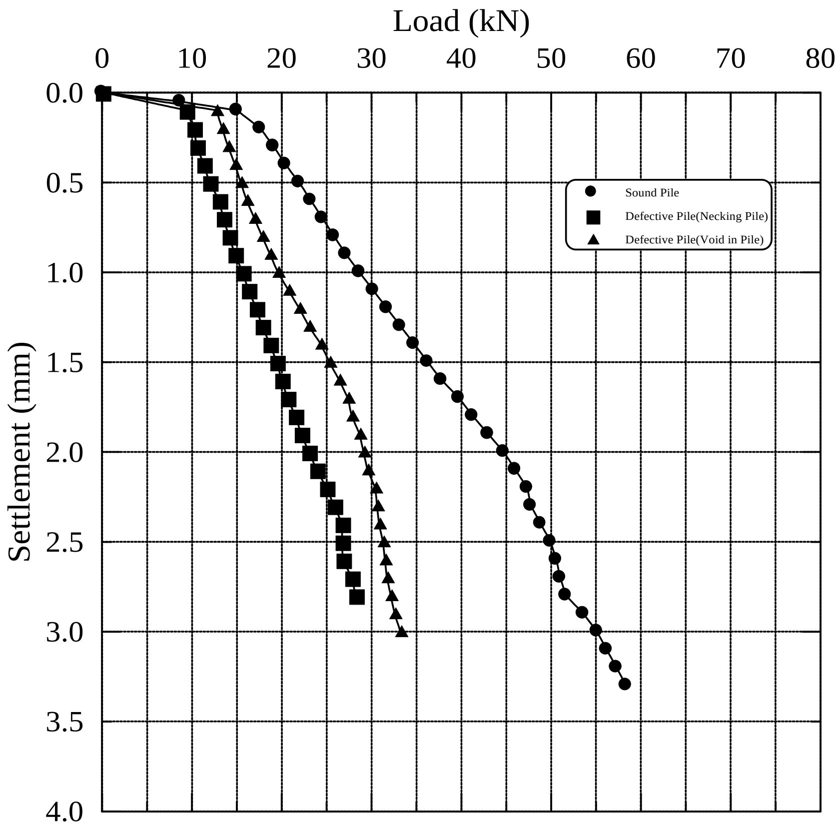

Figure 10. Effect of the Defect Type for End Bearing Pile.

7. PHOTOGRAPHIC DOCUMENTATION OF TEST RESULTS:

The test results are also documented with photographs as shown in photos (1) to (8).

In photo (1), a sound pile is shown before and after testing. The failure is shown to be at the first (1/3) of the pile length.

In photo (2) to (4), defected piles with neck located at L/3, L/2 and 2L/3 are presented, respectively. In all cases, the pile failed at the position of neck where the section of the pile is weak.

In photo (5) to (7), piles with internal void are presented. The voids are located at L/3, L/2 and 2L/3, respectively. It can be seen that a wide crack propagates from the pile head or tip towards the void where a complete failure takes place.

In photo (8), external void is made in the pile. The failure zone seems like a bulging has occurred in the first third of the pile length where the void is located.

Destructive Test for Model Pile.

The Model Pile Before Testing	The Model Pile After Testing	Description of Model Pile
		- Sound pile. - 30 cm length. - P_u = 58.4 kN.
Photograph (1)		
		- Defected pile (Neck). - 30 cm length. - Neck 5% at L/3. - P_u = 28.21 kN.
Photograph (2)		

<u>Note:</u> All diameters of pile (55 mm).

The Model Pile Before Testing	The Model Pile After Testing	Description of Model Pile
		- Defected pile (Neck). - 30 cm length. - Neck 5% at L/2. - P_u = 37.93 kN.
Photograph (3)		
		- Defected pile (Neck). - 30 cm length. - Neck 5% at 2L/3. - P_u = 43.4 kN.
Photograph (4)		

Note: All diameters of pile (55 mm).

The Model Pile Before Testing	The Model Pile After Testing	Description of Model Pile
		- Defected pile (Internal void). - 30 cm length. - Void 5% at L/3. - P_u = 34.94 kN.
Photograph (5)		
		- Defected pile (Internal void). - 30 cm length. - Void 5% at L/2. - P_u = 26.26 kN.
Photograph (6)		

<u>Note:</u> All diameters of pile (55 mm).

The Model Pile Before Testing	The Model Pile After Testing	Description of Model Pile
		- Defected pile (Internal void). - 30 cm length. - Void 5% at 2L/3. - P_u = 39.28 kN.
Photograph (7)		
		- Defected pile (external void). - 30 cm length. - Void 5% at L/3. - P_u = 33.2 kN.
Photograph (8)		

<u>Note:</u> All diameters of pile (55 mm).

8. CONCLUSIONS:

1. For floating pile:

- The critical case for (5%) neck defect, at which the minimum bearing capacity is obtained, is seen to be when the defect is at the one third of the pile length, the bearing capacity is decreased to about (21%) while the decrease in bearing capacity is found to be (14%) and (10%) when the defect is at (L/2) and (2L/3), respectively.

- The decrease in the bearing capacity is found to be (31%) and (21%) for (5%) void and neck defect, respectively.

2. For end bearing pile:

1. The critical position of (5%) external defect is found to be at the one third of the pile length at which the bearing capacity is decreased by about (52%) while the decrease in bearing capacity is found to be (35%) and (26%) when the defect is at (L/2) and (2L/3) respectively.

For piles with internal defect of (5%), the critical position of the defect is at the mid length of the pile where the bearing capacity decreases to about (55%) compared with sound pile while the loss in bearing capacity is found to be (40%) and (33%) when the defect is at (L/3) and (2L/3), respectively.

2. The decrease in the bearing capacity is found to be (43%) and (52%) for (5%) void and neck defects, respectively.

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