



EXPERIMENTAL INVESTIGATION OF MODEL PILES IN SLOPING GROUND SUBJECTED TO SURCHARGE LOADS

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Abstract: *This study deals with experimental studying of the influence of an adjacent surcharge loads on pile's behavior in both horizontal and sloping ground surface. A number of laboratory tests were performed on instrumented aluminum pipe piles of 25 mm outer diameter embedded in sandy soil subjected to surcharge load. The study took into consideration the effect of surcharge intensity, sloping ground and soil's relative density on lateral deformation of piles in terms of displacement and bending moment. The study was performed on different sloping ground [vertical to horizontal (V:H)] such as, "1V:3H", "1V:2.5H", "1V:2H" and "1V:1.5H", in addition to horizontal ground. Three different relative densities of sand (29% , 50% and 75%) were adopted in this study. The results showed that the increasing in the surcharge loads increases lateral displacement and bending moments of piles in horizontal and sloping ground surface. It was also calculated that the bending moments and displacement of piles increase with increasing sloping ground and decreasing relative density of soil.*

Keywords: pile, sand, surcharge load, sloping ground, relative density, lateral displacement and bending moment.

1. INTRODUCTION

Pile foundations are primarily used for providing resistance against direct "active" loads (vertical, lateral or both) which are directly applied to the pile head by a structure. However, with rapid development of cities and transportation systems, pile in existing structure is also subjected to indirect "passive" loads induced from lateral soil movements due to surcharge loading, tunneling operation, deep excavation, pile driving operation, etc. Besides, there are situations where piles are designed for stabilizing the moving



slopes and liquefiable soils. In all these conditions, the ground movement may inform extra force, cause increase in the lateral deformation of piles which may finally cause problems and even damage to the structure of piles (Pan et al, 2002 and Al-Abboodi et al, 2015). Although the soil movement is likely in both lateral and vertical directions, lateral ground movements are more important as pile foundation is not designed for sustaining important lateral load (Bauer et al, 2014).

Several authors, such as Bransby (1995), Yang et al. (2002), Poulos (2007) and Karkush and Jafar (2015) conducted many laboratory tests for investigating the effect of an adjacent surcharge loading on pile's behavior in horizontal ground surface. The results showed that the surcharge load increases the lateral displacement of piles.

Mezazigh and Levacher (1998) , Zhang et al. (2004), Begum et al. (2008), Sivapriya and Gandhi (2011), Muthukkumaran(2014) and Muthukkumaran and Begum (2015) investigated the pile's behavior in sloping ground subjected to horizontal active load at their head. They found that the horizontal force capacity of piles decreases with increasing sloping ground surface and decreasing the relative density of soil or shear strength of soil.

Muthukkumaran et al. (2004) investigated influence of applied surcharge loads on pile's behavior embedded in both horizontal and slope surface of 1V:1.5H (i.e., 1 vertical to 1.5 horizontal). The results found that the displacements of piles in slope surface condition are higher than that in horizontal condition. Muthukkumaran and Krishnan (2012) and Sharafi and Sojoudi (2016) , presented three dimensional finite differences analyses for investigating the pile's response in different slope surface subjected to surcharge loads.

However, all these studies with the exception of Muthukkumaran et al. (2004) have been directly towards the behavior of piles in either horizontal ground under surcharge loads or in sloping ground under lateral active loads. Therefore, the present study aims to examine the influence of an adjacent surcharge loads on pile embedded in horizontal and different sloping ground with different relative densities of sandy soil. The engineering properties of sand, details of experimental apparatus, sand placement method, measurement system and properties of tested pile are described below.

2. SOIL PROPERTIES

Clean dry sand was used in this study for all the tests as a model ground, it was sieved on the sieve no (10) to remove the coarse particles. Table (1) shows the physical and mechanical properties of this sandy soil .It is classified as poorly graded sand (SP) based on the "Unified Soil Classification System" (USCS).

Table (1): Physical and mechanical properties of sand

Property	Value
Specific Gravity, Gs	2.65
D ₁₀ (mm)	0.18
D ₃₀ (mm)	0.31
D ₅₀ (mm)	0.41
D ₆₀ (mm)	0.48
Coefficient of curvature, Cc	1.11
Coefficient of uniformity, Cu	2.67
USCS-soil type	SP
Maximum dry unit weight, γ_{dmax} , kN/m ³	16.78
Minimum dry unit weight, γ_{dmin} , kN/m ³	14.1
Angle of internal friction ϕ degree(for Dr = 29%)	30
Angle of internal friction ϕ degree(for Dr = 50%)	33
Angle of internal friction ϕ degree(for Dr = 75%)	39

3. TESTED PILE

Hollow aluminum pipes of 25 mm outer diameter, 1.2 mm wall thickness and 600mm embedded length with a bottom plugged was adopted as a model pile in this study. The pile's flexural stiffness was calculated by performing simply supported beam test. By measuring the deflection at the center the model pile of under a given load, Pile's flexural stiffness was found ($351 \times 10^6 \text{ N.mm}^2$).

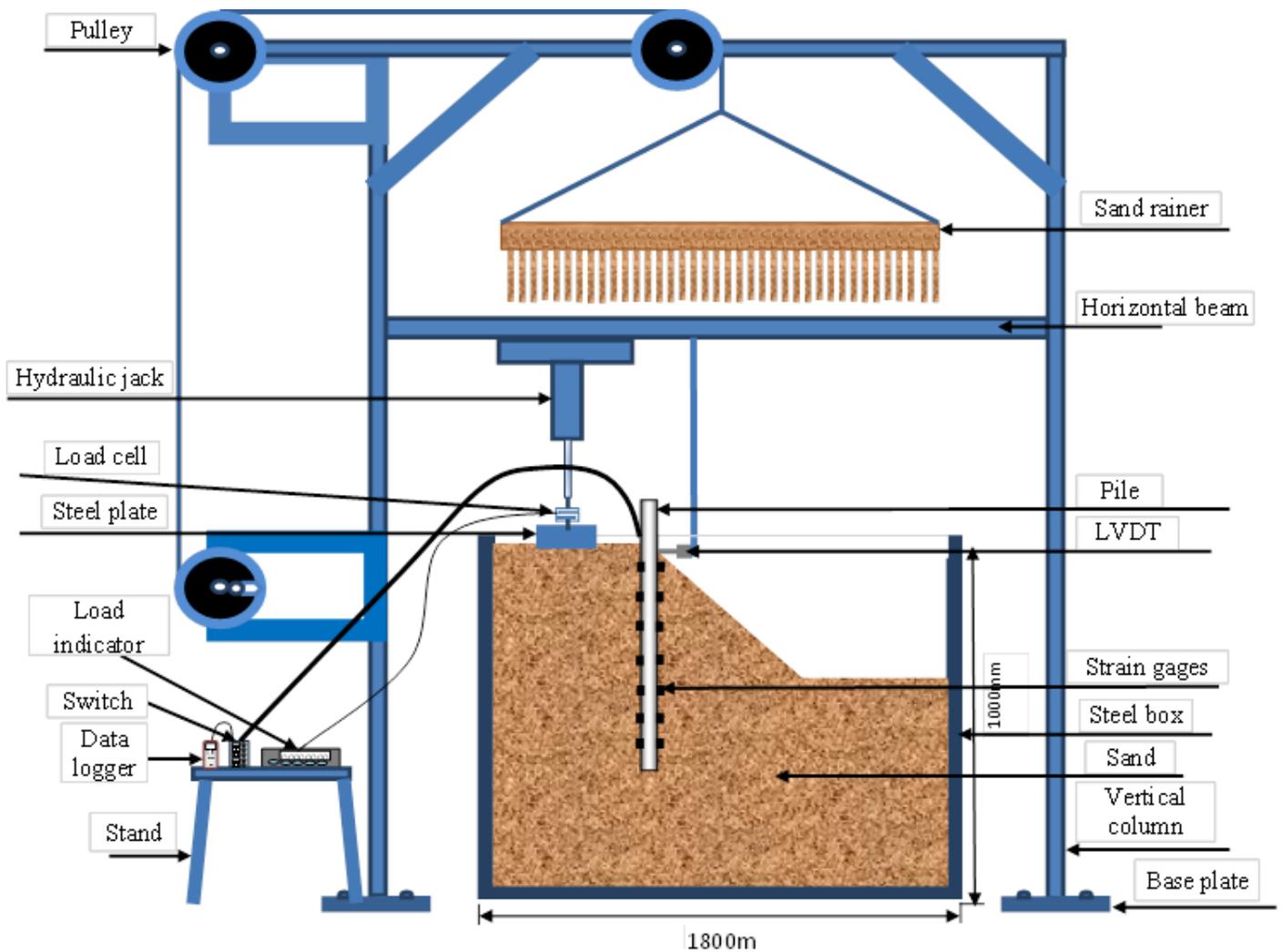


Figure (1): Test Set Up

4. TEST SET-UP

An experimental apparatus was designed and fabricated for the current study to investigate the effect of an adjacent surcharge loading on pile foundation embedded in sloping ground. It consisted of four main parts (i.e., steel box, loading system, sand raining system and measurements system). Figure (1) shows the overall arrangement of the testing apparatus and all the component details are presented below.



4.1. STEEL BOX

The experimental study was performed on the model pile in a rectangular steel container with the size of 1.8 m length x 1 m width x 1 m height. The steel container was made of thick steel plate having a thickness of 6.5 mm. The dimensions of the box were designed such that to eliminate the boundary effects in the result.

4.2. LOADING SYSTEM

The loading system includes the load reaction frame, hydraulic jack and square plate (square footing). The load reaction frame consisted of two vertical c-channels (as vertical columns) and horizontal c-channel (as a horizontal beam). A square steel plate of size 350 mm x 350 mm with 40mm in thickness was used as a square footing. The hydraulic jack (with capacity of 10 tons) was used to apply vertical loading on the instrumented pile (to insert the pile in sand) and also to apply vertical loading on the square footing (surcharge loading).

4.3. SAND RAINING SYSTEM

The sand raining technique of sand placement can produce the most uniform and reproducible deposits (Pathak and Dalvi, 2011) .This technique was adopted for pouring the sand in the steel box since this method is simple to adopt and forms the most uniform and reproducible sand beds and is able to reproduce a greater range of sand densities. A special raining device was fabricated from timber pieces, having internal dimensions of 1780 mm by 980 mm, and 150 mm. The sand raining base was perforated with 6 mm diameter holes on a 40 mm by 40 mm grid pattern. The sand raining is suspended over the box with a guide at each of the four corners; it is then connected to a hand winch by means of pulley system. The winch permits the sand raining to move up or down within the guide frame. The velocity of the raining sand is controlled by varying the fall height, which is maintained at a constant. A number of calibration tests were carried out to find the relationship between falling height and the density of the sand, and to allow a suitable height to be chosen for raining the sand in the testing box. The results of these calibration tests are plotted in Figure (2).

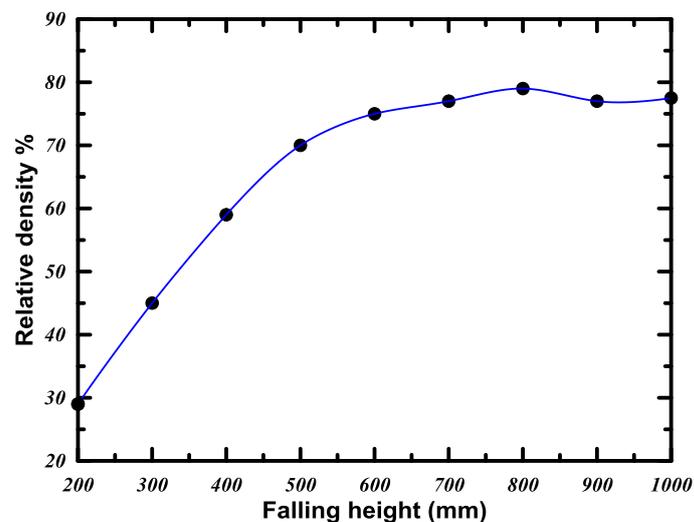


Figure (2): Falling height versus relative density of sand



4.4. MEASUREMENTS SYSTEM

A load cell with a capacity of 10 tons was connected with the hydraulic jack to measure the applied vertical load on the square footing (surcharge load). The model pile in each test was instrumented with seven pairs of strain gauges (TML type FLA-5-23-3L) attached along its shaft. The gauge length, gauge factor and gauge resistance were 5mm, 2.16 and 120 Ohm, respectively. The strain gauges were wired in pairs to constitute half-bridges for measuring the bending moments along the pile's shaft during the test. A handheld digital data logger (TC-32K) combined with switching box (CSW-5A) were used for recording and storing data from strain gauge measurement for each pile test. Since seven pairs were attached along pile's shaft, two sets of data loggers and switching boxes were used in this study. The strain gauges were calibrated by testing the instrumented pile as a simply supported beam under known applied bending moments. Dead loads and a pair of strain gauges were putted at the beam's center (instrumented pile's center) for applying bending moments and measuring the strains, respectively. The aim of this calibration was to find the relationship between the strain gauge readings and the bending moments. A linear relationship was obtained between the bending moment and the strain response for pile used in this study as shown in Figure (3). A linear variable differential transformer (LVDT) of 100mm full range was attached on the pile at the sand surface to measure the lateral pile head displacement.

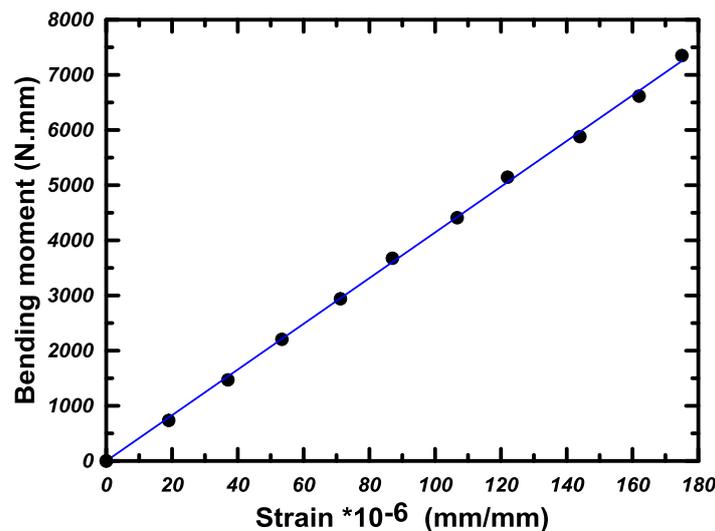


Figure (3): calibration of strain gauges

5. TESTING PROCEDURE

The tests were conducted on instrumented pile inserted in both horizontal and different sloping ground with different relative densities. The sand was placed in the steel box for three different relative densities say 29 % , 50 % and 75% by using sand raining method. After the sand was filled the steel box, the hydraulic jack was used to insert the instrumented pile into the sand to a desired embedded length. Prior to the pile installation process, the pile is initially pushed by hand into the sand, with the pile tip penetrating about 50 mm in the sand. The pile was located in the top edge of the slope for sloping ground condition and the same position was used for horizontal ground condition. When the installation process of the instrumented pile was finished, a required slope was constructed with cutting process. The square footing was placed near the crest of the slope and the loads were applied slowly on the soil through the jack with increment of 5 kN. The readings of the strain gauges, LVDT and load cell were recorded at each increment load.

6. RESULTS AND DISCUSSION

6.1. PILE HEAD DISPLACEMENT

The surcharge loads were applied through the hydraulic jack and LVDT was utilized for measuring the lateral displacement of the model pile. Initial tests were performed on the condition of piles in horizontal ground surface followed by the sloping ground ("1V:3H", "1V:2.5H", "1V:2H" and "1V:1.5H") with different relative densities of soil (29%, 50% and 75%). The first test was conducted on pile embedded in horizontal surface sand of 50% relative density (for convenience in comparison with other cases, this test was referred to hereafter as the "reference" test). Figure (4) presents the relationship between the pile's displacement and the applied surcharge load for "reference" test. It can be noticed that the pile's displacement increases with increasing the surcharge load which is due to the increment in the lateral soil movement.

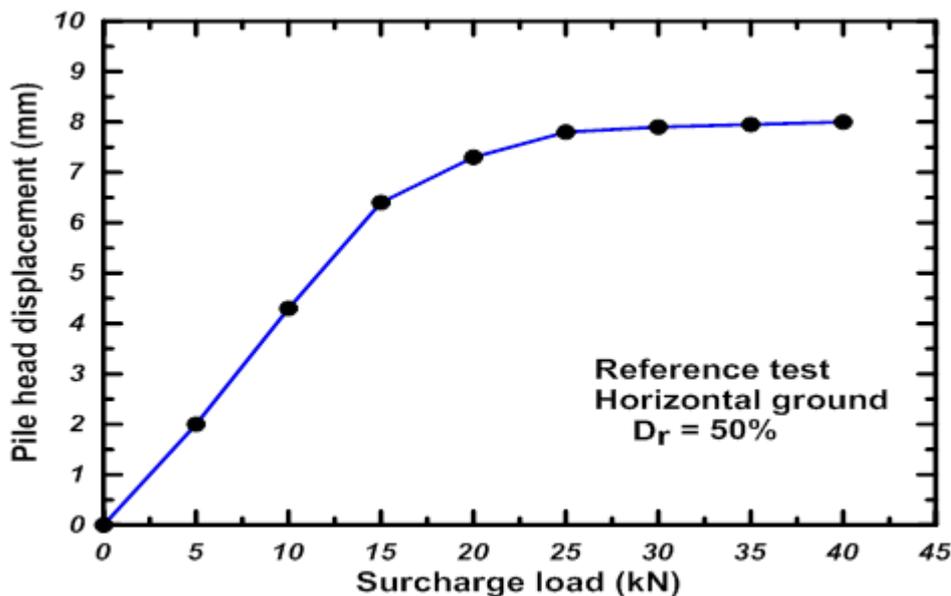


Figure (4) : Surcharge load versus pile head displacement for "reference" test.

For investigating the influence of slopes ground on the surcharge load-pile head displacement curve, four tests were performed on piles embedded in different sloping ground with the same density of the "reference" test ($D_r = 50\%$). The relationship between the surcharge loads and the pile's displacement for different sloping ground ("1V:3H", "1V:2.5H", "1V:2H" and "1V:1.5H"), together with that for the "reference" test (horizontal ground) is presented in Figure (5). It can be noticed that, the pile head displacement increases with increasing in the sloping ground. This increment is because of the decrease in passive resistance of the soil in front of the pile. At 40 kN surcharge load, the pile head displacement increases by (13%), (29%), (118%) and (250%) as the soil surface changes from horizontal to sloping surface of "1V:3H", "1V:2.5H", "1V:2H" and "1V:1.5H" respectively.

For exploring the influence of relative density on the surcharge load-pile displacement curve, different tests were performed on the model pile embedded in both horizontal and sloping ground corresponding to different relative densities (29%, 50% and 75%). Figure (6) presents the influence of the relative density of sand on the load-displacement curves embedded in horizontal ground surface. It can be noticed that, the pile displacement decreases with increasing sand's relative density. At 40 kN surcharge load, the pile head displacement decreases by (25%) and (37%) as the relative density of sand increases from 29% to 50% and



from 50% to 75% respectively. Figures (7, 8, 9 and 10) demonstrate the relationships between the surcharge loads and pile's displacement in sloping ground of "1V:3H", "1V:2.5 H", "1V:2H" and "1V:1.5H" respectively for different relative densities of sand. It clears that, the pile displacement increases with increasing the sloping ground but the rate of the increase reduces as the density increases. The highest value of pile's displacement is found about 34 mm (425% more than that for "reference" test) in the case of pile embedded in slope surface of "1V:1.5H" with 29% relative density.

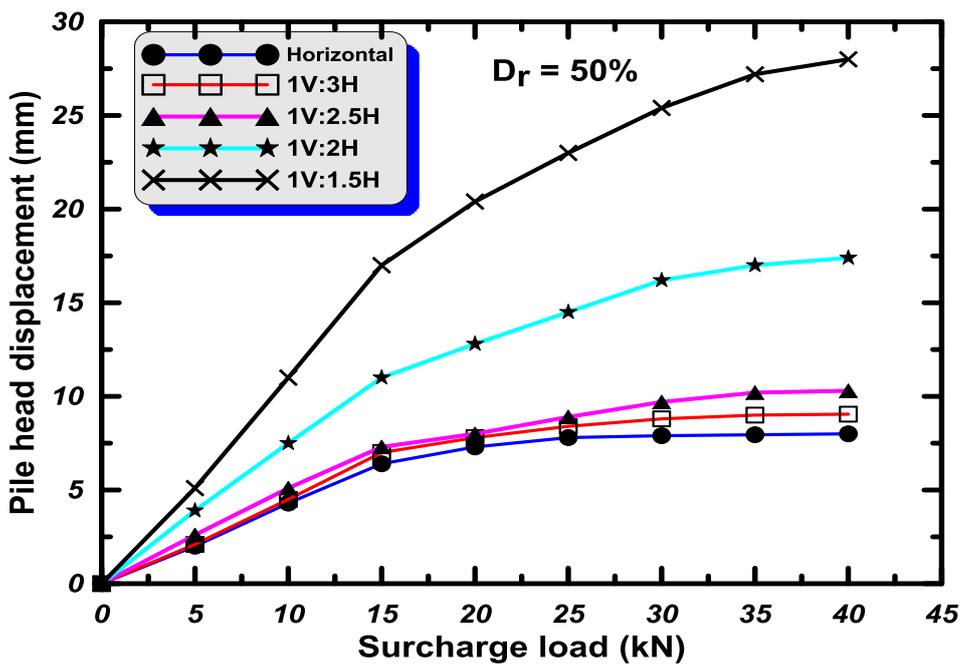


Figure (5): Surcharge load versus pile head displacement for different sloping ground

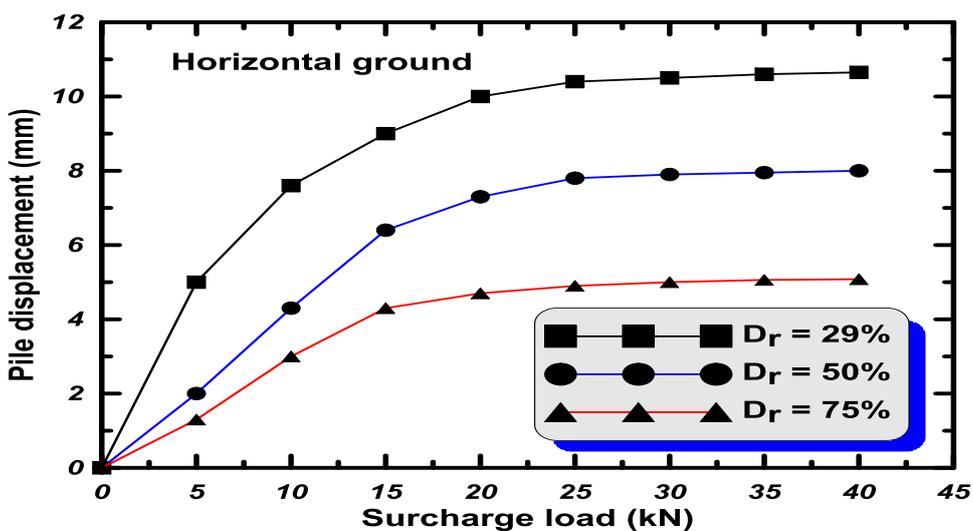


Figure (6): Surcharge load versus pile head displacement in horizontal ground for different relative densities of sand.

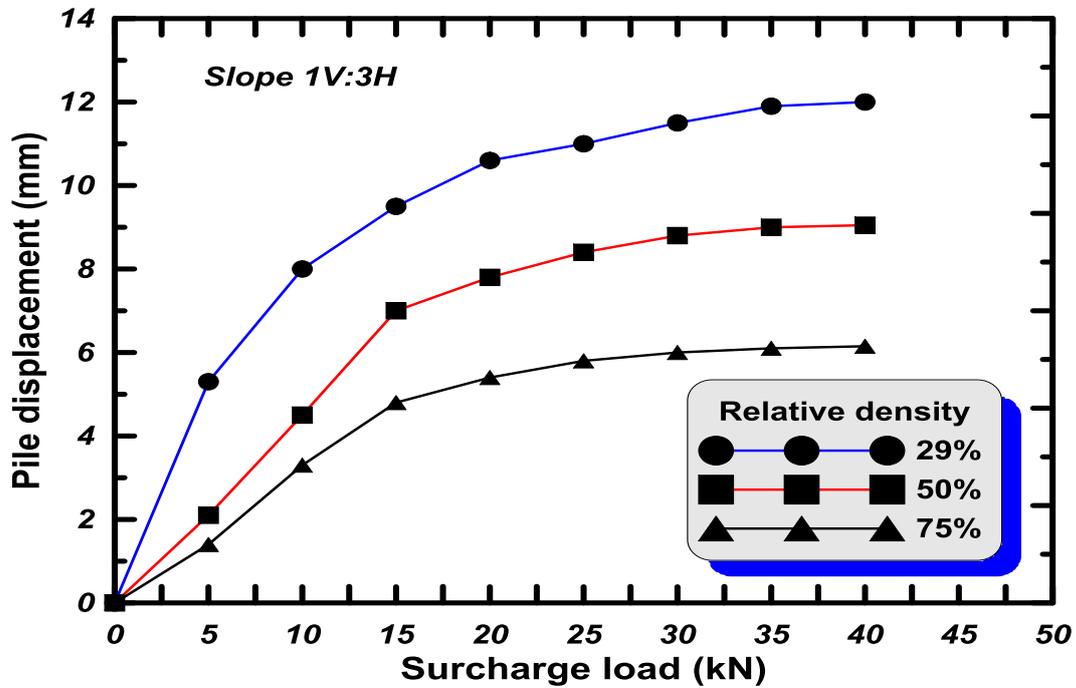


Figure (7): Load - displacement for pile in 1V:3H sloping ground.

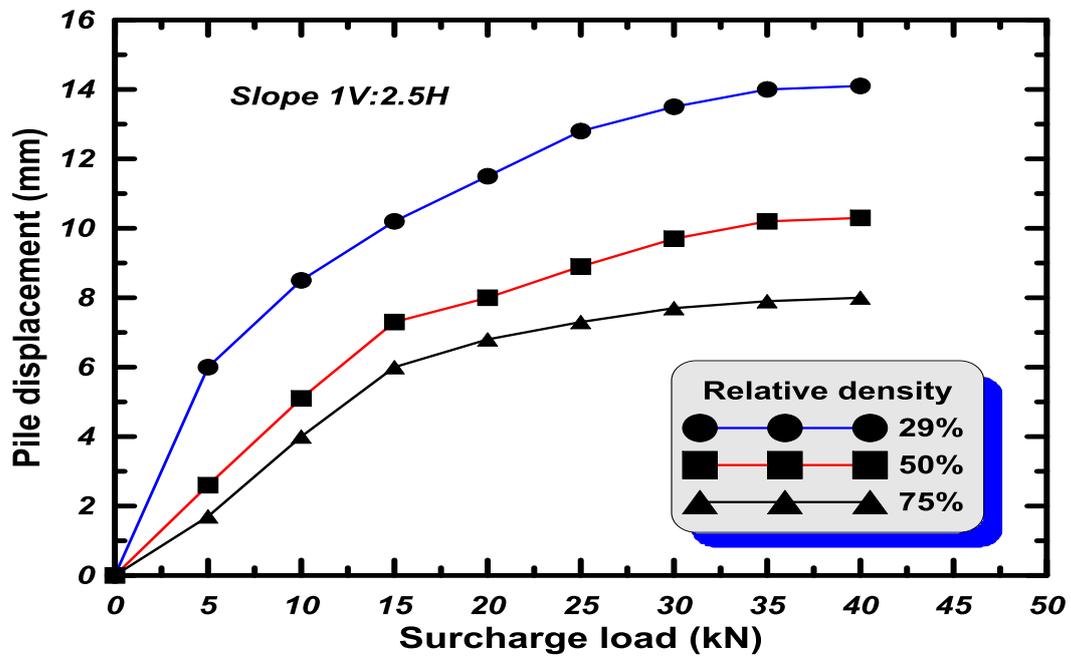


Figure (8): Load - displacement for pile in 1V:2.5H sloping ground.

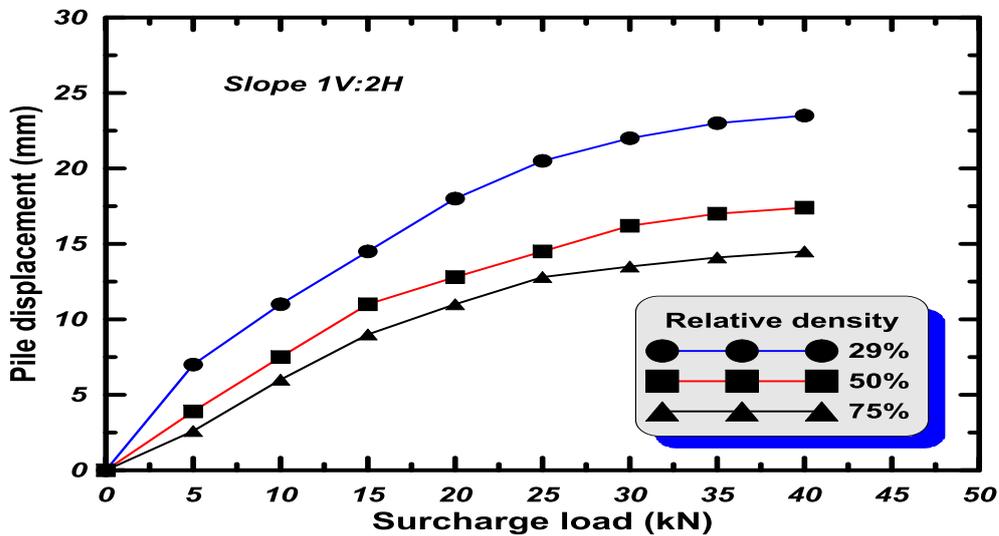


Figure (9): Load - displacement for pile in 1V:2H sloping ground.

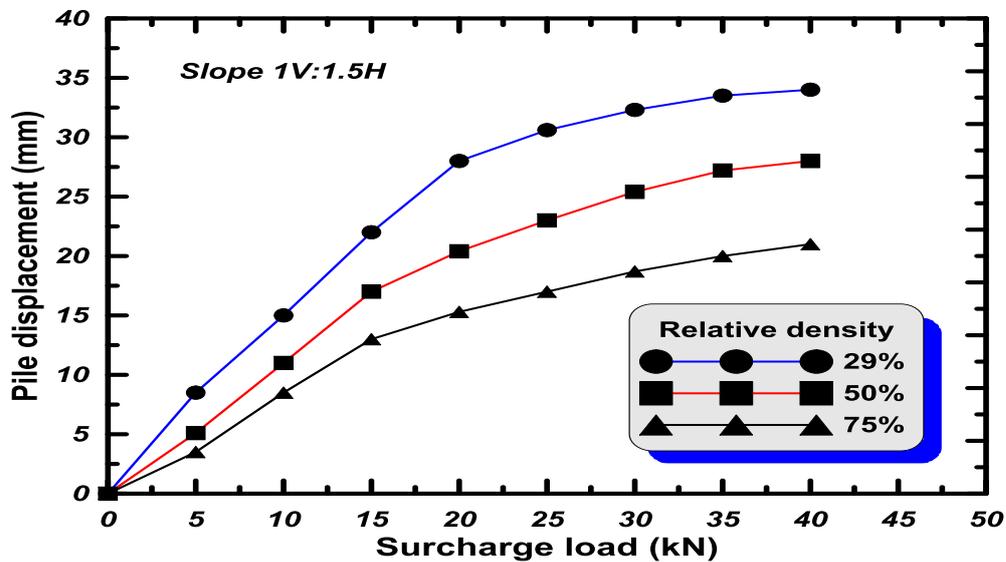
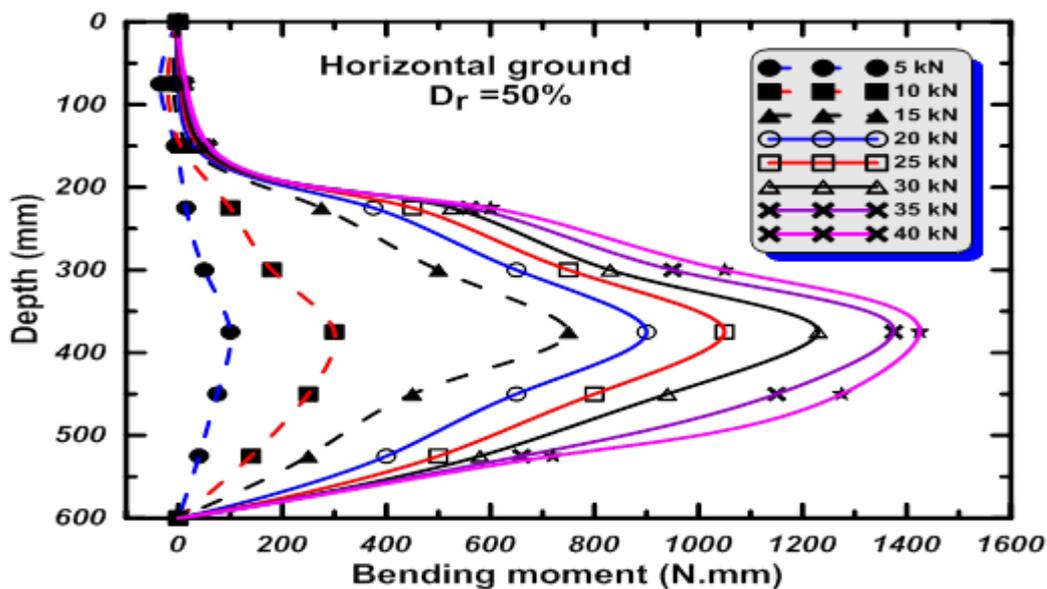


Figure (10): Load - displacement for pile in 1V:1.5H sloping ground.

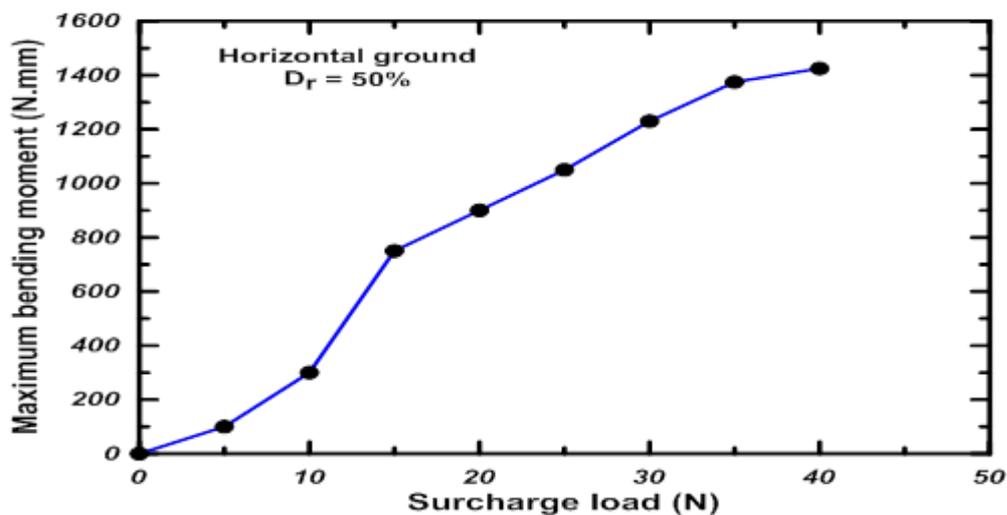
6.2. BENDING MOMENT

Figure (11a) presents the profiles of the bending moments along pile's shaft for "reference" test corresponding to different values of surcharge load. It clears that the bending moment's profiles are essentially the same in the shape for all the values of the applied surcharge, but the magnitude of the bending moment increases with increasing the load which is due to the increment in the lateral soil

movement. Because of the interval of 75 mm between two adjacent pairs of strain gauges along the pile's shaft, the recorded maximum bending moment's depth may not really correspond with the accurate depth.



(a): Bending moment profiles for different surcharge load



(b): Maximum bending versus surcharge load

Figure (11): Bending moment versus surcharge load for the "reference" test

Figure (11b) presents the relationship between the maximum bending moments and the applied surcharge load for "reference" test. It is established that the maximum bending moments increase with the increment in surcharge loads but the rate of increase reduces, especially when the surcharge load is greater than about 35 N because of the decreasing in the ground resistance.



The distribution of bending moments along the pile's shaft at different sloping ground with different relative densities of sand corresponding to 40 kN surcharge load is presented in Figures 12 to 14. Figure (12) represents the bending moments variation along pile's shaft for different sloping ground (i.e., horizontal, "1V:3H", "1V:2.5H", "1V:2H" and "1V:1.5H") corresponding to 29% relative density of sand.

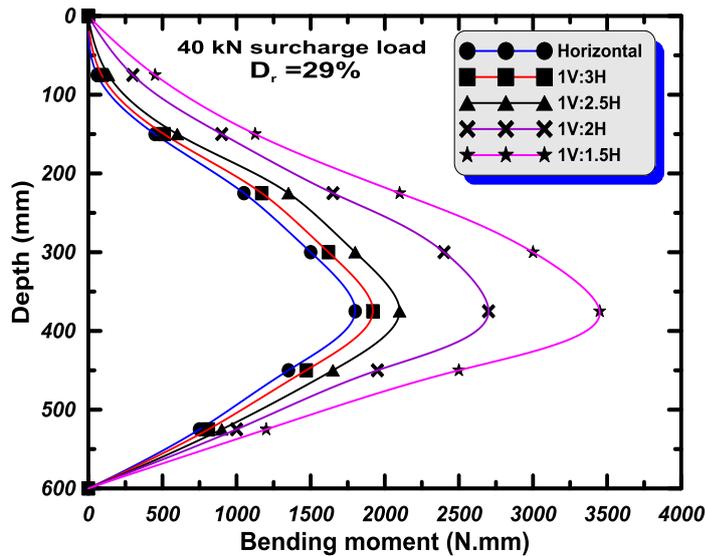


Figure (12): Bending moment profile for different sloping ground with 29% relative density

The same bending moment profiles with 50% and 75% relative densities are presented in Figures (13 and 14) respectively. Based on these plots, it can be seen that the bending moments increase with increasing the sloping ground because of the decreasing in the passive resistance at the top zone of the ground mas. For both horizontal and sloping ground, the maximum bending moments decrease with increasing the sand's density because of the increment in the shear strength of the soil.

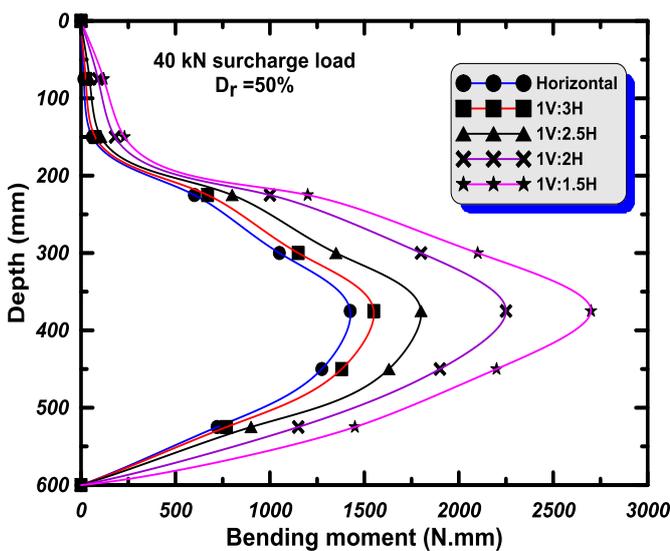


Figure (13): Bending moment profile for different sloping ground with 50% relative density

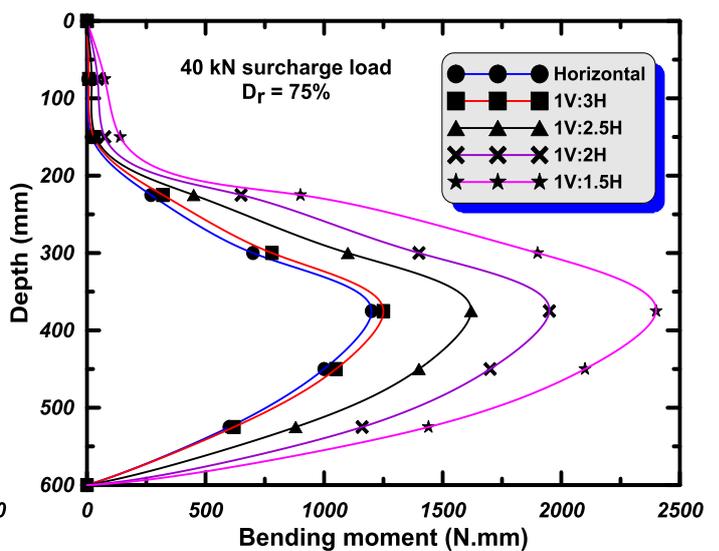


Figure (14): Bending moment profile for different sloping ground with 75% relative density



Figure (15) presents the relationship between the moments and the slopes of soil surface with different relative densities of sand. It can be noticed that, the bending moments decrease with increasing the relative density. The maximum moment increases by 189 % as the soil surface transfers from horizontal to "1V:1.5H" slope surface with same relative density ($Dr = 50\%$). Also, for sloping ground of 1V:1.5H, the moment decreases by (22%) and (11 %) as the sand's relative density changes from 29% to 50% and from 50% to 75% respectively. The highest value of the maximum moment is obtained in the condition of pile embedded in "1V:1.5H" slope with 29% relative density (about 240% greater than that for "reference" test) while the lowest value is obtained in the case of pile embedded in horizontal ground surface with 75% relative density of soil (about 16 % smaller than that for "reference" test).

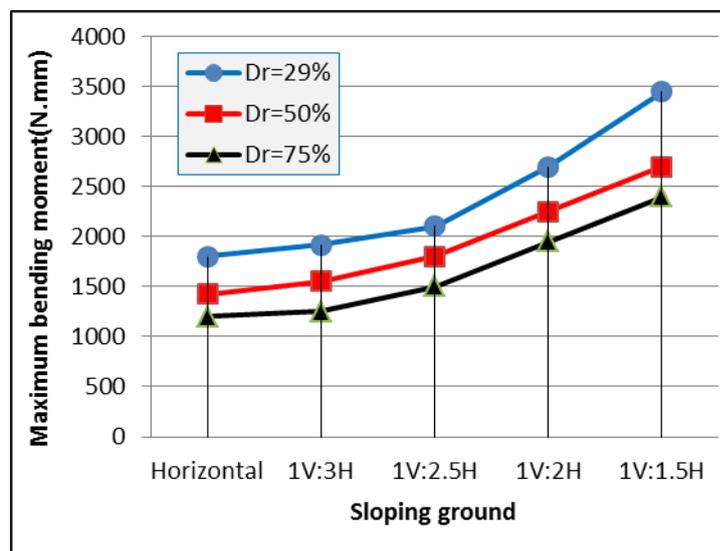


Figure (15): Maximum bending moment versus sloping ground with different relative densities

7. CONCLUSIONS

Laboratory model tests have been conducted on pile in both horizontal and sloping ground surface corresponding to different relative densities adjacent to surcharge loads. The results of the tests indicate that the deformation of pile in terms of displacement and bending moment increases with increasing in surcharge loadings and sloping ground. Also, the deformation of pile decreases with increasing the relative density of sand. The highest values of pile's displacement and moment are found in the case of pile in sloping ground of "1V:1.5H" corresponding to 29% relative density while the lowest values are found in the case of horizontal surface corresponding to 75% relative density. The displacement of pile is considerably increased as the surface transfers from horizontal to sloping surface. Its value increases by 13%, 29%, 118% and 250% as the ground transfers from horizontal to sloping surface of "1V:3H", "1V:2.5H", "1V:2H" and "1V:1.5H", respectively. The displacement of pile decreases with increasing the relative density of sand for all ground surface conditions. For 40 kN surcharge load in the case of horizontal ground, the pile displacement decreases by (25%) and (37%) as the relative density of sand increases from 29% to 50% and from 50% to 75%, respectively. The maximum bending moment decreases by 16% when the relative density of sand increases from 50% to 75%. For 40 kN surcharge load and 50 % sand's relative density, the pile's bending moment increases by 9 %, 26 %, 58 % and 90% as the ground transfers from horizontal to slopes of "1V:3H", "1V:2.5H", "1V:2H" and "1V:1.5H", respectively.



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