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Effects of Surcharge on the Behavior of Passive Piles in Sandy Soil

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Abstract— The effects of adjacent embankment on the behavior of pile in sandy soil, river sand, had been investigated through manufacturing an experimental model of steel. The soil sample classified as (SP-SM) according to USCS of dry unit weight 13.5 kN/m^3. The pile model was an aluminum tube of 10 mm outer diameter. An incremental surcharge was applied at distances of 2.5D, 5D and 10D from the edge of pile model, where D is the outer diameter of model pile. Also, two embedded lengths were investigated Le = 360 mm which classified as rigid pile and Le = 420 mm which classified as flexible pile. The effects of these parameters had been studied on axially loaded pile (LP) and unloaded pile (UP). The results obtained from the model piles are: the displacement at the soil surface, the rotation at the soil surface, bending moment profiles, pile deflection profiles, pile rotation profiles, and shear force profiles. Some of these results are measured experimentally an others are calculated theoretically based on measured values.Based on the results of tests, it was concluded that increasing the distance between the embankment and pile reduces the effects of embankment on the pile, also the axial loading on pile reduces the effects of embankment on the pile. While, increasing the embedded depth exhibited more effects for the embankment on the pile.

Index Terms—Embankment load, geotechnical properties, passive pile, pile foundation, surcharge, and sandy soil.

1 Introduction

THE Pile foundations are slender structural elements used to transfer loads from structures into deep hard strata below the ground level. It should designed to carry various types of loads including axial and lateral loads. Piles are primarily designed to carry axial loading, but in several situations they are subjected to a horizontal force resulting from direct application of load on the pile or soil movement. The laterally loaded piles are mainly classified as active or passive piles depending on the way of how the lateral loads are transmitted to the piles. Active piles are subjected to a direct horizontal load at the head of the pile and transmit this load to the surrounding soil along their lengths. On the other hand, passive piles are loaded by lateral movement of surrounding soil, therefore, movement of soil is the cause and the deflection of the pile is the effect in this case. Typical examples of passive piles are piles that supporting bridge abutments nearby approach embankments and piles used in slope stabilization. The construction of embankments can apply clearly vertical and horizontal movements of the soil under the embankment. Pile foundation that used to support the bridge abutments must designed to resist the axial and lateral forces which were come from the soil movements [1].

Springman et al. [2] carried out two highly instrumented tests at the Cambridge Geotechnical Centrifuge at 100 gravities to reveal the complex interaction of mechanisms which arise between an embankment, an abutment wall, a pile cap, piles and the underlying soft soil layer. The data recorded from these tests have been analyzed to obtain bending moment and displacement profiles for the piles and wall. The test configurations differed only in the inclusion of wick drains in the soft soil layer for the second test, when the embankment was also constructed over a long period. Poulos [3] studied with model tests the response of single piles which were embedded in embedded in calcareous sand and subjected to lateral soil movement. Parametric study has been carried out to investigate the effects of the ratio of the depth of moving soil to the pile embedded length, pile head fixity condition, pile stiffness and diameter on the maximum bending moment of pile. Bransby [4] conducted a series of centrifuge tests to investigate the behavior of two rows of piles in a group, where the piles are loaded passively by applying an adjacent vertical surcharge on the soil. To require the stress path of the soil, the pore pressures were recorded during all testes and the consolidation degree of the clay layer at each loading stage were determined. Bransby and Springman [5] conducted a pair of centrifuge model tests to investigate the behavior of a two row pile group when an adjacent vertical surcharge load is applied. The pile cap is in contact with the surface of the deforming soil and interactions observed between the pile cap and the soil in addition to between the deforming soil and the pile. The new "buttonhole" foundation technique reduced passive lateral pile pressures as intended, but increased pile cap shear force.

Pan et al. [6] carried out a series of experimental model tests to study the response of single and coupled piles subjected to lateral soil movements in soft clay. Different distributions of limiting soil pressures along the pile shaft were found for the single and coupled passive piles. Guo and Ghee [7] developed a new shear box to investigate the influence of lateral soil movements on the bending moment, shear force and soil reaction of vertical piles. Two tests conducted on instrumented piles of 32 mm and 50 mm diameters were presented. The test results indicate the limiting force mobilized along the piles in movable soil is quite similar to that due to a lateral load. Guo and Qin [8] developed an experimental apparatus to investigate the behavior of vertically loaded, free head piles in sand undergoing lateral soil movement. The results were the applied force, induced shear force, bending moment, and deflection along the piles. The

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International Journal of Scientific & Engineering Research Volume 6, Issue 10, October-2015
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maximum moment is generally linearly related to the sliding force even for the initial frame movement and the extra-large for the trapezoidal movement profile.

2 SOIL SAMPLING AND PROPERTIES

The disturbed soil sample used in the present work was obtained from the bed of the Tigris River at the north of Baghdad city. The soil sample can be classified as river sand (SP-SM). The geotechnical and chemical properties of soil samples were investigated firstly, then, the soil samples were used to investigate the effects of soil movement on the behavior of piles. The results of geotechnical properties are shown in Table 1.From x-ray diffraction test, the primary minerals in tested soil are quartz, dolomite, calcite and feldspar and the secondary minerals are kaolinite and montmorillonite.

TABLE 1
THE GEOTECHNICAL PROPERTIES OF TESTING SOIL SAMPLE

Index Property	Value
Specific gravity (Gs)	2.67
D_{10}, mm	0.075
Coefficient of uniformity (Cu)	2.934
Coefficient of curvature (Cc)	1.188
Fines (clay and silt) (%)	9.8
Sand (%)	90.2
Liquid limit (LL)	29
Soil classification (USCS)	SP-SM
Relative density (%)	56
Dry unit weight at Dr = 44% (kN/m^3)	13.5
Minimum dry unit weight (kN/m^3)	11.87
Maximum dry unit weight (kN/m^3)	15.14
Angle of internal friction (Ø) at Dr =56%	35°
Cohesion, c (kN/m^2)	9
Initial void ratio, eo	0.9778
Compression index, Cc	0.239
Decompression index, Cr	0.0116
Modulus of elasticity, E (kN/m^2)	12760

3 PILE MODELING

An aluminum closed ends pipe piles were used as pile model in the experimental work. The engineering properties of pile model material are given in Table 2. The pile model was instrumented with strain gauges to measure the bending strain along the embedded pile length. The strain gauges were fixed on the two vertical lines on the front and rear sides of pile with respect to the surcharge location, four pairs of strain gauges were installed on the outer surface of the tested piles with a spacing of 120 mm. In order to protect from damage during the installation of pile, the strain gauges were sealed with a protective coating by 1 mm epoxy resin. The gauges wires were wrapped and fixed on the outer surface of the pile using tapes as shown in figure 1. To simulate the axially loaded piles subjected to passive loading come from an embankment, an experimental model was manufactured and consists of steel container of dimensions (80×80×80) cm, steel loading frame, axial loading system, raining frame and instruments such strain gauges, strain indicator, load cell and dial gauges. The bed of soil is prepared by raining drops from a height of 24 cm to get dry unit weight of 13.5 kN/m^3. The cone is filled with sand to pour it into the container freely in homogenous layers. After completing the final layer, the top surface was scraped and leveled to get as near as possible a flat surface, then the installing process is followed to drive the pile model. A hydraulic jack was used for the installation of the pile into the soil to a desired embedded length. Prior to the driving process, the pile was pushed into the soil bed, by hand, to an approximately depth of 10 cm. Then, the pile was left standing and the verticality of the pile was checked and adjusted with a leveler. More care was given to make sure that the line joining the center of the pair of strain gauges coincides the center line of surcharged area which was used to simulate the embankment. Subsequently, the hydraulic jack was secured to the model pile head and the driving process continued to reach the desired depth with the advance of pile into the soil, the pile verticality was checked and adjusted if necessary. The setup of pile mode testing is shown in Plate 2.

TABLE 2
PROPERTIES OF PILE MODEL

Property	Value
Outer diameter of pile (D)	1 cm
Wall thickness	0.1 cm
Length of pile (L)	50 cm
Weight of pile	42 gm
Density of pile material	2.97 gm/cm^3
Modulus of elasticity (Ep)	69.871 GPa

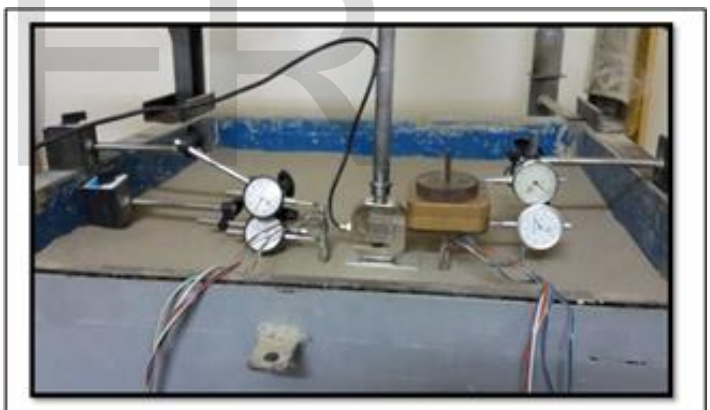

Fig. 1. Setup of pile model testing.

The purpose of using strain gauges on the pile model is to measure the bending moment that developed in the model pile during the test. According to the beam theory, four pile responses including displacement, rotation, shear force and soil reaction are derived from bending moment. By differentiating the bending moment profile to the 1st and 2nd order, the shear force and the soil reaction can be obtained, respectively. On the other hand, by integrating the bending moment profile to the 1st order, the pile rotation can be obtained. Subsequently, the pile rotation profile is integrated, in turn, to obtain the pile deflection.

$$y(z) = \int \left(\int \frac{M(z)}{E_p I_p} dz \right) dz \quad (1)$$

$$S(z) = \int \frac{M(z)}{E_p I_p} dz \quad (2)$$

International Journal of Scientific & Engineering Research Volume 6, Issue 10, October-2015
ISSN 2229-5518

$$T(z) = \frac{dM(z)}{dz} \quad (3)$$

$$P(z) = \frac{d^2M(z)}{dz^2} \quad (4)$$

where
z is the depth measured downward from the soil surface.
M (z) is the bending moment as a function of depth.
y (z) is the lateral displacement of the pile.
S (z) is the rotation of the elastic curve defined by the axis of the pile in radian.
T (z) is the shear force in the pile.
P (z) is the soil reaction per unit length.

In order to derive these pile responses, the bending moments were then subjected to extensive analysis and data processing. One approach involved fitting the profile to a best-fit polynomial curve, which ranged from the 4th to 7th order, to obtain a continuous distribution of the bending moment profile along the pile length. This approach was used successfully by Springman [5], Steward [9] and Chen [10] to analyze piles subjected to lateral soil movements.

4 TESTING PROCEDURE

The following procedure is conducted to study the effect of embankment construction nearby axially loaded model pile and unloaded piles:

1. Preparing of soil bed by using raining technique as described before.
2. Connecting the channels of strain gauges, 8 pairs, fixed on the pile model to the data logger, which was connected to the computer and starting the program "MULTI-CHANNEL DATA LOGGER 12" to view and store the data.
3. Driving the first model pile (LP-loaded pile) at distance larger than (10D) from the walls of steel container to avoid the effect of tip resistance (Bolton et al, 1999), where (D) is the diameter of pile model, then the second model pile (UP-unloaded pile) was driven at distance larger than (15D) to eliminate any rigid boundary [11]. The driving process was carried out as described before.
4. Applying axial load on the model pile (LP) equal to the working load, was calculated theoretically according to the soil and pile properties, by placing weight blocks directly on the pile head.
5. Installing two mechanical dial gauges for each pile model (LP and UP), which were placed horizontally to measure the horizontal displacement of the model pile at two separate points on the upper part of the model pile over the soil surface. One of them on the soil surface and the second at apart from the soil surface within free length of pile.
6. Applying the surcharge load, which was used to simulate the embankment with increments of (0, 10, 20, 40, 40, 50 and 60) kPa each increment maintained for to 2 minutes.
7. Recording the dial gauges readings and time of readings at the end of each loading increment. Also, the readings of strain gauges saved at the data logger for each load increment.

5 RESULTS AND DISCUSSION

The embankment applies vertical load on the surface of soil, which causes densification of soil under the embankment and soil movement away from the source of loading due to the weak structure of sandy soil used in the present work. The soil movement applies soil pressure on the front side of the pile which decreased with increasing the distance between the embankment and the pile. The distance between the embankment and the edge of a single pile is one of the important factors that influences the behavior of the pile. In order to investigate the effects of embankment location from the edge of the pile, three different distances were chosen through the study, 2.5D, 5D and 10D, where D is the outer diameter of model pile. Also, the effects of embedded depth (Le = 360 mm and Le = 420 mm) on the response of passive piles. The variation of displacements at the soil surface with embankment load increments are presented in Figure 1. The maximum displacement for Le = 420 mm decreased by (24 – 42) % and for Le = 360 mm, the maximum displacement decreased by (31 – 64) % by increasing the distance between the embankment and edge of pile model as shown in figure 2. The unloaded pile model exhibited less response than loaded pile, where the axial load on pile gave more stability to the pile model and help to resist the lateral loads generated from adjacent embankment.

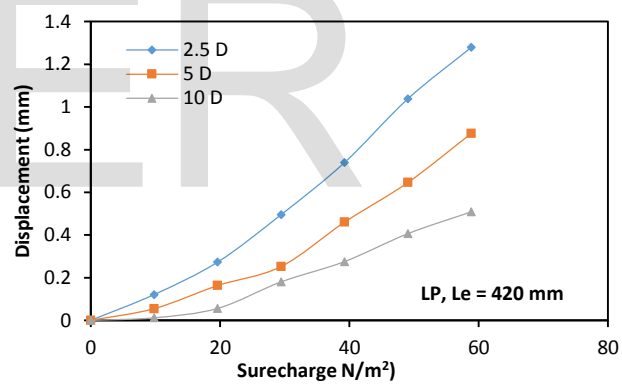

Fig. 2 (a). Surcharge load versus displacement at soil surface.

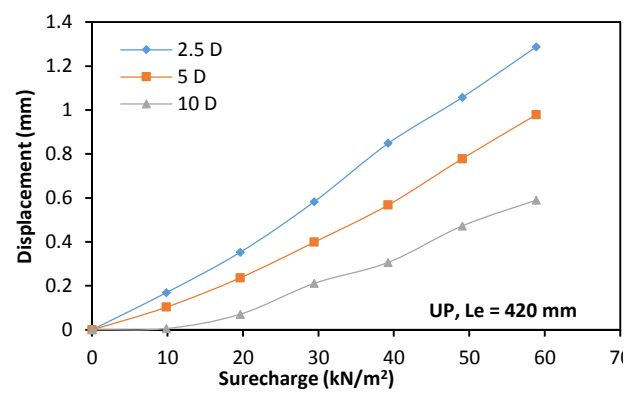

Fig. 2 (b). Surcharge load versus displacement at soil surface.

International Journal of Scientific & Engineering Research Volume 6, Issue 10, October-2015
ISSN 2229-5518

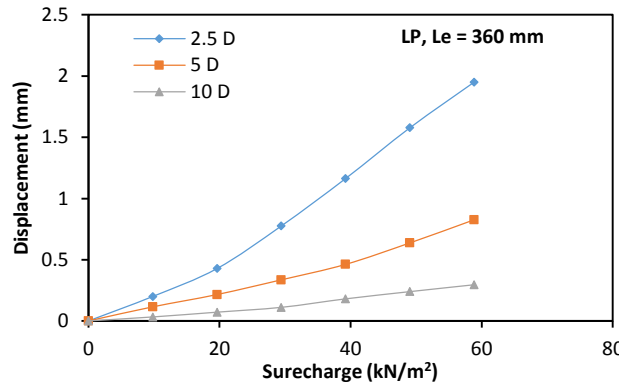

Fig. 2 (c). Surcharge load versus displacement at soil surface.

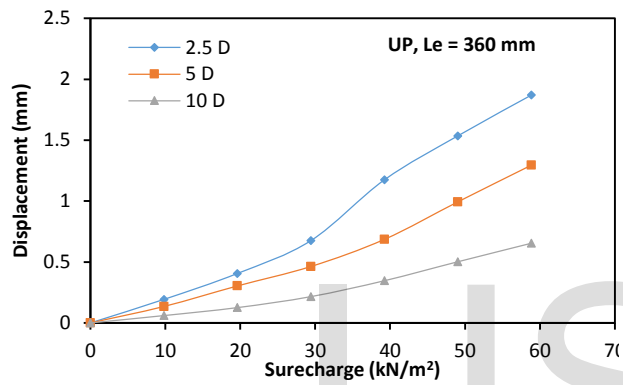

Fig. 2 (d). Surcharge load versus displacement at soil surface.

The results of tests represented by the rotation at the soil surface and bending moment profiles are shown in figures 3 and 4. For the pile of embedded length, Le = 420 mm, the rotation at soil surface of LP was increased by (28– 48) % with increasing the distance between the embankment and the edge of pile from 2.5D to 10D, while the rotation of UP was increased by 97 % when spacing increased from 2.5D to 5D and decreased by 48 % when spacing increased from 5D to 10D. This behavior is resulting from the application of an axial load and relative flexibility due to the long embedded length of the pile.

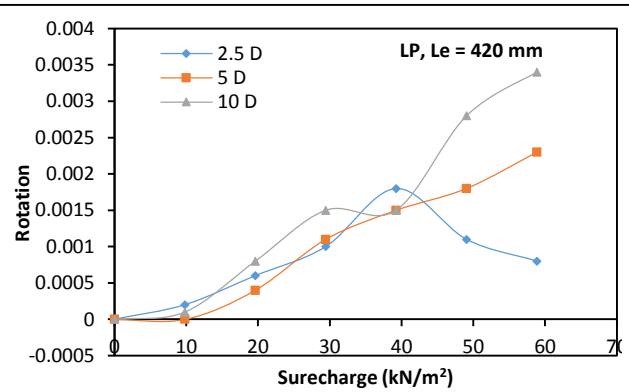

Fig. 3 (a). Surcharge load versus rotation at soil surface.

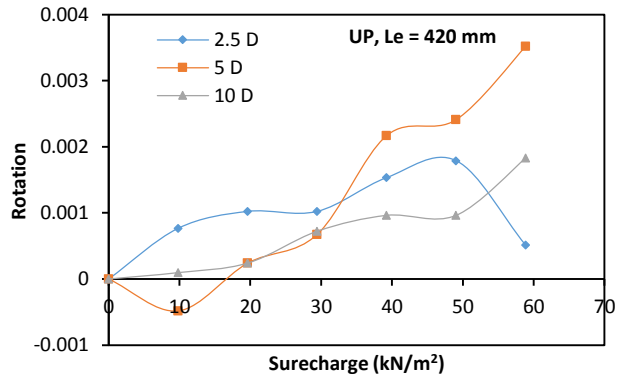

Fig. 3 (b). Surcharge load versus rotation at soil surface.

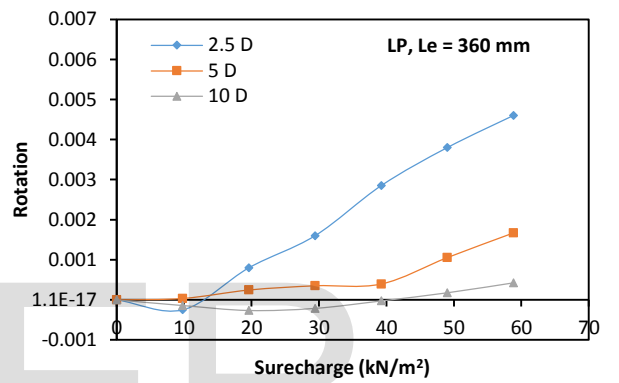

Fig. 3 (c). Surcharge load versus rotation at soil surface.

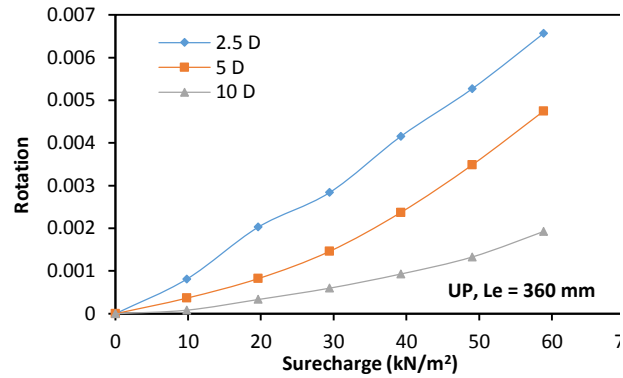

Fig. 3 (d). Surcharge load versus rotation at soil surface.

For the pile of embedded length, Le = 360 mm, the pile behaves as rigid therefore the rotation was decreased by (64–75) % in LP and decreased by (28– 59) % in UP with increasing the distance from 2.5D to 10D as shown in figure 3. The bending moment profiles were shown in figure 4, where the maximum bending moment begins with positive sign when the distance equal to 2.5 D that means the pile bent by soil movement pressure, except UP with Le = 420 mm the maximum bending moment is negative because the pile moved through the soil. When the distance increased from 2.5D to 5D, the

International Journal of Scientific & Engineering Research Volume 6, Issue 10, October-2015
ISSN 2229-5518

moment of soil movement that acts on the LP is reduced by 250 % and 175 % for Le = 420 mm and Le = 360mm respectively.

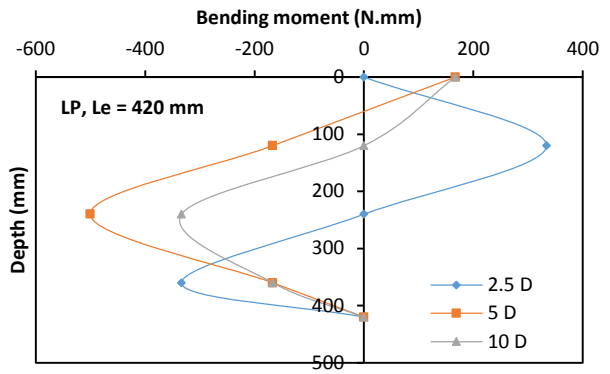

Fig. 4 (a). Variation of bending moment with depth.

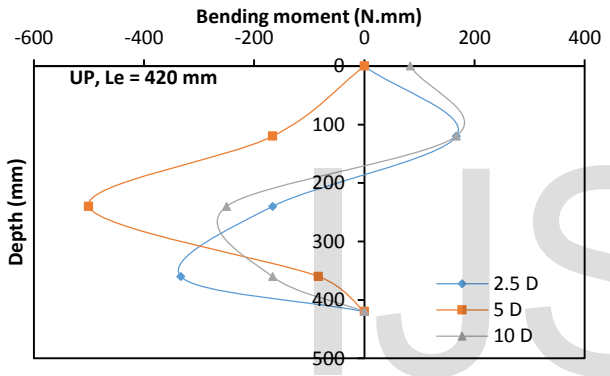

Fig. 4 (b). Variation of bending moment with depth.

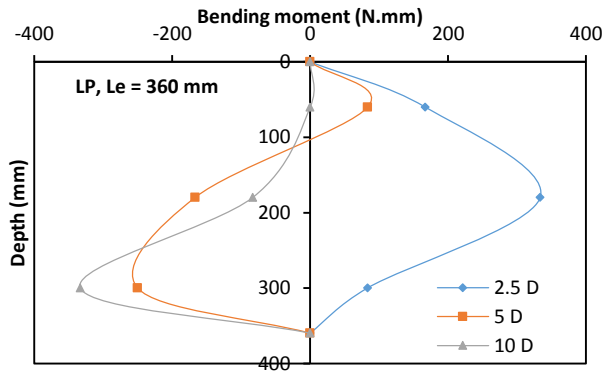

Fig. 4 (c). Variation of bending moment with depth.

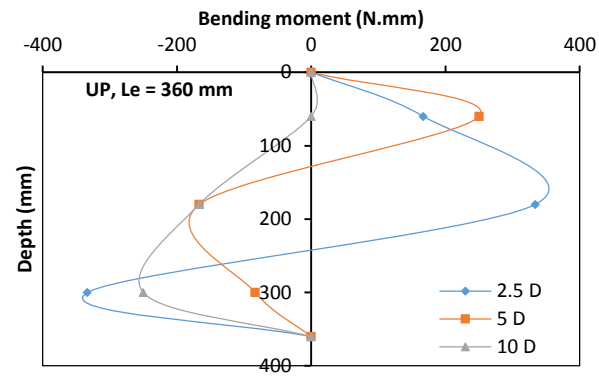

Fig. 4 (d). Variation of bending moment with depth.

The deflection was decreased significantly with increasing the distance due to the reduction in soil movement that caused by the application of a surcharge. The maximum deflection of an LP with Le = 420 mm was located at the pile head due to the application of axial load which restrained the tip when the embankment at 2.5D and 5D, while at 10D the maximum deflection located at the pile tip because the pile is rotated at shallow depth. The pile was moved through the soil due to the high soil movement pressure at distance 2.5D, thus the maximum deflection was located at UP head, but at 5D and 10D the maximum deflection located at the pile tip. On the other hand, the maximum deflection of piles with Le = 360 mm, located at LP head for 2.5D, 5D and 10D, while its located at UP tip for 2.5D and 5D and at UP head for 10D. The deflection profiles of an LP with Le=360mm were crossed the center line of pile at one point at a depth of 180mm from the soil surface and at distance 0.2 mm from the original location of the piles. That is mean, the piles were moved with soil movement 0.2 mm due to the weak structure of medium sand, then rotate to move away from the loading source. While for UP, the point of crossing lays at shallow depth equal to 110mm and at distance 0.3 mm from the original piles location because the piles were not loaded with any axial load.

Based on the results of rotation profiles, for LP with Le = 420 mm, the maximum rotation decreased by 17 %, then increased by 69 % in LP, while increasing by 250 %, then decreased by 27 % in UP when the distance between pile and surcharge increased from 2.5D to 5D and from 5D to 10D respectively. For pile with Le = 360 mm, the maximum rotation decreased by (77– 187) % in LP, and decreased by (35– 64) % in UP with increasing the distance from 2.5D to 10D due to the rigidity of the piles. The shear force depends on the reduction in the maximum bending moment, because such reduction comes from decreasing in resistance of soil behind the pile to soil movement that means the pile subjected to more soil movement pressure. For pile with Le = 420 mm, as the bending moment increased in LP and UP with increasing the distance from 2.5D to 5D the shear force does not affect. When the maximum bending moment decreased by 33 % and 50 %, the maximum shear force also decreased by 25 % and 33 % for LP and UP with increasing the distance from 5D to 10D respectively.

International Journal of Scientific & Engineering Research Volume 6, Issue 10, October-2015
ISSN 2229-5518

The soil reaction decreased with increasing the distance between the edge of the pile and the surcharge due to the reduction of soil movement pressure. For pile with Le = 420 mm, the maximum soil reaction decreased by (20 – 38) % in LP and decreased by (7– 46) % in UP with increasing the distance from 2.5D to 10D as shown in Figure 6. For pile with Le = 360 mm, the maximum soil reaction remained constant in LP due to the rigidity of the pile and application of the axial load which restrained the pile, while increasing to 12 %, then decreased to 81 % in UP with increasing the distance from 2.5D to 5D and from 5D to 10D.

6 Conclusion

Based on the results obtained from the present work, the following conclusions can be drawn: the maximum displacement at soil surface and the maximum deflection decreased with increasing the distance between pile and the constructed embankment, the unloaded piles shows less decreasing than loaded piles. The maximum rotation at the soil surface depends on the distance between the surcharge and pile and embedded pile depth which exhibited different behaviors. The maximum bending moment decreased with increasing the distance between the pile and surcharge. The maximum rotation decreased, then increased in LP, while increased then decreased in UP. The maximum shear force sometimes not affected or decreased in both LP and UP for Le = 420 mm, but different behavior exhibited for Le = 360 mm. The soil reaction decreased with increasing the distance between the edge of the piles and the embankment due to the reduction of soil movement pressure.

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