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LATERAL CAPACITY OF AL NAJIBIYA BRIDGE PIER FOUNDATION

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ABSTRACT

Al-Najibiya Bridge was designed to be constructed on Shat Al Arab River in Basra district, Iraq. The bridge consists of five spans 33m length each with four intermediate piers. Each pier is supported on pile cap of 9m width, 17m length and 2m depth. The pile cap is stand over six cast in drilled hole piles of 1.8m diameter arranged at five meter center to center in both directions. The piles are stand 10 to 12m above river bed and embedded 30m in an over consolidated clayey soil with stiffness vary linearly with the depth. Each pier was designed to carry a maximum of 10000 KN lateral forces. The design engineer considered the average lateral capacity of each pile in the group as 70% of the lateral capacity of a similar single pile. In this paper, the justification of the efficiency factor of (0.7) was studied by analyzing the single pile and the pile group in a finite element model with the soil represented in two ways, as linear elastic and elastic-plastic material (Drucker- Prager plasticity model). The ANSYS 12.1 finite element program was employed for the analysis; the results are given based on displacements at the piles head, shear forces and bending moments throughout the pile length.

KEYWORDS: Single Pile, Group of piles, Lateral Capacity, Finite Element analysis.

INTRODUCTION

Pile foundations are often used to support structures such as offshore platforms, bridges, high rise buildings, transmission towers, wind frames, and variety of units in industrial plants which are subjected significant amount of lateral loads. Lateral loads on piles occur due to earth pressure, earthquake, wave action, impact of berthing ships, wind forces, operating machines, traction of braking vehicles, etc. Piles are always found within group and arranged in rows where leading row and trailing rows can be recognized. Mechanics of the behavior of the group of laterally loaded piles is more complex than those of the axially loaded pile group (Reese 2006)[1]. Piles in the group subjected to lateral loading are influenced by the existing of similarly loaded nearby piles due to pile-soil-pile interaction (Rollins et al 1998, Ashore et al 2004 and Chandrasekaran et al 2008)[2,3,4] as shown in figure 1.

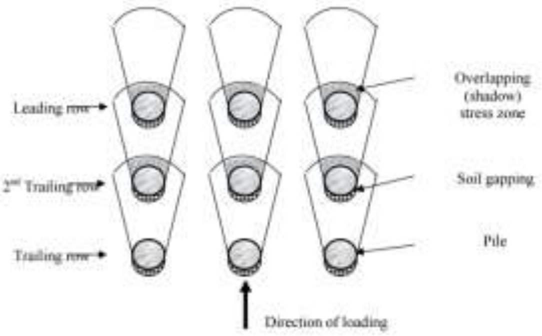

Figure 1: Illustrated of reduction in lateral pile resistance due to pile soil pile interaction

Piles in trailing rows tend to exhibit less lateral resistance because of the interaction with the failure surface of the piles in front of it, and this effect is known as "shadowing" (Brown et al 1988)[5]. Group interaction becomes less significant as piles spacing increases and overlapping decreases. Several theoretical and numerical approaches have been developed and implemented to consider this effect for the design and analysis of pile groups. These methods can be categorized into: continuum methods which include: (1) subgrade reaction method using finite difference (Matlock and Reese 1960)[6]. (2) Finite element methods (Ottaviani 1975, Randolph 1981, Hoit et al 1996)[7,8,9]. (3) Boundary element method (Butterfield and Banerjee 1971, Butterfield and Gosh 1980)[10,11]. (4) elastic and hybrid methods based on Mindlin's solution (Focht and Koch 1973, O'Neill et al 1977, Polus 1979)[12,13,14]. And (5) load transfer (P-Y) curve method (Brown et al 1988, Bogard and Matlock 1983 and Reese et al 1990)[5, 15,16]. In continuum based methods, the soil is represented by a discretized elastic or elastic-plastic continuum whose behavior is described by an appropriate constitutive law. Although, the continuum model approaches provide versatile solutions, they are computationally elaborate because of the three-dimensional nature of the problem (Jeong et al 2003)[17]. In this respect the method based on the assignment of a set of P-Y curves is recommended for the approximate, yet accurate pile-soil-pile interaction. The method is based on reducing the stiffness of the P-Y curve for the piles in the group by using a multiplier (f_m <1) (Brown et al 1988)[5]. As seen in figure 2. The method suggested to use a constant value of the multiplier (f_m) in the same soil at any level of loading (Marjanovic 2016)[18] which seems to involve significant compromise as the interface among piles in the group varies with depth even with same soil and increases with level of loading and is sensitive to the distance between piles in the group (Ashore et al 2001, Parsiya and Dave 2012)[19,20] .

In this paper, the finite element method is used to analyze the response of a bridge pier foundation to lateral loading with the soil discretized as elastic and elastic-plastic material to justify if the multiplier used in the design (f_m=0.7) is fairly evaluated.

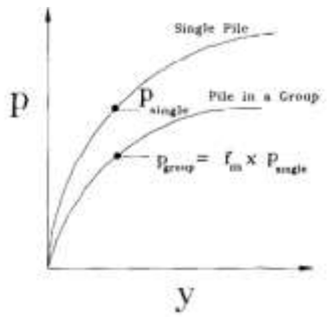

Figure2: p-multiplier (f_m) concept for pile group

PROBLEM DEFINITION AND OBJECTIVE

Al Najibiya bridge is to be constructed on Shat Al Arab river in Basra Province, Iraq. The bridge consists of five spans at 33m each, two abutments and four piers. Each pier is founded on a pile cap of 9m in width, 14m in length and 2m in depth. The pile cap is resting on 6 cast in drilled hole piles of 1.8m diameter, the embedment depth of the piles is 30 meters (below river bed) and the piles extended 10 to 12 meters above river bed as shown in figure 3. The geotechnical data of the site show that the soil profile consists of an over consolidated clay layer of an average depth of 30m below the lowest point of the river bed underlined by a thick very condensed silty sand layer which extend to more than 50m below river bed (the end of depth of the bore holes). Soil properties of the site are given in table 1.

Table 1: properties of the soil in the site

Depth in (m)	Modulus of Elasticity (MPa)	Cohesion (KPa)	Bulk Density (KN/m^3)	Poisson's ratio μ	Angle of internal friction Ø	Dilatancy angle Ψ
0 - 10	6 - 13	15 - 33	17	0.4	6	4
10 - 18	13 - 19	33 - 54	18	0.4	8	4
18 - 24	19 - 25	54 - 64	18	0.4	9	4
24 - 30	25 - 30	64 - 75	19	0.4	10	5

The design data of the bridge gives the maximum lateral load on the pile cap is 10000KN. The designer assumes that the average lateral capacity of the piles in the group is 70% of the lateral capacity of a single pile. It is required to investigate if

1) This assumption is justified or not.

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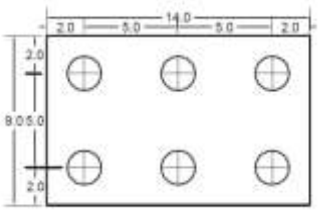
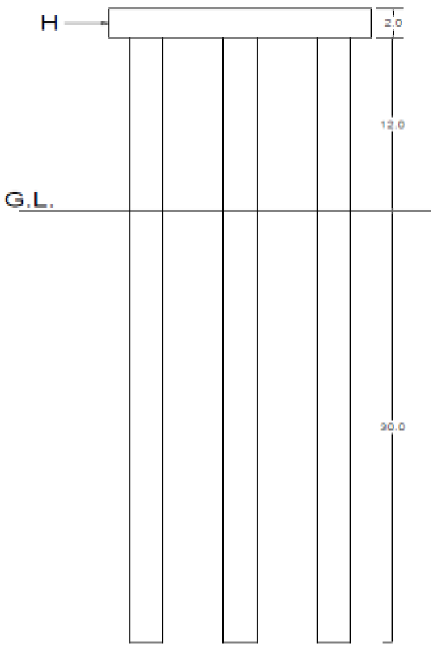
2) What is the maximum expected lateral displacement.
3) The shear force and bending moment distributions along the length of the piles.

NUMERICAL MODELING

Finite element continuum method is employed for the modeling and analysis of the case study. The ANSYS 12.1 program is used for the solution. The piles are modeled as linear elastic two nodes frame element with circular section and six degrees of freedom at each node (three translations and three rotations). The Young's modulus, Poisson's ratio and unit weight for the piles are equal 25.75 MPa, 0.25 and 24KN/m^3 respectively. Pile cap is modeled as linear elastic 4 nodes thick shell element with six degrees of freedom at each node, the same properties of the pile material (Young's modulus, Poisson's ratio and unit weight) are used for the pile cap. The soil is modeled as an elastic and elastic-plastic material using the 8 nodes brick element with three translational degrees of freedom at each node. In the elastic model, the only required properties for the analysis are the Young's modulus and Poisson's ratio. The Young's modulus for the soil is linearly varying with depth from 6 MPa at the river bed to 30 MPa at 30m below river bed (the end of pile depth) and remain constant (30 MPa) for the remaining depth. The Poisson's ratio which is considered to be constant and equal 0.4. In the elastic-plastic modeling of the soil, the Drucker- Prager plasticity model is used. In addition to the Young's modulus and Poisson's ratio, cohesion, angle of internal friction and dilatancy angle of soil are required. The geotechnical data of the site shows that the cohesion value is linearly varying with depth from 15 KPa at river bed to 75 KPa at 30m below river bed and is considered to remain constant for the rest of the model depth. All the soil data required for the analysis are given in table 1.



(a) Pile Cap Dimensions and piles lay out



(b) Vertical Section in Piles and Pile Cap

Figure 3: piles and Pile Cap Details

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The soil domain used to model the problem is extended to 10 pile diameter on each side and below the pile and pile group (Cook 1995)[21]. The boundary conditions applied at the side ends of the soil domain are (no translation in the perpendicular direction), at the bottom no translation in all directions while the top surface of the soil is kept free. The connection between the pile and soil is considered as perfect bond.

RESULTS AND DISCUSSION

Single Pile

To evaluate the reduction factor of the lateral pile capacity in the group compared to a single pile, the behavior of a single pile is studied first. The load on a single pile is equal to the load on the pile cap divided by the number of piles in the group. Therefore the maximum applied load on a single pile is 1666.7KN. The load is applied at the pile head 12m above ground level. To mimic the pile in the group, the head of a single pile is assumed fixed against rotations. The load is applied in different percentage of the maximum load to compare the lateral pile displacement for the two soil models (elastic and elastic-plastic) and also to predict the variation of the pile displacement at the pile head with the applied load. Figure 4 show the lateral pile displacement with the applied load for the two models and figure 5 show the variation of the pile head displacement with the applied load. It can be seen from figure 4 that the pile displacement in the elastic and elastic-plastic soil modeling are identical for the applied loads up to 70% of the maximum, which means that the soil is remain in the elastic range up to this load. For loads of 90% and 100% of the maximum, the elastic-plastic model resulted in higher displacement than the elastic model which indicates the yielding of the soil in the top layers. Figure 5 show the variation of the pile head displacement with the applied load is approximately linear which is expected in the low range of loads as the maximum displacement at the pile head is only 6.2% of the pile diameter in the elastic model and 6.6% of the pile diameter in the elastic-plastic model. For design purposes, the limit lateral displacement at the pile head is assumed 10% of the pile diameter (Langer et al 1984, USACE 1998 and Al-Jassim and Qasim 2016)[22,23,24].

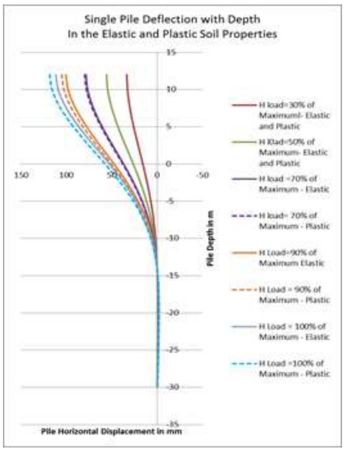

Figure 4: lateral displacement of a single pile with the applied load

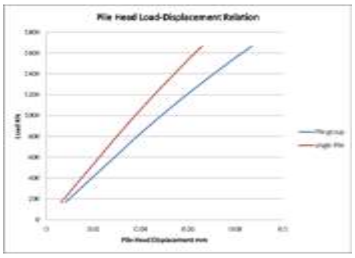

Figure 5: Variation of lateral pile head displacement with the applied load for single pile and pile in a group

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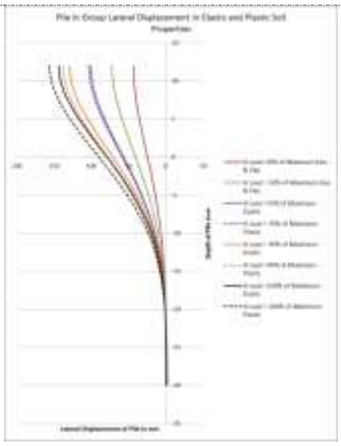

Figure 6: : lateral displacement of a pile in a group with the applied load

Pile group

Similar to the case of a single pile, the variation of average lateral displacement of a pile in a group with the applied load is given in figure 6. The variation of the bottom center of the pile cap with the applied is shown in figure 5. It is visible from figure 6 that at 70% of the maximum lateral load, the elastic-plastic model show a little increase in displacement than the elastic model while in lower loads both models exhibit same displacement. For higher loads, the displacement of the elastic-plastic model show more increase than the displacement of the elastic model. This indicates that the behavior of a single pile is stiffer than that of the pile in a group. The maximum displacement at the pile head is 8% of the pile diameter in the elastic model and 8.7% of the pile diameter in the elastic-plastic model. Figure 5 show that the pile head displacement is greater for the piles in a group than the single pile for all the load levels. For the same displacement of the single pile at maximum load, the load on the piles in a group is 78.6% of the maximum load. This result indicates that the selection of a reduction factor of 0.7 is adequate.

Figure 7 show the variation of the lateral displacement along the length of the pile with the applied load for both single pile and pile in group, (a) for the elastic soil model and (b) for the elastic- plastic soil model. It is clear that not only the displacements of the piles in a group is greater than those of the single piles but the effective length of the piles in a group is about 50% greater than that of the single piles.

Shear Force and Bending Moment in single pile and piles in a group

The variation of the shear force and bending moment along the length of the piles due to maximum applied load are shown in figure 8 and figure 9 respectively. Both figures show that the variation in shear forces and bending moments between the two models of soil is little and can be ignored. But this different in the case of single piles and piles in a group. The difference in maximum shear force between a single pile and a pile in a group is about 30% , and the difference in maximum bending moment between the single pile and a pile in a group is about 11%.

Difference of Lateral Displacements between piles in a group

Figure 10 show the difference in the lateral displacement between piles in a group. It is visible that the displacement of the trailing pile is greater than the displacements for the center pile and leading pile. The amount of reduction in the load carrying capacity of the trailing piles from those of the leading piles will depend on the distances between piles in the group, soil properties and level of loading(Rao et al 2015)[25].

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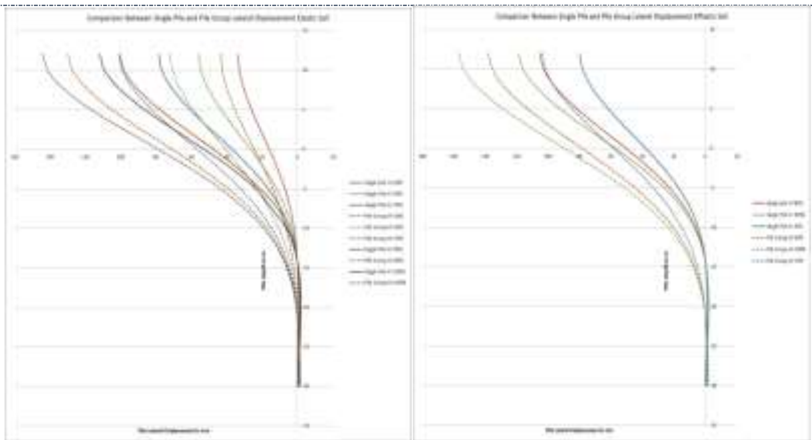
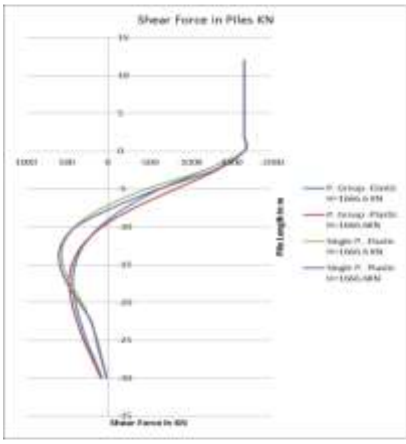


(a) Elastic Soil *(b) Elastic- Plastic Soil*

Figure 7: Variation of lateral displacement with the applied load (a) Elastic soil model and (b) Elastic-Plastic soil model



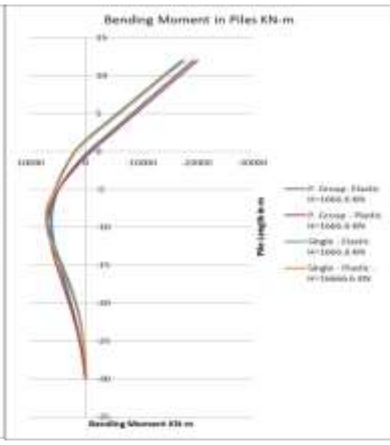


Figure 8: Shear Force Distribution along the pile

Figure 9: Bending moment distribution along the pile

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study is to investigate the justification of using a reduction factor of 0.7 for the lateral load carrying capacity of the piles in a group forming the pier foundation for Al-Najibiya bridge from the capacity of a single pile. From the finding of the study, the following conclusions are drawn:

a) for the level of loading on the bridge pier, the average capacity of the pile in a group is 78.6% of the capacity of a single pile.
b) the difference in the maximum shear force (below river bed) on a single pile and a pile in a group is within 30%.
c) The difference in maximum bending moment (below river bed) on a single pile and a pile in a group is within 11%.
d) Maximum lateral displacements of the pile head under the maximum design load are 6.2%, 6.6%, 8% and 8.7% of the pile diameter for the ases of a single pile in elastic soil, a single pile in elastic plastic soil, a pile in a group in elastic soil and a pile in a group in elastic-plastic soil respectively.

These results indicates that the piles are slightly over design.
For getting better results of the lateral capacity of a pile in a group, it is recommended to include interface elements between the piles and the soil.

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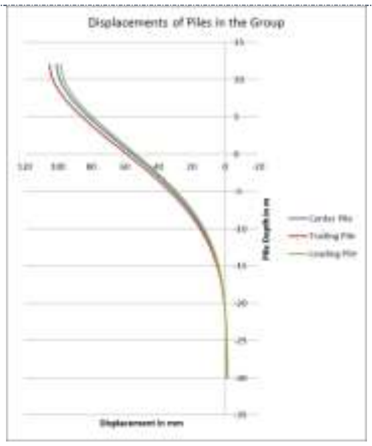

Figure 10: difference in lateral displacement between piles in a group

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