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Study on the Behavior of Bored Pile Foundation for Sixteen-Storeyed RC Building

Nan Thida Htway
Department of Civil Engineering
Technological University (Thanlyin),
Myanmar

Nyan Phone
Department of Civil Engineering
Technological University (Thanlyin),
Myanmar

Kyaw Lin Htat
Department of Civil Engineering
Technological University (Thanlyin),
Myanmar

Abstract: Pile foundation are used extensively for the support of bridges and other structures to transfer structure loads to the ground and to avoid excess settlement or lateral movement. It can be installed without appreciable noise or vibration. This paper presents the behavior of bored pile foundation for sixteen-storeyed reinforced concrete building. Superstructure analysis and design are carried out by using ETABs software. All reinforced concrete members are designed by ACI (318-99) and load considerations are based on UBC-97. Necessary checking is carried out for the stability of the superstructure. All checking for stability of superstructure are within the limits. Required soil properties are obtained from soil report. The allowable bearing capacity is calculated by Meyerhof's Method, Vesic's Method and SPT Method and the average value of these result is finally selected. Analysis and design of pile foundation are made by using ETABs software and pile caps are designed by SAFE software. In design of pile foundation, the required pile length and pile diameter is 50m and 800mm. Number of pile in the group are vaired depending on column load and total required number of pile is 114 nos. The required thickness of pile caps are 1.4m,1.8m and 2m. The tensile strength of bored pile is greater than the pullout capacity for single and group pile. And then checking the pile settlement, lateral load and deflection is within the allowable limit. Therefore, the design of bored pile foundation for this proposed building is satisfactory.

Keywords: bored pile foundation; soil bearing capacity; pullout capacity; lateral load; settlement; deflection

1.INTRODUCTION

Nowadays, the rate of population is increased and the cost of lands is very expansive. Its lead to construct many high-rise building in urban areas. The tall building must have strength and safety, so bored pile foundation is widely used over the world. The design of bored pile foundation has been established by many researchers [1], [2], [3], [4]. The effect of installing the piles reduced the soil stiffness within the bored pile group, making the soil less efficient in resisting lateral pile movements than in the driven pile group. Structurally, however, bored piles were more resistant to flexural loading. The net effect was that the system of bored piles was stiffer than the system of driven displacement piles [5]. The comparisons of experimental results and theoretical analysis for laterally loaded pile showed encouraging results for the prediction of ultimate lateral load, but the prediction of lateral deflection was not satisfactory and needs further work [6]. Elastic solution for laterally loaded piles are analyzed using the fourier FEM [7]. The comparisons of ultimate uplift capacity of pile developed by Kulhawy et al (1979): Das (1983) and Chattopadhyay and Pise (1986) [8]. This study considers the behavior of bored pile foundation for sixteen-storeyed reinforced concrete building. Superstructure is analysis by ETABs software. Allowable bearing capacity is calculated by Meyerhof's Method, Vesic's Method and SPT Method. Analysis and design of pile foundation is made by ETABs software and pile cap is designed by SAFE software. Pullout capacity is calculated from piles for resisting uplift equation and settlement of single pile and group pile by semiemprical method. And then lateral load capacity is calculated by using Brom's method. The rest section is compared the result on single and pile group.

2.IMPLEMENTATION PROGRAM

Firstly, a 16^{th} storeyed superstructure is modelled by ETABs software and checked the stability of superstructure. To get foundation design, the bearing capacity of soil on each type is calculated and then chosen the foundation type. And the compression capacity, settlement, deflection and pullout capacity are checked. And then lateral loads and bending moment are calculated and checked. Finally, the figure of axial force, shear force, bending moment and deflection along the length of pile are showed.

3.PROPOSED SUPERSTRUCTURE

The superstructure is sixteen-storeyed residential building and it is firstly analyzed by ETABs software. It is situated in seismic zone 2B in Kamaryut township, Yangon Region. In these building concrete strength, fc' is 4000psi and reinforcing yield strength, f_y is 50000psi.The intermediate moment resisting frame and dynamic analysis procedure are used. The overall height of the building is 57m, basement height is 3.66m, ground floor level height is 3.66m and typical floor height is 3m. The building is square shape and its length is 33m and 33m width. Loading consideration is based on UBC-97 and the load combinations are considered as per CQHP guideline. 3D model of superstructure which is analyzed in ETABs software is shown in Figure 1.

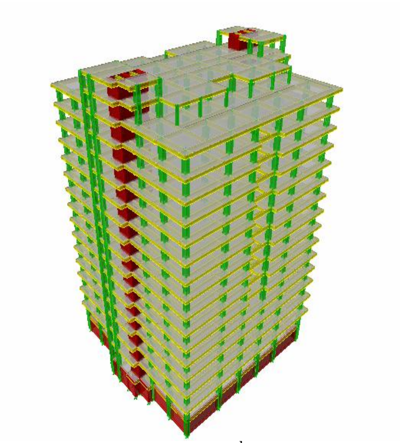

Figure 1. 3-D model of 16^{th} storyed building

4.RESULT OF STABILITY CHECKING

Overturning moment, sliding, storey-drift and P-Δ effect are checked for the stability of superstructure. All checking of superstructure stability are within the allowable limit. So, the superstructure is stable. The result of checking is shown in Table 1.

Table 1

Checking	X-Direction	Y-Direction	Limit	Remark
Overturning Moment	7.82	7.01	1.5	satisfied
Sliding	4.4	4.9	1.5	satisfied
Storey-Drift	0.49065	0.03888	2.16	satisfied
P-Δ Effect	0.00209	0.00261	0.1	satisfied

5. STUDY ON SOIL REPORT

The proposed building is located in Kamaryut township, Yangon Region. The required soil parameters such as C, Ø, ϒsat and ϒ' are taken from soil report. Three number of borehole are used. The depth of borehole is 72m and the water table is found at 16.5m below the ground surface.

5.1Calculation of Allowable Bearing Capacity of Soil

The allowable bearing capacity is calculated by Meyerhof Method, Hansen Method and Vesic Method. The allowable bearing capacity is finally taken the average value of these three methods. The value of allowable bearing capacity are shown in Table 2.

Table 2

Methods	Q_{all}(ton/m^2)
Meyerhof	13.3
Hansen	12.3
Vesic	16.7
Average	14.1

5.2 Selection of Foundation Type

Foundation type is chosen by comparison the allowable bearing capacity of soil and the required bearing pressure of structure.

Allowable bearing capacity =14.1ton/m^2

Unfactor column load =31257.08ton

Foundation Area = 1089m^2

$$\text{Required bearing pressure} = \frac{31257.08}{33x33} = 28.7\text{ton/m}^2$$

The required bearing pressure is greater than the allowable bearing capacity of mat foundation. Therefore, mat foundation is not suitable for the proposed building So, pile foundation should be used.

6.LOAD CARRYING CAPACITY OF SINGLE PILE AND GROUP PILE FOUNDATION

The unfactored column load are taken from superstructure. According to the critical unfactored column load, single pile and four pile group are chosen to design pile foundation. The values of critical unfactored column loads are shown in Table 3.

Table 3

Point	Critical Unfactored Column Loads (tons)	Remark
13,20,21,22,27,28,30,35,36, 37,44	316.94	Single pile
14,15,16,17,18,19,38,39,40, 41,42,43	542	Group-1
1,2,3,4,5,6,7,9,10,12,45,47, 48,50,51,52,53,54,55,56	604.55	Group-2
8,11,46,49	683.53	Group-3
(69+70+71+72+282+283+287+288+1197+1198+1201+1202+1203),(73+74+75+76+284+285+290+291+1199+1200+1204+1205+1206)	2795.765	Group-4

7.DESIGN OF BORED PILE FOUNDATION

To design the bored pile foundation, ETABs software is used and all of piles are satisfied with compression capacity checking, settlement checking and deflection checking. The results of pile foundation from software represent in Table 4.

Table 4

Name	Single pile	Group 1	Group 2	Group 3	Group 4
Diameter (mm)	800	800	800	800	800
Length(m)	50	50	50	50	50
All:Bearing Capacity	334	334	334	334	334

(tons)					
Control Point	20	3054	3019	3063	3095
Load Per Pile (Tons)	330	289	320	250	303
Settlement (mm)	9.49	8.96	9.79	8.82	9.13
Deflection in X-Direction (mm)	3.22	3.17	3.73	3.51	2.97
Deflection inY-Direction (mm)	3.56	2.91	3.60	3.01	3.44
All: Settlement (mm)	10	10	10	10	10
Remark	OK	OK	OK	OK	OK

7.1 Design Result of Pile Cap

According to design analysis result from SAFE software the maximum punching shear ratio is 0.95 and this value is lower than the allowable limit. And required reinforcement for the pile caps are obtained. For single pile and group pile required pile cap size and steel schedule are shown in Table 5 and Table 6. Pile cap foundation plan is shown in Figure 2.

Table 5

Name	No of Pile	Length (m)	Width (m)	Thickness (m)
Single pile	1	1.8	1.8	1.4
Group 1	2	3.6	1.8	1.8
Group 2	2	1.8	3.6	2
Group 3	3	3.6	3.28	2
Group 4	10	10.8	4	2

Table 6

Name	Top Steel		Bottom Steel	
	X-Strip	Y-Strip	X-Strip	Y-Strip
Single pile	#8@4″c/c	#8@4″c/c	#8@4″c/c	#8@4″c/c
Group 1	#8@3″c/c	#8@3″c/c	#8@3″c/c	#8@3″c/c
Group 2	#8@3″c/c	#8@3″c/c	#8@3″c/c	#8@3″c/c
Group 3	#8@3″c/c	#8@3″c/c	#8@3″c/c	#8@3″c/c
Group 4	#8@3″c/c	#8@3″c/c	#8@3″c/c	#8@3″c/c

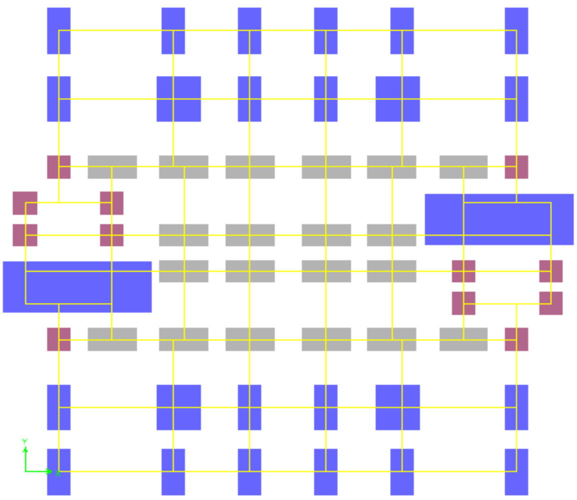

Figure 2. Cap Foundation Plan

7.2. Allowable Pullout(uplift) Capacity of Bored Pile

The uplift capacity of piles is generally controlled by the unit shearing resistance, either adhesion or friction, available at the interface of pile and soil. The design of bored pile foundation should be considered checking the pullout capacity. In checking the allowable pullout capacity is not greater than tensile capacity of pile. Furthermore, the uplift capacity of the pile group must also be checked. The pullout capacity for single pile is estimated from equation 1.

$$\text{Pullout Capacity, } P_{tu}=\sum P_{si} + P_{pb} + W \qquad (1)$$

In equation (1) $\sum P_{si}$ is skin resistance from the several strata over the embedment depth, P_{pb} is pullout capacity from base enlargement and W is total weight of pile.The allowable pullout capacity of single pile and pile groups are shown in Table 7. Since the tensile strength of bored pile is greater than the ultimate uplift capacity of pile. So, the design is satisfied.

Table 7

Name	All: Pullout capacity of pile (Tons)	Tensile capacity of pile (Tons)
Single pile	44.14	173.96
Group 1	88.28	347.92
Group 2	88.28	347.92
Group 3	132.42	521.88
Group 4	441.38	1739.6

7.3 Settlement of Single Pile and Group Pile

The settlement analysis plays an important role in building foundation. The settlement of pile is calculated by semiemprical method. The calculated value of settlement is lower than the allowable limit(25mm). The results of settlement for single pile and pile group are described in Table 8.

Table 8

Name	Single Pile Settlement(mm)	Group Pile Settlement(mm)
Single Pile	11.08	11.08
Group 1	9.47	14.21
Group 2	10.56	15.84
Group 3	7.96	16.12
Group 4	9.77	21.84

7.4. Lateral Load Capacity of Bored Pile

Lateral loadings are included wind loads, earthquake loads, wave loads and inclined loads. Many different methods of analysis have been proposed to solve the problem of a laterally loaded pile. For this paper the analysis is done with Brom's method. The actual values of lateral load, lateral deflection, and bending moment are taken from ETABs result and it value is lower than the allowable value. So, the pile can resist the imposed lateral load. The results of pile capacities under lateral load are as shown in Table 9.

Table 9

Pile Capacity		Lateral Load (tons)	Lateral Deflection (mm)	Bending Moment (ton. m)
Single pile	Actual	2.87	3.56	5.03
Group 1	Actual	2.21	3.17	1.45
Group 2	Actual	3.13	3.73	3.97
Group 3	Actual	2.31	3.51	2.78
Group 4	Actual	2.36	3.44	5.31
Allowable		21.20	10.00	42.55
Remark		OK	OK	OK

8. ANALYSIS RESULT DESCRIPTION

The following figures are shown axial force, shear force, bending moment deflection and settlement of pile.

8.1 Axial force along pile

The following Figure 3 shows the axial load distribution in the pile. The axial force is maximum at the top portion of the pile, it reduces with depth and is minimum at the bottom portion of the pile. The maximum axial force of the pile is 319.62tons which is occurred in group 2. The minimum axial force of the pile is 282.42tons which is occurred in group 3.

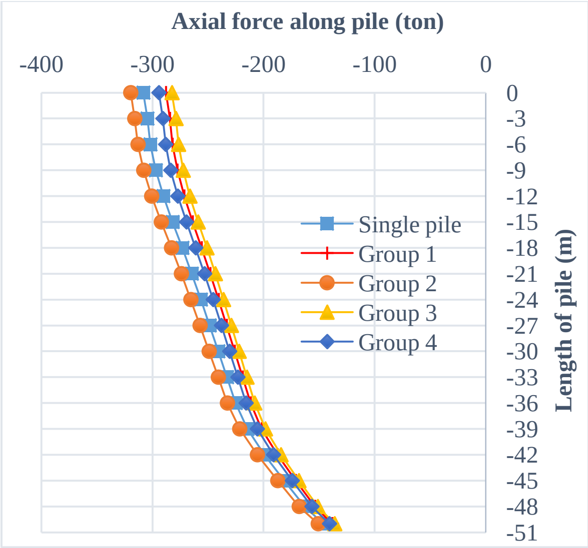

Figure 3 Axial Force of Pile

8.2 Shear Force along pile

Figure 4 describes shear force along the pile. The maximum shear force is occurred at the top portion of pile and the minimum at the bottom portion of pile. The maximum shear force of the pile is 2.04 tons which is occurred in group 4 and the minimum value is 0.37 tons which is occurred in group 1.

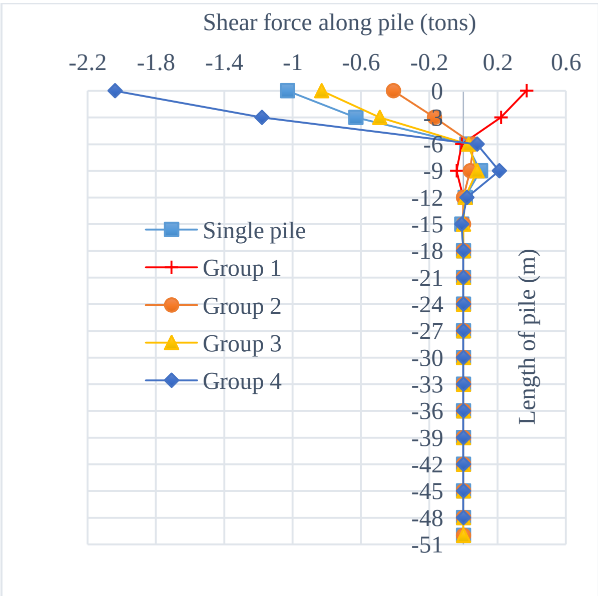

Figure 4 Shear Force of Pile

8.3 Bending Moment along pile

The effect of bending moment along the pile length is described in Figure 5. The maximum bending moment of pile is occurred at the top portion of pile and the minimum at the bottom portion of pile. The maximum bending moment of the pile is 8.745 ton-m which is occurred in group 4 and the minimum value is 1.44 ton-m which is occurred in group 2.

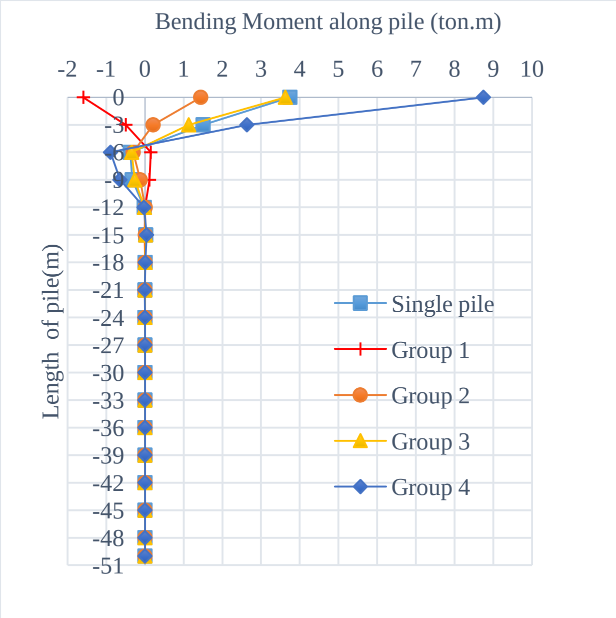

Figure 5 Bending moment of Pile

8.4 Pile Deflection in X-Direction

The value of deflection along pile for X-Direction is shown in Figure-6. It was found that the deflection value is decreased with increase in length of pile. The maximum deflection is 3.73mm which is occurred at group2 and the minimum values is 2.97mm which is occurred at group 4.

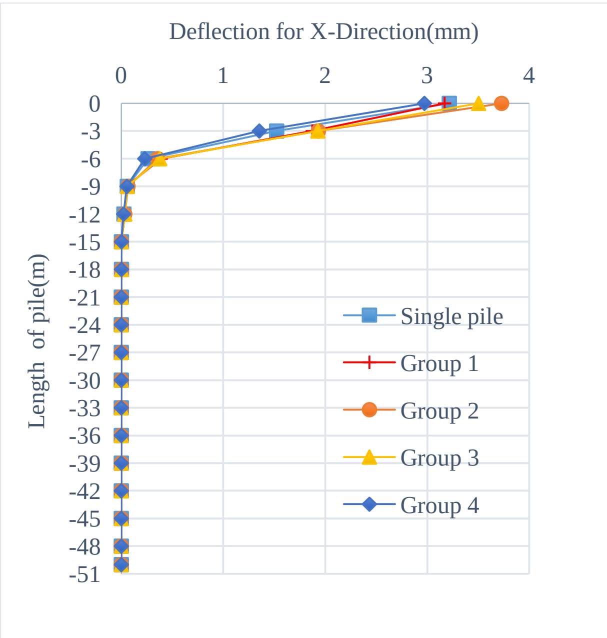

Figure 6 Pile deflection in X-Direction

8.5 Pile Deflection in Y-Direction

The value of deflection along pile for Y-Direction is shown in Figure-7. It was found that the deflection value is decreased with increase in length of pile. The maximum deflection is 3.6mm which is occurred at group2 and the minimum values is 2.91mm which is occurred at group 1.

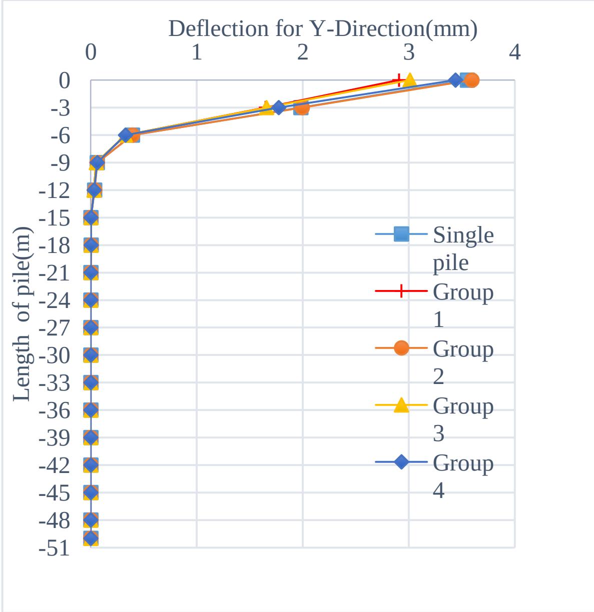

Figure 7 Pile deflection in X-Direction

8.6 Settlement

The value of settlement is shown in Figure 8. The maximum value of settlement is 9.79mm which is occurred in group 2 and the minimum is 8.96 mm which is occurred in group 1.

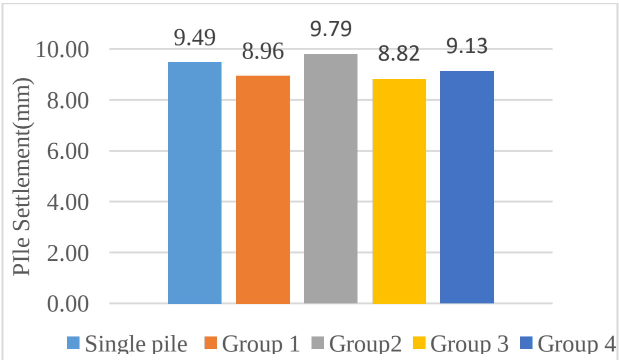

Figure 8 Settlement

9. PILE REINFORCEMENT

For piles, a minimum amount of vertical steel reinforcement is 1% of the cross sectional area of pile. According to ACI code, spirals should consist of a continuous bar or wire not less than 5/8" in diameter and clear spacing between turns of spirals must not exceed 3" nor less than 1". For this proposed building the required reinforced bars are10#8 longitudinal reinforcement with 3"clear cover @8″c/c spacing and 5/8" spiral bar diameter @ 3" c/c is used throughout the length of pile.

10.DISCUSSION AND CONCULSION

In these study 16th storeyed building is designed in seismic zone 2B and bored pile foundation is considered. Single pile and four pile groups are used. In the pile design, the diameter of pile is 800mm and the length of pile is 50m. The reinforced design is 10#8 longitudinal bar with 3″ clear cover @8″ c/c spacing and 5/8" spiral bar diameter @3" c/c is used throughout the length of pile. Pile cap are designed with 3D spacing and checking punching shear ratio by SAFE software. They are satisfactory in punching shear ratio. Reinforcement design for pile cap is #8 bar but number of pile are varied according to the pile cap size. The value of settlement, deflection in X&Y direction and lateral load are less than the allowable limit. The tensile strength of bored pile is greater than the pullout capacity for single and group pile. So, the bored pile foundation is satisfied for the proposed building. According to the result, the axial force in group 2 is maximum and minimum is occurred in group 3. The shear force and bending moment in group 4 is maximum and minimum is occurred in group 2. The maximum deflection in X-direction and Y-direction is occurred at group 2 but the minimum is occurred at group 4 in X- direction and at group 1 in Y-direction. The base settlement is maximum at group 1 and the minimum is occurred at group 3.

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