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Analysis and design of spun pile Foundation of Sixteenth Storyed Building in cohesion less soil

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Abstract – This aim of the paper is the study on the analysis and design of spun pile foundation in cohesion less soil. This foundation describes the axial force, bending moment, lateral deflection due to seismic load, pile working load and settlement. The pile working load compares the result of pile applying load by analyzing ETAB software. The two results of pile settlement are gained by using Brom:s method and by analyzing ETAB software. To design the foundation, the super structure of sixteenth storeyed R.C building with basement is analyzed by applying E-tab software. According to the result of unfactored load of superstructure, the same number of pile is divided into four groups. Allowable bearing capacity is gained from the soil report of Inya Lake Residence Project in Yangon. The allowable bearing capacity of soil is calculated by Myerhof's and SPT methods. The size of spun pile is used outside diameter 16″ and thickness 3″ slender shape. The pile working load from materials for spun pile is 60 tons. The required length for 60 tons spun pile regard to 85 ft according to calculation of the allowable bearing capacity .The analyzing result and calculations of deflection and settlement is lesser than the allowable limits. The analysis and design of spun pile foundation in cohesion less soil is available for the sixteenth storeyed building.

Keywords – Design of superstructure, spun pie foundation, deflection, settlement and working load.

I. INTRODUCTION

Pile foundation is the part of a structure used to carry the applied column load of a super structure to the allowable bearing capacity of the ground surface at the same depth. The common used shape of pile is rectangular and slender which applied the load to the stratum of high bearing capacity. In the case of heavy construction, the bearing capacity of shallow soil will not be satisfactory; the construction should be built on pile foundation. It is used where soil having low bearing capacity respect to loads coming on structure or the stresses developed due to earthquake cannot be accommodated by shallow foundation. To obtain the most economical and durable foundation, the engineers have to consider the super structure loads, the soil condition and desired to tolerable settlement. Pile foundations are convened to construct the multi-storeyed building and work for water, such as jetties as bridge pier. The types of prestressed concrete pile are usually of square, triangular, triangle, circle and octagonal section which are produced in suitable length in one meter interval between 3 and 13 meters. Nowadays, most people use spun pile foundation addition to precast concrete pile to construct most of the buildings and bridges. Spun pile is one of the types of piles are widely used in the world construction. Prestressed concrete cylinder pile is a special type of precast concrete pile with a hollow circular cross section. Advantage of using spun pie are spun pile is less permeable than reinforced concrete pile, thus it has a good performance in marine environment. So the design of two pile foundation can be based on the deflection and settlement due to earthquake.

II. PREPARATION FOR ANALYSIS OF PILE FOUNDATION

Information of structure and material properties are prescribed as follows. Dead load, live load, wind load and earthquake loads are considered in proposed building. The typical beam plans and 3D view of the proposed buildings from ETABs software are shown in Figure 1 and Figure 2.

A. Site location and Profile of structure

Type of Structure	: 16-storeyed R.C Building	
Location	: Seismic zone (4)	
Soil Type	: Silty Sand, S_D	
Type of Occupancy	: Residential	
Shape of Building	: Rectangular shape	
Size of Building	: Length	= 81 ft
	: Width	= 73 ft
	: Height	=162 ft
Height of Building	: Typical story height	= 10 ft
	: Bottom story height	= 12 ft

B. Design Codes

Design codes applied for superstructure are ACI (318-99) and UBC-97. There are 26 numbers of Load combinations which are accepted for beam, column, etc.

(1)Material Properties

Analysis property data

Weight per unit volume of concrete = 150 pcf

Modulus of elasticity	= 3.12 x 10^6
Poisson's ratio	= 0.2

Design property data

Reinforcing yield stress (f_y)	= 50000 psi
Shear reinforcing yield stress (f_y)	= 50000 psi
Concrete cylinder strength (f'_c)	= 3500 psi

C. loading Considerations

The applied loads are dead loads, live loads, earthquake load and wind load.

(1) Gravity Loads: Data for dead loads which are used in structural analysis are as follows;

Unit weight of concrete	= 150 pcf
4½ inches thick wall weight	= 50 psf
9 inches thick wall weight	= 100psf
Light partition weight	= 20 psf
Finishing Weight	= 20 psf
Weight of elevator	= 2 ton

Data for live loads which are used in structural analysis are as follows:

Live load on slab	= 40 psf
Live load on lift	= 100 psf
Live load on stairs	= 100 psf
Live load on corridors	= 60 psf
Live load on roof	= 20 psf
Weight of water	=62.4 pcf

(2)Lateral loads: Data for wind loads which are used in structural analysis are as follows;

Exposure Type	= B
Basic wind velocity	=100mph
Important factor, I_w	= 1.0
Windward Coefficient	= 0.8
Leeward Coefficient	= 0.5

Data for earthquake load are as follows:

Soil profile type	= S_D

Seismic Zone	= 2A
Seismic Zone Factor	= 0.2
Building period coefficient, C_t	= 0.03
Important Factor, I	= 1
Seismic coefficient, C_a	= 0.28
Seismic coefficient, C_v	= 0.4

(3)Lateral Load Combination: According to (ACI 318-99) codes, the design of load combination are as follows:

1. 1.4 DL
2. 1.4 D + 1.7 LL
3. 1.05DL + 1.275LL + 1.275WX
4. 1.05DL + 1.275LL – 1.275 WX
5. 1.05DL + 1.275LL + 1.275 WY
6. 1.05DL + 1.275LL - 1.275 WY
7. 0.9DL + 1.3 WX
8. 0.9DL -1.3 WX
9. 0.9DL + 1.3 WY
10. 0.9DL - 1.3 WY
11. 1.05DL + 1.28LL + EX
12. 1.05DL + 1.28LL - EX
13. 1.05DL + 1.28LL + EY
14. 1.05DL + 1.28LL - EY
15. 0.9DL + 1.02 EX
16. 0.9DL - 1.02 EX
17. 0.9DL + 1.02 EY
18. 0.9DL - 1.02 EY
19. 1.16DL + 1.28 LL + EX
20. 1.16DL + 1.28 LL - EX
21. 1.16DL + 1.28 LL + EY
22. 1.16DL + 1.28 LL – EY
23. 0.79DL + 1.02 EX
24. 0.79DL - 1.02 EX
25. 0.79DL + 1.02 EY
26. 0.79DL - 1.02 EY

III.DESIGN RESULTS OF PROPOSED BUILDING

The design results of beam and column for proposed building are described

TABLE I DESIGN RESULTS FOR COLUMN, BEAM AND SLAB

Section	Size
Column	28″× 28″, 26″×26″, 24″×24″, 22″×22″, 20″×20″, 18″×18″, 16″×16″, 14″×14″, 12″×12″
Beam	9″×9″, 9″×12″, 10″×12″,12″×16″, 12″×18″, 12″×20″,14″×18″,14″×20″
Slab	4″ thick, 4.5″ thick and 5″thick
Wall	12″ thickness and 14″ thickness

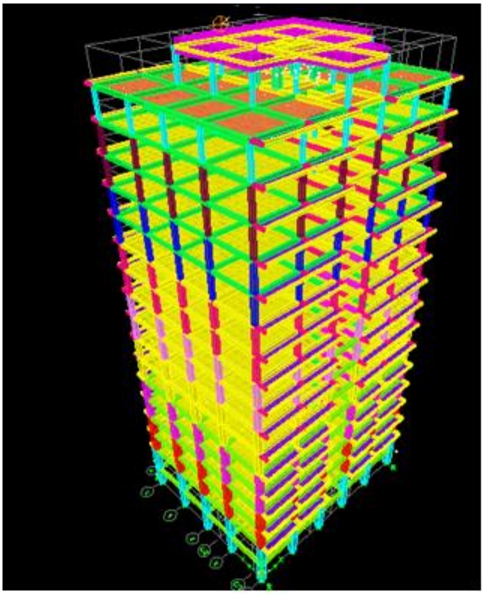


Figure.1 3D Model of Proposed Building

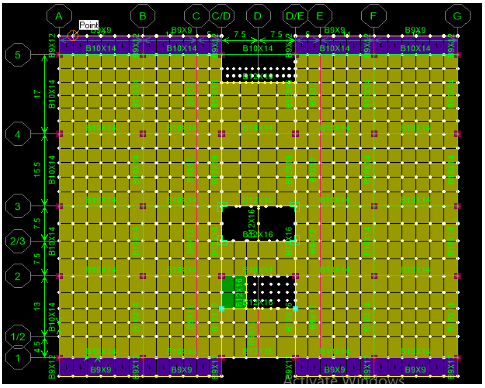


Figure.2 Beam and Column Layout Plan

IV. STABILITY OF THE SUPERSTRUCTURE CHECKING

The design superstructure is checked for

(1) Overturning,
(2) Sliding
(3) Story Drift
(4) Torsional Irregularity
(5) P-Δ Effect

All checking for stability of superstructure are within the limits.

TABLE II STABILITYCHECKING

Checking	X-direction	Y-direction	Limit
Overturning Moment	14.03	11.51	> 1.5
Sliding Resistance	4.81	4.81	> 1.5
Story Drift	0.22	0.26	< 2.4
Torsional Irregularity	1	1	< 1.2
P-Δ Effect	0.001	0.01	< 0.1

The superstructure of sixteenth storeyed building with basement is available by checking five methods.

TABLE III SOIL PROPERTIES

Depth (m)	N (Blow/m)	γ_{sat} (KN/m^2)	N_q	(ϕ') ($^\circ$)	σ_{vo} (KN/m^3)
4.50	7	9.95	0	0	44.775
6.00	7	10.53	0	0	60.57
7.50	7	10.98	8	28	77.04
9.00	13	10.48	8	28	92.76
10.50	5	7.98	0	0	104.73
12.00	8	7.98	0	0	116.7
13.50	9	7.98	0	0	128.67
15.00	14	8.65	0	0	141.64
16.50	21	9.76	10	30	156.28
18.00	29	9.76	12	31	170.92
19.50	28	9.76	12	31	185.56
21.00	26	9.76	10	30	200.20
22.50	23	9.76	10	30	214.84
24.00	24	9.76	10	30	229.48
25.5	28	9.76	12	31	244.12
27	10	8.45	0	0	257.55
28.5	23	10.36	10	30	273.09
30	17	10.36	10	30	288.63

The allowable bearing capacity (Qult)all is calculated by Myherhof's method.

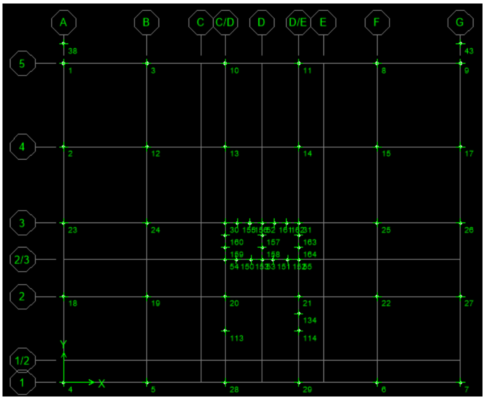


Figure3.Point Levels from load of superstructure

TABLE VI GROUPS OF UNFACTORED COLUMN LOAD

Group of Spun Pile	Points	Range	Maximum Unfactored Load	Control Point
1	113,114	300-500	306.02	4
2	1,4,7,9,20,21	500-700	611.81	36
3	2,3,5,6,8, 10,11,12, 13,14,15, 17,18,19, 23,24,25, 26,27	1007.33	1007.33	207
4	SW	4028.47	4028.47	54

V. Pile working load from Material

(Outside diameter = 16 inches, thickness =3 inches slender pile.)

Shear reinforcing yield stress (fy) = 50000 psi

Concrete cylinder strength (f'c) = 4000 psi

Modulus of elasticity = 3.37×10^6

$\phi PT = 0.7\ (0.33\ f'c\ Ac + 0.39\ fyAst)$(ACI318-99)

$= 0.7\ (0.33 \times 4000 \times 122 + 0.39 \times 50000 \times 10 \times 0.31)$

= 155043 lbs.

= 69 Tons

$0.86\phi PT = 0.86 \times 69$

= 59.34 Tons (Use 60 Tons)

According to CQHP Guideline

Up to 10,000 ft^2 Area – one bore hole for 2,500 ft^2(min) ≥ Two bore hole

For this project,

Project area = 81′-0″ × 73′-0″

= 5913 ft^2

Three bore holes are adequate.

The results of unfactored load are received by applying ETAB software. The base point levels of super structure are described in Figure3.

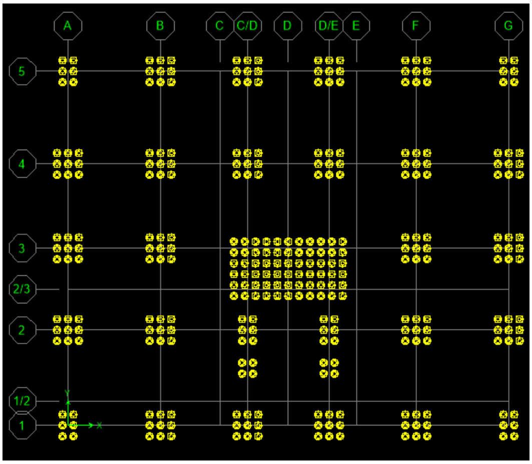
The group 1 is applied in bore 1, Group 2 in bore hole2 And Group 3 in bore hole 3 and Group 3 in bore hole 2.

The allowable bearing capacity Q_{ult} = 618.68 KN (in bore hole 1)

The allowable bearing capacity Q_{ult} = 608.06 KN (in bore hole2)

The allowable bearing capacity Q_{ult} = 633.02 KN (in bore hole 3)

The analysis results of spun pile foundation are described as the pile layout plan in Figure 4.



Figsure4. Spun pile layout plan

VI. Design of Pile Group 1 (Spun concrete pile)

The results of settlement are calculated by Brom's method to compare the software results.

Unfactored load = 611.8 kip

Assume pile cap thickness = 3 ft

B = 6ft

Pile cap weight = 3 × 6 ×4×0.15

= 10.8 kips

Total weight of pile group = 611.81 + 10.8

= 622.61 kips

Load per pile $= \frac{622.61}{6}$

=103.7kip<146kips

(b) Allowable bearing capacity of pile group

The ultimate bearing capacity of the pile group in cohesion less soil is at least equal to the sum of individual pile capacities.

Pile group capacity, $(Q_G)_{ult}$ $= n \times (Q_x)_{ult}$

$= 16 \times 410.075$

= 2460.45 kips

$(Q_G)_{all}$ $= (Q_G)_{ult}/F.S$

$= \frac{2460.45}{3}$

= 820.15kips

The group capacity is 820.15 kips, which is greater than the loads 622.61 kips on the pile group. Therefore, it is acceptable from a bearing capacity point of view.

(c) Settlement of pile

Semi-empirical method is used. To calculate the settlement

Total load on pile group = 622.61 kips

Q_p = 85.47 kips

Q_{pa} $= \frac{85.47}{3}$ = 28.49 kips

Q_f = 324.6 kips

Q_{fa} $= \frac{324.6}{3}$ = 108.2 kips

Total allowable load, $(Q_v)_{all}$ = 136.69 kips

When actual load on each pile is 103.7 kips.

$$Q_{pat} = Q_{pa} \text{ x } \frac{\text{Load per pile}}{(Q_v)_{all}}$$

$= 28.49 \times \frac{103.77}{136.69}$

= 21.63 kips

$$Q_{fa} = Q_{fa} \text{ x } \frac{\text{Load per pile}}{(Q_v)_{all}}$$

= 108.2 × 103.77/136.69

= 82.14 kips

L = 85 ft

$\dot{\alpha}_s$ = 0.55

B = 16 in

A_p = 1.38 ft^2

E_p = 3.37×10^6 psi for concrete

C_p = 0.02 (Table)

q_p = Q/A

= 85.47/1.38

= 61.93 k/ft^2

$$C_s = \left[0.93 + 0.16\sqrt{\frac{L}{D}} \right] C_p$$

= 0.066in

$$S_s = \frac{(Q_{pa} + \alpha Q_{fa})L}{A_p E_p}$$

= 0.1in

S_p = $C_s Q_{fa} / L q_p$ = 0.12

$$S_{ps} = \frac{C_s Q_{fa}}{L q_p}$$

= 0.01 in

S_t = $S_s + S_p + S_{ps}$

= 0.1+ 0.12 + 0.01

= 0.23 in < 1 in (satisfied)

(ii) Empirical method

S_t = $\frac{B}{100} + \frac{QuaL}{ApEp}$

S_t = 0.31 in

The results obtained from these methods are compared and then higher value 0.2 in is chosen. Therefore, the settlement of pile group is

S_G = $S_t \sqrt{(\overline{b}/B)}$

= 0.31 $\sqrt{(24/10)}$

= 0.37 < 1 in

TABLE V COMPARISON OF LOAD OF GROUP PILE

Spun Pile	Pile No	$(Q_{uG})_{all}$	Total load on pile group
Group 1	4	413.56	312.43
Group 2	6	820.15	640.61
Group 3	9	1251.71	1028.93
Group 4	54	22530.84	4190.47

TABLE VI COMPARISON OF DESIGN OF PILE CAP

Spun Pile	No of Pile	L (ft.)	B(ft.)	Thickness (ft.)
Group 1	4	4	4	2.67
Group 2	6	6	6	4
Group 3	9	6	6	4
Group 4	54	18	12	5

TABLE VII DESCRIPTION OF DEFLECTION, SETTLEMENT & LOAD

	Deflection		Settlement		Load	
	X	Y	Broom' method	ETAB software	Applied Load	Working load
GP 1	0.13	0.11	0.33	0.04	54.91	60
GP 2	0.15	0.18	0.37	0.5	10	60
GP 3	0.2	0.18	0.41	0.3	51.63	60
GP 4	0.16	0.14	0.41	0.38	54.86	60

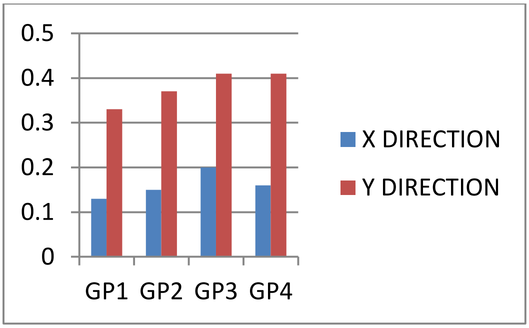


Figure5. Comparison of X & Y direction of spun pile foundation

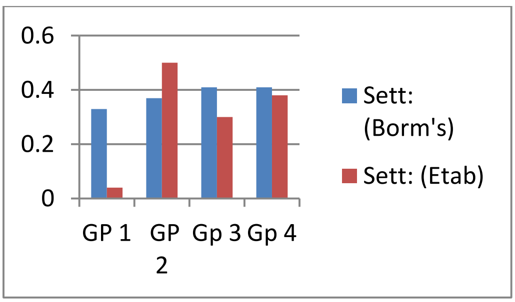


Figure6. Comparison settlement of spun pile foundation

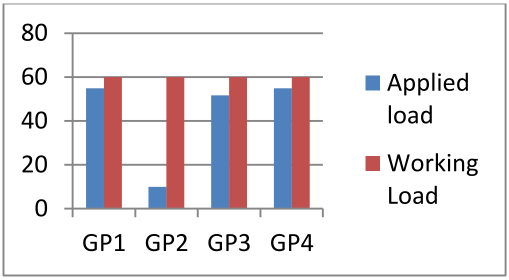


Figure7. Comparison pile working load and applied load of spun pile foundation

VII. DSICUSSION AND CONCLUSION

For the design of spun pile foundation, the required soil parameters are obtained from the soil report on, Yangon. The allowable bearing capacity of the soil is calculated by Tomlinsom, Myerhof in Rules of Thumb and SPT methods. The soil condition of the proposed building at the base of mat foundation is soft soil. The proposed site is located on seismic zone 2A. The superstructure is analyzed and designed by using ETAB software. The lateral load and gravity loads are considered and the design superstructure is checked for sliding resistance, overturning effect, story drift, and torsional irregularity. The sum of critical unfactored loads from superstructure is 29867.01 kip. In design of spun pile foundation the use of the same number of pile divided into four groups. The required pile length for four groups of two pile foundations is 85 Ft. The deflection of two pile foundations is satisfied. The calculated settlement of group1, 3,4 by using Brom's method are greater than ones from ETAB software and group 2 settlement is less than one In comparison two results of settlement for spun pile foundation these are more satisfactory than the Allowable limits. The deflections of two directions are less than the allowable limits. The applied load of spun pile foundation are more responsible than the working load. Finally, the spun pile foundations are accepted to support the proposed sixteenth-storey R.C building with basement.

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