Static Analysis of Piled Raft Foundation System for A Multi-Storeyed Building on Alternating Layers of Sand and Clay Soil

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Abstract— The proposed study aims to conduct a comprehensive static analysis of a piled raft foundation system for a multi- storeyed building constructed on alternating layers of sand and clay soil. This research is a live project work motivated by the need to ensure the safety, stability, and optimal performance of buildings situated in regions with heterogeneous soil conditions . Collecting geotechnical data to characterize the parameters of the sand and clay layers. The superstructure is analyzed using the software E-TABS, and an appropriate foundation can be designed. The soil parameters are characterized using geotechnical data and input this information into ABAQUS for precise material modelling. Using ABAQUS, a finite element program, as the main analysis tool, the study will offer crucial insights into how foundations behave in varied soil conditions under static loads. Performing parametric studies based on the numerical analysis to investigate the influence of changing important design parameters and soil conditions on the response of the foundation and to offer insights into possible design optimizations.

Index Terms- Piled Raft foundation , static analysis , FEM modelling , ABAQUS

I. INTRODUCTION

The growth in modern multi- storey building construction, which began in late nineteenth century, is intended largely for commercial and residential purposes. Various urban areas in the world are experiencing scarcity of land, and the spatial expansion of buildings and structures is becoming increasingly problematic. High- rise structures are the only solution to this problem .The development of the high-rise building has followed the growth of the city closely. The process of urbanization, that started with the age of industrialization, is still in progress in developing countries like India. Industrialization causes migration of people to urban centres where job opportunities are significant. The land available for buildings to accommodate this migration is becoming scarce, resulting in rapid increase in the cost of land. Thus, developers have looked to the sky to make their profits. The result is multi-storey buildings, as they provide a large floor area in a relatively small area of land in urban centres. The design of the foundation for this high rise building can be carried out in accordance with the geotechnical research and structure loading requirements to ensure the safe and efficient construction.

II. LITERATURE REVIEW

Jayarajan P ,et.al discussed that the paper presents a detailed analysis of stacked raft foundations using the finite element approach and the PDR method for preliminary design. Four distinct pile configurations are taken into consideration for the parametrical research of piled raft using PLAXIS-3D software.

Santosh Niraula, et.al discussed Using PLAXIS2D as a FEM tool, this study examines the parameters of the piled-raft foundation system one at a time. The stacked raft foundation system has undergone a straightforward strain analysis through a series of parameter adjustments.

Biya Degefu Teji ,et.al discussed in this study, the effects of raft thickness, number of piles, pile length, spacing of piles, and pile diameter on the response of piled-raft foundations were investigated using the finite element based program Plaxis 3D for layered soils (medium to very stiff high plastic silty clay and medium to very dense silty sand soil) subjected to uniform vertical loading.

Al- Ameri ,et.al discussed in this paper about the analyzes a piled-raft foundation on non-homogeneous soils with variable layer depth percentages. The present work aims to perform a three-dimensional finite element analysis of a piled-raft foundation subjected to vertical load using the PLAXIS 3D software. Parametric analysis was carried out to determine the effect of soil type and initial layer thickness.

III. MATERIALS AND METHODS

- Geotechnical data has been collected to characterize the parameters of the sand and clay layers.
- Location of the site is Pondicherry.
- Water table met at a depth of 1.5m .
- This site falls in zone 3 as per the seismic zonation map provided in IS 1893 – part 1:2016.

IV. STRUCTURAL ANALYSIS

The planned building can be constructed as multi-storey building (G +12).The structure is designed as a shear wall structure. The superstructure is analyzed using the software E-TABS so that an appropriate foundation can be designed. Load analysis can be carried out by applying the appropriate loads, including dead loads, live loads, wind loads , seismic loads, and any other relevant loads. Load combinations are defined as per the design codes and standards.

Building Information

Plan Area	**40.4m x 16.27m**
Total Height of Building	**39m**
Number of Stories	**G+12**
Floor Height	**3m**
Wall Thickness	**At base -200mm, top -160mm**
Slab Thickness	**200mm**
Beam Dimension	**400x500mm**
Grade of concrete	**M40**
Grade of steel	**Fe500 , Fe415**

Table.1

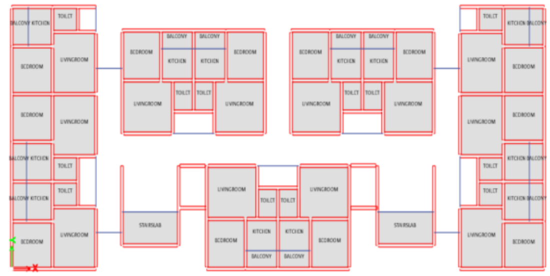

Fig. 1 Plan view in E-TABS

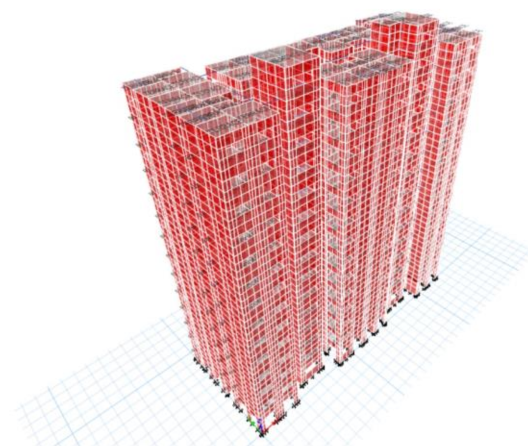

Fig.2. 3D View Of Structural Modelling

From the structural analysis ,
The total load from super structure = 165539.8 kN

V. FOUNDATION DESIGN

The subsoil of the site consists of alternate layers of loose sand /soft clay upto deeper depths from the ground level. Hence , considering the anticipated load intensity induced by the proposed buildings and nature of the soil strata at the site, it is recommended to adopt load transfer type of piled Raft foundation to support the proposed buildings . The type of pile used for the construction of foundation is Bored cast in –situ pile. The design can be carried out as per IS456:2000.

Calculation:
Bearing capacity of pile , Qsafe = 1270.8 kN
Number of piles = 165539.8/1270.8
= 130 piles

5.1 Design Of Pile (As per IS 456)
Diameter of pile = 0.6m = 600mm
Length of pile = 38m = 3800mm
Grade of concrete M40 , fck = 40 N/mm2

fy = 500 N/mm2

5.1.1 Structural Capacity Of Pile

Pu = 0.4fckAc + 0.67fyAsc
Where,
Pu = Axial load on member
fck = characteristic compressive strength of concrete
Ac = Area of concrete
fy = characteristic strength of compression reinforcement
Asc = Area of longitudinal reinforcement .
Ag = Pd4/4 = (P*6002)/4 = 282600mm2
Asc = 0.4 of Ag
= (0.4x 282600)/100 (As per IS2911)
= 1130.4mm2
Ac = Ag – Asc = 282600 – 1130.4 = 281469.6mm2
Pu = (0.4 x 40 x 281469.6) + (0.67 x 500 x 1130.4)
Pu = 4882.19kN
Structural capacity of pile , Psafe = 4882.19/1.5
= 3257.79kN
Reinforcement Detail

Provide 16mm dia bar reinforcement,
Ast = $pd^4/4$ = $px16^2/4$ = $200.96mm^2$
Number of bars = 1130.4/ 200.96
= 6 bars.
Provide 16mm diameter of bar for vertical reinforcement at the length of 39.6m.
Provide Double helical reinforcement of 10mm bar diameter with 150mm spacing.

5.2 Design of Raft slab

Since the soil in the site has low bearing capacity and also to distribute the load from the shear wall frame superstructure, the raft foundation was provided in the site. As the slab covers a wide range of 867 sq. m., it would be critical to comprise such a large amount of work in this report. The slab is divided into strips of width(1meter). The raft designed by the thickness of raft as 800mm over the area.

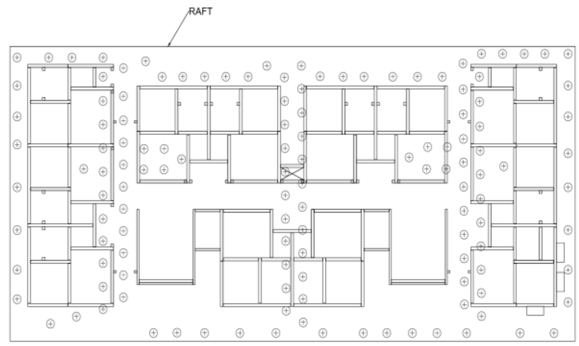

Fig.3. Piled Raft Foundation layout

VI. SOIL AND FOUNDATION MODELLING

The soil parameters are characterized using geotechnical data and input in ABAQUS for precise material modeling. The project will provide vital insights into the behavior of foundations in heterogeneous soil conditions under dynamic loads by utilizing the finite element software ABAQUS as the primary analysis tool.

LAYER		SOIL TYPE	SPT 'N' VALUE	γ	Φ	C	α	YOUNG'S MODULUS	POISSON RATIO	DILATION ANGLE	SHEAR MODULUS
FROM	TO										
0	1.5	S	0	18	0	0		50	0.1	30	45.45454545
1.5	3	S	22	18	34.5	143		50	0.1	4.5	45.45454545
3	4.5	S	23	18	34	150		50	0.1	4	45.45454545
4.5	6	S	25	18	34.5	163		50	0.1	4.5	45.45454545
6	7.5	C	14	18	0	91	0.45	25	0.3	30	19.23076923
7.5	9	C	5	18	0	33	1	25	0.3	30	19.23076923
9	10.5	C	8	18	0	52	0.82	25	0.3	30	19.23076923
10.5	12	S	12	18	30.5	78		20	0.35	0.5	14.81481481
12	13.5	S	14	18	31	91		20	0.35	1	14.81481481
13.5	15	C	9	18	0	59	0.85	30	0.45	30	20.68965517
15	16.5	C	12	18	0	78	0.55	30	0.45	30	20.68965517
16.5	18	C	7	18	0	46	1	30	0.45	30	20.68965517
18	19.5	C	9	18	0	59	0.85	30	0.45	30	20.68965517
19.5	21	S	31	18	33.5	202		25	0.2	3.5	20.83333333
21	23	S	33	18	33.5	215		25	0.2	3.5	20.83333333
23	25	C	19	18	0	124	0.3	50	0.45	30	34.48275862
25	27	C	27	18	0	176	0.3	50	0.45	30	34.48275862
27	29	C	16	18	0	104	0.35	50	0.45	30	34.48275862
29	31	C	24	18	0	156	0.3	50	0.45	30	34.48275862
31	33	C	12	18	0	78	0.55	50	0.45	30	34.48275862
33	35	S	52	18	35	338		80	0.3	5	61.53846154
35	37	S	10	18	29	65		80	0.3	1	61.53846154
37	38/40	S	24	18	32	156		80	0.3	2	61.53846154

Table.2 ABAQUS Input paramaters of Ground soils

a. Plan Details

- Raft area = 20m x 20m
- Thickness of raft = 0.8=800mm
- Pile depth = 38m
- Pile diameter = 0.6m=600mm
- Soil depth = 40m
- No of soil layers = 23
- No of piles = 4

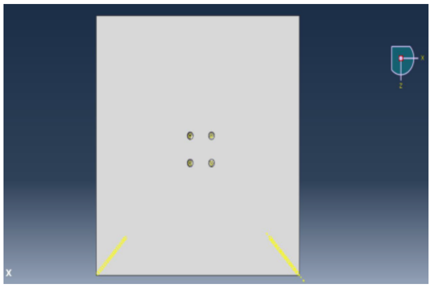

Fig.4 Plan view

b. Material modelling

- Soil model – Mohr coulomb plasticity model
- Input parameters – Density , young's modulus , Poisson Ratio , Friction angle , Dilation Angle , Shear modulus , Absolute plastic strain and cohesive strength.
- Foundation model – Elastic property
- Input parameters – Density of concrete young's modulus , Poisson Ratio.

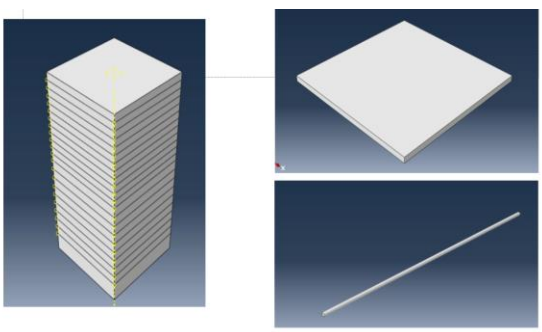

Fig.5 Models of soil layer, pile and raft

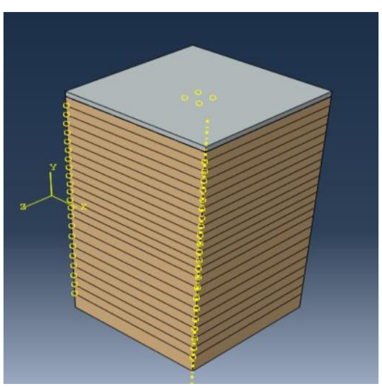

Fig.6 Assembled soil and Foundation model

6.2.1 Boundary Conditions

- Constraints and support condition were given based on the actual conditions at the foundation-soil interface.
- These boundary conditions should accurately reflect the real-world conditions.

6.2.2 Pile -soil Interaction

- Model the interaction between the piles and the surrounding soil accurately.
- Depending on the complexity of the analysis, this could involve using various techniques like beam elements for piles and appropriate interface elements to represent pile-soil interaction.

6.2.3 Mesh Generation

- The model was meshed appropriately, ensuring finer mesh near areas of interest such as where the piles interact with the soil layers.
- The mesh size is taken as 500mm.

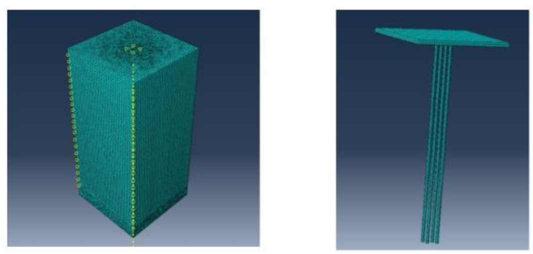

Fig.7 Mesh Generation- soil layer and piled raft

VII. STATIC ANALYSIS

Static analysis of a piled raft foundation involves assessing the behavior and performance of the foundation system under static loads, which may include dead loads ,live loads, and environmental loads , considering both the interaction of the raft and the piles with the soil. The analysis evaluates the stability of the foundation system against various failure modes of excessive settlement to ensure that the structure remains level and does not experience differential settlement that could lead to structural damage.

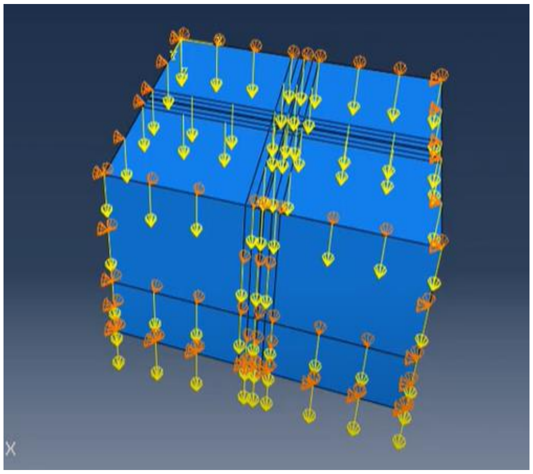

Fig.8 Model under loading conditions

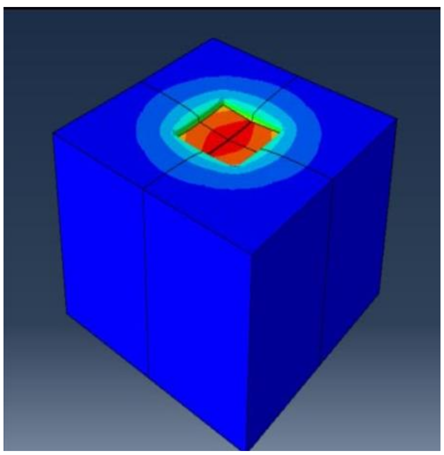

Fig.9 Settlement due to Static load

7.1 Estimation of settlement of pile

Data:

Diameter of pile (d) = 0.6m =600mm

Length of pile (L) = 38m

Load in bearing (Qb) = 339.7kN

Load in frictional Resistance(Qf) = 2837.5kN

Load in compression (Qp) = 3177.2kN

Total Elastic settlement of pile ,

St = Sf + Sb + Sp

Where ,

St = Total settlement

Sf = Settlement due to friction by pile shaft

Sb = Settlement due to bearing by the end of the pile

Sp = Elastic settlement of piles due to load

1. Calculation of friction settlement (Sf)

$$S_f = \frac{Q_f}{(\text{Surface area})}\left(\frac{\text{Diameter of the pile}}{E_s \text{ of soil}}\right)(1-\mu_s^2)(I_f)$$

where ,

Qf = Frictional resistance of the pile

If = influence factor

2. Calculation of settlement in Bearing (Sb)

$$S_b = \left(\frac{Q_b}{A}\right)\left(\frac{D}{E_s}\right)(1-\mu^2)I_b$$

Where,

Qb = Load in bearing

A = Area at tip of pile

Es = Modulus of elasticity of soil

μ= Poisson's ratio = 0.35

Ib = Empirical constant = 0.85

3. Calculation of Elastic compression of the pile (Sp)

$$Sp = \frac{(Qp + \alpha Qf) * L}{Area * Ec}$$

Where , Ec = Modulus of elasticity of concrete = 20 x 10 kN/m^2

α = A factor depending on frictional resistance along the pile (0.5)

Total settlement of the pile (St) = 54.4mm

VIII. RESULTS AND DISCUSSION

The results of the static analysis of piled raft on alternate layers of sand and clay indicate that increasing the pile diameter leads to a decrease in settlement. This finding is consistent with the general understanding in geotechnical engineering that larger diameter piles distribute load more effectively, resulting in reduced settlement.

(I)Effect of Pile Diameter on Settlement:

- As the pile diameter increases from 400mm to 600mm, there is a noticeable decrease in settlement. This trend suggests that larger diameter piles are more effective in reducing settlement under the applied load.
- The settlement values obtained for each pile diameter (72.4mm for 400mm, 69.2mm for 450mm, 66.3mm for 500mm, and 61.4mm for 600mm)
- Larger diameter piles offer greater surface area for load distribution, resulting in reduced stress exerted on the underlying soil layers. This leads to

decreased settlement as the load is spread over a larger area.

(II)Graphical Representation:

The graph depicting incremental load versus settlement demonstrates a consistent downward trend as pile diameter increases. This graphical representation reinforces the inverse relationship between pile diameter and settlement.

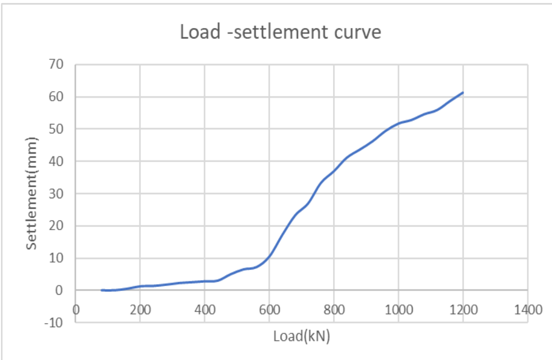

Fig.10 Maximum settlement =61.4mm
(pile diameter = 600mm)

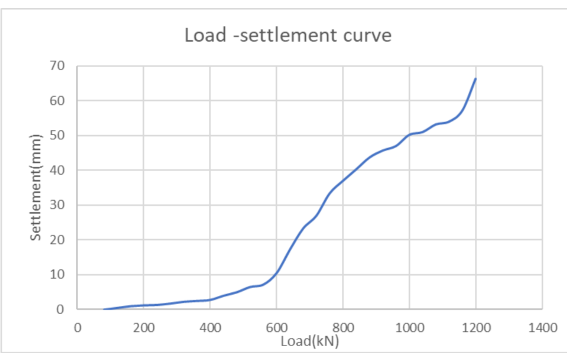

Fig.11 Maximum settlement = 66.3mm
(Pile diameter=500mm)

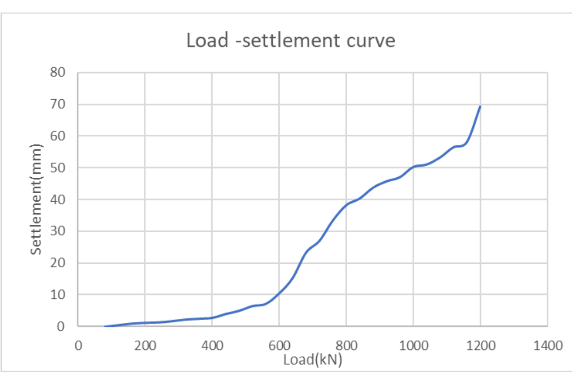

Fig.12 Maximum settlement = 69.2mm
(Pile diameter= 450mm)

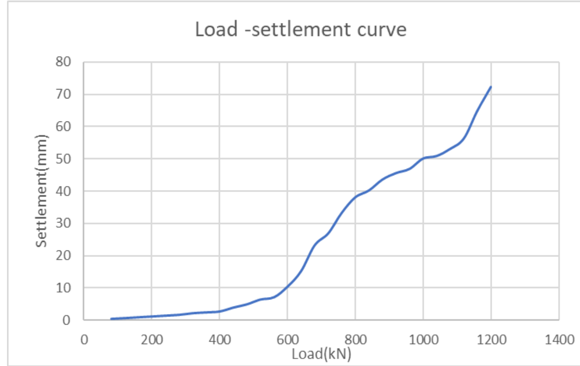

Fig.13 Maximum settlement= 72.4mm
(pile diameter=400mm)

CONCLUSION

- The proposed study aims to conduct a comprehensive static and dynamic analysis of a piled raft foundation system for a multi-storeyed building constructed on alternating layers of sand and clay soil .
- Geotechnical data has been collected to characterize the parameters of the sand and clay layers. The superstructure is analyzed using the software E-TABS and appropriate foundation was designed as per IS codes.
- The static analysis results indicate that increasing pile diameter leads to reduced settlement in piled raft foundations on alternate layers of sand and clay. This finding underscores the importance of considering pile diameter as a critical design parameter for minimizing settlement and ensuring the structural integrity of foundations built on layered soil profiles.
- The comparison between theoretical and numerical investigation results shows that the finite element model has been verified .This validation provides confidence in the accuracy and reliability of the numerical simulations used for analyzing the behavior of piled raft foundations. Engineers can rely on these simulations for further analysis and design optimization.

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