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Load-Sharing Behavior of a Piled Raft Foundation Founded on Layered Soils for a High-Rise Building in Addis Ababa: A Finite Element Study

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Abstract

This research investigates the behavior of piled raft foundation on layered soils with a significant difference in stiffness between the soil beneath the raft and the soil under the pile tips. The study focuses on the foundation of the tallest building in Ethiopia, the Commercial Bank of Ethiopia Headquarters (G+48). To capture the complex soil-structure interaction of the foundation, a three-dimensional finite element (FE) model was developed using ABAQUS. The FE analysis results were validated by comparison with the actual measured settlement of the building and with other studies available in the literature. The findings demonstrate that piled raft performance is heavily influenced by the stiffness ratio between the pile-tip and the raft-supporting soils. Although the raft alone satisfies load-bearing capacity within serviceability limits, the addition of 46 piles beneath it, altered the load-sharing behavior. In this specific configuration, the piles are shown to carry approximately 93% of the total structural load. These results indicate that in high stiffness variation, the foundation should be carefully analyzed as it may behave like a traditional pile group than a shared bearing system.

Keywords: Piled rafts, pile-raft coefficient, finite element analysis, weak soil, layered soil, hard strata, pile tips

1. Introduction

The primary function of a foundation is to transmit structural loads to the underlying soil while ensuring safety, reliability, and serviceability. Traditionally, pile foundation design relies on the conservative assumption that the pile group carries the entire structural loads which neglect the contribution of the raft. However, modern design philosophy recognizes the piled raft foundation (PRF) as a more cost-effective and efficient system [1-2]. This foundation system is successfully implemented globally, particularly for tall buildings founded on geologically young clay deposits in cities such as Frankfurt, London, and various Asian countries [3-5].

The success of these projects has led to the increasing application of PRFs in diverse soil conditions, including dense sand and layered soil profiles [6-10]. Moreover, extensive field monitoring and numerical modeling have demonstrated that PRFs are most efficient when the raft provides adequate load capacity and the piles beneath the raft serve to control average or differential settlements [11-13].

This is particularly common in geological profiles consisting of relatively stiff clays or dense sands [14]. The Behavior of piled raft foundations is governed by complex load-sharing mechanisms that are influenced by the configuration of the foundation elements and the relative stiffness of soil layers [15]. Results from three-dimensional finite element analyses (3D FEA) indicate that material characteristics, pile spacing, and group geometry significantly govern the distribution of loads between the raft and piles [16].

For instance, Raj et al. [17] recommends that to minimize differential settlement in layered soils, the pile-group area to the raft area ratio (B_g/B_r) should ideally range between 0.4 and 0.6. Other studies by Prasun and Bappaditya [18] and Deb and Pal [19], reveal that as raft settlement increases, the load proportion carried by the raft rises while the pile contribution decreases. Even in soft clayey ground, Kongpop et al. [22] demonstrated that a raft can contribute up to 10% of the load capacity, even when the foundation was traditionally designed as a purely pile foundation with a high factor of safety.

The International Piled Raft Foundation Guideline [20] states that a piled raft foundation (PRF) is considered effective only when the soil beneath the raft is not substantially weaker than the stratum at the pile tips. The guideline recommends a minimum stiffness ratio between the soil layers underlying the pile tips to the soil layers underlying the raft. Specifically, it is suggested that if the stiffness ratio exceeds ten (10), the raft's contribution drops below 10% of the total load. This restriction is further validated by Tariq [21], who found that the raft provides no visible contribution to load capacity or settlement control when the stiffness ratio is greater than nine (9).

Under these conditions, Tariq [21] recommended that assuming a free-standing pile configuration is more realistic. Furthermore, in the specific context of Addis Ababa, Mahidere and Gebregziabher [23] found that many existing foundations function more like traditional pile groups due to the low stiffness of the upper soil layers. For such soil conditions, they recommended that widening of pile spacing (up to 6 times the diameter) will enhance the raft's load-sharing potential.

Despite these existing studies, there remains a research gap regarding the behavior of PRFs in multi-layer systems with extreme (exaggerated) stiffness contrasts between the near-surface soil and the deep harder strata. This study addresses this gap by analyzing the foundation of the Headquarters of the Commercial Bank of Ethiopia (CBE) located in Addis Ababa. The soil profile under this structure is a multilayer system with an exaggerated stiffness difference between the raft-level soil and the pile-bearing strata. Using the 3D FEM software ABAQUS [24],

this research evaluates the settlement and load-sharing characteristics of the CBE foundation under static vertical loads to provide insights into optimizing PRF designs in high-contrast layered soil conditions. The Commercial Bank of Ethiopia (CBE) headquarters building, shown in Figure 1, was selected as the case study for the numerical investigation.



Figure 1: CBE Headquarters building

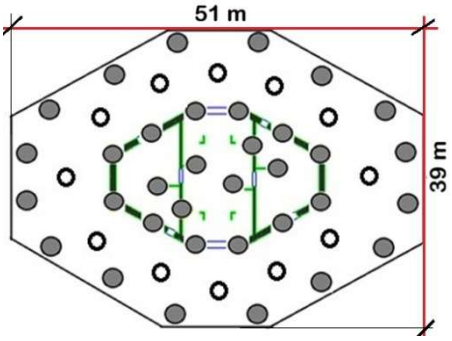
2. Materials & Methods

The study focuses on the new Commercial Bank of Ethiopia (CBE) headquarters building located in Addis Ababa. The building comprises a G+46 story office tower with total height of 186.4 m. The foundation system of the tower is a 3 m thick raft supported by 46 bored piles. The configuration of the raft foundation is shown in Figure 2(a). As illustrated in the figure, the pile spacing ranges from 2D to 4D where D is the pile diameter. The bored piles have lengths ranging from 5 to 10 m. The diameter the piles are as follows:

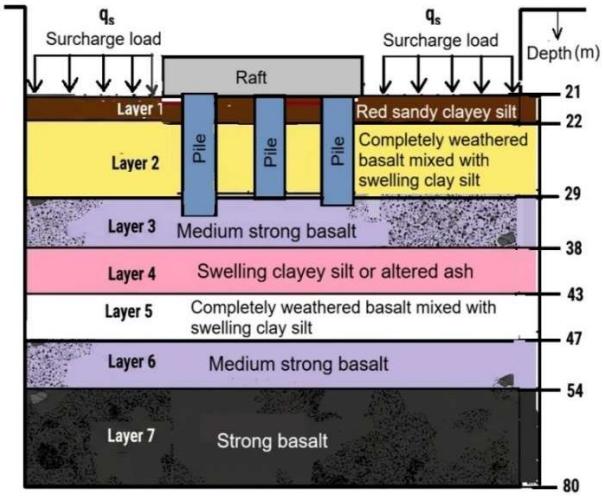
- Twelve (12) piles with a diameter of 1.8 m.
- Thirty four (34) piles with a diameter of 2.2 m.

The vertical cross-section of the piled raft foundation system is shown in Figure 2(b). As illustrated in the figure, the geological conditions of the site are highly stratified, ranging from silt-clay to sound basaltic rock. The investigated profile extends 59 m below the foundation level is divided into seven distinct layers. The soil profile above the foundation level is considered as surcharge load (q_s) in the Finite Element (FE) model as shown in the Figure 2 (b).

The groundwater table was located at an average depth of 5.5 m below the ground level.



a) Foundation layout (S = 2D to 3D)
Where: S = Spacing and D = Diameter



b) Cross-sectional view of the piled raft foundation

Figure 2: Schematic representation of piled raft foundation system & soil stratification used in the finite element model.

Three-dimensional (3D) Finite Element Analysis was performed using ABAQUS. A linear elastic constitutive model was used for simulating the piles and raft because the reinforced concrete properties were assumed to be remains within elastic range under the applied service load. The soil was modeled using the modified Drucker-Prager/Cap plasticity model. The parameters defining the model are presented in Figure 3. Commonly

used constitutive models for geotechnical analysis includes Mohr–Coulomb, Drucker–Prager, Modified Cam-Clay, Hardening Soil, and Modified Drucker–Prager/Cap plasticity. The Drucker–Prager/cap plasticity model was selected because it is capable of considering the effect of stress history, stress path, dilatancy, and the effect of the intermediate principal stress programs for a variety of geotechnical engineering applications. These characteristics make it suitable for simulating the nonlinear behavior of layered soils supporting piled raft foundations.

The reinforced concrete properties were defined using a Poisson's ratio of 0.2 for both the raft and piles, with Young's moduli of 35 GN/m² and 36 GN/m², respectively, based on the structural design specifications. The soil properties were obtained from the geotechnical site investigation, and the Modified Drucker–Prager/Cap model parameters were derived from the measured soil properties using established procedures reported in the literature. The input parameters for the soil layers are summarized in Table 1.

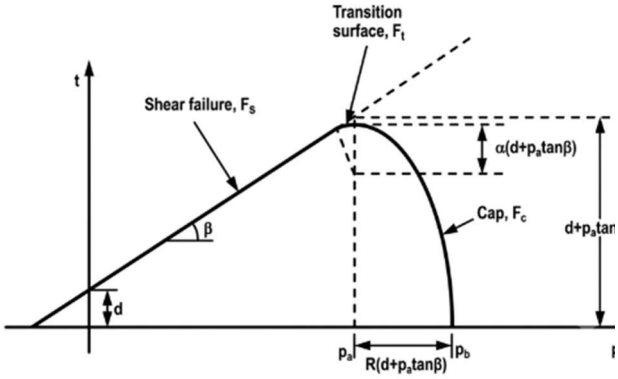


Figure 3: Modified Drucker-Prager/Cap model: yield surfaces in the p–t plane [36]

Table 1: Summary of basic soil parameters used for the software

	Layer 1	**Layer 2**	**Layer 3**	**Layer 4**	**Layer 5**	**Layer 6**	**Layer 7**
E [MN/m^2]	104	400	1000	131	400	1000	1500
γ' [kN/m^3]	7	12	14	7.7	12	14	18
(v)	0.3	0.3	0.25	0.3	0.3	0.25	0.25
ø'[º]	27	42.8	45	27	42.8	45	45
C [kN/m^2]	25	25	5000	25	5000	5000	5000
β [º]	47	58	61	47	58	61	61
d [kN/m^2]	52.4	53.65	9600	52.4	9600	9600	9600
K	0.888	0.888	0.888	0.888	0.888	0.888	0.888
R	0.5	0.6	0.8	0.5	0.8	0.8	0.8

E = Modulus of Elasticity, γ' = Effective Unit weight, (v) = Poisons ratio, ø = Frictional angle, C = Cohesion, β = Slopeof the yield surface Fs in the p-t plane, d = Intersection of yield surface Fs with the t axis, K = Flow stress ratio, R = Cap Eccentricity (See Figure 3)

3. Numerical Modeling of Foundation

To investigate the behavior of the piled raft foundation, a three-dimensional finite element model was developed using ABAQUS. Due to geometrical symmetry half of the foundation was developed in the model as shown in Figure 4. This optimizes the computational efficiency. The soil, piles, and raft were discretized using 8-noded linear brick elements with reduced integration (C3D8R).

3.1 Model Geometry & Boundary Conditions

The model boundaries were selected sufficiently far from the foundation system to minimize boundary-induced stress and displacement interference within the zone of foundation influence. The lateral boundary was placed at a distance of 30D from the pile center, while the bottom boundary was located at a depth of 2L below the pile tips [16]. The dimensions of the FE model were 120 m in the x direction, 60 m in the y direction, and 30m in depth (z direction). These dimensions were chosen to ensure that the stresses and deformations generated by the piled raft foundation dissipate before reaching the model boundaries, thereby reducing artificial boundary effects on the numerical results. The geometry and boundary conditions of the FE model are shown in Figure 4.

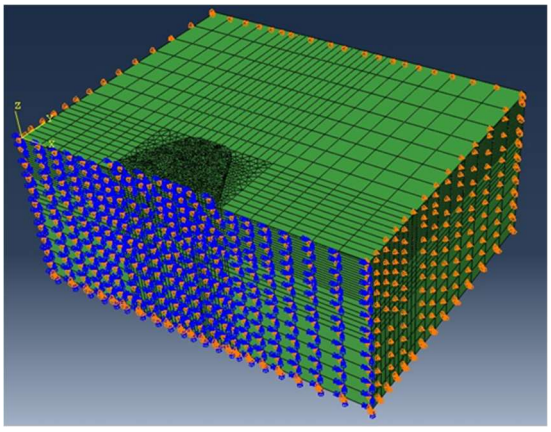


Figure 4: Discretized model and boundary conditions.

3.2 Soil-Structure Interaction (SSI)

To accurately capture the soil-structure interaction (SSI) a precise modeling of the pile-soil and raft-soil interfaces is required. There are two techniques commonly used for modeling soil–structure interfaces in FEM analyses: slip interface elements and thin-layer continuum elements. Slip interface elements simulate relative displacement and separation between soil and structural components through contact formulations, whereas thin-layer continuum elements represent the interface using thin solid elements with material properties identical to the surrounding soil. Although slip elements can explicitly simulate interface sliding behavior, they may introduce numerical convergence difficulties in large 3D piled raft analyses [25, 26]. In contrast, Gebregziabher [23] and many other recommend the thin-layer continuum elements since it provide stable numerical performance and have been widely adopted in piled raft foundation studies [16, 27, 29, and 32]. In this study the thin-layer continuum interface approach was adopted because it provides improved numerical stability and allows realistic stress transfer between the soil and structural elements without introducing excessive contact nonlinearity. Previous studies have shown that this method is effective for simulating soil–structure interaction in deep foundation systems subjected to complex loading conditions. Based on the recommendations of [23, 27], the thickness of the interface elements was established as 0.1D for the pile-soil interface and 0.1H for the raft-soil interface, where D is the pile diameter and H is the raft thickness respectively.

3.3 Mesh Sensitivity Analysis

To assess the influence of mesh density on the numerical results, a mesh sensitivity analysis was performed using five different mesh configurations while maintaining constant material properties and boundary conditions.

As illustrated in Figure 5, further increases in the number of element beyond 850,000 yielded no significant change in the predicted settlements. This shows that mesh convergence. Accordingly, the selected mesh density was considered sufficient to achieve reliable numerical accuracy while maintaining computational efficiency. A graded mesh refinement was adopted near the raft and pile regions where stress and deformation gradients were expected to be highest.

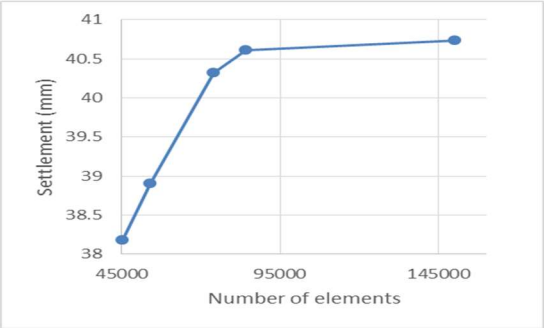
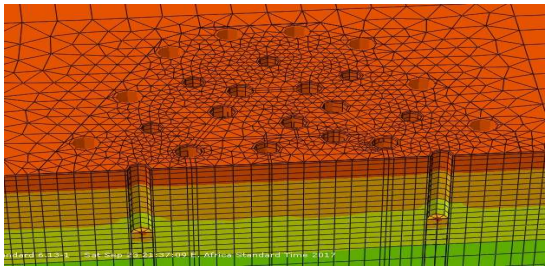


Figure 5: Mesh sensitivity analysis

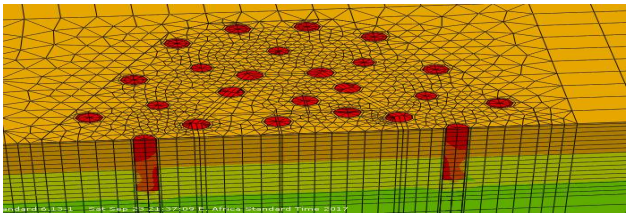
3.4 Analysis Procedure

Prior to applying the superstructure loads, the numerical model was developed to simulate the actual construction sequence of the piled raft foundation system. The analysis procedure consisted of the following stages, as summarized in Figure 6.

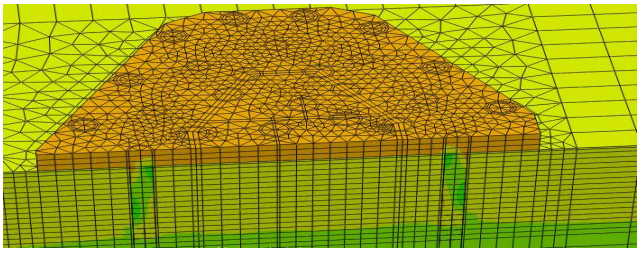
- *Initial Phase*: To establish the initial stress state, first the boundary conditions were defined.
- *Geostatic Phase*: The self-weight of the soil was applied to achieve geostatic equilibrium prior to structural intervention.
- *Excavation Phase*: The soil elements located at the pile locations was removed by deactivating them as shown in Figure 6a.
- *Foundation Installation Phase:* As illustrated in Figure 6b and 6c, the raft and piles were installed by activating their elements.
- *Loading Phase:* As illustrated in Figure 6d, the superstructure loads were applied to the raft foundation. As depicted in the figure these loads are transferred to the raft through columns and shear walls. The columns are positioned along the perimeter of the raft, aligning with the peripheral bored piles, while the shear walls are concentrated toward the center of the raft.



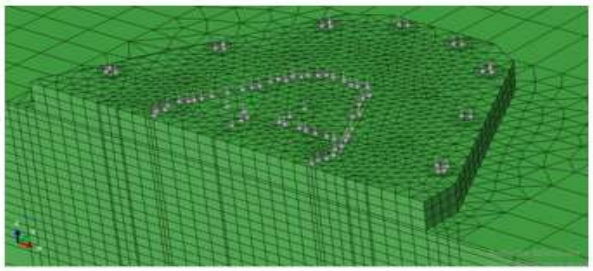
a) Excavation of soil at the locations of piles



b) Pile installation step



c) Raft installation step



d) Load application step

Figure 6: Application of the super structural load on the raft

4. Model Validation

The piled-raft foundations example reported by the American Society of Civil Engineers (ASCE) Technical Committee 18 (TC -18) [28] was adopted to validate the developed numerical model. Due to symmetry, only one-quarter of the foundation system was modeled in the FE simulation. In the validation model, nine piles were considered within the quarter-foundation domain. A concentrated load of 2 MN was applied at the middle row pile locations, while 1 MN was applied at the edge pile locations, following the loading configuration adopted in the reference benchmark study [28].The settlement contours obtained from the developed model is illustrated in Figure 7. The predicted settlements obtained from the developed ABAQUS 3D model were found to be reasonably consistent with the published numerical results reported in the literature, particularly with the PLAXIS 2D and GARP5 solutions summarized in Table 3. Differences among the models may arise from variations in modeling assumptions, constitutive laws, and 2D/3D analysis approaches. Therefore, Table 3 is intended for general benchmarking rather than exact quantitative comparison.

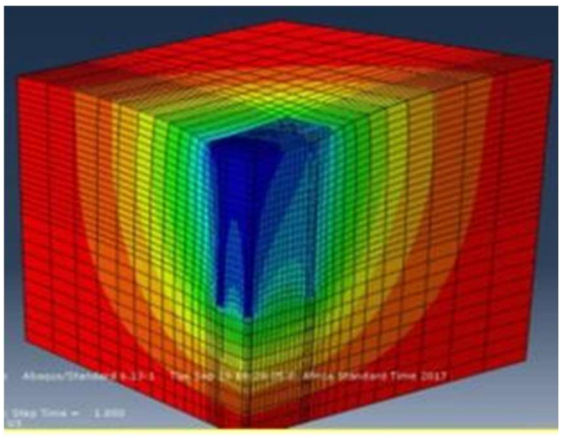


Figure 7: ABAQUS settlement contours in vertical direction

Table 2: Comparison of settlement predictions from the developed ABAQUS 3D model and previously published numerical models under a total applied load of 12 MN.

Model	Central Settlement (mm)	Corner Settlement (mm)
FLAC 2D Predicted by Poulos (2001)	65.9	60.5
FLAC 3D Predicted by Poulos (2001)	39.9	35.8
DR Method	36.8	-
GASP	33.8	22
GARP5	34.2	26
PLAXIS 2D Predicted by Omeman (2013)	32	26
The developed ABAQUS 3D (in this paper)	31	26.4

5. Results and Discussions

In this section, the behavior of the piled raft foundation is investigated by numerical modeling of a real case history under axial loads. The Commercial Bank of Ethiopia (CBE) headquarters building located in Addis Ababa is the case study. The same modeling approach used for the model validation has been applied to the current case study. In addition to the original design, the behavior of the raft foundation without the piles has been investigated. Then, based on the obtained results comparisons are made with respect to settlements, pile load distributions and load sharing behavior of the foundation with the allowable values. Finally, the results obtained from this finite element analyses have been compared with the actual measured settlement of the foundation.

5.1 Performance Analysis of the Un-piled Raft Foundation

To examine the performance of the foundation, initially the raft without the piles was analyzed. Figure 8 illustrates the

settlement contours for the raft alone under full design load. As expected, the maximum settlement is concentrated at the center of the raft, whereas the minimum settlements are observed at the corners. From the serviceability and stability viewpoint of the structure, differential settlement is often more critical than the maximum settlement. According to the standards defined in ES-EN 1997:2015, the main causes of structural distress in office buildings are differential settlement.

To control a damage structures, the standard limits that the maximum allowable differential settlement should not exceed 75% of the total settlement, with a permissible tilt limit of 1:500.The finite element analysis (FEA) results are summarized in Table 3. These results indicate that the raft foundation is within the safety margin against the building codes. The differential settlement of the raft is significantly below the 75%, and the calculated tilt is also less than 1:500 limits. Therefore the raft foundation alone is adequate in terms of bearing capacity and settlement requirements under the specified load conditions.

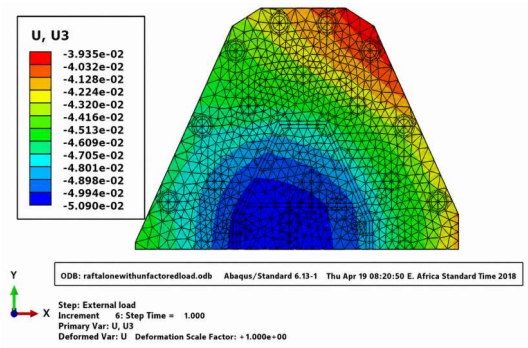


Figure 8: Settlement contours of the raft alone (m)

5.2 Performance Analysis of the Piled Raft Foundation

After evaluating of the raft foundation alone, this section investigates the behavior of the piled raft foundation as per the design. Figure 9 illustrates the settlement contours for the piled raft foundation under the full design load. The following results are given in Table 3 for easy comparison with the no-pile option. As illustrated in the figure7, the piled raft foundation exhibits lower and more uniformly distributed settlement profiles compared to the raft-only foundation system. The predicted settlements remain within the allowable serviceability limits.

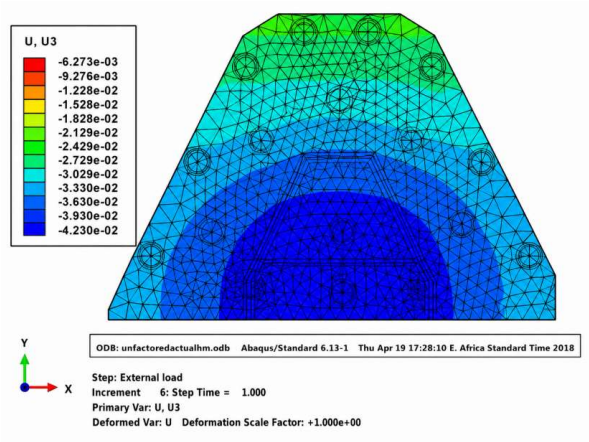


Figure 9: Settlement contours of the piled raft at (m)

A comparative summary of the performance of raft foundation alone and the piled raft foundation is presented in Table 3.

Table 4: Foundation performance (Raft vs. Piled raft)

	Raft alone	Piled raft	Variance
S_{max}(cm)	5.1	4.23	17% Reduction
S_{min}(cm)	3.93	2.43	38% Reduction
ΔS (cm)	1.16	2.2	+1.04 cm
Tilt	1:2232	1:1179	

$S_{max/min}$ = Maximum/minimum settlement, ΔS = Differential settlement

A critical analysis of Figure 8 and 9 reveals that the addition of 46 bored piles beneath the raft resulted in a 17% reduction in maximum settlement compared with the raft-only foundation system. This suggests that,

under the investigated loading and subsurface conditions, the raft foundation alone may provide adequate settlement performance. From an optimization perspective, the piles are not effectively contributing to settlement reduction.

Furthermore, the settlement reduction achieved by incorporating piles may provide limited practical benefit for this particular foundation, despite the increased construction cost. The observed behavior should not be attributed solely to the stiffness ratio between the pile-tip strata and the raft-supporting soil. Rather, it reflects the combined influence of the raft–pile–soil interaction and the fact that the raft alone provides adequate serviceability performance.

The calculated stiffness ratio of 9.6 is close to the threshold reported in current piled raft design guidelines [20], which indicate that a pronounced stiffness contrast may reduce the effectiveness of piles in further decreasing settlement. Similar observations have been reported in previous finite element studies of piled raft foundations in weak rock, where the settlement reduction provided by piles diminished as the stiffness modulus ratio approached nine [17].

5.3 Load-Settlement & Axial Distribution

The load-settlement response of the piled raft foundation obtained from the FEA is presented in Figure 10. The results show a non-linear increase in settlement with increasing applied load. Unlike conventional foundations with pile groups, the piled raft foundation maintains its stiffness without abrupt increases in settlement. This behavior suggests that the piled raft foundation remained within the serviceability range and that the pile capacity was not fully mobilized under the total loads. The observed response is consistent with typical piled raft behavior reported in previous studies available in the literature (see Figure 12).

Figure 13 illustrates the axial load distribution along the piles. The results indicate that the maximum axial load is occurs near the pile head and gradually decreases toward the pile tip due to load transfer through shaft resistance. Moreover, the load distribution within the pile group is not uniform. Piles located at the periphery of the raft carry higher axial loads, whereas the central piles transfer lower loads. This is a classical piled foundation behavior due to the pile group effect. Such findings are consistent with previous empirical studies reported in the literature [29].

5.4 Load-Sharing behavior of piled raft

To assess the efficiency of the foundation system, a pile-raft coefficient (αCPRF) was calculated. This coefficient represents the ratio of the total load carried by the piles to the total applied load of the structure. As illustrated in Figure 14, the load sharing coefficient of αCPRF = 0.93 is obtained. This result indicates that the 46 piles carry approximately 93% of the total applied load. This indicates that the piles mobilize the majority of the applied load. This behavior is governed primarily by the stiffness interaction between the raft–pile system and the surrounding soil strata, rather than significant mobilization of pile tip resistance, which remains relatively small in this study.

The observed response is consistent with international design guidelines for piled raft foundations in conditions where there is a significant stiffness difference between the soil strata supporting the raft and the deeper strata at the pile tips [20]. These guidelines state that when the stiffness ratio exceeds approximately by a factor of ten, load transfer becomes increasingly pile-dominated, and the raft contribution to overall bearing capacity becomes limited

(typically below 10%). In the present study, a stiffness ratio of 9.6 leads to a calculated pile load.

5.5 Empirical validation of the model using measured settlement data

To validate the reliability of the developed finite element (FE) model, it is essential to move beyond the theoretical simulations and undertake empirical validation. In this section, the numerical settlement results were compared with field-monitored settlement data obtained during construction. Since the measured settlements were available only up to the construction of the 19th floor (G+19), the finite element (FE) model was developed and analyzed corresponding to this construction stage. the finite element (FE) model was accordingly developed for the building up to this stage. At this stage, the foundation was subjected to approximately 32% of the total design load. The field monitoring indicated a maximum settlement of 5.00 mm, while the finite element (FE) analysis predicted a settlement of 5.65 mm (See Figure 11).The close agreement between the measured and predicted values demonstrates the capability of the FE model to reasonably capture the settlement behavior of the piled raft foundation system

Figure 15 illustrates the load settlement response of the piled raft foundation for the G+19 stage of the building. A linear behavior is observed for both the numerical model and the physical measurements.

This linear relationship indicates that the piled raft system is operating within its initial elastic phase, where the load is insufficient to produce the non-linear soil-structure interactions typically observed at higher stress levels.

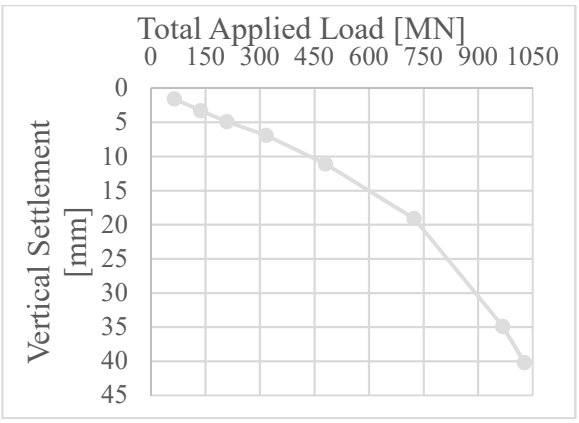


Figure 10: Load settlement behavior of the piled raft foundation obtained from the FEA result.

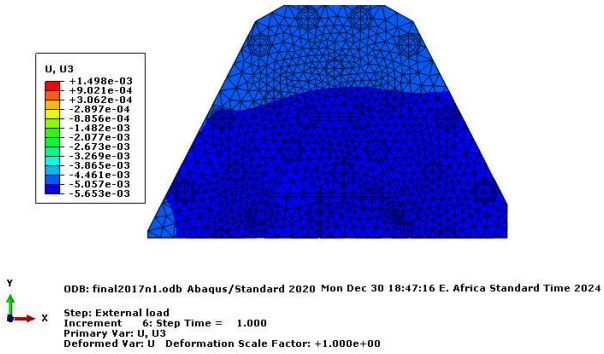


Figure 11: Settlement contours of the piled raft foundation for the G+19 building (m).

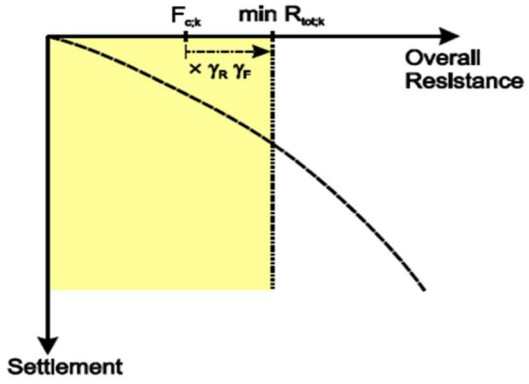


Figure 12 Non-linear behavior of a piled raft and determination of the overall resistance [33]

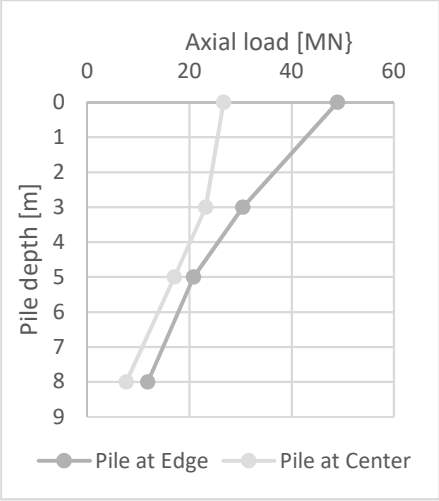


Figure 13: Axial load distribution of piles

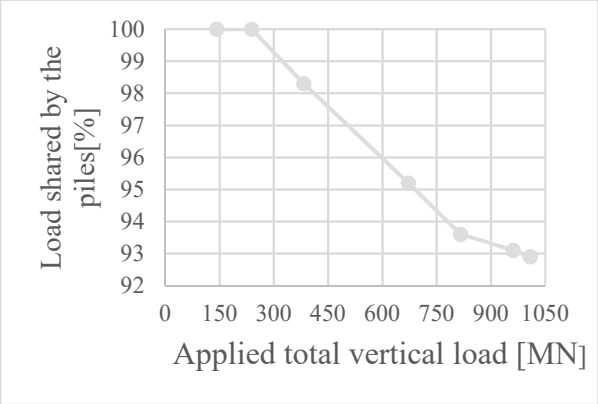


Figure 14: Load sharing behavior of the piled raft

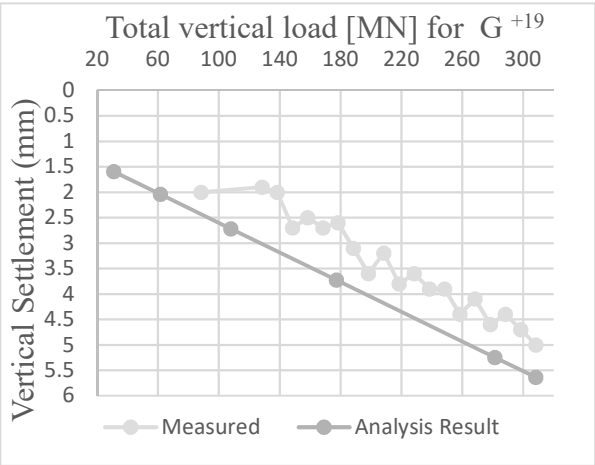


Figure 15: Load settlement behavior of the piled raft foundation up to G^{+19}

CONCLUSIONS

This study investigates the behavior of piled raft foundation constructed on layered soils with a significant stiffness difference between the pile tips strata and raft-level soil layers. The Commercial Bank of Ethiopia (CBE) headquarters located in Addis Ababa is taken as a case study. To capture the complex soil structure interaction of the foundation, a three-dimensional finite element (FE) model was developed using ABAQUS. Reliability of the FE was examined by comparison with the actual measured settlement. The result showed that the FE results are in good agreement with the measured settlement as well as with the predictions from other previous studies available in the literature.

Based on our findings the following important conclusions are drawn:

- The finite element (FE) predicted settlements were compared with field-monitored settlement data obtained during the construction stages up to the 19th floor (G+19). The measured maximum settlement at this stage was 5.00 mm, while the FE model predicted 5.65 mm under the corresponding loading condition. The close agreement between the measured and numerical results indicates that the developed FE model reasonably represents the settlement behavior of the piled raft foundation system.
- The findings indicate that the raft contribution to load bearing capacity is insignificant when combined with piles in the investigated soil profile. Although the raft alone satisfies capacity to support the load within allowable serviceability limits, the addition of 46 piles beneath it, altered the load-sharing behavior. The piles carry approximately 93% of the total structural load. This behavior is

governed primarily by the stiffness interaction between the raft–pile system and the surrounding soil strata, rather than significant mobilization of pile tip resistance, which remains relatively small in this study.

- The finding of this study indicates that the performance of a piled raft foundation is governed primarily by the overall stiffness interaction between the raft-pile system and surrounding soil strata rather than by the stiffness ratio between the pile-tip strata and the raft-supporting soil alone. These results suggest that in highly heterogeneous layered soils, the piled raft foundation should be carefully evaluated because the load sharing mechanism may shift toward pile dominated behavior, causing the system to behave like a traditional pile group than a true shared-bearing piled raft foundation.

Data Availability

The data used to support the study are available fromthe corresponding author upon request (henok.fikre@aait.edu.et) /(fsaha.kiros@adu.edu.et).

Disclosure

A preprint has previously been published in AddisAbaba University of Thesis Work [34].

Conflicts of Interest

There is no conflict of interest.

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References

[1] Katzenbach, R. (2004), New Exhibition Hall 3 in Frankfurt—Case History of a Combined Pile Raft Foundation Subjected to Horizontal Load, Proc. 5th Int. Conf. on Case Histories in Geotechnical Engineering, New York.

[2] Katzenbach, R., Choudhury, D. (2013), Technical Committee 212: Deep Foundations, Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering.

[3] Cooke, R., Sillett, D.F., Bryden Smith, D.W., Smith, D.W. and Gooch, M. (1981), Some Observations of the Foundation Loading and Settlement of a Multi-Storey Building on a Piled Raft Foundation in London Clay, Proceedings of the Institution of Civil Engineers, London.

[4] Yamashita, K., Kakurai, M. and Yamada, T. (1994), Investigation of a Piled Raft Foundation on Stiff Clay, Proc. 13th Int. Conf. on Soil Mechanics and Foundation Engineering (ICSMFE'94), New Delhi.

[5] Maharaj, R. and Gandhi, K. (2004), Non-linear Finite Element Analysis of Piled-Raft Foundations, Proc. Institution of Civil Engineers, Geotechnical Engineering.

[6] Poulos, H.G., Small, J. and Chow, H. (2011), Piled Raft Foundations for Tall Buildings, Geotechnical Engineering Journal of the Southeast Asian Geotechnical Society.

[7] Badelow, F., Kim, S., Poulos, H. and Ahmad, A. (2009), Foundation Design for a Tall Tower in a Reclamation Area, Proc. 7th Int. Conf. on Tall Buildings, Hong Kong.

[8] De Sanctis and Russo (2008), Analysis and Performance of Piled Rafts Designed Using Innovative Criteria,

Journal of Geotechnical and Geoenvironmental Engineering.

[9] Yamashita, K., Yamada, T. and Hamada, J. (2011), Investigation of Settlement and Load Sharing on Piled Rafts by Monitoring Full-Scale Structures, Soils and Foundations.

[10] Poulos, H.G. (2002), Simplified Design Procedure for Piled Raft Foundations, Deep Foundations, American Society of Civil Engineers.

[11] Shukla, S.J. (2011), Behavioral Study of Piled Raft Foundation in Layered Soil Deposits, International Journal of Advanced Engineering Technology.

[12] Lin, D.-G. (2016), Load Transfer and Deformation Analysis of Piled Raft Foundation in Taipei Metropolitan, Journal of Marine Science and Technology.

[13] Alnuaim, A., El Naggar, H. and El Naggar, M.H. (2013), Performance of Piled Raft System under Axial Load, Changes and Innovations in Geotechnics.

[14] Poulos, H.G. (2002), Simplified Design Procedure for Piled Raft Foundations, Deep Foundations, American Society of Civil Engineers.

[15] Ningombam, T. (2013), Load Sharing Characteristics of Piled Raft Foundations in Clay Soil, International Journal of Innovative Research in Science, Engineering and Technology.

[16] Sinha, A. (2013), Three-Dimensional Modeling of Piled Raft Foundation, International Journal of Geomechanics, American Society of Civil Engineers.

[17] Raj, B., Srijit, B., Aniruddha, S. and Reddy, R. (2020), Settlement Behaviour of a Pile Raft Subjected to Vertical Loading in Multilayered Soil, Geomechanics and Geoengineering.

[18] Prasun, H. and Bappaditya, M. (2020), Performance Evaluation of Piled Rafts in Sand Based on Load-Sharing Mechanism Using Finite Element Model, International Journal of Geotechnical Engineering.

[19] Deb, P. and Pal, S.K. (2020), Load-Settlement and Load-Sharing Behaviour of a Piled Raft Foundation Resting on Layered Soils, Acta Geotechnica Slovenica.

[20] Briaud, J.-L. (n.d.), International Piled Raft Foundation Guideline, International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE).

[21] Chaudhary, M.T.A. (2007), FEM Modelling of a Large Piled Raft for Settlement Control in Weak Rock, Engineering Structures.

[22] Kongpop, W., Pornkasem, J., Pastsakorn, K., Tatsunori, M., et al. (2021), Measurements and Analysis of Load Sharing Between Piles and Raft in a Pile Foundation in Clay, Geomechanics and Engineering.

[23] Mahidere, M. and Gebregziabher, H.F. (2020), Assessment of "Piled-Raft" Foundation Design Practice in Addis Ababa, EACE Journal.

[24] Gebregziabher, H. (2020), Practical Considerations for Diminishing Piled Rafts on Weak Layered Soils, Journal of EEA.

[25] Taghavi, A. (2016), Numerical Analysis of Settlement and Bearing Behaviour

of Piled Raft in Babol Clay, European Journal of Environmental and Civil Engineering.

[26] Lee, J. (2010), Three-Dimensional Analysis of Bearing Behaviour of Piled Raft on Soft Clay, Computers and Geotechnics.

[27] Reul, F. and Randolph, M.F. (2004), Design Strategies for Piled Rafts Subjected to Non-Uniform Vertical Loading, Journal of Geotechnical and Geoenvironmental Engineering.

[28] Poulos, H.G. (2001), Methods of Analysis of Piled Raft Foundations: A Report Prepared on Behalf of Technical Committee TC18 on Piled Foundations, International Society for Soil Mechanics and Geotechnical Engineering.

[29] Gebregziabher, H. and Achmus, M. (2020), Influence of Raft Rigidity for Piled Rafts Resting on Stratified Subsoil, International Journal of Geotechnical Engineering.

[30] Bowles, J.E. (1996), Foundation Analysis and Design, 5th ed., McGraw-Hill.

[31] Ethiopian Building Code Standard (2013), EBCS-7: EN 1997-1.

[32] Gebregziabher, H.F. (2011), Optimized Use of Combined Pile-Raft Foundation Design for High-Rise Buildings on Semi-Soft Soils, Ph.D. Dissertation, Technische Universität Darmstadt, Germany.

[33] Katzenbach, R., Bachmann, G. and Gutberlet, C. (2008), Soil-Structure Interaction and ULS Design of Complex Deep Foundations, Proc. 6th Int. Conf. on Case Histories in Geotechnical Engineering.

[34] Kiros, F. (2019), Investigating the Load Sharing Behavior of Piled Raft with Pile Tips on Hard Strata Using the Finite Element Method: Case of Commercial Bank of Ethiopia Headquarters Building, Master's Thesis, Addis Ababa University.

[35] Wang, G. and Sitar, N. (2004), Numerical Analysis of Piles in Elastoplastic Soils under Axial Loading, Proc. 17th ASCE Engineering Mechanics Conference.

[36] Dassault Systèmes (2015), Abaqus 6.15 Analysis User's Guide, Providence, RI, USA.