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Case study of a piled raft foundation for a new air traffic control tower in Ghana

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ABSTRACT: The new Air Traffic Control (ATC) tower for Kotoka International Airport (KIA) in Accra, Ghana, is part of the expansion of one of Africa's gateways to the continent. Ghana is known for its deeply weathered tropical soils and variable phyllite rock. Often, when founding heavily loaded structures in Ghana, conventional solutions such as reinforced concrete rafts or shallow pad foundations are favoured. These conventional solutions are not always the most efficient for the project but are often selected for convenience or familiarity. Possible variable laterite, saprolite of varying strength and composition, and phyllite bedrock that varies in both depth and rock quality, deem it prudent to also explore other innovative foundation options, such as piled raft foundations. Yet, piled raft foundation solutions are rare in Ghana and in the greater Africa. This paper describes the design and implementation of a piled raft foundation solution for the new 50 m tall, KIA ATC tower. The paper describes the structural design, the variability of the ground, especially the phyllite bedrock, schedule constraints and limitations of available piling equipment, which when combined, provide the right conditions for a piled raft solution to mitigate uncertainties of ground condition, variable rock level and strength, and ability to drill into the rock, whilst meeting schedule constraints. The paper also compares analysis done analytically and using finite element analysis to show the value of initial analytical analysis in defining the piled raft layout. The objective is to contribute to the body of knowledge of case studies of piled raft foundations in Africa.

KEYWORDS: Piled raft, phyllite, tropical soil, Ghana, Air Traffic Control Tower.

1 INTRODUCTION

Originally a British military airport, the Kotoka International Airport (KIA), located in Accra, Ghana, became the base for Ghana Airways in 1958. Since then, numerous improvements and upgrades of the airport have been undertaken, with one of the most recent including the construction of a new Air Traffic Control (ATC) tower located on a 1000m^2 plot within the airport boundary. Since the construction of Terminal 3 at KIA there have been challenges to the tower controllers to observe the parked aircraft at the Southern Aprons because the Terminal 3 structure and its ancillary structures have obscured the lines of sight on some aircraft movement surfaces. The height of the Terminal 3 building also hinders direct sight to the cockpit of most aircraft parked nose-in at the passenger loading bridges. The new ATC tower will significantly improve visibility, operational safety and efficient working of the air traffic navigation process at KIA.

The new ATC tower was designed as a 50m tall tower, with reinforced concrete stem and glass and steel canopy. A ground building, comprising of a light single-storey structure, will be located next to the main tower structure. Traditionally the ATC tower would have been founded on piles or a reinforced concrete raft. This paper provides a rare African case study of the KIA ATC founded on a RC piled-raft foundation. The KIA ATC would qualify as a high-rise structure.

2 STRUCTURAL DESIGN BASIS

The structural design of the tower and its foundations was undertaken in accordance with Eurocode (Standardization, 2002-2004). The design philosophy focused on optimising material specification, reinforcement detailing, and cover to ensure adequate strength, robustness, stability, and long-term durability. Particular attention was given to achieving an efficient load path through the piled raft system, maintaining overall structural integrity, and facilitating practical constructability within the constraints of the available resources.

3 FOUNDATIONS IN ACCRA

Reinforced concrete (RC) raft foundations and pile foundations are both known and common in Ghana. RC raft foundations are often preferred due to simplicity of construction and because of the occurrence of competent laterite near surface. Examples are the Exim Bank, which is founded on an RC raft, the Ghana Civil Aviation Authority building (a seven storey and double basement structure) for which both RC raft and bored piling options were considered and the 4-storey, KIA Terminal 2 building, for which pad and beam solutions were proposed, to be founded on near-surface laterite. Despite both piling and RC rafts being common foundation systems, the combination of raft and piles, into a potentially more efficient piled raft solution, is not common and no references could be found of such projects having been reported publicly in Ghana.

4 PILED-RAFT FOUNDATIONS

Katzenbach *et al.* argued that the piled-raft solution is an innovative way to reduce settlement and differential settlement due to concentrated loads and load eccentricities and is also used to reduce bending moments in rafts (Katzenbach, et al., 1998). Poulos (Poulos, 2001) reported that where a raft foundation is unable to meet serviceability and/or bearing capacity, those aspects can be enhanced by adding a limited number of strategically located piles. These piles act as stiffeners (or settlement reducers) and transmit some of the load to more competent horizons. Louw investigated the use of piled-raft foundations for wind turbines subjected to dynamic and overturning wind loads (Louw, 2024). It was found that loading could efficiently be carried by the combination of raft and piles. As load cycles increased, load could also be distributed more efficiently across the piles. Raut *et al.* gives a summary of several successfully implemented piled raft foundations across Germany, Japan, Malaysia, Dubai and Egypt (Raut, et al., 2019). These case studies cover high-rise (greater than 12 storeys) to super-tall structures (>600m tall), indicating the versatility of application of piled-raft foundations.

5 DESIGN CONSIDERATIONS

5.1 *The ATC Structure*

The ATC tower is intended to be an ultra-modern, 50m tall, reinforced concrete structure, with a glass and steel canopy housing the air traffic control team and instrumentation. The reinforced concrete stem structure is a stadium or rounded rectangle shape, 12m long and 6m wide in plan (see Figure 1). It was intended that the ATC tower and single-storey ground building be founded on the same foundation. This has the advantage of mitigating differential movements between the tower and the ground building and assisting with damping of the structure under dynamic loading, such as seismic induced loading.

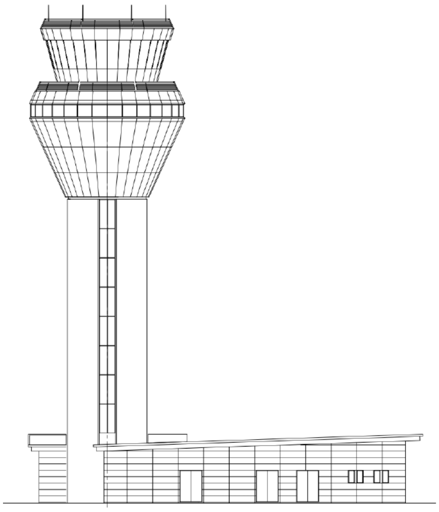

Figure 1. KIA ATC tower and ground building schematic.

5.2 *Geology and ground conditions*

According to the Environmental and Engineering Geological map of the Greater Accra Metropolitan area, the site is underlain by finely banded phyllite and phyllonite. Phyllite has good strength but is foliated which means it can be weak along certain planes.

Through a campaign of intrusive ground investigation (rotary core drilling and test pitting), inspection of existing ground cuttings in the general vicinity of the site, and laboratory testing, the ground profile at the ATC site was defined as follows:

- 0-0.5m: The site was used as a parking area and was covered by 0.5m of gravelly pavement.
- 0.5-8.5m: Medium dense to dense, laterite gravel.
- 8.5-17m: Completely weathered phyllite, weathered to sand with clay.
- 17-24.5m: Moderately to highly weathered, very weak to weak, phyllite.
- 24.5-35m: Medium to strong phyllite, grading into slightly weathered schist.

The water table at the site was encountered at a depth of 6m below ground level.

The phyllite rock is known to be variable in occurrence, weathering, fracturing and quality. Unconfined Compression Strength (UCS) values ranged between 20.4 and 87.4MPa, but Rock Quality Designation (RQD) values ranged between 0% and 89%, depending on the borehole (and not related to depth). Ong and Choo also reported high strength variability for constructing bored cast in situ piling installed into highly variable phyllite bedrock in Kuching, Malaysia (Ong & Choo, 2011). Like the phyllite rock encountered at the KIA ATC site, the rock reported by Ong and Choo displayed highly variable UCS and RQD qualities. This made it challenging to recommend suitable rock socket lengths. Rock socket lengths for a 600mm diameter pile, loaded to 2500kN/pile, varied between 1.2m and 12m for UCS values ranging between 2MPa and 10MPa. This was exacerbated by the difficulty of sampling the rock in the first instance. In this case the situation was mitigated using an extensive pile load testing, laboratory testing and pressuremeter testing campaign to define suitable design UCS values and associated rock socket lengths.

An illustration of this variability in occurrence and variability of phyllite rock encountered near the KIA ATC site is shown in Figure 2. Discussions with piling contractors revealed that a common strategy for piling in variable phyllite is to disregard end-bearing and design for carrying load entirely in shaft friction. This can lead to uneconomic design and time-consuming construction.

Figure 2. Phyllite bedrock variability exposed in a cutting close to the ATC tower site.

5.3 *Structural design considerations*

For the tower foundations the following design considerations were considered during the design:

- Load path & Distribution: Permanent, Imposed, Seismic and wind loads from the tower are resisted by the tower core and stem and be transferred through the raft to the piles and underlying soil.
- Stability: A raft foundation of adequate size and geometry was selected to ensure overall stability under all design load cases.
- Reinforcement Layout: Raft reinforcement was placed in both the top and bottom layers, with additional reinforcement provided for shear resistance, anchorage, and to meet ductility and seismic detailing requirements.
- Durability Measures: Material specifications and reinforcement cover were selected to ensure long-term performance in the local environmental conditions.

5.4 *Seismicity*

Accra has historically experienced several earthquakes and continues to experience tremors. Earthquakes ranging between 3.7 and 6.4 on the Richter scale have been experienced and tremors of between 1.0 and 4.3 on the Richter scale have been experienced recently (Amposah, 2004). From a seismic loading perspective and based on a literature study of regional seismicity and geotechnical recommendations for sites close to the current site, the design was conducted for a Peak Ground Acceleration (PGA) of 0.15g. Due to its consistency (generally medium dense to dense sandy soils, or firm to very stiff sandy silty soil), materials below the water table are not expected to be liquefiable under this seismic loading. The ground is classified as ground type C in accordance with Eurocode 8 (BSi, 2013).

The ATC tower is classified as a Class IV structure whose integrity is of vital importance. The design therefore applied a damping ratio of 5% and behaviour factor of 2.5. Seismic loading, as defined under the project's design basis, formed a critical input for the structural design of the piled raft foundation.

5.5 *Equipment availability*

For this particular contract the contractor could do large RC raft foundations and had 600mm diameter and 800mm diameter cast in situ bored pile capacity. The available machinery was, however, old and the contractor expressed concern about drilling rock sockets for piling.

5.6 *Quality Assurance and Control*

Quality Assurance and Control (QA and QC) of concrete manufacturing, installation of foundations, steel and soil materials used for construction is important. For this project, the contractor was able to control concrete manufacturing using their own concrete batch plant and concrete laboratory located close to the ATC site. Accra also has laboratories that can conduct soil testing and are able to conduct Pile Echo Testing (PET) and cross-hole sonic testing (although the latter is not commonly done in Ghana). These factors allowed the designer and the contractor to consider more innovative foundation solutions.

5.7 *Capability of local construction industry*

Ghana's construction industry is characterized by many small contractors that are underfunded and have a lack of credit facilities. They often also lack appropriate technological capabilities, plant and equipment as well as key personnel to conduct construction projects (Ayarkwa, et al., 2010). There are however also some international companies that provide more specialized construction services.

6 DESIGN STANDARD, LOADS AND THRESHOLDS

The design was conducted according to Eurocode, with British National Annexures. The following load cases and associated thresholds were considered for design:

- Permanent Loading: Self weight of the tower and the foundations were calculated using the analysis software. Other permanent loads were added based on different material unit weights, namely concrete (25kN/m^3), screed (23kN/m^3), masonry clay bricks (20kN/m^3), masonry hollow blocks (14kN/m^3) and glass (25kN/m^3). The rest of the loadings were added as per suppliers' specifications.
- Imposed loads were added as per Eurocode according to different areas and uses.
- Wind loads were assessed with a desktop study using local weather data. Basic wind velocities of 29m/s were used as the basis for the design with an altitude of 70m above sea level.
- Seismic loading: Although this is viewed as an accidental case, the project requires that the ATC tower remains functional after an earthquake event. The geotechnical viability was tested for a vertical load of 90MN. Vertical deflections are limited to 70mm. The total horizontal load on the raft was calculated as 4.16MN and bending moment as 49MNm.
- Ultimate Limit State (ULS): This case represents the ULS without seismicity. A vertical load of 57MN is anticipated. Like the Seismic case, the ATC tower must remain functional when subjected to the ULS load. Vertical deflections are limited to 50mm.
- Serviceability Limit State (SLS) loading is defined as 48.6MN vertical, and movements are limited to a maximum vertical deflection of 35mm and an angular distortion of 1/500, Vertical: Horizontal (0,002 radians).
- Material specifications: The piles, raft foundation and tower core were designed using C30/37 structural concrete with reinforcement grade B500B and a yield strength of 500MPa.

7 FOUNDATION SOLUTIONS CONSIDERED

Three different foundation solutions were considered.

7.1 *Reinforced concrete raft*

RC raft options of up to 20m x 20m square foundation solutions were considered, founded at a depth of up to 2.6m below ground level on laterite. Due to the high lateral loading under seismic conditions, the foundation was found to be at risk of uplift and induced high local stresses, exceeding 365kPa. Settlements exceeding 120mm were estimated in the seismic condition. This was not tolerable.

7.2 *Bored pile foundation*

Piled foundations were considered to transfer the loading of the ATC tower to the phyllite bedrock. The level of the phyllite bedrock varied between 16.5m and 18m below ground level. "First rock" (the depth at which rock is first encountered) occurred in one of the boreholes at 14.5m depth, followed by a zone of completely weathered rock (resembling soil). Substantial rock was found only at 17.3m depth. This made predicting the length of piles across the footprint of the piled foundation challenging. To ensure an effective pile design, the piles were designed to carry loading in shaft friction and end-bearing. The end-bearing was however limited to zero in soil and 3.3MPa in rock, when creating a rock socket of more than two pile diameters (2D_p). Since the contractor was able to create either 600mm or 800mm diameter cast in situ bored piles, the piled solution envisaged 36No. x 0.8m D_p x 24m long piles (establishing a 6m socket), or 36No. x 600mm diameter piles extending to a depth of 26m, with an 8m deep rock socket. A 600mm pile solution was estimated to deflect 20 to 25 mm, whilst an 800mm diameter solution was estimated to deflect 10 to 15mm under SLS loads. Because of the potentially high variation of foundation installation depth, predrilling was recommended for each pile position to pinpoint the phyllite rock depth and the required socket depth per pile. Due to the silty and clayey nature of some soils, care was needed in roughening the pile shaft to avoid "caking". The pile bases also needed cleaning (and verification thereof) to ensure end-bearing.

7.3 *Piled raft*

Consideration was given to a piled raft solution to enable gaining the benefit of the RC raft carrying some of the load and distributing load and stiffening the ground using piles. The use of piles as stiffeners also allowed the use of more of the pile load-bearing capacity than would have been the case when designing a piled foundation. Since the piled raft solution anticipated larger movements than a piled solution the piles could be activated efficiently in conjunction with the RC raft. The contractor's preference was the use of 800mm diameter piles installed above and up to the phyllite rock level. This would save installation time and did not require the time and resource intensity of predrilling each position, drilling into rock and cleaning of the pile bases, other than the normal bucket-cleaning that the contractor was used to do. Care needed to be taken to ensure firm contact of the RC raft with the founding material and pile shafts needed to be rough and free from "caking.

8 THE PILED RAFT SOLUTION

8.1 *Design process*

The piled raft design process is an interactive one to capture the soil-structure interaction that occurs. The first process entailed deciding on a likely RC raft dimension, the number of piles and the depth of installation to achieve the design thresholds given in Section 6. Space constraints dictated that a maximum RC raft of 17m x 17m could be considered. The contractor indicated that an 800mm diameter pile size was preferable to enable cleaning the bases of the piles and ensuring roughness of the pile shaft. Since first rock levels varied between 14.5m and 18m, a target depth of 16m was considered. The screening process involved: (1) Estimating the length of a single pile to carry the anticipated average pile load. This estimate was done using each of the four boreholes drilled, considering them as unique soil profiles and applying an effective stress methodology to estimate the pile length required to carry the estimated single pile load. (2) Utilising the factored skin friction capacity, $q_{s;i;k}$, for use in a piled raft stiffness and settlement. (3) Estimating the mass modulus, E_m, of the ground system using Poulos's method (Poulos, 1994). (4) Estimating piled raft stiffness, the contribution of the RC raft and the piles respectively, as well as the settlement of the piled raft under vertical load only, using Randolph's method (Randolph, 1994) and Poulos's method (Poulos, 2001). This process requires iteration between Steps (1) to (4) until the lengths of a single pile in step (4) and (1) align. (5) Once a likely pile configuration was found, finite element analysis (FEA) of the chosen configuration and optimising the proposed pile numbers and depths were done using Plaxis 3D. During this stage the full vertical, shear and bending moment loading is applied onto a representative ground profile and the likely ground movement during specified loading cases are determined. In this instance these included the following cases: (a) Case 1 – Seismic with a limiting pile base resistance of 600kPa (to reflect that pile bases will only be cleaned using a cleaning bucket and that pile base mobilisation requires significantly more strain to mobilise compared to skin friction mobilisation). (b) Case 2 – ULS without seismic and limiting the base resistance to 260kPa (reflecting that lower base resistance may be expected than in the seismic case). (c) Case 3 – SLS (limiting base resistance to 260kPa). (d) Case 4 – SLS with no base resistance, as a conservative estimate where all the load is carried in skin friction. An iterative process was followed between the Plaxis 3D analysis and the structural design.

8.2 *Sensitivity to pile numbers*

To apply the methods of Randolph and Poulos, the following estimates were made of mass modulus, E_m, ultimate skin friction resistance of a single pile, $q_{s;i;k}$, for each of the borehole soil profiles and a combined ground profile, denoted the "Plaxis profile". The estimated single pile load to be carried within the piled raft was found to be 1658kN under seismic loading.

It should be noted that the values of $q_{s;i;k}$ are obtained from Step 1 described in Section 8.1, by applying the Eurocode material and resistance factors for bored piles. This results in a combined factoring of the skin friction by a value of 2.24 and end-bearing by 2.8.

Table 1. Parameters for the piled raft calculation.

Ground Profile name	Mass modulus, E_m, below a 17m square, 1.35m thick, RC raft	Ultimate Skin Friction on a single pile, $q_{s;i;k}$
BH1	30 MPa	C1: 20kPa C2: 22.0kPa C3: 23kPa. C4: 25kPa
BH2	30 MPa	C1: 20kPa C2: 23kPa C3: 23kPa. C4: 25kPa
BH3	37 MPa	C1: 21kPa C2: 23kPa C3: 23kPa. C4: 25kPa
BH4	34 MPa	C1: 16kPa C2: 19kPa C3: 19kPa. C4: 21kPa
Plaxis profile	48 MPa	C1: 17kPa C2: 20kPa C3: 20kPa. C4: 23kPa

Legend:

C1-C4: Load cases 1 to 4 as described in Section 8.1

E_m: Mass modulus linked to a specific ground profile and size of foundation.

Plaxis profile: A combined ground profile used in the Plaxis 3D analysis.

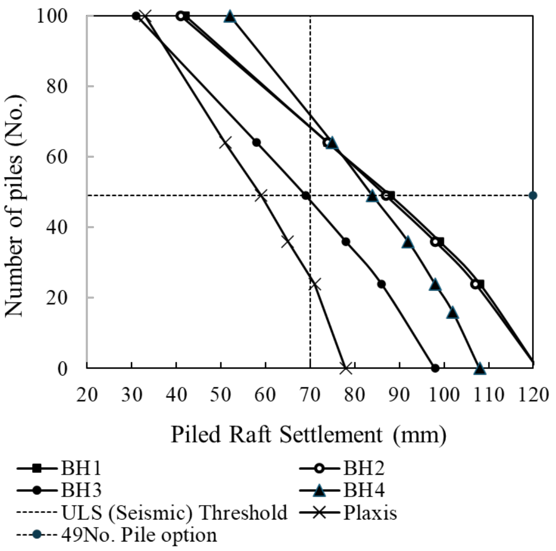

Figure 3. Settlement vs number of piles in the piled raft.

Using the values in Table 1, a sensitivity analysis was conducted applying Case 1 (ULS with seismic loading) and applying the threshold of a maximum of 70mm settlement. Based on the estimations shown in Figure 3 a Plaxis 3D FEA was conducted, modelling a 17m x 17m x 1.35m thick RC raft, with 49No. x 800mm diameter x 16m long piles. This choice allowed equal spacing of the piles across the 17m square RC raft, at 2.615m centres, which is slightly more than $3D_p$ apart (see Figure 4 showing a schematic of the piled raft pile layout).

The different profiles estimate the piles carrying between 86% and 93% of the load, depending on the stiffness of the ground. The softer ground profile (BH1) carries more load in the piles, as may be expected.

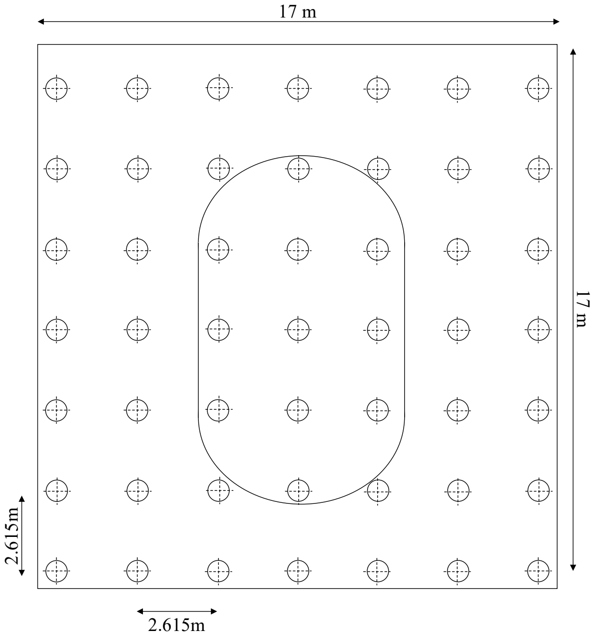

Figure 4. Schematic of pile layout (49No. piles).

9 PLAXIS 3D ANALYSIS

The Plaxis 3D FEA model was made sufficiently large in plan, to minimize boundary effects. The model was made 51m deep; approximately three times the width of the foundation, beyond which it is assumed minor deformation would occur. The load was applied in a similar form to how the ATC tower would apply the load to the ground. The foundation itself was modelled as a plate and the piles as embedded pile elements. The latter allowed for controlling the end-bearing resistance as described in Section 6. No limitation was placed on the development of skin friction in the analyses. The soil was modelled using a Mohr-Coulomb failure criterion.

A comparison of the vertical settlement utilising the analytical methods of Randolph (Randolph, 1994) and Poulos (Poulos, 1994), with that observed using the Plaxis 3D model, are shown in Table 1.

Table 1. Comparison of settlement using analytical methods and FEA.

Analysis	Case 1 ULS seismic	Case 2 ULS	Case 3 SLS	Case 4 SLS (no base)
RP-BH1	88	39	27	24
RP-BH2	87	38	26	23
RP-BH3	69	29	20	17
RP-BH4	84	40	30	27
RP-Plaxis	59	27	20	17
Plaxis FEA	71	37	29	40

Notes:

1. RP refers to the Randolph and Poulos analytical methods.
2. RP-Plaxis refers to the generalised ground profile used in the Plaxis FEA model, but analysed using the Randolph and Poulos analytical methods

The Plaxis 3D and the analytical results are reasonably close in predicting the vertical settlement of the piled raft. A reasonable initial estimation is therefore possible using single pile capacity methods and piled raft estimates utilising the methods of Randolph (Randolph, 1994) and Poulos (Randolph, 1994). The Plaxis 3D FEA predicted a slightly softer response, interpreted as the more accurate modelling of pile-soil interaction. These outcomes are considered sufficiently conservative for the design of the KIA ATC, since no dilative responses or benefit of small strain stiffness was modelled in this instance. The reason for this is that such ground information was not available.

10 STRUCTURAL REINFORCING

Pile design assumed pinned conditions at the pile-raft interface, with axial loads derived from the Plaxis 3D analyses and verified by Prokon raft models. Partial fixity due to raft rotation-induced moments was accounted for, reflecting pile-raft interaction. Reinforcement was based on a 16m pile length. Loads from the superstructure transfer through the raft and pile group, inducing axial, shear, and edge bending moments. The design used finite element internal forces, considering a full 1658kN axial load and nominal moments. A shear reinforcement ratio, As/Sv, of 3.03 resists 580kN shear at pile tops due to raft bending as well as the 85kN shear load due to seismic action. Axial load was assumed constant with depth, while moments and shear decreased due to soil resistance, allowing reduced reinforcement below critical zones. Analysis showed 2011mm² longitudinal bars sufficed for the 800mm diameter pile over the full depth of a 16m long pile. The RC raft was designed to work in unison with the piles to distribute loads to the underlying soil.

The 1.35m thick raft carries all shear and moment forces and transfers these forces as axial and horizontal shear forces to the piles. Reinforcement values, include nominal top and side reinforcement of 2283mm²/m, and bottom reinforcement of 4021mm²/m, except below outer walls where concentrated reinforcement of 7564mm²/m is required. The central tower area, including the lift pit, requires nominal reinforcement (2283mm²/m).

Additional design checks using internal pile cap methodologies confirmed that the raft has adequate strength to resist internal forces based on strut-tie method analysis, with bottom reinforcement requirements governed by the finite element analysis. Shear stresses concentrate around piles and were accounted for in the punching shear design. Concrete shear resistance without reinforcement was calculated at 390kN/m. Significant areas of the raft required beam shear reinforcement, which is provided at As/Sv of 2.4 per meter width of raft.

Punching shear was checked for concentrated forces over piles. Key observations in this regard are:

- Corner punching shear calculations show reinforcement is required but is covered by the beam shear reinforcement.
- Edge punching shear checks near corner columns also confirm that the raft thickness is adequate, with beam shear reinforcement assisting punching resistance.
- Internal punching forces were analysed for both full raft thickness and a reduced 700mm thickness below the shaft. Punching reinforcement is required for the reduced thickness but is covered by the existing beam shear reinforcement.

11 STRUCTURAL PROKON ANALYSIS MODEL

A structural Prokon model was developed, representing the piled supports as springs with stiffness values of 24.5MN/m in the horizontal directions and 186.5MN/m in the vertical direction. The design incorporated all relevant load cases, including permanent, imposed, wind, and seismic actions.

The Prokon structural model was used in conjunction with the Plaxis 3D geotechnical analysis to validate and verify results. The most conservative outcomes from both models were adopted for the final design of the piled raft foundation system.

Results indicate that seismic loading governed the tower structure and the piled raft design and thus primarily dictated the structural requirements for the piles and the raft. It is important to highlight that the structure is designed with an importance factor of 1.4 as per Eurocode, increasing seismic loads by 40%. This introduces a good safety margin, resulting in design loads exceeding typical Ultimate Limit State (ULS) requirements.

12 CONSTRUCTION CONTROLS

To ensure that the design intent translated to construction on site, the following controls were enacted: (1) Verifying ground conditions during pile hole creation by an experienced geotechnical engineer or engineering geologist. (2) Checking groundwater conditions against expectations in design. (3) Verifying the diameter of the pile hole (to exceed 800mm), shaft stability and roughness. (3) Witness the cleaning of the pile base. (4) Check and control concrete mix design and control testing at 7, 14 and 28days. (4) Witness the tremie process of concrete placement. (5) Conduct PET testing on every pile. (6) Before placing the RC raft, the ground preparation shall be confirmed via compaction testing.

During the construction period, continuous deflection monitoring is being conducted to verify theoretical deflection data with actual on-site measurements. This allows timely identification of any unexpected structural behaviour or settlement, enabling prompt corrective actions to ensure the integrity and performance of the foundation system throughout construction.

13 CONCLUSION

This paper discussed the case study of a piled raft foundation for the proposed new KIA ATC tower in Accra, Ghana. It was shown that the piled raft solution gave an efficient alternative to conventional RC raft or piled foundations. The use of the RC raft combined with piles acting as stiffeners of the ground, creates a robust foundation that limits foundation movement and minimizes risks such as the installation of piled foundations into the variable phyllite bedrock. It also minimizes the differential movement across the foundation, with piles expected to carry between 86% and 93% of the load, depending on the stiffness of the ground at a particular pile location. It was further shown that analytical methods such as those developed by Randolph and Poulos are effective in estimating the initial layout of the foundation, from whence more sophisticated modelling, such as FEA can be conducted. The combination of structural and geotechnical finite element modelling allowed a robust design to be achieved. A combination of controls required for RC raft and pile foundation construction are needed to ensure installation of an effective piled raft. This also includes foundation movement control as the structure develops.

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15 REFERENCES

Amposah, P. E., 2004. Seismic activity in Ghana: Past, present and future. *Annals of Geophysics,* 47(2/3).

Ayarkwa, J., Ayireby-Dansoh & Amoah, P., 2010. Barriers to implementation of EMS in construction industry in Ghana. *International journal of engineering science,* Volume 2, pp. 37-45.

Katzenbach, R., Arslan, U., Moormann, C. & Reul, O., 1998. *Piled raft foundation - interaction between piles and raft.* Darmstadt, Germany, International conference on soil-structure interaction in urban civil engineering.

Louw, H., 2024. Soil-structure interaction of horizontally loaded piled-raft foundations (Thesis for PhD), Pretoria: University of Pretoria.

Ong, D. E. L. & Choo, C. S., 2011. *Sustainable construction of a bored pile foundation system in erratic phyllite.* Kuching, Sarawak, Malaysia, ASEAN Australian Engineering Congress.

Poulos, H. G., 1994. An approximate numerical analysis of pile-raft. *International Journal of Numerical and Analytical Methods in Geomechanics,* 18(2), pp. 73-92.

Poulos, H. G., 2001. Piled raft foundations: Design and applications. *Geotechnique,* 51(2), pp. 95-113.

Randolph, M. F., 1994. *Design methods for pile groups and piled rafts.* New Delhi, India, XIII ICSMFE.

Raut, J. M., Khadeshwar, S. R. & Bajad, S. P., 2019. Piled raft foundation: Case study review. *International Journal of Innovations in Engineering and Science,* 4(8).

Standardization, E. C. f., 2002-2004. Eurocode suite: EN 1990 Basis of structural design, EN 1991 Actions on structures, EN 1992 Design of concrete structures, and EN 1997 Geotechnical design., s.l.: CEN.