SCIENTIARUM POLONORUM ACTA
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Acta Sci. Pol.
Architectura 21 (2) 2022, 31–41
ISSN 1644-0633 eISSN 2544-1760 DOI: 10.22630/ASPA.2022.21.2.12

ORIGINAL PAPER

Received: 16.05.2022
Accepted: 07.06.2022

EVALUATION OF THE DAMAGE AND REINFORCEMENT OF THE FOUNDATION IN A TEN-STOREY MULTI-PURPOSE BUILDING IN PORT HARCOURT, RIVERS STATE, NIGERIA

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ABSTRACT

The research work examined the evaluation of the damage and reinforcement of the foundation in a ten-storey building in Rivers State. The following tests: deep boring test, standard penetration test, boreholes sampling, and crack monitoring by Demec gauge have been carried out to check all kinds of damages related to a strong connection with the ground since the behaviour of the ground determines the stability of the building foundation and the long-term performance of the building. Foundation failures have a major impact on the performance of the building structure. If the base is not stable and moves easily, distortion and deflection will occur. It causes damage to the structure, such as cracks in walls, beams, and floors, and becomes a problem for residents. This problem needs to be fixed and corrective work is the option to fix the error. The following recommendations were considered as follows; maintenance of the building and subsoil to avoid deformation and damage to the building structure at least every six months. Periodic on-site inspection is very important to determine if there is any damage to the building structure. The inspection can be carried out at least once every six months or once a year.

Key words: foundation damage, concrete reinforcement, wall crack monitoring, ground behaviour, building structure, deflection and distortion of foundation base, crack in beam, Demec gauge, foundation movement, borehole

INTRODUCTION

The number of large cities with 5 to 10 million inhabitants has been increasing from 18 in 1970 to 22 in 1990, and will reach 33 towards 2010, 21 of them belonging to developing countries including but not limited to only African countries and such forecasts justify the need for studying the urban environments in order to ensure that this development will occur in a sustainable a mode (Młynarek, 2007). The ten-storey multi-purpose building is located in Port Harcourt city Local Government Area of Rivers State, Nigeria (and has the same building design erected in other local government areas of the state). The building was constructed between the years 2005 and 2010. It was planned as a multi-purpose building that would include a hotel, social club, shops, residential and offices.

In 2011, the owners of the building decided to reform it and turn it into a luxury home. The building consists of two bodies separated by an expansion joint. The highest part of the building has ten floors, including one partially underground floor. On the lower floors, there are still shops and a post office. The lower part goes up to the eighth floor. The structure of the building consists of reinforced concrete frames.

First of all, the redevelopment was carried out by renovating the facade, demolishing the inner partition, and keeping the whole structure intact after repairing

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and strengthening some beams and pillars. Only a central reinforced concrete core was added, containing the two holes for the elevators.

The work took longer than originally planned because the technical management found problems in the original foundation of the building. The subsoil of the area consists mainly of clay with allowable stresses of 0.30–0.45 MPa.

The original foundation was calculated based on this data. To verify the foundation of the building, an examination was carried out on the pavement of the main facade of the building, which revealed that the foundation was built on a layer of clay with the allowable stress reduced from 0.25 to 0.35 MPa.

The data obtained in the probe were verified by inspections in the building, which partially had a basement. The technical management responsible for the renovation of the building decided to replace the existing foundation with a new foundation at two depths 75 m from the depth of the original foundation to ensure adequate power transmission into the ground.

This work contains a detailed description of the considered problem and the solution adopted to solve it. Given the nature of the terrain and the depth of the solid layer, the solution chosen was the construction of caissons. To reach the new solid layer of soil, the process of making the caissons consisted of unloading the concrete piers through an auxiliary metal structure, using epoxy resins as a bond between the steel and the concrete.

The basic principle of a building is to unite all structures as a nation to carry and transfer the loads all together and arranged on the ground.

The foundation is the load-bearing connection between the building and the subsoil. They transfer the loads from walls, floors, and ceilings to the ground.

These foundations act as a support to absorb loads and forces from the building structures and then deflect and distribute them over an area large enough to utilize the maximum allowable soil strength. Any loads transferred to the floors below result from some movement. Usually, there is an allowable movement determined by the geotechnical engineer and also by the applicable building code, but if the support cannot bear and resist the loading forces, and the ground pressure exceeds the limit, the eventual failure of the foundation is inevitable.

Foundation movement is likely to cause distortion and damage if the building cannot support the movement because it exceeds the building's tolerable limit for distortion.

Identifying the damage is very important to know the types of failures that have occurred because when the failure occurs, the causes of the foundation failure and the possible types of failures must be immediately investigated and repaired, and rectified.

RESEARCH PROBLEM, AIM AND OBJECTIVE OF THE STUDY

Statement of the problem

The foundation of the building was designed with site conditions and environmental factors in mind, in addition to the loads to avoid failure. Foundation movement, like settlement, is the problem that often occurs in the construction of multi-purpose buildings.

Due to the movement, there will be errors, and the deformation of the building is inevitable. Cracks in walls, floors, and other construction defects appear. The defects are magnified as the movement of the base deteriorates.

Not all residents are aware of the incident, when they notice the damage, patching the cracks in the wall will be one of the solutions for different residents. This condition will shock and possibly become dangerous to the occupant of the building; it will also cause damage when the building collapsed. Because of this, knowledge about foundation failure is very important for people to prevent undesirable things from happening. It is very important to identify the types, sources or causes, and defects of foundation failure.

The aim of the study

The aim of this research is to evaluate the failure and reinforcement of the multi-purpose ten-storey building and to understand the various causes and categories of foundation failure, including types of repair and rehabilitation works. With this understanding, it is hoped that people's knowledge of the damage caused by the outage can be increased so that they can take early action and know how to prevent it before it becomes more severe.

The objectives of the study

To achieve the objectives, several objectives are stated as follows:

- Identify the types of foundation failures, and causes using deep boring to conduct the experiments consisting of six drill holes drilled into the existing residential area.
- Identify types of repair work and repair techniques using standard penetration testing procedure into existing residential areas.
- Identify and determine the damage to a real case of foundation damage using the boreholes sampling technique in the existing residential area.
- Identify and verify the cause of damage and determine the rate of movement at the construction site using the Demec gauge.

Scope of the study

The scope of the investigation reviews the assessment of foundation failure and strengthening and types of remedial actions to solve problems. A case study of foundation failure is observed in the existing housing developments in Port Harcourt Local Government Area of Rivers State, Nigeria. The scope of the case study consists of an analysis based on the site and building conditions when the failure occurs. The types of failures, causes, and defects are determined by analysis and evaluation, and the types of repair work performed are identified, including proposing appropriate methods of maintaining foundations in residential buildings to prevent similar failures.

LITERATURE REVIEW

Structural failure is a complex process influenced by multiple factors. The complementary nature of the plant's underground foundation construction model clearly defines the causes of construction failure. These causes are the result of doubts or even design errors, doubts, and errors of assessment regarding the resistance and deformation parameters of the soil, as well as errors in the process of execution and use of the facility. Based on European statistics, Brandl (2004) found that between 80 and 85% of all construction defects were soil-related.

Cheng, Jack and Evett (2004) conducted an important study in which they observed that approximately 50% of the faults analysed showed discrepancies between the conditions presented in the geotechnical documentation of the soil survey and the actual subsurface conditions. The role of the above factors in structural failure can vary, but structural failure is rarely caused by all factors simultaneously and the qualitative involvement in this process is comparable. Such a case is presented in this article. The identification of individual groups of factors that occur when a building fails made it possible to propose a concept to stop this process, which is also analysed in the article.

Figure 1 shows part of the layout of the building and the knowledge gained during the on-site inspection gave worrying indications that the bell tower and rectory had already settled unevenly during construction.

Fig. 1. Buildings' layout: A – the northern part; B – the southern part of the multi-storey building at Port Harcourt (photo by the author)

After the completion of the construction work, the walls and ceiling of the vicarage showed cracks 3–5 cm wide (Fig. 2). Figure 3 shows cracks that are visible on the walls of the garage next to Part A of the vicarage. The cracks and scratches that appeared are still spreading. However, no scratches were found on the walls of the church. The inspection also revealed another problem that is crucial for the operation of the building, namely the high level of moisture in the basement walls.

Fig. 2. Scratches of the external bearing wall of the linking part between the northern and southern part of the building (photo by the author)

Fig. 3. Cracks/collapse on the external wall of the staircase at the multi-storey building at Port Harcourt (photo by the author)

To determine the causes of the damage to the building and the flooding of the basement, it was necessary to consult design and geological documentation, recommend the discovery of the foundation, and conduct additional underground cone penetration tests.

DETERMINING THE METHOD OF REPAIRING, REINFORCING, AND SECURING BUILDING STRUCTURES AND SUBSOIL IMPROVEMENTS

Causes of cracks

In the introduction to the article, the causes of design failures were discussed, highlighting failures in some adverse conditions and incidents. Such a situation arose in the case of the analysed constructive failure of the vicarage.

The circumstances are as follows: incorrect interpretation of the soil conditions in the 2002 documentation. The documentation states that the subsoil consists of mineral sands with fine mechanical parameters that allow the direct placement of the planned building. However, it turned out that the subsoil contains slopes and organic soils that do not meet the criteria for erecting regular and direct foundations.

The faulty construction of the building with its laying on the heterogeneous and compressible subsoil, in particular:

- conducting a very original laying on prefabricated, loose (unfixed) foundation slabs, instead of monolithic reinforced concrete foundations,
- dispensability concentration of the entire structure of the building by using: reinforced concrete foundations, reinforced concrete outer walls at ceiling height on each floor and reinforced concrete dowels connecting the foundations with the outer walls,
- none expansion between A and B Part of the buildings.

Concept for reinforcing the building and improving the subsoil foundations

The selection of the concept for the reconstruction of the building is determined by the distribution and nature of the scratches, the diversification of the depth at which parts of the building (A or B) were placed and the different conditions of the subsoil affect the foundations of the A and B Part of buildings. After examining the above factors, it was concluded that two different rehabilitation methods should be considered and developed for the separate building parts (A and B).

At the substructure of Part A, there are better soil conditions than under foundations more superficially in Part B. For part A of the building, the structural reinforcements in the areas of cracks and scratches in the walls are sufficient and necessary.

Part B has a shallower foundation, placed directly on the slopes and organic soils. In order to stabilize the building settlement, it is important to improve the weak soil under the foundation.

The excavation must not expose the foundation slab and the bottom of the excavation must be built to a depth equal to the level of the basement floors. Jet grout columns should be built in a sloping array to potentially create complete caking of the weak soil beneath existing foundations. The first phase of column construction should be the erection of the column, which is below the centre of each prefabricated foundation plate.

It can be very beneficial to build these pillars in a slanted configuration and drill a hole through the foundation plate. An important element in the construction of columns is the fact that the concrete floor in the built column before caking (thick liquid) weakens the subsoil under the foundation. Therefore, it is necessary to build the supports alternately, preserving sections of the protection zones, and also taking into account the time required for the concrete floor to adhere. The second stage necessary for strengthening the vicarage, as mentioned above, will be the strengthening of the walls of the building, probably with structural steel sections and bars. However, such a solution must be subjected to a separate technical concept.

Types of remediation work. Remediation methods depend on environmental factors such as soil behaviour and the type of foundation.

Site survey. Site surveys are very important to gather adequate information to determine the status of the site. From there, the counsellor makes the decision and assumptions about the work that needs to be done to overcome the failures. The site survey steps generally consist of the following points.

Testing and monitoring. Testing and monitoring are very important to accurately determine soil conditions. Location monitoring is divided into three categories; Monitoring to determine the cause of damage, monitoring to measure the speed of movement, and monitoring to verify the success of correction.

Shoring. When a building or structure is in poor condition due to settlement and shoring is required to limit or stop the resulting movement, external shoring is likely to be required. The main supporting elements can be made of wood, steel, or scaffolding. When wood is used, expansion and contraction will occur and provision must be made in the form of hardwood wedges to allow for any necessary adjustments.

Underpinning. The process of modifying an existing foundation system by extending it into or into subterranean strata that are deeper and more stable than the surface soil that supports the existing foundation system.

There are several methods of underpinning strip foundation:
- traditional shoring,
- Pynford stool method,
- raised pilot shoring.

There are several methods of underpinning pad foundation or column bases:
- Temporary column support. Before substructure, the columns should be relieved by dead struts erected under all support beams. Reinforced concrete columns and fracture piers can be supported using a horizontal yoke consisting of two pairs of laminated steel beams placed in slots on the sides of the columns.
- Needle and piles. The column loading is transferred from the collar to the crossbeams or needle, which in turn transfers the load to the ground at a safe distance from the designated shoring cut-outs. Typically, one end of the needle is rested on a concrete base slab on a firm base and then the loads are distributed with a hydraulic jack on a precast or drilled pile to a secure base.
- Soil improvement. It is commonly referred to as soil stabilization to improve the natural properties of the soil to provide more adequate resistance to erosion, bearing capacity, water infiltration, and other environmental influences: chemical grouting; jet grouting.

METHODOLOGY OF THE RESEARCH STUDY

Introduction

This study is to evaluate the failure and reinforcement of the ten-storey multi-purpose building located in Port Harcourt Local Government Area of Rivers State, Nigeria and to understand the various causes and categories of foundation failure, including types of repair and rehabilitation works.

This research is conducted in existing developments in six Local Government Areas in Rivers State, namely; Port Harcourt, Obio Akpor, Ikwerre, Okrika, Eleme, and Oyigbo. Contractors involved in the housing development were contacted to obtain some relevant data. The housing complex was built between 2005 and 2010 and consists of 70 units of one-storey residential terraced houses. The area of the houses used to be a paddy field, and the buildings are built and supported by reinforced concrete piles as the foundation structure.

Just like all tall projects, difficult structural engineering problems needed to be addressed and resolved (Baker, Korista & Novak, 2007).

Project background

Structural damage to the community was noted in 2011 when there were resident complaints to the developer reporting damage to their home. The damage consists of cracks in the wall, beam, pillar, and base and floor surfaces, which also settled at this time. Based on the information provided by the resident, the developer conducted the site visit to assess the damage and then attempted to fix the problem on-site by repairing the damage. But the repaired structure cannot withstand, and later the damage continues to appear.

Site project condition

The Port Harcourt residence lands in a paddy field area that was built on an area filled with earth, and according to the information from the SI report, up to 1.8 m of fills with soil had to be placed. The initial ground level is 18 m and is required to reach the expected final ground level of 20.5 m. The building is erected on 250 × 250 mm square reinforced concrete piles driven to a maximum depth of 10 and 22 m.

Measured quantities and calculations

Modulus of constrained deformation (*M*). The numerical value of the stiffness modulus $M = M_0$ in the pre-consolidation area is calculated from modulus M.

Total overburden stress and separate empirical correlations of cohesive and non-cohesive soils were applied. Regarding the cohesive soils and layers shown in the geotechnical layout with 4, 5, and 6, the formula is expressed as follows:

$$M = \alpha,\ q_c, \tag{1}$$

where α is an actor was assumed for loamy sands from fifth layer, which contained significant amounts of fines and silt fraction 3.

For a section of loamy sands mixed with humus sands, probably organic silt, the value of an α-factor equal to 2 was assumed.

To determine the compressibility modulus for fine and silty mineral sands, the Lunne formula (Lunne, Robertson & Powell, 2007) was used, which is as follows depending on the value of the cone resistance (normally consolidated soil):

$$q_c < 10\ \text{MPa}\ M = 4\ q_c, \tag{2}$$

$$10\ \text{MPa} < q_c < 50\ \text{MPa}, \tag{3}$$

$$M = 2q_c + 20\ \text{MPa}. \tag{4}$$

Due to the high particle size heterogeneity, the modulus M was calculated for dammed soils with an α-factor equal to 3 at the limits of variability, which were determined by detailed interpretation.

The extraordinarily high level of agreement between the evaluation of module changes and changes in the liquidity index or the soil density index is remarkable.

Undrained shear strength (s_u). For cohesive soils without drainage, shear strength was determined according to Lunne:

$$s_u = \frac{q_c - \sigma_{v0}}{N_k}, \tag{5}$$

For silty sands found in the soil, in fourth layer with a mixture of organic soils, the s_u values were calculated using the factors N_k equal to 19 calculated.

Empirical correlations. Initial evaluations for preliminary designs are often based on the results of simple *in situ* tests such as the standard penetration test (SPT) and the static cone penetration test (CPT).

Correlations with SPT. The following typical correlations used by the author are based on the work using the SPT:

Raft ultimate bearing capacity:

$$P_{ur} = K_1 \cdot N_r \text{ kPa.} \quad (6)$$

Pile ultimate shaft resistance:

$$f_s = a[2.8N_s + 10] \text{ kPa.} \quad (7)$$

Pile ultimate base resistance

$$f_b = K_2 \cdot N_b \text{ kPa.} \quad (8)$$

Soil Young's modulus below raft:

$$E_r = 2N \text{ MPa.} \quad (9)$$

Young's modulus along and below pile (vertical loading):

$$E_s = 3N \text{ MPa,} \quad (10)$$

where:
N_r – average SPT (N_{60}) value within the depth of one-half of the raft width,
N_s – SPT value along pile shaft,
N_b – average SPT value close to pile tip,
K_1, K_2 – factors.

Small strain shear modulus (G_0). Many correlations have been proposed to relate the small extensional shear modulus to the SPT N value. These usually have the following form:

$$G_0 \approx X[N_{1(60)}]^y \text{ MPa,} \quad (11)$$

where:
$[N_{1(60)}]$ – SPT value corrected for overburden pressure and hammer energy,
X, Y – parameters that may depend on soil type.

Correlations with CPT. The corrections involve bearing capacity and resistance measurements.

Ultimate square or circular raft (or footing) bearing capacity:

$$p_{ur} = a_1\left[1 + a_2 \cdot \frac{D}{B}\right]q_c + q_0, \quad (12)$$

where:
a_1, a_2 – parameters depending on soil type and condition,
q_0 – overburden pressure at the level of the base,
q_c – measured cone tip resistance,
D – depth of embedment below surface,
B – width of footing or raft.

Pile ultimate shaft resistance:

$$f_s = \frac{q_c}{k_s} \leq f_{sl}. \quad (13)$$

RESULT AND DISCUSSION

Site investigation works

Deep boring test. In this research, the contractors used the deep boring test and standard penetration testing procedure to conduct the experiments. Samples were collected by continuous sampling, and initial site surveys by some contractors consisting of six drill boreholes (BH1–BH6), drilled into existing homes in Port Harcourt, Obio-Akpor, Ikwerre, Okrika, Eleme, and Oyigbo Local Government Areas of Rivers State the maximum depth has been estimated at 30.45 m.

Standard penetration test. The test is based on British Standard 1377 (British Standards Institute [BSI], 1990) and it was performed to collect information about the bearing capacity of the soil. Samples in 75 mm pipe were dropped into a 450 mm deep hole using a drill (63.5 kg) and each 7.5 cm gap was recorded up to 45 cm and the value of N was determined by the impact amount for the sampler's penetrating tube from 15 to 45 cm. The SPT test was performed on every 1.0–6.0 m depth and then at 1.5 m intervals to collect N values. From the data report, the number of SPTs performed is approximately 73 SPT numbers. Due to a low SPT value, a low load-bearing capacity of the floor can be demonstrated. Soil with low bearing capacity and low strength to withstand loads may settle. Table 1 and Figure 4 show the value of the SPT test result to a depth of 18 m of BH1–BH6 six drill boreholes, drilled into existing homes in Port Harcourt, Obio-Akpor, Ikwerre, Okrika, Eleme, and Oyigbo Local Government Areas of Rivers State taken from the SPT data from the plot.

Table 1. Result value of the SPT test to a depth of 18 m from BH1–BH6 taken from SPT plot data (own elaboration)

Borehole	Tube depth [mm]	Boring rig [kg]	Bearing capacity [$kN \cdot m^{-2}$]
BH1	80	75.5	50.2
BH2	65	70.4	35.6
BH3	70	73.5	37.8
BH4	55	60.8	25.2
BH5	85	78.5	55.6
BH6	80	76.0	51.5

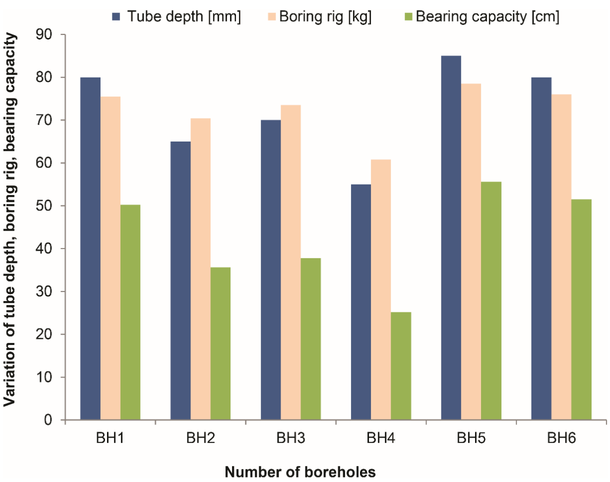

Fig. 4. Result value of the SPT test showing the tube depth, boring rig and bearing capacity (own elaboration)

Analysis and discussion. The groundwater is prone to changes in the rainy season. In general, the groundwater table rises in the rainy season and falls in the dry season. It makes sense to monitor and record the groundwater level over a longer period of time, as fluctuations in the water table can be discernible. The charts below are from the two sets of standpipe readings that appear to stabilize the ground between 1.40 m and 1.77 m underground. High groundwater or an unstable water table disturbs the character of the soil and reduces the strength of that soil to bear the load, especially when the soil type is expansive. Because this floor covering shrinks very easily when it is dry and also expands when it is very humid.

Boreholes sampling. From this drill test, two undisturbed and 14 disturbed samples are obtained for laboratory testing soil strength test:
- one-dimensional consolidation,
- undrained consolidated triaxial.

Site monitoring. The purpose of site monitoring is to verify the cause of damage and determine the rate of movement at the construction site. The contractors divided the monitoring work into crack measurement, ground, and building settlement measurement and monitoring of the groundwater level.

The crack measurement and building settlement monitoring project are located in houses in Obio-Akpor and Port Harcourt Local Government Areas and the ground monitoring team checked in all the six local government areas. All monitoring works were recorded every week and the duration of the monitoring period is three months.

Permeability. The capacity of a soil to conduct liquid or gas, affects leachate flow and landfill gas migration. The increment of excess pore water pressures while loading the fill might be prevented by the usage of a well-drained material. It will also improve the structure stability by providing a drainage path for underlying low permeable soils

ANALYSIS AND DISCUSSION

Demec gauge was used to measure accurately very small movements. For this crack monitoring, plastic Tell-Tale is the device to be measured, this device is very flexible as the measurement can be done without any time limit and without the need for additional devices. Table 2 shows the overall crack monitoring result at Port Harcourt using a Demec gauge.

It shows that the crack is quite stable and sometimes there is no movement at all, but from the value of the cracks, we can see that the movement has affected the opening of the crack in the building. As you can see from the data, the parameters *X* and *Y* depend on the different types of soil. The clayey soils have the highest value of 132.5 for the *X* parameter and 0.42 for the *Y* parameter and the sandy soil has 115.8 for the *X* parameter and 0.56 for the *Y* parameter while all other soils have the lowest value for the *X* parameter and 0.48 for the *Y* parameter. In Table 3, it is shown that the ultimate bearing capacity of square shallow footings and rafts have their highest in parameter a_1 on clay at 0.52 and it is lowest on gravel, which is dense at 0.12. It also has it highest at parameter a_2 in gravel at 0.85 and it is lowest in chalk at 0.36.

Chen and Fang (2009) opined that the interpretation of an ultimate bearing capacity from a load test is not straightforward as each interpretation criterion is based on some assumptions and that these assumptions sometimes include engineering judgment and extrapolations from the original measured load–displacement curves which results may vary significantly from one engineer to another. This variability is not ideal for verifying the performance of a constructed drilled shaft.

Table 2. Typical parameters for small-strain shear modulus correlations with respect to soil type (own elaboration)

Soil type	*X*	*Y*
Sandy soils	115.8	0.56
Clayey soils	132.5	0.42
All soils	108.2	0.48

Table 3. Parameters a_1 and a_2 for ultimate bearing capacity of square shallow footings and rafts with respect to soil type (own elaboration)

Soil type	Condition	a_1	a_2
Clay	all	0.52	0.56
Silt	loose	0.24	0.56
Sand	medium	0.18	0.52
Gravel	dense	0.12	0.85
Chalk	–	0.28	0.36

Figure 5 data represents the ultimate bearing capacity of square shallow footings and rafts with respect to soil type. The clay soil has the highest value of 0.52 for the ultimate bearing capacity of square shallow footings with 0.56 for the ultimate bearing capacity of square shallow rafts while Silt has the lowest value of 0.24 for the ultimate bearing capacity of square shallow footings and 0.56 for the ultimate bearing capacity of square shallow rafts.

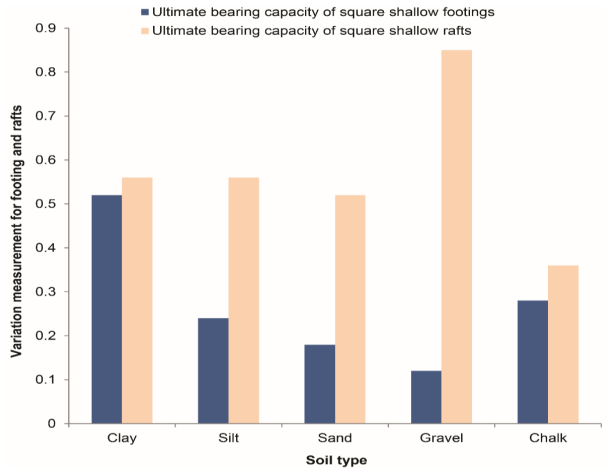

Fig. 5. Chart representing the ultimate bearing capacity of square shallow footings and rafts with respect to soil type (own elaboration)

The soil structure interaction effects are usually omitted in the seismic vulnerability analyses of buildings even though it has been proved that they might notably affect their seismic performance. In fact, European seismic codes establish that they should be included in the analyses of certain structures (Bermingham, Ealy & White, 1994).

Table 4 shows the different configuration of examples of soil settlement with tall structural foundations (raft, piled raft) reaction with the soil and there effects on the structures and the number of cases as according to findings that has occurred over a period of two decades. Stiff clay is affected by seasonal changes causing them to swell in winter and shrink in summer, this can adversely affect foundations.

Table 4. Examples of settlement of tall structure foundations with the soil interaction at the different locations (own elaboration)

Foundation type	Funding condition	Location	Number of cases	Settlement per unit pressure [$mm \cdot MPa^{-1}$]
Raft	stiff clay	Port Harcourt,	5	205–250
	limestone	Obio--Akpor	4	27–40
Piled raft	stiff clay	Ikwerre	5	83–90
	dense sand	Okrika	3	40–45
	weak rock	Eleme	2	80–100
	limestone	Oyigbo	3	50–70

Ikram (2006) define settlement of soil as movements of the ground followed by footings because of the unreliable or weak ground by carrying loads from the structure or resulting from soil moisture changes. When the ground movement excesses the acceptable limit.

Badelow, Kim, Poulos and Abdelrazaq (2009) opined that it is safe to conclude that the tolerable settlement for tall structures can be well in excess of the conventional design values of 50–65 mm.

Figure 6 shows the number of cases and settlement per unit pressure with respect to different locations. From the result, we can see that Port Harcourt has fifth cases with 205–250 settlement per unit pressure and it is built with a funding condition with stiff clay using raft as foundation type while Eleme has two cases of 80–100 settlement per unit pressure and it is built with a funding condition with weak rock using raft as foundation type.

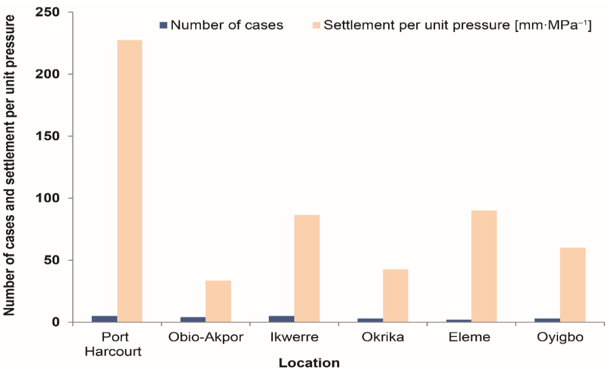

Fig. 6. Number of cases and settlement per unit pressure with respect to location (own elaboration)

CONCLUSION AND RECOMMENDATIONS

Conclusion

The research work examined the evaluation of the failure and reinforcement of the foundation in a ten-storey multi-purpose building in Rivers State. the following tests deep boring test, standard penetration test, boreholes sampling, and crack monitoring by Demec gauge have been carried out to check all kinds of failures related to a strong connection with the ground since the behaviour of the ground determines the stability of the building foundation and the long-term performance of the building. Foundation failures have a major impact on the performance of the building structure. If the base is not stable and moves easily, distortion and deflection will occur. It causes damage to the structure, such as cracks in the wall, beam, and floor, and becomes a problem for residents. This problem needs to be fixed and corrective work is the option to fix the error.

Recommendations

Maintenance to avoid foundation failure. The foundation is the load-bearing connection between the building and the subsoil. They transfer the structure to the ground. But at the same time, they transmit every movement from the ground to the structure. If the foundation does not transmit this movement, it will lead to deformation and damage to the building structure.

Understanding the importance of maintaining the foundation structure. Knowledge of the importance of the foundation structure is essential to spread further, especially for common people who have no relation to the behaviour of this building. The occupant, the owner of the building, and also the tenants need to know the condition of the structure of their building or houses and how to maintain the stability and performance of the structure itself.

On-site inspection and surveillance. A periodic on-site inspection is very important to determine if there is any damage to the building structure. The inspection will maintain the performance of the building structure by taking early action if there are signs or indications of minor damage or cracks in the wall or column. The inspection can be carried out at least once every six months or once a year. It is already suitable and can maintain the stability of the structure itself. It can also reduce the risk of default.

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OCENA AWARII I WZMOCNIENIA FUNDAMENTU W DZIESIĘCIOPIĘTROWYM WIELOFUNKCYJNYM BUDYNKU W PORT HARCOURT, STAN RIVERS, NIGERIA

STRESZCZENIE

W niniejszej pracy badawczej dokonano oceny zniszczenia i zbrojenia fundamentu w dziesięciopiętrowym budynku mieszkalnym w stanie Rivers (Nigeria). W celu sprawdzenia wszelkiego rodzaju zniszczeń związanych z silnym połączeniem z podłożem przeprowadzono test głębokich odwiertów (DBT), badanie sondą z końcówką cylindryczną (SPT), odwierty próbne oraz pomiary głębokości pęknięć z użyciem miernika Demec, ponieważ zachowanie gruntu determinuje stabilność fundamentu budynku i możliwość długiej eksploatacji budynku. Awarie fundamentów mają duży wpływ na wydajność konstrukcji budynku. Jeśli fundament nie jest stabilny i łatwo się porusza, to wystąpią odkształcenia i ugięcia. Powoduje to uszkodzenia konstrukcji, takie jak pęknięcia w ścianach, belkach i podłogach. Dla użytkowników obiektu stanowi to problem, który trzeba usunąć, a jedną z opcji naprawienia błędów są prace naprawcze. Wydano następujące zalecenia: konserwacja budynku i podłoża w celu uniknięcia deformacji i zniszczeń w strukturze budynku przynajmniej co sześć miesięcy. Okresowe inspekcje *in situ* są bardzo ważne, jeśli w strukturze budynku doszło do jakiegokolwiek zniszczenia. Inspekcje te można przeprowadzać przynajmniej raz na sześć miesięcy albo raz w roku.

Słowa kluczowe: zniszczenie fundamentu, zbrojenie betonu, monitorowanie pęknięć ścian, zachowanie gruntu, konstrukcja budynku, ugięcie i odkształcenie podstawy fundamentu, pęknięcie w belce, miernik Demec, ruch fundamentu, otwór wiertniczy