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Analysis of Different Scenarios Load of One Combined Pile Raft Foundation

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Abstract

In the Metropolitan Region of Recife (MRR), there is an increased demand for pile raft in the construction of buildings due to its verticalization and the presence of the foundation soils with low bearing capacity. This article presents a performance analysis of a foundation solution by combined pile raft (CPRF) of a building located in the MRR. Four numerical scenarios of the building were developed to consider the Soil-Structure Interaction (SSI). In each model, the supports between raft-soil and raft-piles varied between elastic supports, Winkler's Model (1867), and rigid supports, conventional modeling, in order to evaluate the behavior of the foundation. The spring coefficients of the elastic supports were determined by two different methods: one by an equation adapted from Hooke's Law, using the results of the Static Load Test, and the other through empirical correlations of the standard penetration test number (N_{SPT}). The scenarios were created using the SAP2000 software. Subsequently, a statistical analysis of the results was performed. For all scenarios, it was observed that the settlement tends to be smaller in the piles *and larger in the raft, more intensely in the regions between piles, where the influence of the stiffness of the piles on the raft is minimal. Scenarios 3 and 4 were the most realistic, as the foundation solution behaved as CPRF and not as a group of piles.*

Keywords: Combined foundation, Numerical models, Foundation performance.

INTRODUÇÃO

The economic development of Pernambuco state provided modern constructions and united large urban conglomerates, giving rise to the Metropolitan Region of Recife (MRR). To keep up with this high population growth, there was an increase in vertical constructions in the RMR (Oliveira et al., 2016).

In the opposite direction to urban verticalization, the RMR plain is supported by deposits of soft soils, quite heterogeneous, formed mainly by layers of sands and organic-silt clays, with low support capacity and high compressibility. One of the alternatives found was the use of the combined pile raft foundation (CPRF) in the RMR (Barbosa, 2018).

The association of piles to raft proved to be a good solution to decrease high values of total and differential settlements to acceptable values, therefore improve the performance of the soil providing foundation support (Liu, Bishop; Lindsey, 2016).

The use of this mixed foundation in RMR has intensified due to its good performance and remarkable productivity gain when associated with more efficient construction systems, such as the concrete wall system (Patricio, 2019).

Traditionally, in pile raft foundation projects, piles are the agents responsible for transmitting all superstructure load to the foundation soil. This design condition that does not consider the pile raft as a load transmission element to the soil is typical of conventional modeling (Freitas, 2018).

Commonly the CPRF solution is oversized. Due the need to make projects more economical and efficient, a new design philosophy was conceived. Different from conventional modeling, this philosophy attempts integrated projects that consider both the load capacity of piles and raft in a combined way, as well as the interaction of these structural elements with the foundation soil. Therefore, a more complex and realistic numerical model, for consideration of soil-structure interaction (SSI), is generated, generating more reliable results and more economical and safer projects (Poulos, 2001).

The article presents a study about the performance analysis of a foundation solution by piled raft of a building located in the MRR. The information about the project and the site consisted of architectural design of the building, structural design of the foundation, static load test of the piles, SPT probing and stratigraphic soil profile.

This study is included in the research project entitled "Study of CRPF of buildings with and concrete wall construction system", in which was already carried out in the same area: Analysis of the foundations project using finite element methods in the analysis of load test (Silva, 2021); Evaluation of SSI with monitoring of settlements and analysis of the influence of the constructive sequence on the performance of CRPF (Silva Junior, 2021); Evaluation of the settlements by angular distortion (Jordão Júnior, 2021); and, Reliability and safety of a foundation with CRPF (Silva, 2021).

BIBLIOGRAPHIC REVIEW

Pile Raft

A combined of pile raft foundation (CPRF) is a type of foundation which this the advantages of both shallow foundation (e.g., raft foundations) and deep foundations (e.g., pile foundations). The ideal soil profile for the CPRF is a combination of stiff clay and dense sand (Liu, Bishop; Lindsey, 2016).

The CPRF transmits the building load to the soil foundation in two ways: (I) by the base of the shallow foundation (raft); (II) by the tip (tip resistance) and lateral surface (shaft friction) of the deep foundation elements (cuttings) (Bacelar, 2003).

The use of this foundation solution is increasing due to the high-magnitude shipments that are mobilized by buildings on soils with insufficient support capacity (Ahner; Soukhov; Konig, 1998).

Safety Criteria

To this date, there are no rules for project of CPRF. However, due to the increase of its use in recent years, the search for guidelines that guide its elaboration is of fundamental importance (Ahner; Soukhov; Konig, 1998).

Similar to the other foundation types, the pile raft must transmit the loads from the superstructure to the soil, safely, complying with the basic requirements of a foundation project: (I) deformations acceptable for working conditions; (II) safety to the collapse of structural elements and soil foundation (Velloso; Lopes, 2011)

Solo-structure interaction

Technological and scientific advances have enabled the development of complex software and advanced methodologies for structural calculation. Despite the advances, conventional modeling is still predominant in the dimensioning of structural elements. In this process, the superstructure (building) and infrastructure (foundation) are evaluated separately. Thus, the structural design of the structure-foundation system is carried out in independent stages: (I) dimensioning of the building, considering that it is supported by no displaceable support; (II) sizing of the foundation from the efforts obtained in step (I) (Crespo, 2004).

The consideration of soil-structure interaction occupies a prominent function in the analysis of the foundation's behavior. In view of this, several models have been developed that simulate soil behavior. In general, the available models allow the soil to be evaluated as an elastic-linear medium, nonlinear elastic, elastoplastic and viscoelastic, and the elastic-linear being the most used medium (Souza, 2014).

Elastic-linear scenery

The use of elastic supports to represent the soil was the central point of the Winkler's Model (1867) that approximates the behavior of the soil to a set of springs that deforms with the application of a load. In this model, there is a linear relationship between the tension applied to the soil and the displacement suffered by it, determined by the vertical settlement coefficient, in which it's a proportionality constant, coming from an adaptation of the equation of Hooke's Law (Antoniazzi, 2011).

Numerical modeling

More sophisticated numerical models that consider the work together of the raft-pile-soil group have been developed. These more rational models not only increase the support capacity of the foundation system, but also increase the overall rigidity of the structure that acts directly in the control of settlements (Mandolini, 2013).

These models usually evaluate the performance of each element of the foundation considering the infrastructure and superstructure as a single system and analyze the influence of the SSI on the behavior change of each of these elements (Antoniazzi, 2011).

METHODOLOGY

General Characteristics of the Site

The study was performed in project of the residential condominium, located in the city of Jaboatão dos Guararapes belong to the MRR, Pernambuco, Brazil. The development consists of 14 (fourteen) blocks of 05 (five) floors (ground floor + 04 floors), with linear distribution of loads for the foundation, carried out through reinforced concrete walls molded on site. The analyses were performed for block 13, can be considered for the other blocks.

In general, a profile of the soil with heterogeneous foundation, composed initially of a layer of sand with organic matter, soft to little compact, varying up to 6.0 and -7.0 m of depth, followed by a layer of sand, medium compact, ranging up to +1.0 to -11.0 m of depth. The next layer is composed of a silt-clayey sand, little compact, ranging up to -11.0 to -21.0 m of depth, ending with a layer of sand, medium compact to compact, up to the limit of the polls, in -18.0 to -25.0 m of depth. The groundwater level was found around the +7.0m of depth.

Due to the geotechnical characteristics of the soils and the linear transmission of loads from the building to the ground, it was decided to perform a CPRF.

For each apartment block, a single raft with a thickness of 25 cm and an approximate area of 528 m^2 was executed, made of structural concrete molded in the site, with compression resistance of 40 MPa. Figure 1 shows the location and frame of the raft, with the demarcation of the crown blocks of the piles. The raft is generated and delimited with a slat of structural masonry, and on it is born a system of wood shape that delimits the concreting of the foundation (Figure 2).

Figure 1. Located of raft and frame

Figure 2. Construction of raft

Source: The authors.

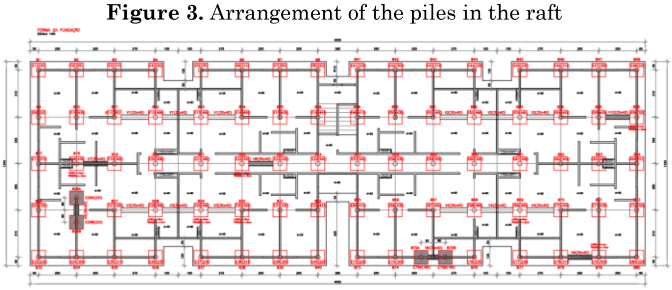
In total, 1490 prefabricated concrete piles were set, square cross section, hollow and with a side of 25 cm, with a thickness of 12 cm and CA-50 steel frame. The cuttings have variable lengths between 12 and 25 m. Figure 3 shows the arrangement of the CPRF.

Numerical models

To verify the performance of the foundation in CPRF, four numerical models of the considering were developed for SSI consideration:

1. Scenarios 1: the piles were modeled with rigid supports and the raft remained free (conventional model).
2. Scenarios 2: the piles were modeled with rigid supports and the soil in contact with the raft was modeled with linear elastic supports (linear spring). The soil spring coefficient was determined based on Perloff (1975).
3. Scenarios 3: the piles and the soil in contact with the raft were modeled with linear elastic supports. The soil spring coefficient was determined according to Perloff (1975) and the spring coefficient of the piles was determined by equation adapted from Hooke's law, using the results of the Static Load Test.
4. Scenarios 4: model equal to the previous one, with the difference that the spring coefficient of the piles was determined through empirical correlations of the soil N_{SPT}.

Figure 3. Arrangement of the piles in the raft



Source: The authors.

Soil Spring Coefficient (K_{ms})

The spring coefficient to soil translation (K_{ms}), in $kN \cdot m^{-1}$, was obtained through Equation 1, which defines its value as the product between the coefficient of vertical settlement (K_v), in $kN^{\cdot m-3}$, and the raft area (A), in m^2 (ANTONIAZZI, 2011).

$$K_{ms} = K_V \times A \qquad \text{Eq. 1}$$

The coefficient of vertical settlement it was determined by Equation 2, proposed by Perloff (1975), where (E_s) is the soil deformability module, in $kN \cdot m^{-2}$; (B) corresponds to the smaller dimension of the raft, in m; (υ) this is the Poisson coefficient, without dimension, and (I) is the raft form factor, without dimension. The calculation of this coefficient was performed considering the soil as an elastic and semi-infinite medium (VELLOSO; LOPES, 2011).

$$K_V = \frac{E_s}{B \times (1-\nu^2) \times I} \qquad \text{Eq. 2}$$

The soil deformability module was obtained through Equation 3, which estimates its value from the penetration resistance index of soil layers (N_{SPT}) and empirical coefficients (α) and (K) that depend on the soil type (TEIXEIRA; GODOY, 1996).

$$E_S = \alpha \times K \times N_{SPT} \qquad \text{Eq. 3}$$

The parameters α, K and ν were determined by Teixeira and Godoy (1996). The N_{SPT} was obtained through the Simple Penetration Tests (SPT). The quantities α and N_{SPT} are dimensional, and K is obtained in MPa.

The raft form factor (I) was obtained through Equation 4, where (I_S) is the raft form factor and its stiffness; (I_h) is the thickness factor of the compressible layer and (I_d) is the depth or inlay factor (VELLOSO; LOPES, 2011)

$$I = I_s \times I_h \times I_d \qquad \text{Eq. 4}$$

The parameters I_S, I_h and I_d are dimensional quantities and were determined by VELLOSO AND LOPES (2011), considering surface loading (I_d = 1), since the raft structure was executed at the emphiscellum dimension.

The same spring coefficient was used for the soil in scenarios 2, 3 and 4.

Piles spring coefficient for Scenario 3 (K_{me3})

The spring coefficient (K_{me3}), in $kN^{\cdot m^{-1}}$, was determined by Equation 5, adapted from Hooke's law, which expresses the coefficient value by the ratio between the load (F), in kN, and the settlement (Z), in m, of the piles (ANTONIAZZI, 2011).

$$K_{me} = \frac{F}{z} \qquad \text{Eq. 5}$$

The load (F) corresponds to the average load per station and its value was estimated by the ratio of total loading of the building by the total number of piles. The settlement (Z), corresponding to the load (F), was estimated by an interpolation of the data of the Load x settlement curve, obtained through the results of the Static Load Test (PCE) performed during the execution of the work

Piles spring coefficient for Scenario 4 (K_{me4})

The spring coefficient (K_{me4}), in $kN \cdot m^{-1}$, was determined by Equation 1, with the difference that the vertical reaction coefficient was determined by empirical correlations with the soil properties (Equation 6) and the area corresponds to the area of influence of each pile node (FREITAS, 2018).

$$K_{ve} = \frac{K_h}{\nu} \qquad \text{Eq. 6}$$

The soil Poisson coefficient (v) was obtained as previously and the soil horizontal reaction coefficient (K_h), in $kN{\cdot}m^{-3}$, was obtained by equation 7, where (n_h) is the horizontal reaction constant of the soil, in $kN{\cdot}m^{-3}$; (Z) is soil depth, in m; and (B) is the diameter of the pile, in m (FREITAS, 2018).

$$K_h = n_h \cdot \frac{z}{B} \qquad \text{Eq. 7}$$

The horizontal reaction constant of the soil was determined by equation 8, in $kgf{\cdot}cm^{-3}$, for the case of saturated sands (FREITAS, 2018).

$$n_h = \left(\frac{N_{SPT}}{N_{SPT}{\cdot}0.36+32}\right)^{1.7} + 0{,}03 \qquad \text{Eq. 8}$$

Numerical building modeling

The numerical modeling of the structural system of the building was performed with the use of the SAP2000 program, version 16, by the Finite Element Method (MEF).

The physical properties of the materials used in the construction of the work were removed from the specifications of the structural project (Table 3).

Only the vertical overload load and own weight of the structural elements were considered in the combination of efforts.

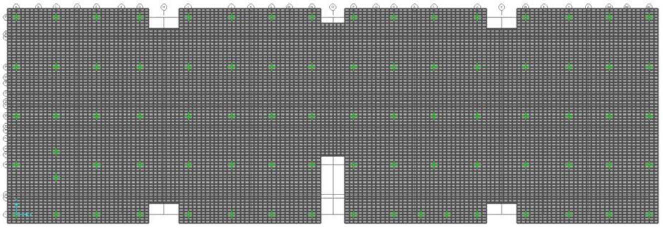
The raft, concrete wall and slabs were modeled by SHELL type plate elements, discretized in grids of 20 x 30 cm, 25 x 25 cm and 25 x 25 cm, respectively. The raft supports on the piles and the soil were modeled according to the description of the scenarios.

RESULTS AND DISCUSSIONS

Numerical modeling of the structural system of the building

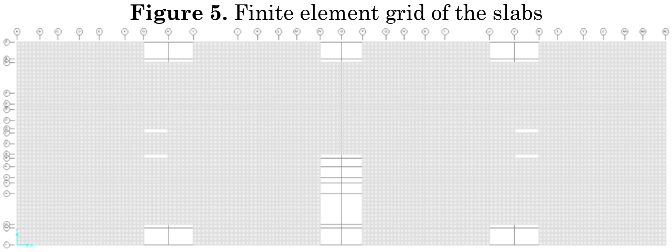
Figures 4, 5 and 6 show, respectively, the finite element grides of the raft, slabs and concrete walls. Figure 7 is the final representation of the numerical model obtained by the SAP2000 program.

Figure 4. Finite element grid of the raft



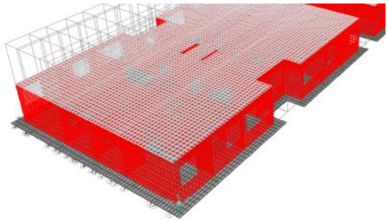
Source: The authors.

Figure 5. Finite element grid of the slabs



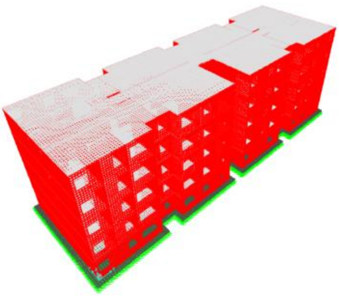
Source: The authors.

Figure 6. Finite element grid of concrete walls



Source: The authors.

Figure 7. Numerical modeling of the completed building



Source: The authors.

Load Analysis

Load transfer by foundation element

Table 1 shows the percentage of load transferred to the ground by each element of the foundation for the 4 scenarios created. As the stiffness of the piles in relation to the soil decreases, the load portion dissipated by the raft is larger. The same occurs when soil stiffness increases, however, at a lower intensity since piles are the main agents of load transfer.

Table 1. Load transferred by foundation element. Source: The authors.

	SCENARIOS	TRANSFERRED LOAD (kN) / % LOAD TRANSFERRED			
Nº	Description of the supports	PILE		RAFT	
1	Rigid in the piles Free raft	30879.07	100	0	0
2	Rigid in the piles Springs in the piles (k_{ms} = 259.28 kN·m^{-1}·node)	30454.91	98.63	424.16	1.37
3	Springs in the piles (k_{me3} = 127927.89 kN·m^{-1}· node) Springs in raft (k_{ms} = 259.28 kN·m^{-1}· node)	24439.13	79.15	6439.58	20.85
4	Springs in the piles (k_{me4} = 53402.65 kN·m^{-1}· node) Springs in the piles (k_{ms} = 259.28 kN·m^{-1}· node)	19180.02	62.11	11699.05	37.89

From the analysis of the results of Table 4, the following aspects were verified in relation to the scenarios:

1. In scenario 1, the percentage of load dissipated by the raft was null, and all the building load was transferred to the ground by the piles (30879.07 kN). Thus, the raft-piles set does not work as a combined foundation, since only one of the elements of the system fully transfers the loads from the superstructure to the soil. The behavior of the foundation in this scenario is equivalent to that of a group of piles, where the raft functions only as a block that has the function of transferring the loads from the building to the deep foundation. Usually, this condition is used in foundation projects that use large blocks associated with piles, such as the case under study, and that do not consider the block as a load transmission element to the ground and may be an oversized and uneconomical solution.
2. In scenario 2, the percentage of load dissipated by the raft was less than 2% of the total load of the building. Similarly to the previous model, the pile foundation also behaved as a group of piles, since almost all the load from the building is transferred to the ground by the piles (30454,91 kN). The small variation in the dissipation of load by the raft between scenarios 1 and 2 (1.37%), occurred due to the resistance that the soil presented due to the adoption of springs in the raft nodes to simulate the soil. This resistance is negligible when compared to the resistance of piles that have infinitely superior stiffness (rigid supports). In practice, this condition amounts to a situation in which the raft is resting on a soil of negligible load capacity in relation to the soil or rock where the piles are spiked.

3. In scenario 3, the percentage of load dissipated by the raft was 20.85% of the total load of the building. Therefore, the raft-piles set works as a combined foundation by presenting a good load distribution between these elements. This considerable variation in the transfer of load by raft to the ground in relation to previous scenarios is explained by the considerable reduction of the stiffness of the piles when elastic supports are used throughout the structure. This scenario that considers the contribution of the superficial foundation and the deep foundation makes the process more complex, however, brings the design condition closer to the real situation.
4. In scenario 4, the percentage of load transferred by the raft was even higher (37.89%), configuring the staked foundation as a mixed solution. Similar to the previous scenario, a joint work of the raft and piles in the transfer of the load to the ground is verified. The load dissipation by the raft increased in relation to model 03 due to the decrease in the stiffness of the pile springs (Table 1), when changing the method of determination of the spring coefficient of the piles.

In summary, scenario s 1 and 2 presented similar results, and the piles were responsible for transmitting all load of the structure to the foundation soil. Foundation solutions for these scenario s behaved like pile block. In models 3 and 4, the raft dissipated a considerable portion of load to the soil, with a joint work of the elements. The foundation solution functioned as CRPF, these scenarios being the most realistic. This occurrence is due to the soil-structure interaction (ISE) of models 3 and 4 that is closer to reality. Finally, the percentage of load transferred by the raft can be significant for a project that was conceived considering only the work of the piles, which ends up resulting in oversized and uneconomical projects.

Statistical analysis of pile loads

Table 2 brings together the main measures of dispersion of loads in the piles for the four numerical scenarios developed.

Table 2. Analysis of load dispersion in piles.
Source: The authors.

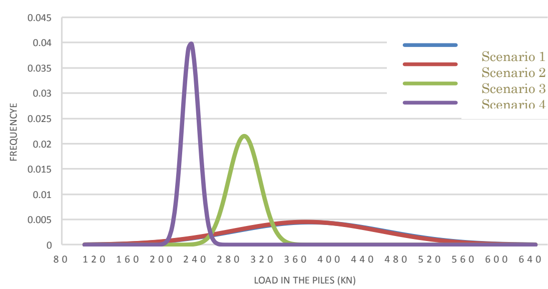
SCENARIO	LOAD (mm)			SPREAD	VARIANCE	STANDARD DEVIATION
	MIN	AVERAGE	MAX			
1	120.15	376.57	606.30	486.15	8033.01	89.63
2	117.93	371.40	596.31	478.38	7738.36	87.97
3	220.58	298.04	335.37	114.79	343.85	18.54
4	193.43	233.90	251.75	58.32	99.11	9.96

According to Table 2, the following observations were made:

1. Scenarios 1 and 2 showed high amplitude values, with little variation between them (7.77 kN). This means that the maximum and minimum load values found in the pile sample are distant from each other, where the maximum load found (603.30 kN for scenario 1 and 596.31 kN for scenario 2) is 5 times higher than the minimum load (120.15 kN for model 1 and 117.93 kN for scenario 2) in both models.
2. Scenarios 3 and 4 showed a reduction in amplitude in the percentages of 76.39% and 88.00%, respectively, in relation to scenario 1, and 76.00% and 87.81%, respectively, in relation to scenario 2. Therefore, in these scenarios there was an approximation between the minimum and maximum load values, where the maximum load found (335.37 kN for scenario 3 and 251.75 kN for scenario 4) is approximately 1.5 of the minimum loads (220.58 kN for model 3 and 193.43 kN), indicating that there was a uniformity of the loads in the piles.
3. The measures of variance and standard deviation of the loads in the piles of scenarios 3 and 4 were significantly lower than those found in models 1 and 2, which varied very little between them. Thus, these results indicated that scenario 3 and 4 presented a more homogeneous data distribution, which means that the loads found in the 82 piles are less dispersed around the average load, that is, they are more uniform.

The above results showed that the loads found in the 82 piles approached each other with the evolution of the models due mainly to the redistribution of efforts in the foundation as a result of the SSI. Consequently, these load values were concentrated in a smaller range, defined by amplitude, reducing the dispersion of loads in the piles.
Figure 6 shows the normal distribution curve of the loads at the piles for the four models considered. You can see an overlap of curves between scenario s 1 and 2.

Figure 6. Normal load distribution curves in piles



Source: The authors.

Figure 6 shows the following aspects in relation to the results.

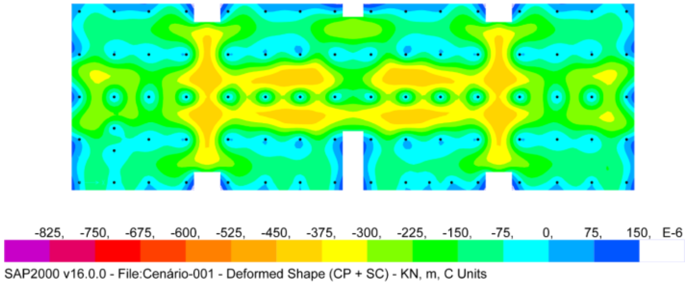
1. The distribution curves of scenarios 1 and 2 have a very flattened aspect in relation to scenarios 3 and 4, indicating that there is a great variation of loads in the piles in the first two scenario s. This measure indicates the possible existence of overloaded and relieved piles due to non-uniform transmission of efforts.
2. Scenarios 3 and 4 presented a distribution curve with a pointed aspect, which indicates that the load values in the 82 piles are little dispersed in relation to the average load. This shows that loads on the piles are less dispersed as the scenario evolves.
3. It is possible to notice that there is a certain symmetry in the four curves, which indicates that the loads in the piles disperse in relation to the average load in a way approximately symmetrical. In other words, there is a relatively similar amount of piles with higher and lower values relative to the average load.

The above results reveal that the loads found in the 82 piles approached the average load with the evolution of the scenarios. This event was the result of the process of standardization in the loads in the piles that occurred due to the distribution of the most realistic efforts of models 3 and 4 due to the consideration of ISE.

Distribution of Settlements by Foundation Element - Raft

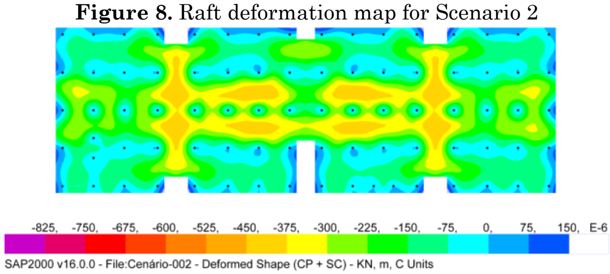
Figures 7, 8, 9 and 10 show raft deformation maps for scenarios 1, 2, 3 and 4, respectively. The analysis of these images showed that the settlements are higher in the central part of the raft, where there is a higher concentration of load, especially in the regions between piles. In addition, the occurrence of generalized settlements was verified throughout the raft grid in scenarios 3 and 4, due to the adoption of elastic supports in the piles that contributed to the increase of the overall displacement of the structure. As for scenarios 1 and 2, it was observed that the settlements obtained were lower because they presented undisplaceable supports in the piles.

Figure 7. Raft deformation map for Scenario 1



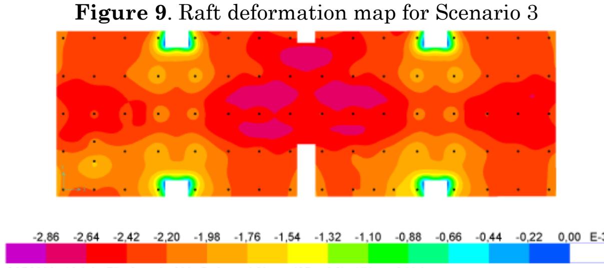
Source: The authors.

Figure 8. Raft deformation map for Scenario 2



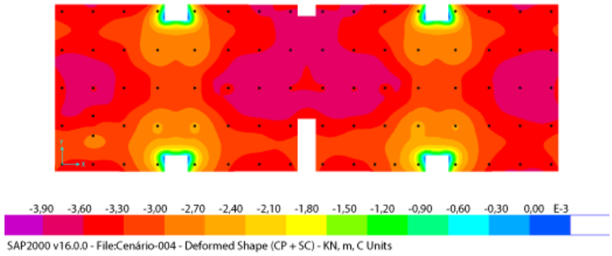
Source: The authors.

Figure 9. Raft deformation map for Scenario 3



Source: The authors.

Figure 10. Raft deformation map for Scenario 4



Source: The authors.

According to the results obtained by SAP2000, the maximum values of vertical displacements presented by the raft were:

1. In Scenario 1, the maximum value of the settlement was 0.879 mm in the inner part of the raft, and the maximum survey was 0.227 mm at the edges of the raft. The nodes of the piles, represented by circles in black, present null displacement because they are without displaceable supports.
2. In Scenario 2, the maximum settlement was 0.874 mm in the inner part of the raft, and the maximum survey was 0.220 mm at the edges of the raft. A null settlement value was also found in the stations for the same reason as the previous model.
3. In Scenario 3, the maximum settlement was 2.769 mm inside the raft. The survey wasn't checked on the raft. The piles didn't present null settlement due to the adoption of elastic supports.
4. In Scenario 4, the maximum settlement was 4.128 mm inside the raft. The survey was also no lifting was checked on the raft. Again, the piles did not present null settlement for the same reason as the previous scenario.

When comparing the displacements of the four models, it was observed that in scenarios 3 and 4 (elastic models), the settlements were higher than the values found in scenario s 1 and 2 (rigid models), which present undisplaceable supports in the piles. This shows that the substitution of rigid supports (undisplaceable) by elastic supports allows more expressive deformations to the structure, due to the reduction of stiffness.

Moreover, when comparing scenarios 1 and 2, it was observed that in scenario 1 (less rigid model) the vertical displacements were higher than those of scenario 2 (more rigid model). Therefore, these observations indicate that the absolute settlements in the raft increase with the decrease of stiffness in the foundation supports. Thus, it is noted that there is an inversely proportional relationship between the rigidity of the support of the structure and the absolute settlement suffered by it.

Distribution of Settlements by Foundation Element - Raft

The adoption of rigid supports in the piles in scenarios 1 and 2 imposed null displacements on these elements. Thus, the settlement in the piles for the four models were estimated from the analytical expression developed in item 2.5, using the load values in the piles obtained in each model through SAP2000. The purpose of this procedure is to predict the settlement generated by the efforts obtained in each model considered.

Table 3 shows the minimum, medium and maximum settlement in the piles and the dispersion measurements for each of the models. It was verified that there was a great variation between the minimum and maximum settlement in the piles in the first two models. This variation is because the higher loads in the piles exceeded the value of the workload of approximately 49 kN, determined by the PCE tests, generating excessive settlement.

Table 3. Dispersion analysis of the estimated settlements in the piles.
Source: The authors.

SCENARIO	SETTLEMENTS (mm)			SPREAD	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
	MIN	AVERAGE	MAX				
1	0.57	3.54	19.96	19.38	8.850	2.97	0.84
2	0.56	3.40	17.43	16.88	6.730	2.59	0,76
3	1.35	2.06	2.44	1.10	0.030	0.18	0.09
4	1.12	1.46	1.62	0.50	0.007	0.08	0.06

The settlements presented by scenarios 3 and 4 showed little variation. This shows that the loads on the piles are more uniform and have not exceeded the workload due to better redistribution of efforts in these models. The opposite occurred in scenarios 1 and 2, where dispersion measurements indicated a large variation in the settlements, indicating a large part of the loads in the piles are higher than the workload determined by the PCE tests, which culminated in discrepant settlements.

CONCLUSION/FINAL CONSIDERATIONS

As expected, the results obtained in this study showed that although the constructive method of a CPRF and a group of piles is the same, there are differences in behavior between structures. The main difference indicated concerns the percentage of load transmitted to the ground by each foundation element, which varies depending on the contact consideration of the block/raft and the piles with the soil.

When the resistance of the soil in contact with the raft was despised (scenario 1) or when the piles is adopted with infinite rigidity (scenarios 1 and 2), it can overestimate the loads in the piles and underestimate the settlements of the raft; while when considering this soil resistance (scenarios 2, 3 and 4) or adopting piles with finite stiffness (scenarios 3 and 4), a uniformity of load in the piles occurs due to the better redistribution of the stresses between the raft and the piles. In this sense, the results showed that models 3 and 4 were the most realistic models since the foundation solution behaved as CPRF and not as a pile block.

The results also showed that the variations of loads and settlements between the models are usually related to the type of support used to model the piles and the foundation soil. Depending on the choice of support, the displacement restrictions that influence the behavior of the structure are modified.

For all scenarios, it was observed that the settlement tends to be smaller in the piles and larger in the raft, more intensely in the regions between piles, where the influence of the stiffness of the piles on the raft is minimal.

Finally, it is inferred that there is an inversely proportional relationship between the rigidity of the support of the structure and the overall absolute reposition suffered by it.

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