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Analysis of the influence of construction sequence on the performance of raft pile foundation

Análise da influência da sequência construtiva no desempenho de fundação por radiers estaqueados

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Abstract: This article presents the analysis of the influence of constructive sequence on the performance of a foundation by raft piles of a building in concrete wall structure. The settlements were monitored in the field and estimated by the finite element method, with and without the consideration of soil-structure interaction (SSI) for the analysis of the redistributions of displacements and efforts in the foundation. The construction process was carried out in 4 stages per floor in a diagonal direction. The settlements in quadrant 1 were the largest, because of the partial execution of the building. In the last stage opposite quadrant 1, there were negative readings of settlements, which indicates lifting of the raft. Monitoring by stages showed the relation between the number of floors and SSI. With the increase in the stiffness of the structure, the maximum differential settlements reduced from 13 mm to the ground floor to 3 mm on the fifth floor. About 62% of the loads were transmitted to the piles and about 38% to the raft. The results showed the importance of a combined analysis of soil-structure interaction with consideration of the construction stage to understand the behavior of foundations by raft piles from a building in concrete wall structure.

Keywords: Monitoring; Settlement; Modelling; Soil-structure interaction.

Resumo: Este artigo apresenta a análise da influência da sequência construtiva no desempenho de uma fundação por radiers estaqueados de uma edificação em estrutura de parede de concreto. Os recalques foram monitorados em campo e estimados pelo método de elementos finitos, com e sem a consideração da interação solo-estrutura (ISE) para a análise das redistribuições de deslocamentos e esforços na fundação. O processo construtivo se deu por 4 estágios por pavimento em sentido diagonal. Os recalques no quadrante 1 foram os maiores, consequência da execução parcial da edificação. No último estágio de concretagem e oposto ao quadrante 1, houve leituras negativas de recalques, o que indica levantamento da placa do radier. O monitoramento por estágios evidenciou a relação entre o número de pavimentos e a ISE. Com o aumento da rigidez da estrutura, os recalques diferenciais máximos diminuíram de 13 mm no térreo para 3 mm no quinto pavimento. Cerca de 62% das cargas foram transmitidas as estacas e cerca de 38% pelo radier. Os resultados obtidos mostraram a importância de uma análise combinada de interação do solo-estrutura com consideração do estágio de construção para entendimento de comportamento de fundações por radiers estaqueados de uma edificação em estrutura de parede de concreto.

Palavras-chave: Monitoramento; Recalque; Modelagem; Interação solo-estrutura.

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1. Introduction

The use of new construction systems becomes increasingly important in the civil construction market, seeking the best performance and cost-benefit of the projects. The concrete wall construction system has been standing out to Brazil due to the growth of the house of Casa Vida (SILVA JUNIOR, 2021). Associated with this constructive system, raft foundations solutions have been used more often due to their high productivity and good performance (PATRÍCIO, 2021). In the case of soft soil deposits with large thicknesses, commonly found in cities located in Brazilian plains, solutions from complex foundations such as stagnant raft pile are needed.

A characteristic of the raft pile foundation model is the reduction of differential settlements due to the rigidity of the raft and the total settlements due to the action of the piles. An important aspect contemplated in NBR 6122 (2010) is the consideration of soil-structure interaction (SSI) in the evaluation of foundation element behavior. In conventional structural analyses non-displaceable supports are usually considered, and the settlements of the foundation elements are estimated based on the distributed loads. However, this hypothesis may not be satisfactory, especially regarding the construction system in question, which has significant global rigidity. Most of the current soil-structure interaction analyses were performed for frame structure (columns, beams and slabs) and the current literature lacks soil-structure interaction analyses for concrete wall buildings with raft foundations (PATRÍCIO et al., 2024).

Extremely important phenomena, such as load redistribution, completely modify the situation of the structure stress by not considering the general stiffness and the soil displacements. NBR 16055:2012 (Brazilian regulatory standard - concrete wall cast-in-place for the construction of buildings - requirements and procedures) states the non-mandatory use of SSI for buildings of up to five floors. Silva Júnior (2021) comments that even for buildings up to five floors, the overall stiffness of the structure can directly influence the redistribution of forces, angular distortions and differential settlements.

Another factor that guides the global and local state of structure tensions is the sequence of construction, emphasizing the importance of not considering the instant loading of the foundation structure in project elaboration (BITTENCOURT, 2018). The speed of construction, the construction methodology (modular) and the significant global stiffness of the structure indicate the need to evaluate specific performance parameters for this type of project, such as: settlement speeds, rotations of the foundation elements, angular distortions, and others (PATRÍCIO et al, 2024).

Based on the raft settlement monitoring data, it is possible to determine the soil deformability parameters by means of retro-analysis and thus contribute directly and objectively to projects of this type. In a usual structural analysis, actions are considered to be applied in their entirety instantaneously. The actions that act in a real structure have a direct dependence on the constructive sequence, through the performance of an evolutionary analysis, trying to modify the redistribution of efforts due to differential displacement between the elements of the structure (FARIAS, 2018; LOPES, 2019). Settlement measurements together with a reliable estimate of loads in the construction stages can reproduce soil stress x deformation behavior, which makes the monitoring procedure a real load proof model (SANTOS, 2018).

With the increase in the use of the construction system of concrete walls associated with raft pile foundations in the Metropolitan Region of Recife, it has become essential to develop works focused on the evaluation of the behavior of the foundation elements, especially with regard to the settlements developed. There is a shortage in this area of research, soil-structure interaction, with the structural system concrete wall associated with a mixed raft piled foundation. Another relevant factor is the knowledge of soil geotechnical parameters of the region that constituent a complex saturated soft soil profile. Its study is very important because the region still has great potential for real estate expansion.

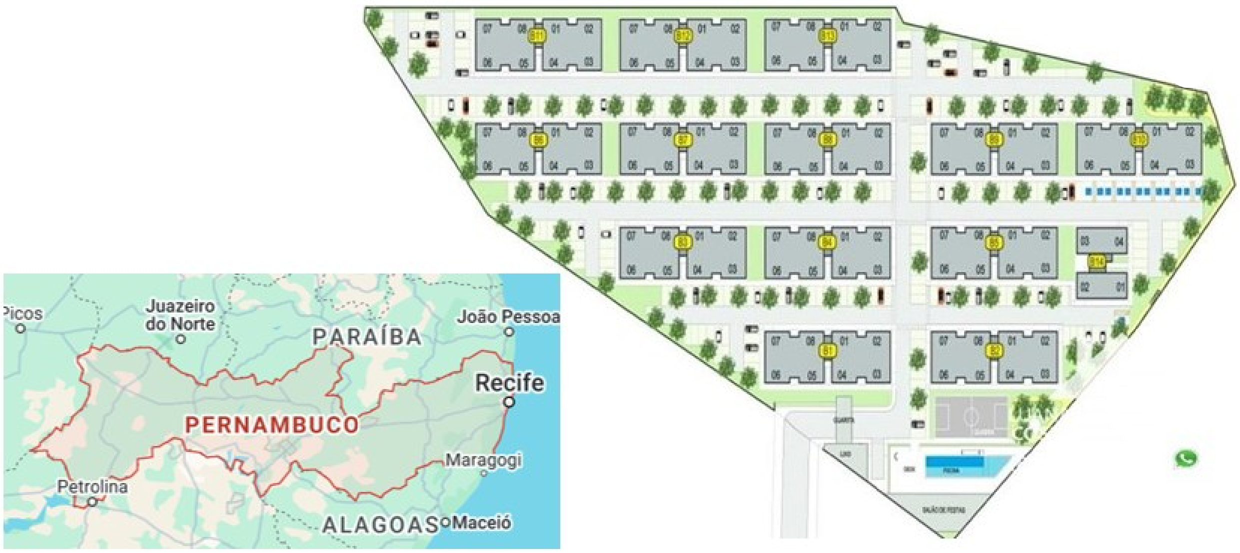
This article presents an analysis of the performance of the raft pile foundation system of a building on saturated soil and concrete wall structure located in the Metropolitan Region of Recife, considering the influence of the construction sequence. It is part of the Silva Júnior's (2021) research, inserted in project entitled "Study of raft pile foundation of buildings with concrete wall construction system", in which several studies were carried out in the same location: (a) finite element method and load proof analysis in the prediction of behavior in a raft pile foundation (SILVA, 2021); (b) analysis of different scenarios of support foundation (ALVES et al., 2022); (c) evaluation of settlements by angular distortion in raft pile foundation (JORDÃO JÚNIOR et al., 2022), (d) reliability and safety of pile raft foundation (SILVA et al. (2022).

2. Methodology

2.1. Study area

The project is located in the Metropolitan Region of Recife (RMR), on the coast of the state of Pernambuco, Brazil (Figure 1a). It is the construction of a residential complex, consisting of 14 residential blocks, each with five floors (ground floor + four standard floors). The residential block under study is number 03 (Figure 1b). The superstructure loads are distributed to the foundation through reinforced concrete walls molded in situ.

The typical soil profile was divided into three layers. The first consists of fine and medium silty sand with organic matter up to the end of the depth of 13.0 m (mean $N_{SPT} = 6$), followed by a layer of fine sand, with little medium and coarse sand, and the presence of soft clay in some holes, up to the depth of 24.0 m (mean $N_{SPT} = 16$). The third layer is composed of compact to very compact silty sand up to approximately 32.0 m (mean $N_{SPT} = 38$).



(a) (b)

Figure 1 – Location of the work: (a) Map of Pernambuco, RMR; (b) Location and location of blocks in plan.
Source: Modified from Silva Júnior (2021).

The foundation system chosen as solution for the characteristics of the soil profile was a structure composed of a horizontal element (raft) and vertical elements (piles). The load transfer takes place to the ground through the raft and through the lateral and tip area of the piles. A raft on an elastic base was adopted with lateral dimensions of 40.70 x 13.60 m and slab thickness of 0.25 m, considering its stiffness. This solution does not eliminate absolute settlements, but the stiffness of the raft and the structure considerably reduce differential settlements. In Figures 2a and 2b shows the raft located and the concrete stage, with the marking of the pile crowning blocks. The foundation piles have square sections of 26.5 cm on a side, with the executive driven system being of the prefabricated type. A total of 1,490 piles with lengths between 12.0 and 20.0 m were used, totaling 24,265 m of pile. For Block 03, 80 piles with an average length of 17.00 m (in design) were calculated. The execution of the foundation was carried out with 82 piles, due to reinforcements to the break in the driving of one of the piles.

2.2 Constructive methodology

The construction process occurred in stages with the construction method being executed in four stages per floor. The concreting followed in diagonal stages in the order: Quadrant 1, Quadrant 2, Quadrant 3 and Quadrant 4 (Figure 3). The assembly of sliding steel forms and concrete were carried out daily. In total, there were 21 stages to complete the structure of each block. Each floor consists of 4 concreting, between walls and slabs.

After the assembly of the form and execution of the concreting of the raft, the concreting of walls and slabs begins in the following order for each blade of the structure:

- Stage 1: assembly of form and concreting of walls in Quadrant 1;
- Stage 2: assembly of the form and concreting of walls of Quadrant 2 and assembly of the slab form and concreting of Quadrant 1;

- Stage 3: assembly of the form and concreting of Quadrant 3 walls and the assembly of the slab form and concreting of Quadrant 2;
- Stage 4: assembly of the form and concreting of walls of Quadrant 4 and assembly of the slab form and concreting of Quadrant 3;
- Step 5: assembly of the slab form and concreting of Quadrant 4, form and concreting of the stairs.

(a) *(b)*

Figure 2 – (a) Location and (b) Frame of the piled raft.
Source: Silva Júnior (2021).

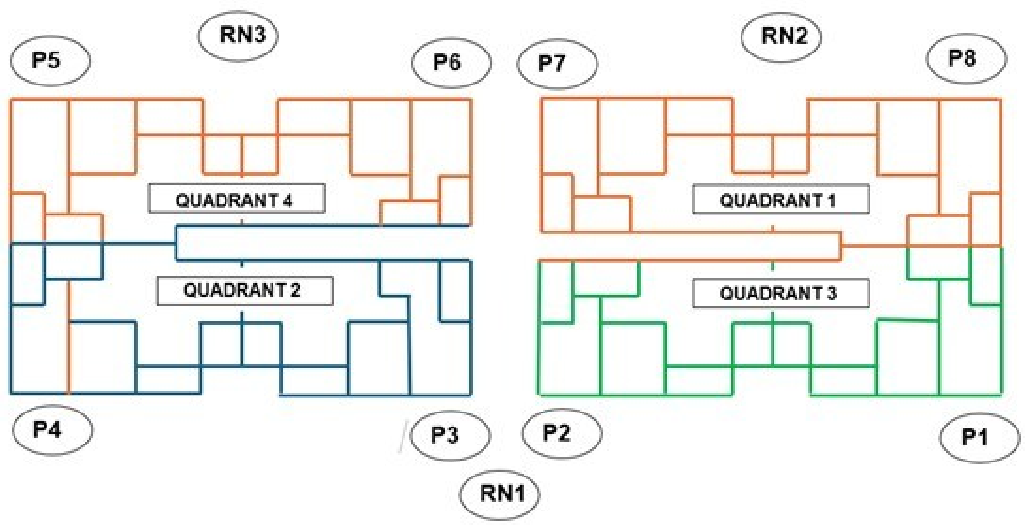


Figure 3 – Construction sequence and location of quadrants and distribution of monitoring pins.
Source: Modified from Silva Júnior (2021).

2.3 Settlement instrumentation and monitoring

The monitoring of settlements occurred at each concreting, totaling 20 readings for each pin. Instrumentation was performed at the optical level, on 8 reference pins fixed at the base of the raft (Pi) and 3 non-displaceable reference pins (RNi) (Figure 3). Quadrants 1 and 2 had settlements measured at pins P7 and P8, and P3 and P4, respectively. Pins P1 and P2 guide the settlement database for Quadrant 3, as well as pins P5 and P6 for Quadrant 4.

The displaceable reference pins (Pi) were fixed together with the raft and their level change occurred through the displacement of the foundation structure. The non-displaceable references (RNi) were fixed in pile profiles driven into the ground. The monitoring begins with the creation of the non-displaceable reference level, with the quota plan (RNi). Subsequently, the plans were generated with the dimensions of the displaceable reference pins (Pi), with views referring to the level (RNi). This procedure was performed in every increase in load. The settlements were established for each pin, when measuring the variation between the elevation of the RNi and the elevation of the Pi connected to the structure. The views referring to the non-displaceable reference point RN1 and the displaceable reference point P1 are observed in Figures 4a and 4b, respectively.

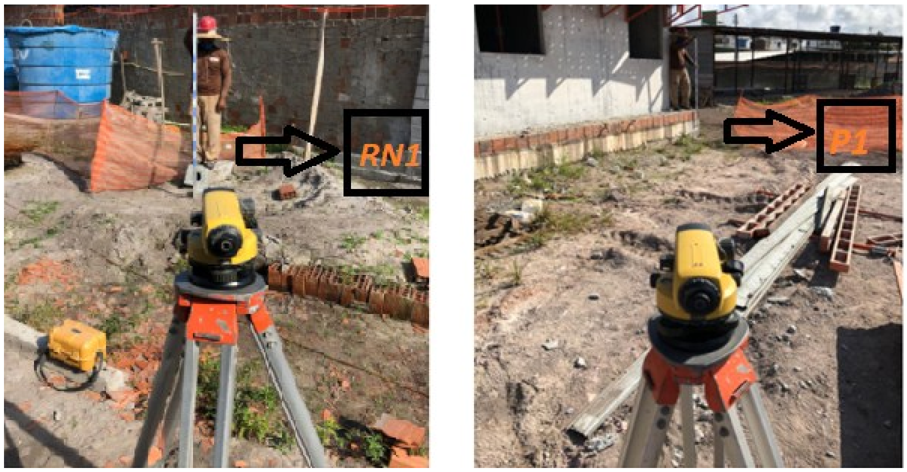


Figure 4 – Location of the monitoring instrumentation: (a) non-displaceable reference point RN1; and (b) displaceable reference point P1.
Source: Silva Júnior (2021).

2.4 Numerical modeling of the structure

The numerical modeling of the structure was carried out using SAP2000, version 16.0 (software for structural analysis by Finite Elements - FEM). The data contained in the architectural, structural and foundation projects were used.

The final representation of the numerical model of the structure presented 262465 nodes and 125779 elements of areas, for ISE evaluation. Details about the methodology used in the numerical modeling presented in this article can be seen in Silva Júnior (2021).

2.5 Numerical analysis

Four loading analyses for the foundation were performed based on the classical model of elastic-linear foundation devised by Winkler (1867). In each analysis, the loading configuration of the raft pile was modified with the intention of evaluating the difference in the behavior of the foundation system due to the consideration, or not, of the ISE. The analyses evolve from a less realistic scenario, in which the total load of the building is applied directly to the raft, to a scenario close to the real one that considers the ISE when modeling the construction method (concrete wall) combined with the foundation system (raft pile). The unification of these systems allows the stiffness of the structure, the number of floors and the construction evolution in the numerical model to be considered. The analyses developed are described below:

• Analysis 1: the settlement prediction for the foundation was carried out through conventional modeling that does not consider the soil-structure interaction. In this analysis, the linear distribution of loads to the foundation, carried out through the concrete walls, was applied directly to the raft pile. The linear loads ranged from 3.96 to 10.15 kN/m and were obtained considering the free raft and non-displaceable support in the walls in the structural calculation.

• Analysis 2: the numerical analysis, in finite elements, was considered from the union of the concrete wall structure with the raft pile. The raft is placed on elastic supports, with the piles and the soil mass represented by springs. The full loading of the superstructure was considered to have been unloaded instantaneously on the raft.

• Analysis 3: a model similar to the one obtained in analysis 2 was created, which considers the building (superstructure + infrastructure + soil) as a system that works in a unified way. However, a non-linear constructive analysis was considered, in which the superstructure is modeled in sequential stages of known duration. At each stage, the execution of a part of the structure was admitted, considering a progressive loading on the foundation that simulates the real execution of the structure (Figure 5), therefore, a more realistic numerical model to represent the behavior of the ISE.

• Analysis 4: this analysis refers to the results of the behavior of the foundation structure as a result of the effect of the constructive evolution, in relation to the number of floors and construction method. These results were obtained by the settlement monitoring carried out during the construction.

In this article, the results obtained in analyses 3 and 4 are presented. Results of the other analyses are presented by Silva Júnior (2021).

2.6. Soil modulus of elasticity back analysis

The soil modulus of elasticity was estimated from Equation (1). Two considerations were applied: the raft-soil interaction and the pile-soil interaction.

$$E_s = q.B.\frac{1-v^2}{w}.I_s.I_h.I_d \quad (1)$$

Where: v: Poisson coefficient; E: modulus of elasticity; B: smallest element dimension; Is: form factor of the foundation element; Ih: thickness factor of the compressible layer; Id: layer embedding factor; Q: structure loading; W: structure settlement.

The vertical reaction coefficient (K_v) was estimated from Equation 2 and the soil-raft spring coefficient (K_{mo}) obtained from K_v multiplied for foundation area.

$$K_v = \frac{E_S}{w.B.(1-v^2).I_S.I_h.I_d} \quad (2)$$

The soil properties corresponding to the pile-solo were based on the analysis of the load proof test performed for a model pile and by means of approximate equations with the characteristics of the SPT borehole profiles.

3. Results and discussion

3.1 Evolution of settlements monitored in the field (raft edge)

In Quadrant 1, settlements from 0 mm to -6 mm and from 0 mm to -8 mm were measured for pins P7 and P8, respectively. The last measurement took place after the full loading of the foundation structure. P7 presented a final settlement of -5 mm, characterized by a raft drop, and pin P8 presented a final settlement of -7 mm.

In Quadrant 2, pin P3 showed settlement ranging from 0 mm to -2 mm and amplitude equal to 2 mm, and final settlement of -2 mm. P4 pin showed settlements between 0 mm and -3 mm. These pins have a similar behavior, showing that for pins of the same region of stages, there are common characteristics guided to the construction process.

In Quadrant 3 there is a characteristic of oscillations of settlements in positive and negative values. These variations are governed by the construction sequence, since pins P1 and P2 are located in the intermediate phase of the four construction steps. On pin P1, the raft is lifted in half the monitoring time. In the last concreting, the vertical displacement of the structure is equal to zero. The settlement range of pin P1 was from -2 mm to 2 mm. The behavior of pin P2 has its settlement always below the reference level, and it is possible to conclude that the offset is always negative for the reference taken. The settlements ranged from 0mm to -4mm.

Pins P5 and P6 located in Quadrant 4, which corresponds to the last concreting performed for all raft loads, showed lifting behavior of the foundation structure. The displacements for the pins are all positive, ranging from 0 mm to 3 mm. At the end of the construction stages, the behavior of the structure was characterized as raised. At the end of the measurements, the raft remained elevated at the 3mm position.

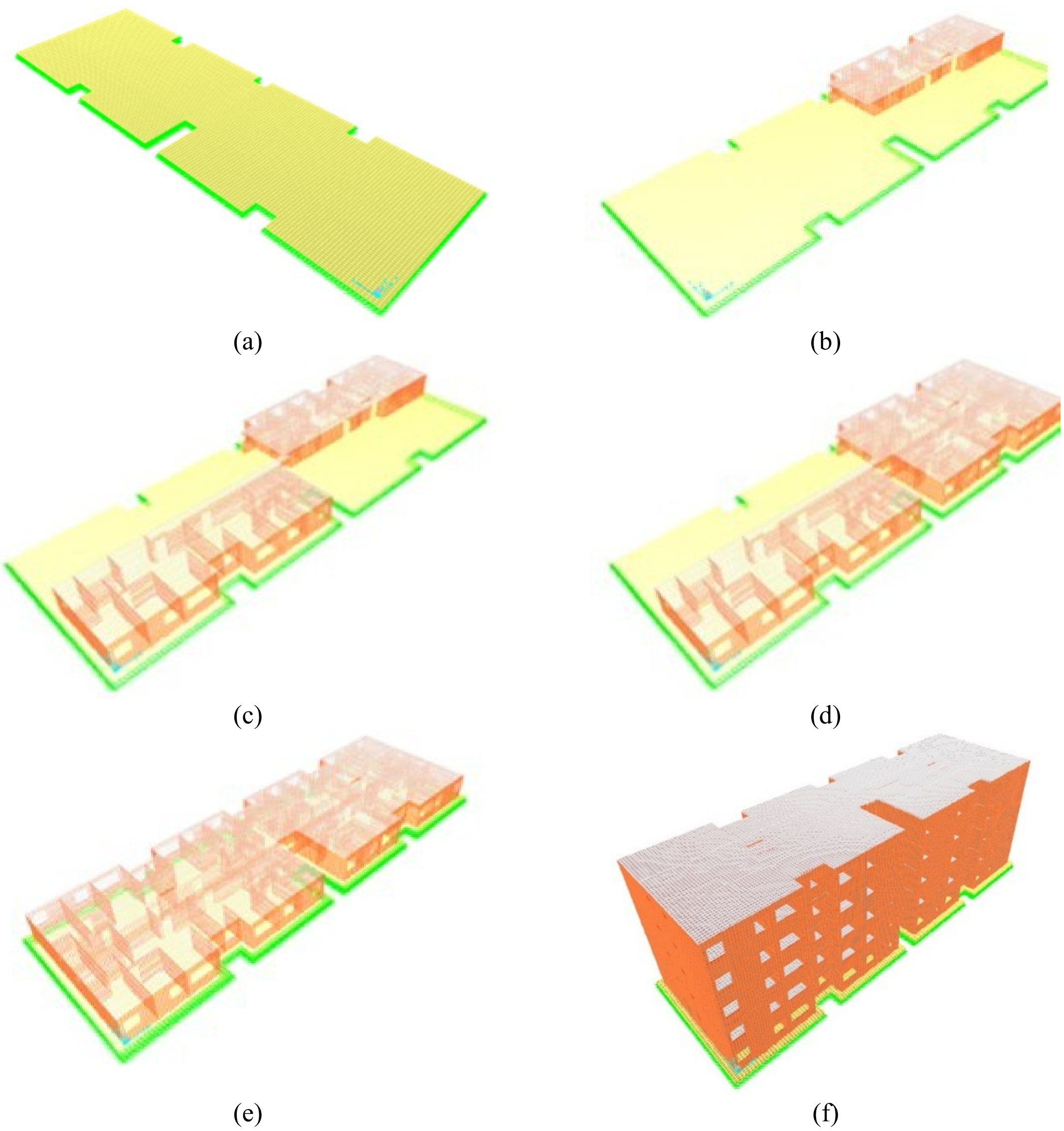


Figure 5 – Numerical model by construction stages: (a) raft; (b) Quadrant 1; (c) Quadrant 2; (d) Quadrant 3; (e) Quadrant 4; and (f) final construction.
Source: Silva Júnior (2021).

The minimum, average and maximum settlement results obtained in each field monitoring pin are presented in Table 1. In pins P5 and P6 there are positive values in the individual analysis of settlements and in all statistical parameters, proving their behavior of lifting the raft structure to the region of the third quadrant. The values obtained in P1, P2, P7 and P8 were above the highest amplitudes of average settlements. This behavior was caused by the construction process (Figure 6). These are the pins with minimum values outside the standard of the rest of the curve, with positive values at P1 and very negative values close to the maximum, changing the behavior of the amplitude curve. Patrício et al. (2024) found similar behavior of the raft pile settlement. The authors declare that the partial execution of the pavements tends to rotate the raft plate and that the increase in the stiffness of the structure throughout the construction reduces the effects of this rotation.

The raft workability can be observed by the amplitude of the measured settlement values. The variation between positive and negative values indicates the movement of the pins during the monitoring period and the work of the raft plate associated with this movement. For the concrete wall construction system, the analysis of the structure in relation to the settlements shows oscillations to the referenced point of origin, being represented by the zero axis, which corresponds to the first measurement. The raft has its displacements varying between settlements and lifts in relation to the origin. The surveys occurred in pins P1, P5 and P6, while pins P2, P3, P4, P7 and P8 had their displacements characterized as settlements.

Table 1 – Minimum, average, and maximum settlement values obtained from the field monitoring pins.

Pin settlements (mm)			
Pin	**Maximum**	**Average**	**Minimal**
1	-2.0	-0.1	2.1
2	-4.1	-1.9	-1.1
3	-2.5	-1.5	0.5
4	-2.2	-1.7	0.3
5	0	-1.5	3.0
6	1.6	-1.6	3.0
7	-6,4	-4.8	-1.0
8	-8.2	-6.8	-5.5

Source: Silva Júnior (2021).

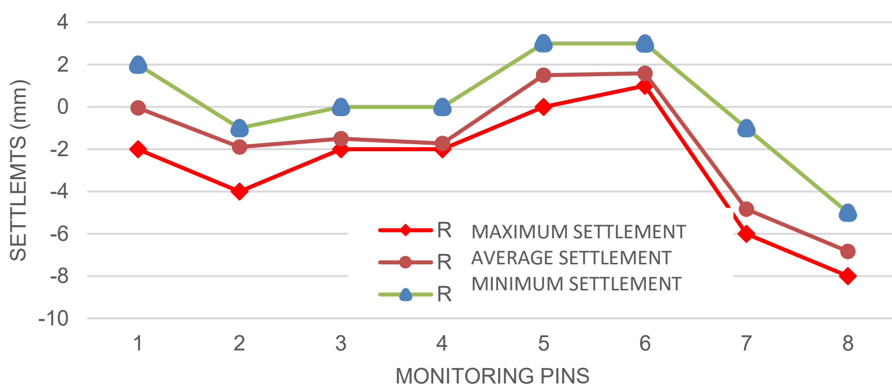


Figure 6 – Minimum, medium, maximum settlements per monitoring pins.
Source: Silva Júnior (2021).

3.2 Estimation of settlements over time from numerical simulations (raft)

The raft behavior in relation to the projection of loads over time, simulating the concreting performed daily, it was analyzed. Figure 7 expresses the behavior of estimated settlements in the pins in relation to the construction stages applied over time. The settlement values for the numerical model with construction stages would grow linearly with the application of loading. For the last construction stage, the average settlement value was -4 mm. The differential settlements values were lower compared to the numerical model without soil-structure interaction. Silva Júnior (2021) and Patrício et al (2024) comments that the linear behavior of settlement curves in relation to construction stages is due to the type of representation of the soil mass (in the linear elastic numerical model, the soil is considered a spring, therefore dependent on the value of the spring coefficient).

Figure 8 shows the behavior curves of the average settlement by construction stages obtained by numerical model and field monitoring. The settlements obtained in the field monitoring show variable behavior. The pins belonging to quadrants 1 and 4 show a singular behavior due to the construction process. The settlements in quadrant 1 obtained in the field monitoring have a greater amplitude in relation to the settlements obtained in the numerical model. Quadrant 4 showed a survey of the structure and a greater difference between monitored settlements and those predicted by the staged model. The variations between the model and the field settlements occur mainly due to simplifications used in soil modeling.

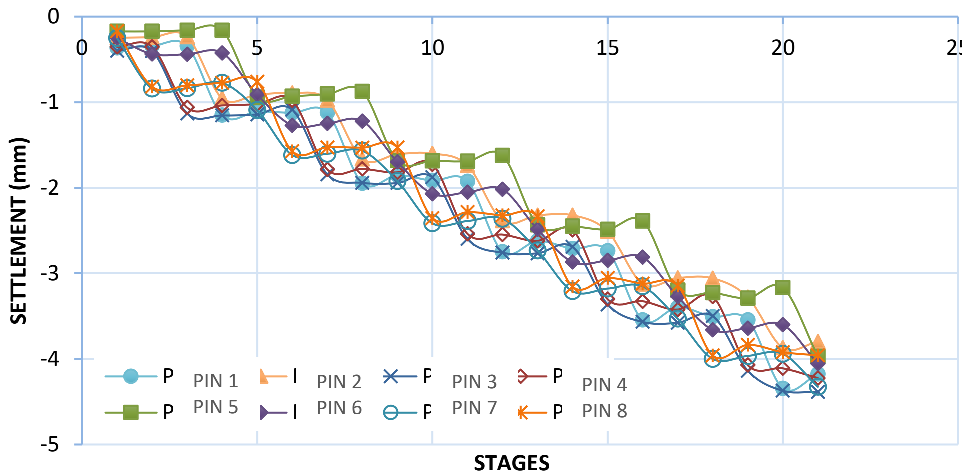


Figure 7 – Average settlement curves by construction stage - numerical model.
Source: Silva Júnior (2021).

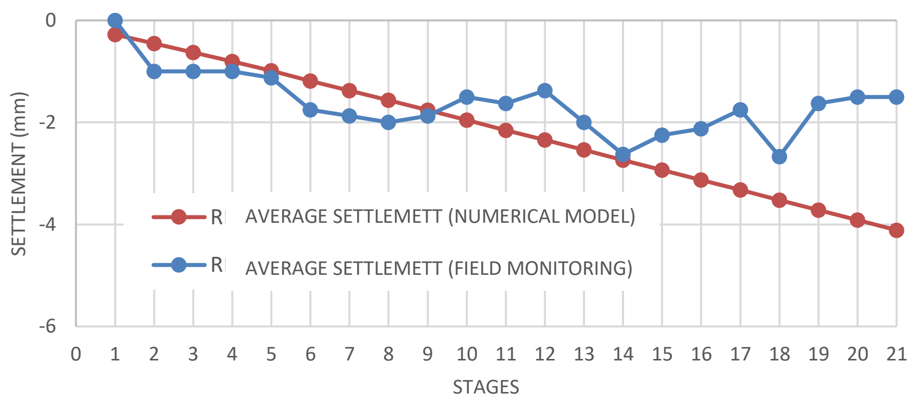


Figure 8 – Average settlement curves by construction stage - numerical model and field monitoring.
Source: Silva Júnior (2021).

3.3 Settlements estimated over time from numerical simulations (piles)

To estimate the pile settlements, three numerical models were used: without considering the soil-structure interaction (SSI); with consideration from SSI and without internships; and with SSI with constructive internships. In the numerical analysis without SSI, the results of the settlements in the piles located in the center of the raft are much higher than the settlements at the edges. In the numerical analysis with SSI and without stages, the settlements showed values without much variation, a consequence of the stiffness of the superstructure that makes the differential settlements smaller. In the analysis considering the ISE and the construction stages, the settlements also had little variation in values, but they are still higher than the settlements of the analysis with ISE without stages, because the construction by stage creates differential forces allowing greater distortions, however, the differential settlements are still smaller compared to analyses without SSI (Figure 9).

The average, maximum and maximum differential settlements values in the piles are shown in Table 2. The percentage variations of settlement presented average values of 20%, a maximum of 74% and a minimum of 0%, for the numerical analysis without considering the SSI (Table 3). It is noted that the representation of SSI in projects may have settlements variations in this order of magnitude due to the consideration of the stiffness of the structure and construction stages. It should be noted that this model, without considering the stiffness of the superstructure, still considers the relative soil-foundation stiffness. If the settlements values were compared to a conventional design model, the differential settlements would be even greater. For the model that considers the SSI without construction stages, an average settlement variation of 6%, a maximum of 14% and a minimum of 0% was observed. Therefore, not considering the construction stages can lead to variations in settlement in projects in the order of 0 to 14 %.

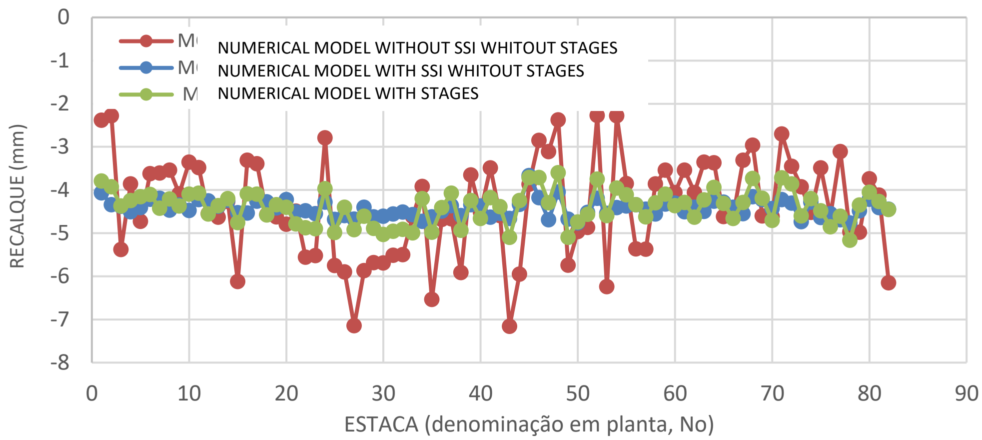


Figure 9 – Pile settlement - numerical models.
Source: Silva Júnior (2021)

Table 2 – Minimum, average, maximum and differential settlement values obtained in the piles – numerical model.

Pile settlements (mm)			
Piles	**Without SSI / without stages**	**With SSI / without stages**	**With SSI / with stages**
Mínimo	-2.27	-3.66	-3.60
Máximo	-7.16	-4.76	-5.16
Médio	-4.38	-4.42	-4.39
Diferencial máximo	-4.89	-1.10	-1.56

Fonte: Modified from Silva Júnior (2021).

Table 3 – Percentage variation values of maximum, minimum and mean settlements between the models.

Variation of settlements in the piles (%)		
Piles	**Without SSI / without stages**	**With SSI / with stages**
Minimal	0	0
Maximum	74	14
Average	20	6

Fonte: Modified from Silva Júnior (2021).

3.4 Analysis of the foundation behavior for the model by stages (raft + piles)

The behavior of the piles was analyzed in terms of load redistribution with the construction advances. With the concreting of the number of floors, there is an increase in load observing each pile individually, thus, the relationship becomes non-linear with the increase in the number of floors. Figure 10 shows the behavior of each floor with the constructive evolution in relation to its stress transmitted to the piles. On the fourth floor, the efforts in the piles becomes a smaller variation, indicating stabilization of the efforts with the construction progress. It is noted the uniformity of the effort values with the trend lines created for each floor.

Figures 11 show the settlements of the foundation in relation to the construction stages. The behavior analyses prove the importance of the construction methodology in the performance of the raft pile, giving credibility the numerical model and the field monitoring.

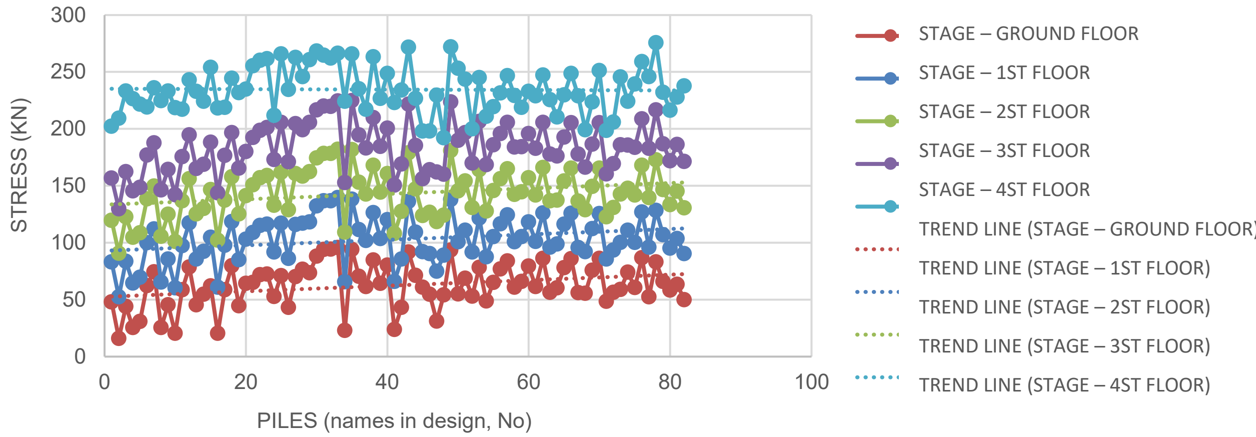


Figure 10 – Distribution of the stress in the piles by construction stages.
Source: Silva Júnior (2021).

For the model considering the construction stages, the values in relation to the stress transmission of each foundation element (pile or raft) to the soil were about 62 % of the loads are transmitted to the piles and about 37% to the raft, showing a good use of the foundation structure in piled raft.

Figure 12 shows the behavior of the foundation in 3D for the first construction stage. There is a great distortion of the raft due to the construction process adopted. The settlement values are from the data obtained from field monitoring.

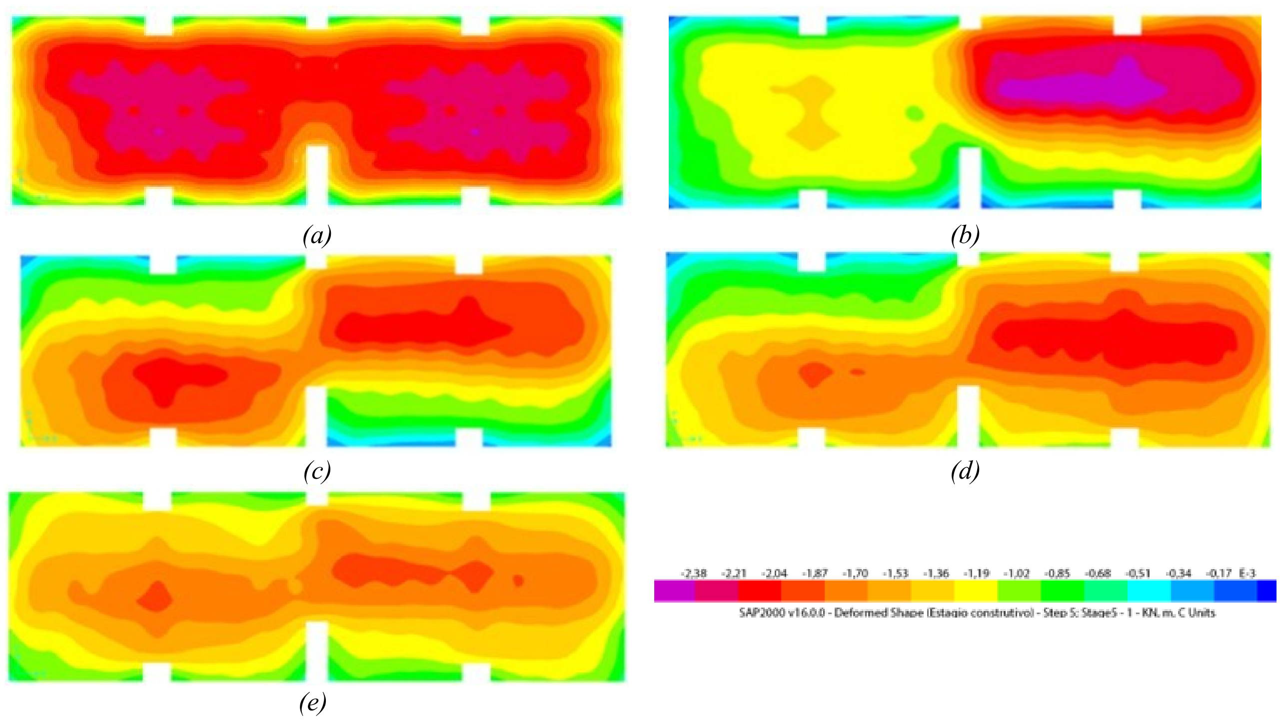


Figure 11 – Foundation settlement in relation to the construction stages: (a) Without concreting; (b) Quadrant 1; (c) Quadrant 2; (d) Quadrant 3; (e) Quadrant 4.
Source: Silva Júnior (2021).

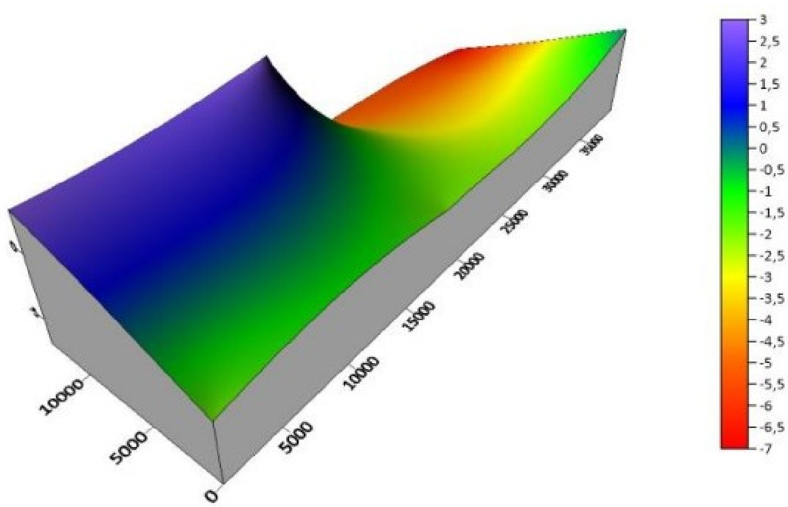


Figure 12 – Foundation structure behavior of the for the first construction stage.
Source: Silva Júnior (2021).

Patrício et al. (2024) reported that a nonlinear approach to building modeling and soil-structure interactions showed that earthworks at the beginning of construction had a significant role in settlements. The authors found that the partial construction of the floors was considered critical in terms of angular distortions and stresses in the raft. The partial survey of the raft presented in the construction stages demonstrates the importance of evaluating the foundation behavior in this phase.

4. Final considerations

From the measures of the settlements in the field, it was possible to follow the behavior of the foundation. The average ferry settlement was -1.7 mm. In quadrant 1, the highest settlement values were measured (in the order of -8 mm), which is a consequence of the construction process because with the partial execution of the building, the first concretes have no stiffness of the structure. The monitoring by stages evidenced the relationship between the number of floors and the ISE in relationship to displacements, showing that with the increase in the stiffness of the structure, the variations in settlement decrease significantly with a reduction in maximum differential settlements, ranging from 13 mm for the ground floor to 3 mm on the fifth floor. The settlements in Quadrant 4, which corresponds to the last pavement concreting, presented negative values, indicating a lifting of the raft. This behavior is relevant to the understanding of the performance of the structure in relation to angular distortions and additional efforts to the construction process, therefore, it is evident the need for evaluation and study around the constructive evolution in projects with partial execution.

The analyses in relation to the settlement behaviors in the piles were carried out without consideration of the SSI, with consideration of the SSI / without stages and with the SSI / with constructive stages. The analysis without consideration of the SSI showed greater variations in relation to the other analysis, with a maximum differential settlement of 4.89 mm. The analyses considering the SSI without and with construction stages resulted in settlements in the order of 1.10 mm and 1.56 mm, respectively, proving the influence of the SSI in the reduction of differential settlements. The evaluation of the redistribution of settlements in percentage in relation to the numerical analysis by stages showed an average variation for the analyses without SSI of 20% and model with SSI of 6%, both without considering stages. The evaluations regarding the behavior of the piles in relation to the consideration or not of SSI, prove how much the state of stress and behavior of the structure can vary, showing its importance even in projects of buildings of up to five floors, where the NBR 16055:2012 standard says it is not mandatory.

The analyses considering the construction stages of the raft pile showed values in relation to the transmission of forces from each element of the foundation to the soil. The piles received 62% of the transmitted loads and the raft received 38%, showing a good use of the foundation structure in piled raft.

Settlement monitoring is a very important instrument for safety issues in relation to the performance of the building during and after its completion and technological control on site.

The results obtained show that the construction stages have a significant influence on the raft pile foundations behavior, contradicting a common assumption of the project. This research confirms that ignoring these aspects in the project of structures with concrete walls combined with raft pile foundations can result in considerable discrepancies between the predicted and field structural behavior.

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