Parametric sensibility study in a stratified soil trough finite elements methods

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Abstract. When constructing any type of building, sometimes engineers don't have all the necessary information. When using an SPT to prospect the soil, correlations formulas and tables are necessary to determine many of this soil properties. By using these correlations, the engineer must choose between ranges of values to use the N_{spt} with. The use of an incorrect correlation can result in the execution of a project that does not correspond to the local characteristics of the construction, which can lead to damage to the structure. This research used the finite element method, through the PLAXIS 2D software, to evaluate the parameters of clayey layers at the construction site of a pier in the city of Rio Grande. According to the alteration of these parameters, varied results of tensions and displacements were obtained, thus, its influence on these alterations can be verified.

Keywords: parametric study, finite element methods, PLAXIS 2D, undrained resistance, elasticity modulus.

1 Introduction

Stratified soils can cause great difficulties for engineers when building any type of structure. The carrying out of prospecting tests in the field is presented as a way to help these engineers so that they can have less doubts about the properties of the soil layers present in the place.

Complex, and generally expensive, tests are often ignored by designers, who seek agility and cost reduction in the work. The Standard Penetration Test (SPT) is one of the most widely used in construction today, especially due to its low cost, ease of execution and possibility of being used in different types of terrain.

On the other hand, this test does not directly inform some soil properties, being necessary to use its penetration resistance index (Nspt) through correlations developed over the years by several authors. When using these correlations, the designer must know how to correctly evaluate the values of the parameters, as usually the formulas in the literature present a range of values to which the Nspt can be related.

When using correlations in the design of a pile, for example, as they are not exact values, the results of efforts and displacements found can often lead the engineer to incorrectly dimension this structure. Correlations can be used to determine different soil properties and, according to their accuracy, these property values will have a greater or lesser influence on obtaining the efforts and displacements.

This work aims to analyze the influence of the parameters of undrained strength (Su) and modulus of elasticity (E) of clays on the results of displacements and efforts in piles of a wharf. A numerical model was generated in the PLAXIS 2D software using the finite element method (FEM), using values of the penetration resistance index (Nspt) to estimate the properties of the various soil layers.

In clayey layers, three distinct values of Su and E parameters were used. Different models will be generated and, through the results obtained for one of the piers on the wharf, the influence of these parameters on the final result can be evaluated.

2 Location and material properties

This study was motivated by previous studies carried out on a wharf at the Honório Bicalho shipyard, located in the city of Rio Grande, southern Brazil. This pier is 216 meters long, being supported by 373 vertical concrete piles.

The region which was used as inspiration for the numerical models has stratified soil layers, with the presence of fine sand and thick layers of clay. The seabed is at an elevation of -11.0 m, the upper layer being formed by hydraulic embankment.

Surveys carried out through Standard Penetration Test (SPT) were carried out on site and, through the survey bulletins, 6 different soil layers were determined. The determination of layer properties follows the same methodology and uses correlations with the Nspt values observed in Martins [1]. In this study, the layers of sandy clays and clayey sands were unified, being simplified as clayey layers.

A summary of the properties of the different soil layers present in the model is presented in Tab.1. Both clayey layers have the same properties, and 'x' and 'y' are the values that will vary in this parametric study.

Table 1. Soil layers and properties

Layer	Initial elev.	Final elev.	γ (kN/m³)	ϕ (°)	*E* (MPa)	*Su* (kN/m²)	ν (-)
1	+2.6	-11.0	21.0	35.0	80.0	-	0.3
2	-11.0	-15.0	19.0	35.2	65.0	-	0.4
3	-15.0	-31.0	18.5	0.0	x	y	0.4
4	-31.0	-36.0	19.0	29.7	65.0	-	0.4
5	-36.0	-38.0	18.5	0.0	x	y	0.4
6	-38.0	~	21.5	49.6	89.2	-	0.4

2.1 Undrained resistance values determination

When a clayey soil mass is loaded, stress variations occur in the application region, which generate excess pore-pressure. In the case of clays, the dissipation of this pore-pressure is basically nil during the loading process. This new request for loading is said to be undrained. The undrained strength, therefore, is a property of the resistance capacity against loads of clayey soils.

As it is a port region of great national strategic interest, several studies were carried out over the years, seeking to better understand the properties of the soil so that structures could be dimensioned in the best possible way. Among these studies Almeida et al. [2], compiled tests carried out in loco and previous studies to assemble a relationship between Su and depth, as seen in Fig. 1.

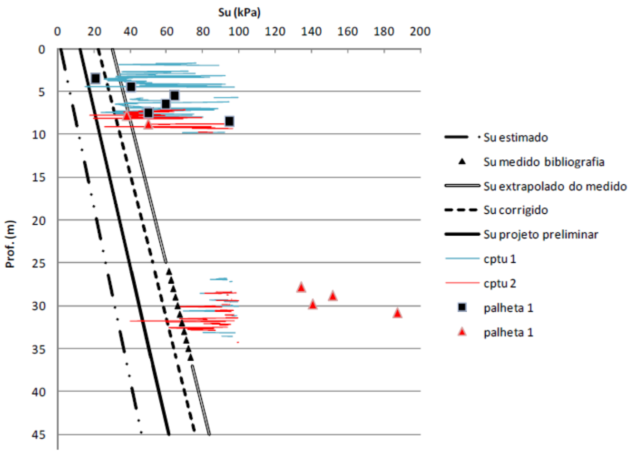

Figure 1. S_u variation through depth

The values of Su were modified using as reference distinct values obtained through the correlations of Stroud [3] and De Mello [4], which can be seen in eq. (1) and eq. (2) respectively. Both equations show variation in values, and it is up to the engineer to select the value in the given ranges.

$$S_u = (4\ a\ 6) * N_{spt} \tag{1}$$

$$S_u = (0{,}4\ a\ 20) * N_{spt} \tag{2}$$

Considering the values found through the correlations and the values observed in the graph in Fig.1, three Su values were determined for the sensitivity study: 30, 50 and 80 kN/m². These will be the Su parameters used in the numerical modeling of the soil.

2.2 Elasticity modulus values determination

The modulus of elasticity, also known as Young's modulus, is related to the normal stress applied to the soil and the deformation resulting from this stress in its direction. The values of E were estimated through Stroud correlations [2] using eq. (3), as well as eq. (4) and eq. (5) Mitchell and Gardner [5] and Bowles correlations [6]. Table 2 presents the results obtained for E according to the correlations.

$$\frac{E}{N_{spt60}} = 1\ a\ 2\ (MPa) \tag{3}$$

$$E = 4{,}88\ (Nspt + 15) \tag{4}$$

$$E = 2{,}93\ (Nspt + 5) \tag{5}$$

Table 2. E values according to correlation formulas

Author	E (MPa)
Stroud (1989)	4.8
Mitchel e Gardner (1975)	2.6
Bowles (min) (1997)	2.0
Bowles (max) (1997)	15.0

Observing the maximum and minimum limits found according to the results in the table, the following results were selected as minimum, average and maximum values: 5, 10 and 15 MPa. These will be the E parameters used in the numerical modeling of the soil.

2.3 Structures parameters

The wharf piles are made of concrete with a length of 37.6 m, circular cross section with 800 mm outside diameter and 500 mm inside diameter. The concrete used has a characteristic compressive strength greater than or equal to 40 MPa. The embedment depth is at 35 m and the piles are 2.6 m above sea level. Seeking to simplify the calculations and optimize the processing time, the piles were considered as solid piles in the modeling.

On the top of the piles there is a platform of 40 m length and 21.4 m width, with a 0.2 m thickness. The platform is made of the same concrete as the piles, so both have the same material properties.

2.4 Interface parameters

Due to its direct contact with the soil, the piles are influenced by it when they receive external stresses. In order to model this influence, interface elements must be added to the piles, being responsible for the representation of the interaction between soil and structure in the model, for the friction in the pillars and for the adhesion of the soil to them. The parameter responsible for this representation is the interface resistance reduction factor (Rinter). This parameters go from 0 (representing no adhesion) to 1 (full adhesion of materials). In this research, the Rinter value used is 0.85.

3 FEM and PLAXIS 2D Software

3.1 Finite Element Method

Engineering problems usually involve complex geometries, large numbers of variables and are solved through differential equations. The finite element method emerged as a simplification alternative for solving problems of great complexity and size. Through this method, there is a sectioning of complex structures into several smaller and simplified structures.

Through the analysis of these small elements, it becomes easier to solve problems of great magnitude. The union of all these elements is called a finite element mesh, and usually the more refined the mesh is, the more accurate the results become, however demanding a higher processing capacity. By using FEM, it is possible to model not only the structures, but the soil non-linear behavior, multiple soil layers with accuracy and the complex geometry of the foundations (Martins [1]).

3.2 PLAXIS 2D Software

PLAXIS Software is a software developed on Delft Technical University in the Netherlands on 1993, with the purpose to analyze geotechnical problems. Soil modelling, tunnel surface settlements, mining, prediction of differential settlements of buildings adjacent to excavation pits, planning for stability and infiltration in excavation pits or lateral displacements of diaphragm walls are some of the common uses for this software.

This software uses the FEM to solve engineering problems involving structures and the construction site soil. Presenting many tools as the different soil constitutive models, multiple mesh creation and quality analysis, dynamic loading, progressive stages analysis and graphics generator, this software was chosen by its capacity to best model the presented situation. The version used in this research is the 2D Anniversary Edition.

4 Situation modelling

After determining the soil parameters and knowing the properties of the cuttings, models were generated. As it is a three-dimensional problem, it had to be adapted for two-dimensional modeling. These adaptations follow the same methodology observed in Martins [1] and Ryltenius [7], in which the strength parameters of structures and their weight undergo adaptations according to their geometry. In these adaptations, the rows of pillars are considered as “walls” in the ground.

Figure 2 presents the model layers and their dimensions, as well as the representation of the columns and platforms and acting stresses. A distributed load of 300 kN/m² was considered along the entire length of the platform, representing the structure's own weight and possible external loads.

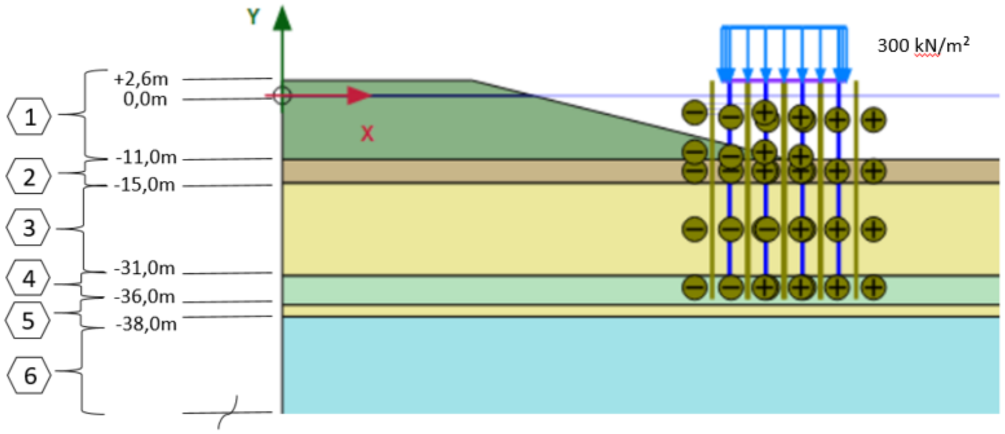

Figure 2. Soil layers, structures and tensions on the PLAXIS 2D model

The parameters of the sandy layers were kept and the minimum, average and maximum values found for the parameters of S_u and E in the clayey layers varied. Table 3 presents the different models generated and the respective S_u and E parameters for the clayey layers.

PLAXIS 2D features automatic mesh generation and analysis, with different levels of refinement. According to observations from previous works, an average refinement mesh was determined, as it presents adequate results and a good processing time.

Table 3. Models and their corresponding parameters

Model	S_u (kN/m²)	E (kN/m²)
MP1	30.0	5000.0
MP2	30.0	10000.0
MP3	30.0	15000.0
MP4	50.0	5000.0
MP5	50.0	10000.0
MP6	50.0	15000.0
MP7	80.0	5000.0
MP8	80.0	10000.0
MP9	80.0	15000.0

5 Results of the parametric study

After performing the calculation steps, the nine different models presented a similar general configuration of stresses and displacements, suffering variations only in the magnitude of their values and actuation orientation. Figure 3 (a) shows the behavior of vertical displacements in the model, while Fig. 3(b) presents the results of horizontal displacements. Although the models present the complete pier, only the results obtained for the first pile from the left to right will be evaluated.

Graphs were generated relating the stresses and displacements suffered by the piles along the depth for the different models. Figure 3 presents the results in which there is no variation of S_u, only of E, while in Fig. 4 the values of S_u are modified, fixing the parameter E.

Table 4 presents the maximum results for all models generated, as the tensions and displacements presents the same behavior on all models. The minus signal only represent the orientation of the forces and displacements on the model.

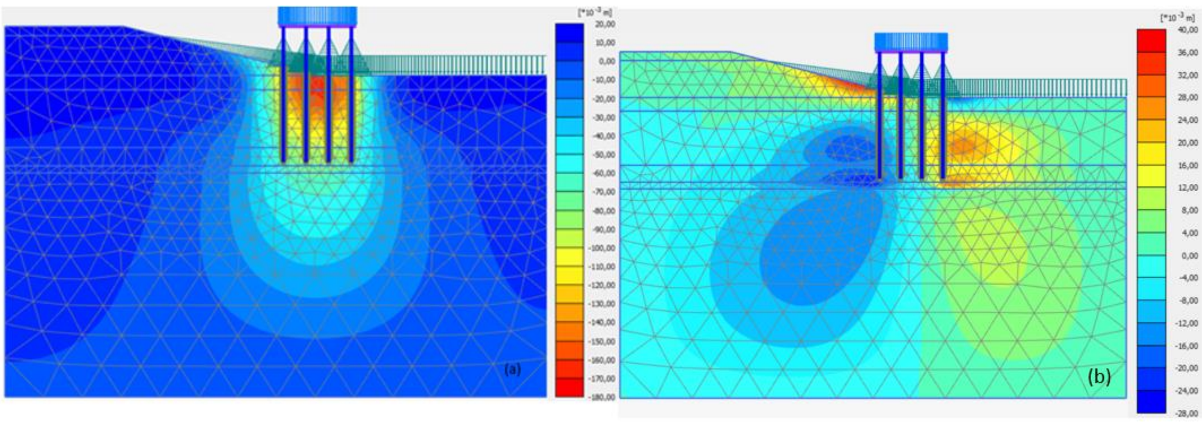

Figure 3 - Vertical and horizontal settlements on the model

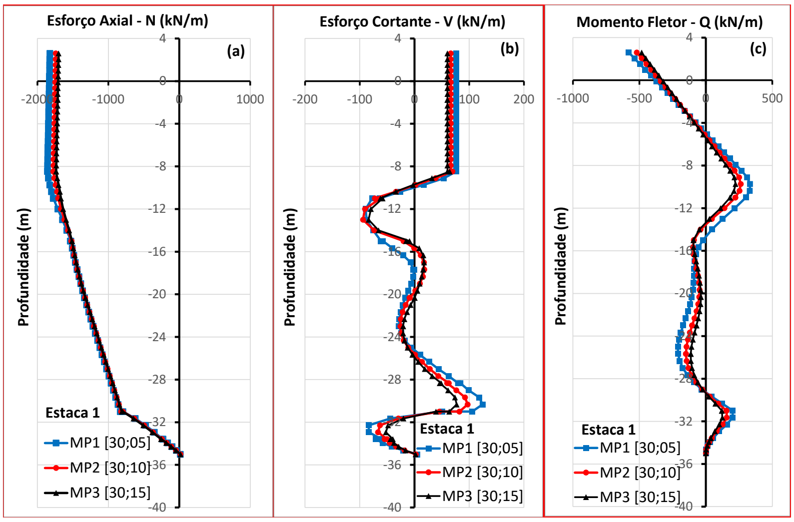

Figure 4. Comparison between tensions on the first pile for the MP1, MP2 and MP3 models

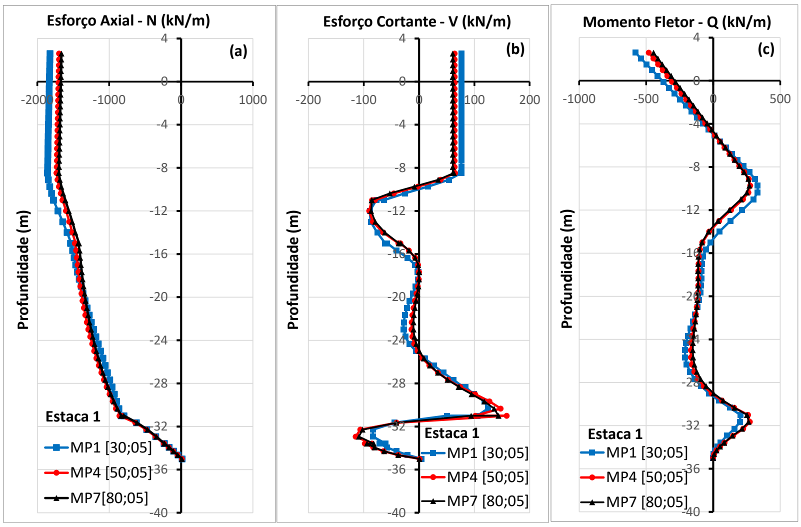

Figure 5. Comparison between tensions on the first pile for the MP1, MP4 and MP7 models

Table 4. Maximum tension and displacements results for the first pile

Model	Maximum Tensions			Maximum displacements (m)	
	Axial (kN)	Shear (kN)	Moment (kNm)	Horizontal	Vertical
MP1	-1858.0	124.5	-579.0	0.120	-0.211
MP2	-1776.0	97.3	-518.9	0.101	-0.142
MP3	-1738.0	-83.9	-483.1	0.090	-0.119
MP4	-1732.0	158.3	-480.3	0.062	-0.142
MP5	-1652.0	100.5	-411.9	0.043	-0.108
MP6	-1613.0	-83.4	-375.7	0.037	-0.096
MP7	-1700.0	143.5	-445.1	0.050	-0.136
MP8	-1627.0	89.3	-384.2	0.032	-0.104
MP9	-1593.0	-75.6	-352.5	0.026	-0.092

It can be observed that the E variation results in greater dispersions for the results of axial, shear and bending moment than when S_u is varied. The highest values of stresses and displacements found can be observed when E presents its minimum value, thus representing a more fragile and volatile soil.

Through the results it is observed that the variations between MP1 and MP3, MP4 and MP6 and MP7 and MP9 do not exceed 5% for the axial tension, showing the little representation of the E in this tension. As for shearing tension, there is a decrease of 22% between MP1 and MP2, 37% between MP4 and MP5 and 38% between MP7 and MP8, thus showing that a change of 5 MPa in E can cause large variations. Moments have their maximum change of 14% occurring between MP4 and MP5 and MP7 and MP8, thus following the maximum changes observed in the shear force.

When the displacements are evaluated, the behavior trend follows the same, with greater results in the models with lower E and Su. Between models MP7 and MP8, the greatest variation in the result of horizontal displacement is observed, with a decrease of 37% (0.018 m) between the first and the second. The second largest displacement drop occurs between MP4 and MP5, with 31% reduction, followed by MP1 and MP2 with 15%. Despite being high percentages, this maximum variation of 37% means less than 2 centimeters for example.

6 Conclusions

Analysing the variation of efforts when fixing the values of E, it is evident that they present a smaller discrepancy in results compared to the fixation of S_u. Along the depth, models with a fixed S_u results don't present great variation, showing that in this study the S_u parameter is less relevant than the E when evaluating efforts and displacements acting in piles.

Changes in the direction of stresses are observed when modifying the soil parameters, evidencing the importance of the correct use of correlations, so that the structures can be executed according to the tensions which they will be submitted.

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