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PROPOSAL OF A PRELIMINARY GEOTECHNICAL MAP OF FOUNDATIONS IN THE CENTER-NORTH REGION OF FORTALEZA-CE

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Abstract

The article deals with the structuring of georeferenced geotechnical information database and the elaboration of a preliminary foundation letter that reflects the north-central region of the city of Fortaleza. Using the Google Earth software, 395 drill holes were collected percussion at local companies and outlined 23 regions, from the statistical treatment, maps of NSPT isovalors were plotted at depths of 2, 5 and 10 m, at water level the representative survey. After establishing three lots of buildings, a preliminary list of foundations was drawn up. It is concluded that the system used in the georeferencing of the collected data is adequate, has an easy handling and uses small files. Considering small buildings, almost always, it is possible to use foundations of the type shoe based to small depths. Medium and large buildings it is estimated, preliminarily, lengths varying with positioning of the region.

Keywords: Drillings; Geotechnical characterization; Foundation.

PROPOSTA DE UMA CARTA GEOTÉCNICA PRELIMINAR DE FINDAÇÕES PARA A REGIÃO CENTRO-NORTE DE FORTALEZA-CE

Resumo

O artigo trata da estruturação do banco de dados de informações geotécnicas georeferenciado e elaboração de uma carta preliminar de fundações refente a região centro-norte da cidade de Fortaleza. Utilizando o software Google Earth, foi coletado 395 furos de sondagens à percussão em empresas locais e delineado 23 regiões. A partir de um tratamento estatístico, traçou-se mapas de isovalores de NSPT nas profundidades de 2, 5 e 10 m, do Nível d'água (NA) e para cada região foi determinada, ainda, uma sondagem representativa. Após estabelecido três portes de edificações elaborou-se uma carta preliminar de fundações. Conclui-se que o sistema utilizado no georeferenciamento dos dados coletados é adequado, possui fácil manuseio e utiliza arquivos de pequeno tamanho. Considerando edificações de pequeno porte, na maioria das vezes, pode-se utilizar fundações do tipo sapata assente a pequenas profundidades. Para edificações de médio e grande porte recomenda-se o uso de estacas e estima-se, preliminarmente, comprimentos que variam com o posicionamento da região.

Palavras-chave: Sondagens; Caracterização geotécnica; Fundação.

PROPUESTA DE UNA CARTA GEOTÉCNICA PRELIMINAR PARA FUNDACIONES PARA LA REGIÓN CENTRO-NORTE DE FORTALEZA-CE.

Resumen

El artículo aborda la estructuración de la base de datos de información geotécnica georreferenciada y la preparación de una carta preliminar de fundaciones que hace referencia a la región centro-norte de la ciudad de Fortaleza. Usando el software Google Earth, se recogieron 395 agujeros de sondaje a percusión de compañías locales y se describieron 23 regiones. A partir de un tratamiento estadístico, se dibujaron mapas de isovalores NSPT a profundidades de 2, 5 y 10 m, desde el nivel del agua (NA) y para cada región, también se determinó una encuesta representativa. Después de establecer tres tamaños de edificios, se preparó una carta preliminar de cimientos. Se concluye que el sistema utilizado en la georreferenciación de los datos recopilados es adecuado, tiene un manejo fácil y utiliza archivos pequeños. Teniendo en cuenta los edificios pequeños, la mayoría de las veces, puede usar cimientos tipo zapato basados en pequeñas profundidades. Para edificios medianos y grandes, se recomienda el uso de pilotes y se estiman longitudes preliminares que varían con el posicionamiento de la región.

Palabras-clave: Sondaje; Caracterización geotécnica; Fundación.

1. INTRODUCTION

Geotechnical cartography can be used as an important tool contributing to the scientific and technological advance of several science fields. For example, in civil engineering it enables the use of geotechnical data, from the planning to the implementation of a civil construction work. Geotechnical cartography is a process that aims to characterize the physical environment (ZUQUETTE, 1987). The data obtained must go through stages of selection, generalization, addition and transformation, allowing correlations that must be interpreted in such a way that they can be represented in maps and charts. Through these representations the user can analyze the physical environment and make a series of decisions.

The large number of buildings built in Fortaleza in recent decades has generated a significant amount of geotechnical information from the subsoil city carried out by companies working in the geotechnical field. In this context, this information can be used in the preparation of geotechnical charts, such as charts of foundations, which can help both in orientation and in the use and occupation of areas in expansion of the various regions of Fortaleza.

Therefore, the percussion drilling test is a process of exploration and recognition of the subsoil widely used in Civil Engineering and which provides a lot of information necessary for the implementation of foundation projects. The SPT (Standard Penetration Test) is the most used test by foundation designers in Brazil due to its low cost, easy handling and because it provides data such as the penetration resistance index (NSPT), identification of the depth of the water level, description of the subsoil stratigraphy and obtaining deformed samples. NBR 6484 (ABNT, 2001) is the norm that regulates the conduction of this test in Brazil.

Borges (2019) analyzes the use of descriptive statistics, geostatistics and multivariate statistics to carry out the geotechnical mapping of the city of Rio Branco-Acre. For this purpose, he used a series of attributes, among them, the percussion drilling (SPT) results.

Thiesen (2016) discusses and analyzes the use of geographic information systems in the treatment and processing of georeferenced geotechnical data to carry out the geotechnical mapping of the city of Blumenau/SC and the foundation suitability maps from 537 percussion drillings onwards. The results proved to be valid not only for enabling the practical application of the database manipulation and modeling in a GIS environment, but also for providing strategic results for decision making, guiding and providing information in technical language.

Nascimento and Larios (2020), when faced with the need to carry out subsoil research, propose the use of a databank of borehole profiles for the construction of a series of geotechnical maps. These maps are constructed by using a digital application fed with data from the resistance to penetration of subsoil within the study area of the Adventist University Center of São Paulo. The software provides the numbers of blows recorded in the Standard Penetration Test (SPT) by layers and the underground water level in statistically reliable data, facilitating the design of foundations for new buildings. The authors performed the statistical X^2 test and the results obtained were reliable, so that all layers investigated confirm that there are no significant differences when compared to real borehole profiles.

Maps cannot replace a detailed local investigation, but they can help in the pre-project phase of the local investigation and in the interpretation of results (SILVA, 2011). Charts, on the other hand, can address several widespread problems and be useful in the early stages of planning as well as in the final stages of engineering projects.

This work aims at structuring a database of georeferenced geotechnical information and preparing a preliminary charter of foundations of an area situated in the center-north region of the city of Fortaleza-CE and has the objective to provide information that may be useful in guiding future geotechnical investigations. In addition, the information contained in this study will indicate, on a preliminary basis, the type of foundation to be used, according to the size of the future building, thus providing useful information for planning the future work.

2. CHARACTERIZATION OF THE PHYSICAL ENVIRONMENT OF FORTALEZA

The Municipality of Fortaleza is situated in a coastal plain in the northern portion of Ceará State, in northeastern Brazil, with 32 km of coastline. This in turn is limited to the north with the Atlantic Ocean; to the south with the municipalities of Maracanaú, Itaitinga and Pacatuba; to the west with Eusébio and Aquiraz; and to the east with the municipality of Caucaia.

The city of Fortaleza is one of the main urban centers of the State of Ceará, having the largest population of the State and, therefore, ranking the position of the fifth largest city in Brazil with a population of 2,447,409 inhabitants (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2011). It is a city that grows vertically, especially in the coastal area. However, the number of buildings in peripheral neighborhoods is increasing more and more.

The gentle topography of the relief of the lands of Fortaleza enabled an almost perfect orthogonal layout of its streets, especially those that comprise Fortaleza downtown.

The region of Fortaleza is characterized by the presence of crystalline rocks (metamorphic and igneous), sediments of tertiary age, besides sediments transported as colluvium and alluvium and the presence of dunes (COLARES, 1996) and according to Fonteles (2003), Fortaleza is divided into four geological regions: Barreiras Formation; Paleodunes; Alluvial Sediments and Dunes.

Barreiras Formation is characterized by the accumulation of sandy-clay detritus, with medium to fine granulometry, covering variable width from the coast and irregular depth in a large area of the Metropolitan Region of Fortaleza (CHAVES, 2000).

In the Metropolitan Region of Fortaleza one notices that the Barreiras Formation extends towards Baturité massif, reaching many districts of Fortaleza, besides, almost all of the towns of Caucaia and Eusébio. The soils of the Barreiras Formation have a sub-rounded shape, are sandy-clay sediments, with a reddish, creamy or yellowish coloration, often having a mottled aspect, poorly selected, having conglomerate levels, a kaolinitic clay matrix with clay-ferruginous and often siliceous cement (BARROSO, 2002).

Concerning the pedology formation, the soils have dystrophic quartz sands and dystrophic red-yellow podzols, occurring in two different structural contexts, in the form of horizontal and undeformed strata or, in the most usual situation, consisting of tilted beds and affected by strong deformation.

The Barreiras Formation is characterized by an expressive facies variation, which provides it with distinct hydrogeological parameters, since it presents alternation of levels with different hydraulic conductivities.

Alluvial sediments correspond to sandy and clay deposits that occur along the banks of lower courses of rivers, such as the Cocó River. The soil in this region is almost always composed of poorly selected sand having a grain size varying from medium to coarse (BRAZIL, 1998). Besides alluviums and deposits of flood plains, in this region there are fluvial-marine deposits composed of sand, gravel, silts and clay with or without organic matter (FONTELES, 2003).

The dunes, originated from the removal of the beach face by the wind erosion, comprise unconsolidated sediments forming a beach ridge of 2 to 3 km wide and a maximum of 30 meters high. They are arranged parallel to the coastline and composed of yellowish to whitish quartz sand, having a fine to medium grain size, with well selected and matt grains, whose shape ranges from rounded to sub-rounded. It is possible to notice grains of afrisite, zircon, monazite and ilmenite. The mobile dunes (without the stabilization vegetation) can cause, by reworking the sediment flow, a silting up of small fluvial channels and/or prevent some water courses from reaching the ocean, thereby contributing to the emergence of interdune lagoons, changing the configuration of the coast. (FONTELES, 2003).

The soils in the region of Fortaleza have well-defined geotechnical characteristics that influence the design and implementation of engineering works that are important concerning the support of building foundations (MIRANDA, 2005).

The crystalline rocks' region presents three distinct horizon levels. The first one, superficial, is characterized as sandy-clayey, having brown colored gravels with the presence of roots and organic matter. The second level, composed of a mature residual soil, is characterized as clayey sand with gravels, having a color varying between yellow and red. The third horizon, known as young residual soil (or saprolitic horizon), has the appearance of gneissic rock with fractions of sand, silt and clay.

Pre-cast concrete piles, Augercast piles, Franki piles and caissons usually lean on the saprolitic horizon (MIRANDA, 2005). When micro piles are used, whose installation requires the use of rotating drills and metallic piles, because of the high capacities and reduced sections, they can go beyond this layer (third horizon) and reach the rock.

In the region of Barreiras Formation, the soils are made of sand, silt and clay in various proportions. Besides, they contain high levels of gravels with layers of clayey sands, silty sands and sandy-silty clays, having a light gray to red color but passing through yellow and orange colors (BRAGA, 2009). In elevations close to sea level there are conglomerate and laterite layers forming ferruginous cement sandstones. These layers are of fundamental importance to define the type of foundation in works close to the seashore. In the case of metallic piles, the pile driving is usually interrupted when it reaches these layers (MIRANDA, 2005).

Colares (1996), constructed a geotechnical map of the Metropolitan Region of Fortaleza, through a set of cartographic documents resulting in a preliminary geotechnical mapping, which divided the entire region according to its geotechnical characteristics, presenting the following products: Documentation Map; Slope Map; Map of Landforms; Rocky Substrate Map; Unconsolidated Materials Map; Map of Areas with Environmental Problems; Water Resources Map and Preliminary Geotechnical Zoning Map.

The preliminary geotechnical zoning map was prepared from the overlapping of the rocky substrate map, map of unconsolidated materials and the slope map aiming to individualize the geotechnical units. This map establishes the possibilities of use and occupation of the physical environment of these units.

Moura (1997) carried out a study aiming at the preliminary geotechnical characterization of an area situated in the northeast region of Fortaleza, presenting digital models related to the soil stratigraphy in the area of the water level positioning. In addition, the author presents a statistical study to represent the number of blows in the Standard Penetration Test (NSPT). An evaluation of the applicability of semi-empirical methods for the determination of the bearing capacity of pre-molded and metallic piles was also conducted.

Fonteles (2003) used the same geotechnical map as Colares (1996). However, he studied only a part of the Ceará State's capital, modifying the code used and creating a new numerical sequence to represent each region according to its geotechnical characteristics. This division of Fortaleza, shown in Figure 1, served as the basis for the present research.

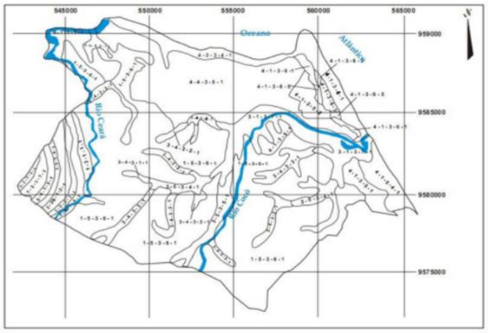

Figure 01 - Preliminary Geotechnical Zoning Map of Fortaleza. Source: Fonteles (2003).

Aiming to guide society concerning the use and occupation of expansion areas, Martins (2005) constructed five basic cartographic documents: documentation map; rocky substrate map; pedological map; water level depth map and declivity map. As a final product, he presented a map of geotechnical units showing the characteristics of the region studied.

3. METHODOLOGY

The methodology used to carry out this research is based on taking the following steps: data collection; digitalization, analysis and address survey of each borehole report; structuring of a system to store the borehole data; subdivision of Fortaleza city; geostatistical treatment; application of geostatistical model and preparation of a foundations' map.

The data collected to conduct this research corresponds to 220 percussion drilling reports (SPT), totaling 395 selected holes that were digitalized and included in a system using the Google Earth tool. Later, these data were overlapped with the geotechnical mapping proposed by Colares (1996) and included in the present system.

The penetration resistance indexes (NSPT) were inserted in the research using Surfer 8 software, thereby allowing the generation of NSPT isovalues' maps at depths of 2m, 5m and 10m. The percussion drillings collected (SPT) were used to determine the percussion drilling profiles representing 23 regions, through a statistical treatment, situated in the center-north portion of the city of Fortaleza-CE.

In the sequence, the representative drillings obtained for each of the 23 regions were used to prepare a preliminary map of foundations considering three different sizes of buildings: small, medium and large. Small buildings were considered as those having only 1 floor; medium buildings, as those having 4 floors and large buildings those having 10 floors or more, beyond the basement.

It is worth mentioning that this article addresses the master's degree research of Pimentel (2015) in which more details can be obtained.

4. PRESENTATION AND ANALYSIS OF RESULTS

4.1. Georeferenced geotechnical information database

The georeferencing of the 220 percussion drillings (SPT) collected and used in this research using Google Earth software is shown below (Figure 2). One also observes in the same figure that data were collected from several regions of Fortaleza, also confirming that there is a high number of drillings situated in the center-north region of the city. Therefore, the geotechnical map of foundations and the isovalues' maps were directed at this part of the city. It is worth mentioning that, in the system used, the visualization of the drilling profile of each point situated on the map can be done simply by clicking on the selected point.

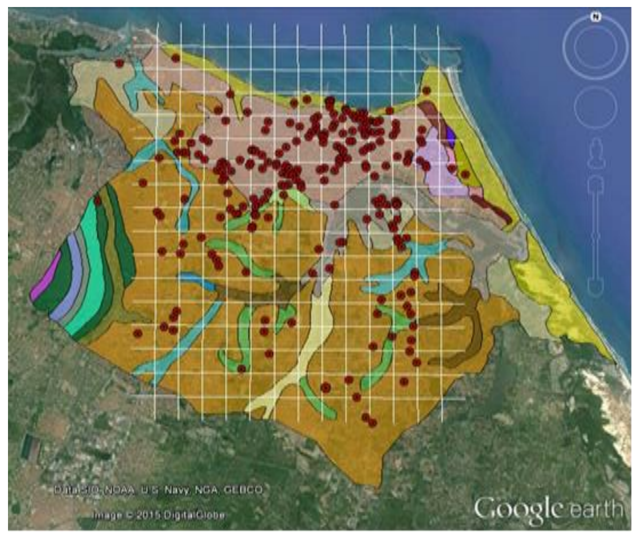

Figure 02 - Schematic location of the drillings used at the research. Source: Pimentel (2015).

4.2. Subdivision of the city of Fortaleza: georeferenced database of geotechnical information

Initially, the city of Fortaleza was subdivided from the indications of the preliminary geotechnical zoning map constructed by Fonteles (2003) and inserted in the Google Earth software, through the transformation of .dwg files to .kml. files. It is worth noting that, in Figure 2, regions having the same geotechnical characteristics (origin, texture, type of rocky substrate, thickness of unconsolidated materials and classes of slope) are represented with the same color tone.

Aiming to divide the town of Fortaleza in areas of 1 km², a mesh was inserted according to the UTM geographic coordinates, and each area, square, was defined by the lines of the mesh.

This way, with the information provided by Fonteles (2003) and with the insertion of the results of the 220 drilling reports, it was possible to establish the areas with characteristics considered homogeneous from the geotechnical viewpoint (Figure 3). In order to use the area in the development of the research, the following criteria were also considered: each area studied must present, at least, 3 percussion drillings (SPT) and each area must be necessarily positioned in the same geotechnical unit delimited by Fonteles (2003).

One observes 23 regions (Figure 3), which meet the criteria established for the subdivision of the areas and which, therefore, correspond to the areas selected to compose the preliminary geotechnical map proposed in this study.

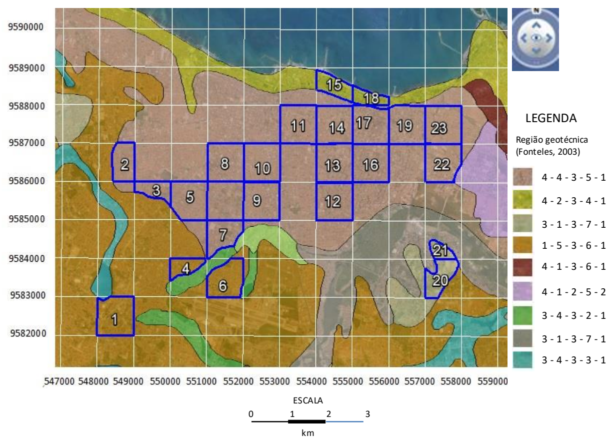

Figure 03 - Definition of the 23 study regions of the research. Source: Pimentel (2015).

4.3. Representative drillings

In each region of Figure 2 a statistical treatment was conducted to determine a representative drilling profile. For that purpose, at each meter of depth, we used the mean, maximum and minimum penetration resistance indexes (NSPT) values of the boreholes situated within the region. The drilling that presented the smallest sum of the residues in relation to the mean was considered as the representative drill of each region.

To show the procedure adopted, we considered the drilling profiles of numbers 9; 12; 41; 96 and 206 situated within the region 18. Among these profiles, the one that presented the smallest sum of the residues in relation to the mean was the profile having the number 96. This way, the drilling profile having the number 96 was used to select the types of foundations according to the size of each work and which will be presented in the preliminary map of foundation proposed in this research.

The same process was adopted in the other regions represented in Figure 3. This way, 23 representative drilling profiles were obtained. Each representative profile contains the subsoil stratigraphy, the depth of the water level and the NSPT values along the depth. The graphical representation of each of the 23 representative drilling profiles is available in Pimentel (2015).

4.4. Isovalues' maps of NSPT and water level values for the north-central region of Fortalezade

With the NSPT values of the representative drillings and the help of the Surfer version 8.0 software, we constructed maps of NSPT isovalues at the depths of 2, 5 and 10 m. In Figure 4, 5 and 6 the NSPT isovalues' maps generated are presented for the mentioned depths and in Figure 7 it is possible to observe the water levels' isovalues' map.

By Figures 4 to 6 we can observe that, at a depth of 2m, the NSPT value along the area studied is significantly lower and, almost always, does not exceed 7 blows (Figure 4). For the depth of 5 m, there is a wider area presenting NSPT ranging from 5 to 10 blows (Figure 5). At this same depth, values above 30 blows could not almost be noticed. For the depth of 10 m, the NSPT exceeds 14 blows in about 75 % of the area analyzed (Figure 6).

From Figure 7 one notices that, in the region studied, the water level is between 2 and 12 m depth. We could also notice that the depth of the water level varies according to the soil stratigraphy and the surface topography. Only occasionally does the water level depth reach higher values.

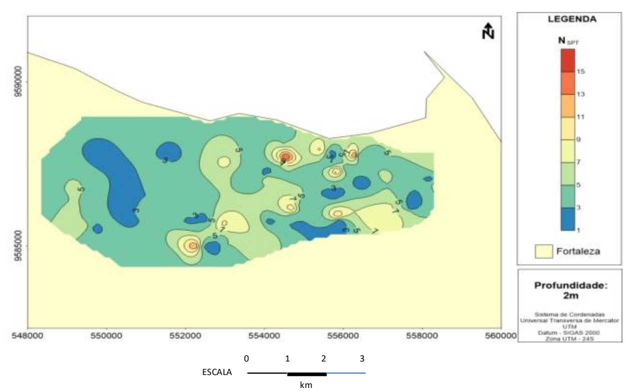

Figure 04 - NSPT isovalues' map at 2 m depth. Source: Pimentel (2015).

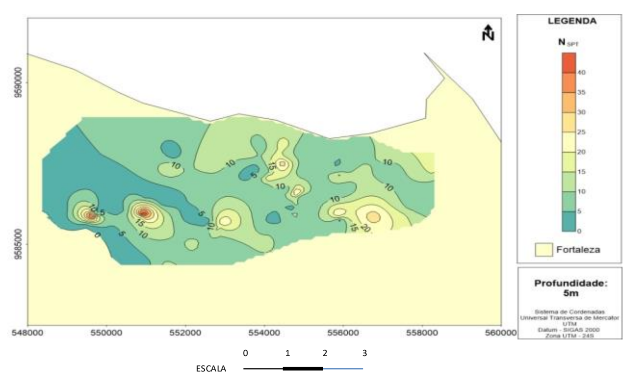

Figure 05 - Map of NSPT isovalues' at 5 m depth. Source: Pimentel (2015).

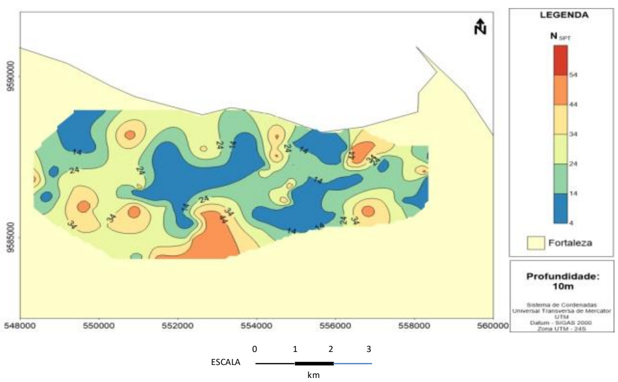

Figure 06 - Map of NSPT isovalues at 10 m depth. Source: Pimentel (2015).

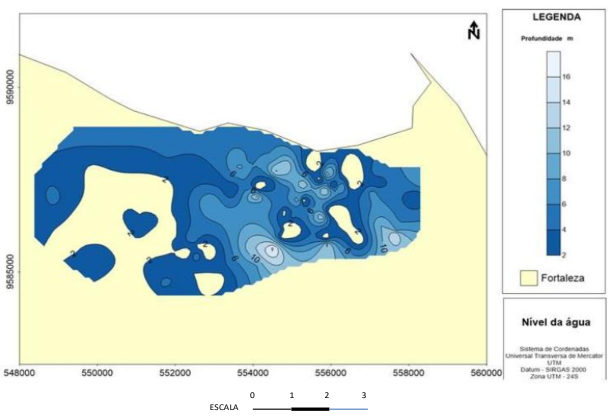

Figure 07 - Map of water levels' isovalues. Source: Pimentel (2015).

4.5. Preliminary geotechnical map of foundations in the central-northern region of Fortaleza-CE

Considering the 23 percussion drillings representative of the area mapped, a geotechnical map was generated with a preliminary recommendation of the most appropriate type of foundation for each region analyzed, according to three sizes of buildings: small (building with only 1 floor); medium size (building with a maximum of 4 floors); and large size (buildings with 10 floors, besides the basement).

For the small size buildings, we analyzed the possibility of using a shallow foundation of the footing type, or slab foundation, and the corresponding settlement depth. The present study aims to provide information only at a preliminary draft level. Therefore, we considered only empirical formulations locally called "practical" formulas to determine the allowable stress (σadm) of the soils from the average resistance index (NPST) at the probable depth of the pressure bulb. This way, for profiles of predominantly sandy soils Equation 1 was used, and for clay soils Equation 2 was used.

$$\sigma_{adm} = \frac{N_{SPT}}{5} \quad (1)$$

$$\sigma_{adm} = \frac{N_{SPT}}{8} \quad (2)$$

Where:
NSPT - is the average resistance index in the pressure bulb
σadm - allowable stress of soil expressed in kgf/cm2

For the buildings considered as medium size ones, according to the characteristics described above, we analyzed the use of precast concrete piles with small dimensions (square section of 25 cm x 25 cm) using the following semi-empirical methods for determining the length of the piles: Aoki and Velloso (1975) and Décourt and Lent (1978). For piles, the working load considered was 400 kN (Velloso and Lopes, 2010). For the situations presenting divergence among methods, concerning the piles length, the Aoki and Velloso (1975) method was used.

In the case of large size buildings, according to the characteristics previously described, we estimated the length of two kinds of piles – Augercast pile and root pile – considering a load of 550 kN when using root piles with a diameter of 250 mm and a load of 1700 kN for the use of Augercast pilies with a diameter of 600 mm. Aiming to estimate the length of the root piles, two methods were analyzed: Cabral (1986) and Aoki and Velloso (1975), with Monteiro (1997) modifications. The following methods were used to determine the length of the propeller piles: Antunes and Cabral (1996) and Aoki and Velloso (1975), also with modifications from Monteiro (1997). If there was a divergence between the methods concerning the length of the piles, we considered the specific methods for each type of piles. That is, the method of Cabral (1986) for root piles and the method of Antunes and Cabral (1996) for Augercast piles.

Figure 8 shows the schematic representation of the preliminary geotechnical map of foundations for the center-north region of Fortaleza, generated on a 1:25,000 scale. It is worth mentioning that the complete foundation map is available in Pimentel (2015).

In 20 out of the 23 regions studied, one suggests the use of foundations of the shooting type, settled at 1 m depth, in small scale works. However, there is a variation from 50 kPa to 170 kPa in the soil allowable stress. In only three of studied regions we preliminarily evaluated that foundations settled at surface depths would not bear small scale works, due to the low estimated allowable stress rate.

In medium scale works, in those regions where the use of precast concrete piles of 25 cm x 25 cm was recommended, in 10 out of the 23 areas studied, the length of the piles ranged from 10 to 12 m. Although there are areas situated in a same geotechnical unit, according to recommendations from Fonteles (2003), a considerable variation in the lengths of this type of pile was observed, as in the case of the region 14 with a 4 m pile length and the region 11, in the same geotechnical unit, with a 16 m pile length. This variation in length is attributed to the remarkable variation in the NSPT values along the depth between regions situated in the same geotechnical unit.

For both regions situated in the geotechnical unit 4-2-3-4-1, according to Fonteles (2003), in large scale works, root piles of 250 mm diameter are recommended with lengths varying from 9m to 10 m. Likewise, the regions situated in the geotechnical unit 4-1-3-5-4-1, defined by Fonteles (2003), also have similar length recommendations in the case of root piles, with lengths varying from 13m and 15 m. However, in the 4-4-3-5-1 unit, which concentrates the largest number of regions analyzed, there is a variation in the length of root piles from 7m to 16 m.

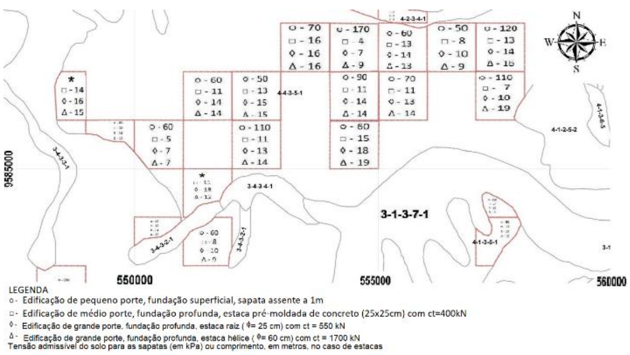

Figure 08 - Schematic representation of the preliminary geotechnical map of foundations in the north-central region of Fortaleza. Source: Pimentel (2015)..

In cases of large-scale works, as described above, the use of Augercast piles with a 600 mm diameter, was the one that presented the greatest length variation, both for regions situated in a same geotechnical unit as for those belonging to different units. The variation in length is between 7m and 19 m. However, in 14 out of the 23 regions studied, it is recommended the adoption of Augercast piles with lengths from 12 to 16 m.

5. CONCLUSIONS

The use of computer resources has pushed the limits of science. In engineering, the use of digital tools contributes to an increase in the speed of project design, optimizing time and, therefore, the cost of works. In this context, the availability of geotechnical data through digital maps provides speed and practicability for builders, students, researchers and society in general.

The methodology proposed proved adequate for the research conducted. The files generated have a small size and can be easily manipulated by e-mail or other memory media.

On the other hand, taking as a basis for comparison the graphs of each of the 23 regions studied, one notices that, for a same depth there was no significant variation in NSPT values within a same delimited region, indicating coherence between the methodology adopted and the homogeneity of behavior in terms of NSPT of each region.

When considering a same depth, we can notice that NSPT values vary significantly in space and we can observe that this variation is even greater between regions situated in different geotechnical units.

Along the depth, as expected, the variation in NSPT values in a same region is remarkable and between different regions is even greater.

Considering the foundation map generated, we conclude that it is possible to adopt shallow foundations settled at small depths in small-scale works. In cases where that kind of foundation is not feasible, an alternative would be to use short pre-cast concrete piles, with an area of 25 cm x 25 cm, in case the vibrations resulting from the implementation of this alternative in close areas do not make their use unfeasible.

For cases medium size works, we preliminarily observed the need to adopt deep foundations. If the neighborhood allows, we recommend the use of precast concrete piles, also with an area of 25 cm x 25 cm. In almost half of the regions considered, the length of these piles varied from 10m to 12 m.

Still for medium size works, in some regions, situated in the same geotechnical unit, defined by Fonteles (2003), we estimated lengths with a high variation. This fact is attributed to the variation in NSPT values along the depth between the same regions.

For large-scale works, we recommended the adoption of one of the following foundation alternatives: 250 mm root piles and 600 mm Augercast piles. If the alternative adopted was root piles, the estimated lengths ranged from 7 to 16 m. When the alternative adopted was Augercast piles, the lengths varied from 7m to 19 m.

Therefore, the foundation map generated proved to be adequate to guide future geotechnical investigations in the center-north region of the city of Fortaleza-CE.

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