

DEEP FOUNDATION REFERENCE FOR METRO MANILA, PHILIPPINES

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ABSTRACT: The study focuses on the analysis of the pile capacity and pile length for various cities of Metro Manila. Standard Penetration Test (SPT) N-values from soil reports were used to compute for the geotechnical parameters such as the undrained shear strength and the angle of internal friction which were directly applied in the computation of the allowable pile capacity. The estimation of the pile length, on the other hand, was done by means of determining the depth of the refusal or rock layer. The proposed minimum pile length and the allowable pile capacity values for each city are plotted to establish a contour map. By means of the collected borehole data, the allowable pile capacity was computed, which was shown in the reference as a series of contour maps. The contour maps were provided to show an overview of the soil's pile capacity at various locations in Metro Manila, Philippines. The contour maps presented vary by means of the design of pile, the size of the pile and the proposed pile length for a specific city or municipality and for the entire Metro Manila. A Geographic Information System (GIS) database was made so as to have storage for the collected borehole data and their locations. The database can be updated for the availability of new data.

Keywords: pile capacity, pile length, deep foundation, foundation reference

1. INTRODUCTION

Metro Manila's buildings are comprised of at least 70% high-rise buildings and skyscrapers, excluding for the cities of Caloocan, Navotas, Las Piñas, Pateros, and Malabon due to the absence of data [1]. High-rise buildings and skyscrapers, compared to low-rise buildings and residential dwellings, would usually require pile foundation. With that, soil exploration or excavation would be needed for every construction.

With such a large amount already allocated to the construction of the structure itself, a great sum of money must again be allotted to the necessary soil explorations, which are not just costly but time-consuming. Reducing the total construction expense would greatly benefit the structural engineer and the owner.

There have been some similar studies related to this research [2]-[8], however, there is not one compiled published or commercially available source of data for the entire Metro Manila, just scattered and separate ones. Due to this, if a structural or geotechnical engineer desires a second reference for the soil data of a specific area in Metro Manila, they would need to acquire them from different sources. This, in turn, would take a tremendous amount of time and effort. Thus, this paper will try to help structural engineers by giving them a reference for the pile capacity and pile length needed for the construction of a structure in need of pile foundation in any specific place of Metro Manila. The main objectives of this paper are to

estimate the necessary pile lengths for the different areas of Metro Manila and to determine the proposed pile capacity in the entire Metro Manila.

1.1 Metro Manila

Metro Manila, Philippines is bounded by the provinces of Bulacan in the northern part, Rizal in the eastern part, Cavite and Laguna in the Southern part. Manila Bay is located in the western part of Metro Manila, while Laguna de Bay is on the eastern part. Metro Manila has a total land area of 615.39 square kilometers. Basing on the geographical coordinate system, the entire Metro Manila lies between 120° 54' and 121° 9' longitudinally and 14° 20' to 14° 47' along the latitude direction.

At some geologic past, the Metro Manila was submerged underwater, which extends up to the mountains in the Eastern part. Intermittent volcanic activities occurred which resulted in the deposition of volcanic materials. During intervening period of inactivity, a layer of sediments is placed on top of the previously laid out volcanic materials which resulted to the common characteristic of the geologic deposit which is alternating beds of tuffaceous materials and transported sediments.

Majority of the sediments present in the geologic deposit of Metro Manila are due to the bodies of water surrounding it which include Manila Bay, Pasig River, and Laguna de Bay. The sediments that were transported consist of sands, pebbly gravels, silts and clays with various traces of

fossil remains of marine shells and several organic particles. The presence of organic particles and fossil remains gives an idea of a swampy environment which prevails during a time which has a shallow water level.

The Guadalupe Tuff formation, the underlying rock formation of Metro Manila, was generally well-consolidated and well-cemented. The tuff formation extends from Quezon City and Novaliches up to the province of Cavite in the south. Majority of its composition is lithified volcanic ash, lapilli, and sands. When it comes to the thickness of the tuff formation, it remains to be uncertain. Several areas where the tuff formation is present are overlain by layers of sediments which generally thicken as it approaches the west side of Metro Manila, which is Manila Bay.

Overall, the composition of the geologic deposit can be attributed to its elevation. For highly elevated locations, it is composed of dense sands and tuffaceous clays. For low – lying areas of Metro Manila, it is generally composed of loose sands and soft clays [9].

2. METHODOLOGY

The aim of this study is to create a deep foundation reference for the district of Metro Manila. Borehole logs with a ratio of one borehole log per square kilometer were collected and compiled accordingly as shown in Figure 1. The borehole logs were accumulated from the different private companies and government institutions in Metro Manila. A total of 677 borehole locations were collected and mapped. For the attained data or soil reports, it already comprised almost 86% of the total target. However, this number of data does not yet include the outskirts of Metro Manila which are from Rizal, Bulacan, Cavite, and Laguna. The outskirt data were used to provide accurate mapping even at the near boundaries of Metro Manila. The data are then analyzed and calculated for the depth of rock formation and geotechnical parameters.

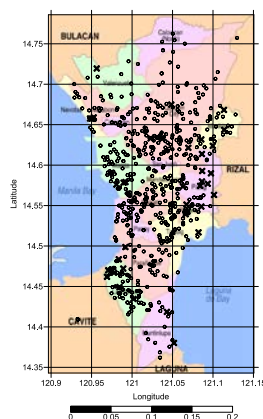


Fig. 1 Map of Manila with borehole locations

The estimation of the pile length and the computation of the allowable pile capacity were performed through an excel program. The soil properties, SPT N-values and RQD were inputted in the program to get some vital geotechnical parameters like the undrained shear strength [10] and the angle of internal friction [11]-[14]. The minimum pile length was estimated depending on the soil condition whether until the refusal layer (SPT-N 50), rock layer (RQD) or even at the last layer of the borehole log in the absence of the refusal or rock layer. The SPT N values that are available in the borehole logs that were collected are the main components used for the computation of the pile capacity. The design of the piles was limited to a range of sizes and shapes. As for the proposed length of the piles, the depth of the rock formation or refusal layer was used as with a one-meter embedment on the hard layer or the last soil layer.

The allowable pile capacity, on the other hand, was computed based on the skin friction and end bearing resistance which are both dependent on the geotechnical parameters. The results were summarized in a form of contour maps for easy visualization and interpretation per city. Likewise, to provide a good analysis of the values of the allowable pile capacity, skin-to-tip ratio were also considered and plotted in the maps. This is to provide a support which between the skin friction and the end bearing resistance contributed greater value in the allowable pile capacity, which in turn, describes what kind of soil does a city, in particular, have and how long the pile length is.

The pile capacity was computed by means of the theory of the alpha and beta method. The alpha method is used to estimate the pile capacity, especially for clayey soil layers. It uses a factor denoted as in approximating the value of the skin friction and a coefficient N_c to compute for the end-bearing capacity. The skin friction for any types of piles using the alpha method includes the coefficient, the undrained shear strength and the lateral surface area of the pile [15]:

$$f_s = \alpha_u S_u; \quad (1)$$

$$Q_f = \sum (f_s) \times (\text{perimeter}) \times (\text{length}); \quad (2)$$

where:

f_s = skin friction stress

α_u = coefficient for skin friction

S_u = undrained shear strength.

Beta Method is similar to the alpha method in such a way that it uses coefficients but this time, it is denoted as for skin friction and N_q for end bearing resistance. Unlike an alpha method, the beta method considers both sandy and clayey soils. The general equations using the beta method is quite

similar to alpha method but instead of undrained shear strength, the effective stress is used.

The skin friction for any types of piles using the beta method includes the coefficient, the effective stress and the lateral surface area of the pile [16].

$$q_f = \sum (\beta \sigma_z) \times (\text{perimeter}) \times (\text{length}); \quad (3)$$

where:

β = coefficient for skin friction;

σ'_z = effective stress;

q_f = skin friction .

Some of the borehole data have rock layers designated by RQD or Rock Quality Designation. The computation using the alpha and beta methods are not applicable to rocks anymore. The pile capacity is now based on the end bearing resistance of the rock which is far greater than the soil. Moreover, the skin friction is neglected in the computation of the pile capacity of a rock. O' Neill and Reese [7] approximated the ultimate end-bearing resistance through the formula:

$$q'_t = 4830 (q_u)^{0.51}; \quad (4)$$

where:

q'_t = end bearing resistance;

q_u = unconfined compressive strength of the rock

ϕ' = drained angle of friction

For a better visualization of the acquired data and computed values, the allowable pile capacity values are then mapped out by means of contour maps, implementing the kriging method. Verification of both the data accomplished and the produced contour maps was done as well. The computed values of allowable pile capacity were stored in the GIS database as well.

3. RESULTS AND DISCUSSIONS OF THE DEEP FOUNDATION REFERENCE

3.1 Proposed Pile Length

The proposed pile length map for the entire Metro Manila can be seen in Figure 2. The map reflects the type of soil present where the majority of the area that is underlain by the Guadalupe Tuff Formation has a pile length that ranges from 5 to 10 meters in length. There are regions, which can be seen as areas shaded with white, have pile lengths of 5 meters for the entire region. These regions are recommended for the use of shallow foundation due to the shallowness of the rock layer or refusal layer. For locations composed of alluvial deposits, the range of pile lengths varies significantly depending on the location. For the western part, the pile length ranges from 10 to 15 meters. Several parts of the region show lengths ranging from 20 to 25 meters. The effect of the Manila Bay, in terms of pile length,

is manifested through these results. For the eastern part of Metro Manila, the proposed pile length ranges from 10 to 25 meters, which shows the effect of the location with respect to Laguna de Bay, where the majority of the data collected near the said body of water possess thick layers of alluvial deposits, namely sand, silts, and clay. Generally, the proposed pile length for Metro Manila ranges from 5 to 15 meters.

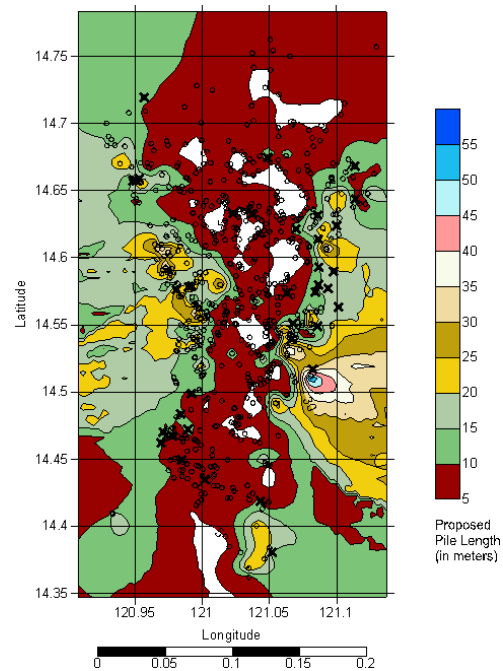


Fig. 2 Proposed Pile Length

3.2 Proposed Skin-to-Tip Ratio

The skin-to-tip Ratio is the ratio between the skin friction and the tip resistance or the end bearing resistance. For the skin-to-tip ratio map for Metro Manila, the values can also be reflected by the type of soil present along those areas, as seen in Figures 3 and 4. The areas underlain by the Guadalupe Tuff Formation produces low skin-to-tip ratio whereas a high ratio is observed in areas where alluvial deposits are prevalent. In general, the skin-to-tip ratio has presented that for a certain type of pile, a particular resisting force is dominant over the other, that is, skin friction is greater than the tip resistance, also known as end-bearing resistance, or vice versa. For driven piles, skin friction usually contributes greater resistance than that of the end bearing resistance due to the larger adhesion factors, α and β . Practically, the process of driving the piles really induces greater friction from the soil but the consequence is to use smaller cross-sections only so that the pressure in driving the piles is greater, thus, producing small end-bearing resistance. For bored piles, end bearing resistance dominates the skin

friction because the cross-sectional area of the type of pile is quite large. Also, some soil layers are neglected for the computation of the skin friction due to the effect of drilling that makes these particular layers disturbed.

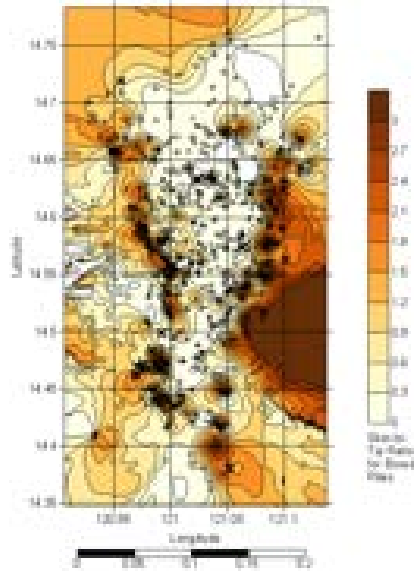


Fig. 3 Proposed Skin-to-tip Ratio (Bored Pile)

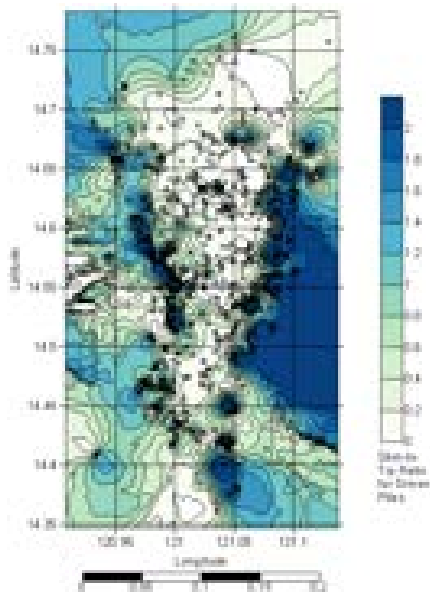


Fig. 4 Proposed Skin-to-tip Ratio (Driven Pile)

3.3 Proposed Pile Capacity

The allowable pile capacity maps presented under Figures 5, 6 and 7 show consistency in terms of their distribution of values. A separated sample pile capacity map where the division of the type of soil can be seen under Figure 8 (Guadalupe Tuff Formation) and Figure 9 (Alluvial Deposits). Higher values of allowable pile capacity are found

in areas where Guadalupe Tuff Formation is located. On the other hand, areas with alluvial deposits have low allowable pile capacities. Generally, it shows that the pile capacity depends on the type and quality of soil present on a specific area.

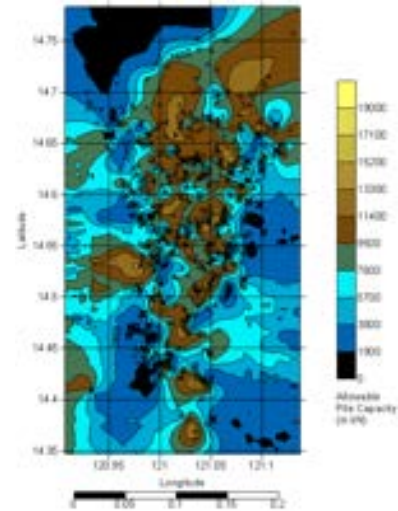


Fig. 5 Pile Capacity (Bored Piles Size 1.50 meter)

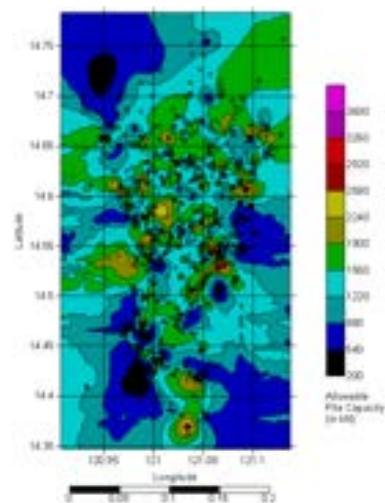


Fig. 6 Pile Capacity (Square Driven Piles Size 0.50 meter)

4. CONCLUSIONS AND RECOMMENDATIONS

In this paper, the pile length and allowable pile capacity are determined through borehole logs. For the cities of Las Piñas, Malabon, Navotas, Pateros and Pasig, they have relatively small allowable pile capacities as compared to the other cities for both driven and bored piles. Pile lengths are shorter because they have reached the refusal layers at somehow a shallow depth thus, lesser skin friction

is induced. Moreover, based on the skin-to-tip ratio, skin friction still plays a great contributor over the end-bearing resistance although, in totality, the allowable pile capacity is still small as compared to other cities.

The cities of Makati, Mandaluyong, Paranaque, Makati, and Quezon are quite remarkable not only due to the high allowable pile capacities that they produce but to the short pile lengths as well. Having a short pile length, in this case, is quite advantageous because it is really cost-effective. Also, it does not affect too much the allowable pile capacity because it majorly relies on the end-bearing resistance. The Guadalupe Tuff formation is actually the factor which makes the end-bearing resistance greater. These cities have shallow rock layers and usually, the shallow foundation is recommended for most of the areas of the aforementioned cities. Skin-to-tip ratio has proven that the end-bearing resistance really governs in these cities.

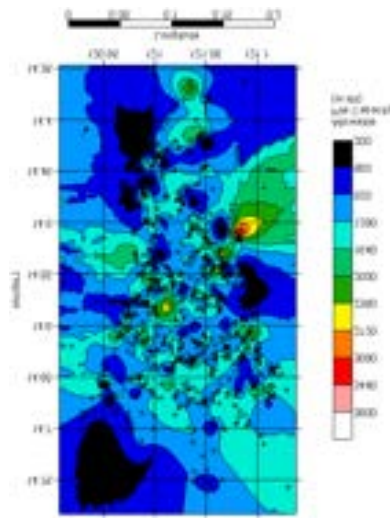


Fig. 7 Pile Capacity (Octagonal Driven Piles Size 0.50 meter)



Fig. 8 Pile Capacity for Bored Pile (Guadalupe Tuff Formation Area)



Figure 6.2.17 Pile Capacity for Bored Pile
(Alluvial Deposits Area)

Fig. 9 Pile Capacity for Bored Pile (Alluvial Deposits Area)

There are cities in Metro Manila which are not recommendable for the shallow foundation just because the top layers are weak especially in bearing capacity. These include Manila, Marikina, and Pasay. However, when pile foundation is used for these cities, a large allowable pile capacity is computed. This is because a longer pile length is recommended to induce large skin friction from several soil layers and to reach the refusal or rock layer at great depth. In these particular areas, both the skin friction and end bearing resistance greatly contribute to the allowable pile capacity. This means that high loadings from the superstructure can be resisted by piles considering also its length. The trade-off, however, is that it is not cost effective anymore due to the long piles that require a lot of materials.

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