International Journal of GEOMATE, April, 2017, Vol. 12 Issue 32, pp. 5-11
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.32.6556

# SOIL BEARING CAPACITY REFERENCE FOR METRO MANILA, PHILIPPINES

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*Corresponding Author, Received: 06 June 2016, Revised: 02 August 2016, Accepted: 30 Nov. 2016

## ABSTRACT

**ABSTRACT:** This study focuses on the analysis of the soil bearing capacities of the various cities and municipalities of Metro Manila, Philippines. The allowable soil bearing capacities to be used for foundation design were calculated through various theories and studies using geotechnical parameters, such as relative density and angle of internal friction. Standard Penetration Test (SPT) results were used to estimate these geotechnical parameters in order to obtain a good approximation of the soil‘s bearing capacity. Because of economic constraints, not all low-rise construction projects choose to perform soil exploration. Due to this, soil data are usually lacking and may cause problems when designing shallow foundations of these kinds of structures. In line with this kind of situation, the study can help engineers in designing shallow foundations by providing them a reference of the allowable soil bearing capacity of any area within Metro Manila. This will be able to give them a good idea of the soil‘s strength in supporting shallow foundations. The allowable bearing capacity of the soil shown in the reference is obtained from collected borehole data within Metro Manila and by using several geotechnical engineering theories. Contour maps of the bearing capacities are then made in order to provide an overview of the soil bearing capacity for shallow foundations. A Geographic Information System (GIS) software database was also made so as to store all the borehole location‘s data as well as serving another basis for estimation. This can be updated whenever new data is available.

*Keywords: Soil Bearing Capacity, Foundation Design, Standard Penetration Test, Geotechnical Properties of Metro Manila*

## INTRODUCTION

Foundation design requires engineers to understand how the soil interacts with the foundations. But, foundations are situated underground, wherein engineers cannot explicitly describe the interactions of the soil underground without conducting some tests. As soil exploration is a very costly test to conduct, engineers cannot always perform these tests; therefore, they rely on previous explorations done by their peers that are close to the project site to approximate the value for the soil bearing capacity for the aforementioned.

Since soil exploration is too costly and mere guessing will not suffice when making foundations, the author decided to come up with a way to fill in the dire needs of engineers. Using the borehole logs available within the Metro Manila, Philippines, the study analyzed the SPT borehole logs, calculated the required soil parameters and compiled everything into a reference that shows the bearing capacities of the covered areas.

The study aims to create a reference that will provide structural engineers the estimated allowable soil bearing capacities at any point in Metro Manila Philippines through the use of contour maps.

## METHODOLOGY

With Metro Manila having an approximate size of 597.47 square kilometers, a density of one borehole log per square kilometer was used to describe the geotechnical characteristics and possible foundation design parameters of the said area. Borehole logs were collected for a total of 486 locations all over Metro Manila.

The amount of borehole logs alone is not the only criterion in gathering data for the study. It is just as important as, that the locations of the borehole logs be properly distributed. To check their distribution, each of the locations of the borehole logs was plotted in a map of Metro Manila. After this, the distribution was visually inspected and the areas that needed more data were determined. Aside from these, borehole logs that seemed erroneous were removed and disregarded.

In properly designing shallow foundations, the geotechnical characteristics and allowable bearing capacity of the soil must be known. This is because the design would largely depend on the strength and the behavior of the soil. The bearing capacities are computed using the SPT N values found in the borehole logs which were corrected using the procedures discussed in [1]-[4], also shown in Equation 1.

$$N_{60} = \frac{E_m C_B C_S C_R C_N N}{0.6} \qquad \text{(Eq. 1)}$$

Where: $N_{60}$ is the corrected SPT-N value (blows/ft), $E_m$ is the hammer efficiency, $C_B$ is the borehole diameter correction, $C_S$ is the sampler correction, $C_R$ is the rod length correction, $C_N$ is the overburden pressure correction and N is the SPT-N recorded in the field.

The corrected SPT, $N_{60}$, values were then used to compute for various geotechnical parameters such as relative density, undrained shear strength and angle of internal friction using different correlation factors [5]-[9]. As such, the group computed the ultimate soil bearing capacity. The Terzaghi's and Vesic's bearing capacity formulas, shown on Equations 2 and 3 respectively, were used to achieve this [10]-[12].

$$q_{ult} = 1.2cN_c + \gamma D_f N_q + 0.4\gamma B N_\gamma \quad \text{(Eq. 2)}$$

where: $q_{ult}$ is the ultimate soil bearing capacity, $\gamma$ is the effective unit weight, B is the width of foundation, $D_f$ is the depth of foundation below ground surface, $N_c$, $N_\gamma$ and $N_q$ are the Terzaghi's factors.

$$q_{ult} = c'N_c s_c d_c i_c b_c g_c + \sigma'_{zD} N_q s_q d_q i_q b_q g_q + 0.5\gamma' N_\gamma s_\gamma d_\gamma i_\gamma b_\gamma g_\gamma \quad \text{(Eq. 3)}$$

Where: $s_c$, $s_q$, $s_\gamma$ are shape factors; $d_c$, $d_q$, $d_\gamma$ are depth factors; $i_c$, $i_q$, $i_\gamma$ are load inclination factors; $b_c$, $b_q$, $b_\gamma$ are base inclination factors; and $g_c$, $g_q$, $g_\gamma$ are ground inclination factors.

A factor of safety of 3.0 was divided to the ultimate soil bearing capacity to determine the allowable bearing capacity of the soil. The allowable soil bearing capacities at different locations were then plotted on to the maps at 1-meter, 2-meters, 3-meters , 4-meters and 5-meter depths. Contour maps were created to visually classify and analyze the allowable bearing capacities at different locations in Metro Manila. With the ever growing technology in data processing, it has become more convenient to show the reference through the use of a Geographic Information System (GIS) program. The map of Metro Manila was first loaded into the GIS program. After this, the locations and all the relevant, data such as the bearing capacities, were placed inside a .csv file.

## ANALYSIS AND DISCUSSION

Metro Manila or the National Capital Region of the Philippines is composed of 16 cities and 1 municipality. It is bounded by the province of Bulacan in the North, Manila Bay at the West, Rizal Province and Laguna Bay in the East, and Cavite Province in the South. It has a total land area of 597.47 $km^2$.

### Soil Characteristic

Manila used to be a submerged area at one time in the geologic past. Intermittent volcanic activities followed and after which, volcanic materials were deposited. During the intervening period of inactivity, transported sediments were deposited on top of previously-laid volcanic materials. Thus, alternating beds and transported sediments became a characteristic feature of the geologic deposit. [13]-[14]

Available geologic information about Metro Manila and the areas surrounding it indicated that Quaternary volcanic rocks generally known as the Guadalupe Formation, locally known as “adobe”, is the predominant rock unit underlying it. It consists of the Lower Alat Conglomerate Member and the Upper Diliman Tuff Member. The Diliman Tuff includes the tuff sequence in the Angat-Novaliches region and along Pasig River in the vicinity of Guadalupe, Makati and extending to some areas of Manila and most of Quezon City. Its upper surface ascends gently from Manila Bay outward Caloocan, Makati, Mandaluyong and Quezon City in which rock exposures can be found. The entire sequence is almost flat lying, thin to thickly bedded and consist of medium to coarse grained vitric tuffs and welded volcanic breccias with subordinate amounts of tuffaceous medium to coarse-grained sandstone, silty and clayey tuffs and tuffaceous conglomerates. These types of tuff are distinguished from their textual characteristics. Silty and clayey tuffs are very fine-grained while conglomerates contain coarse particles. In some areas, this rock formation is overlain by minimal alluvial deposits which tend to thicken towards Manila Bay. The high elevation areas are generally composed of dense sands and tuffaceous clay, while the low-lying areas are generally composed of loose sands and soft clays [13]- [14].

### Topography and Elevation

Figure 1 shows the surface elevation contour map of Metro Manila referenced from the mean sea level. The elevation data is derived from Google Earth and translated into this elevation contour map.

It is observed that the high elevations of Metro Manila are traversing the center, while the low-lying areas are found in the sides which are coastal areas.

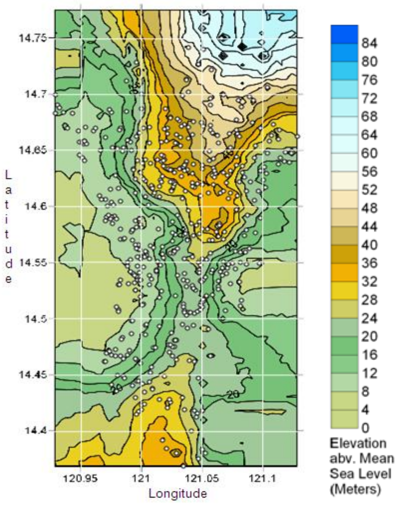


Fig. 1 Surface Elevation Contour

### Borehole Locations

Figure 2 shows the location of the data points that were used in the study while Table 1 summarizes the gathered data in each of the comprising city of Metro Manila and checks for the target density of one borehole location per square kilometer.

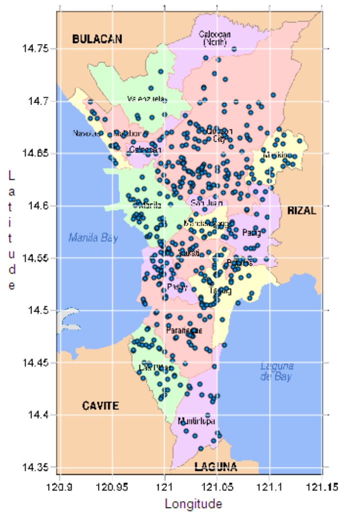


Fig. 2 Map of the Data Points in Metro Manila

Table 1 Number of Borehole Locations and its Density

| City or Municipality | Area (km$^2$) | Borehole Locations (BH) | Density, BH/Area |
|---|---|---|---|
| Manila | 38.55 | 39 | 1.00 |
| Mandaluyong | 11.25 | 14 | 1.00 |
| Marikina | 21.50 | 26 | 1.00 |
| Pasig | 31.00 | 24 | 0.77 |
| Quezon City | 134.26 | 130 | 0.97 |
| San Juan | 5.94 | 3 | 0.51 |
| Caloocan | 53.33 | 15 | 0.28 |
| Malabon | 15.71 | 12 | 0.76 |
| Navotas | 10.69 | 11 | 1.00 |
| Valenzuela | 44.59 | 9 | 0.20 |
| Las Pinas | 41.54 | 38 | 0.91 |
| Makati | 27.36 | 28 | 1.00 |
| Muntinlupa | 46.70 | 17 | 0.36 |
| Paranaque | 46.57 | 40 | 0.86 |
| Pasay | 18.50 | 24 | 1.00 |
| Pateros | 2.10 | 8 | 1.00 |
| Taguig | 47.88 | 48 | 1.00 |
| **TOTAL** | **597.47** | **486** | **81.34%** |

## SOIL BEARING CAPACITY

Figure 3 shows the soil bearing capacity of the region at 1-meter depth. It can be seen that many areas where elevation is high have larger bearing capacities compared to the lower elevated areas. It is observed that the fault line is directly below the part where the soil bearing capacity is high. SPT N values of the outer 1-meter depth have a usual value in the range of 2 to 10 for both sands and clays. A reason why the outer areas have low soil bearing capacity is due to sediment deposits that are left by the rivers and creeks over time.

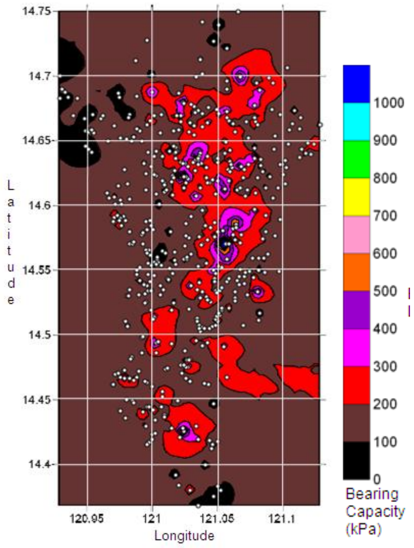


Fig. 3 Soil bearing capacity at a Depth of 1 meter in Metro Manila

The allowable bearing capacities of a depth of 2 meters below the ground surface are shown in Figure 4. It can be seen in the central part of the region that refusal (SPT N-values greater than 50) has been achieved. Bearing capacities of the outer portions has also increased but not as much compared to the center of the map. The blue areas represent the places where the soil has hardened to a point that SPT is not advisable anymore. These blue areas are very near, if not above, the fault line and thus have a large soil bearing capacity.

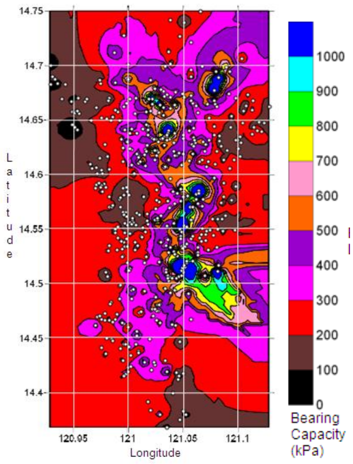


Fig. 4 Soil bearing capacity at a Depth of 2 meters in Metro Manila

Figure 5 shows the bearing capacities of a depth of 3 meters below the ground surface. More areas have now achieved refusal. SPT N values of the areas around the blue areas have increased but the outer areas of Metro Manila still have a small soil bearing capacity as compared to the center.

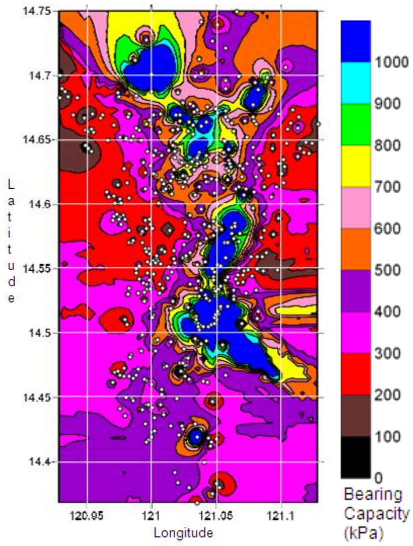


Fig. 5 Soil bearing capacity at a Depth of 3 meters in Metro Manila

Figure 6 shows the soil bearing capacity at a depth of 4 meters below the ground surface. Almost all areas have a soil bearing capacity of 300 kPa or greater except in the northwestern and eastern portion.

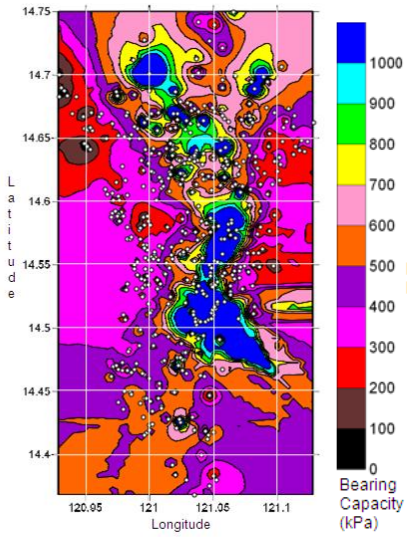


Fig. 6 Soil bearing capacity at a Depth of 4 meters in Metro Manila

Figure 7 shows the soil bearing capacity at a depth of 5 meters below the ground surface. Almost all areas have reached an allowable soil bearing capacity of 300 kPa and above, as expected, due to consolidation of soil over time.

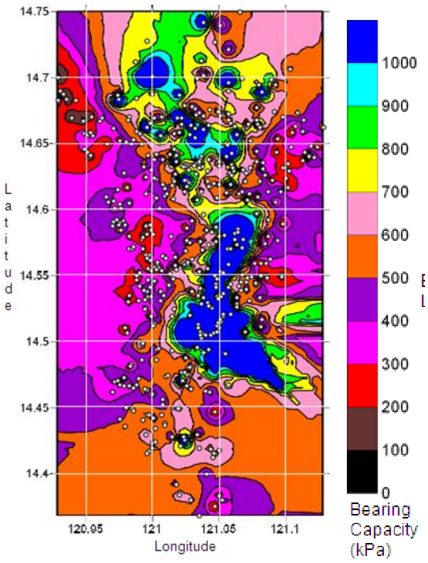


Fig. 7 Soil bearing capacity at a Depth of 5 meters in Metro Manila

Figure 8 shows the geological map of Metro Manila [13]. Looking at this map, deposits are seen in the western and eastern side of the region, while the tuff formation is seen in the central region.

With this information, the region can be further divided into 3 parts: the west coast, the east coast and the central area as shown in Figure 9. The west coast is composed of cities that are near the Manila Bay, which are Navotas, Malabon, South Caloocan, Manila, Pasay, Paranaque and Las Pinas. The east coast is composed of cities that are near the Laguna Bay, which are Marikina, Pasig, Pateros, Taguig and Muntinlupa. The remaining cities of North Caloocan, Valenzuela, Quezon City, San Juan, Mandaluyong, and Makati are the cities that comprise the central area.

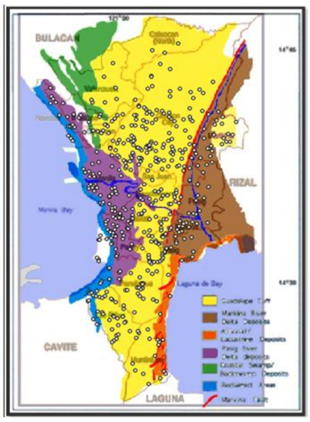


Fig. 8 Geologic Map of Metro Manila [13]

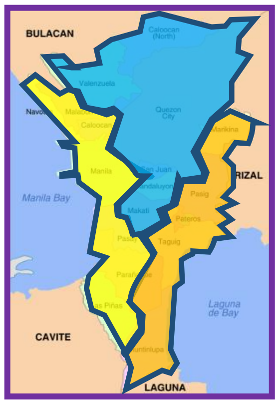


Fig. 9 Division of Cities

Looking at the west coast, as shown in Figure 10, the surface geology of this area is mostly composed of quarterly alluvial soil. SPT N- values on these areas are also very low (2-10) at the surface and average (20-30) as the soil goes deeper. The east coast is generally the same compared to the west coast, having quarterly alluvium soil in the surface as well as having the same SPT value patterns. SPT refusal was not achieved below a depth of 5 meters. Due to the fact that the surface geology of the soil of the aforementioned areas is generally loose, the resulting bearing capacities also reflected the composition of the soil. Allowable bearing capacities of the area at shallow depths of 1 to 2 meters have values ranging from 0 to 200 kPa.

The central area of Metro Manila has a different surface geology compared to its neighboring sides. Tuff was primarily observed in this area, and rock formations are common below the surface. SPT blows depend on the amount of deposits that are present and increase as the soil goes deeper. SPT refusal was achieved at shallow depths of 2 to 3 meters in the outer regions and as shallow as the ground surface in the inner regions.

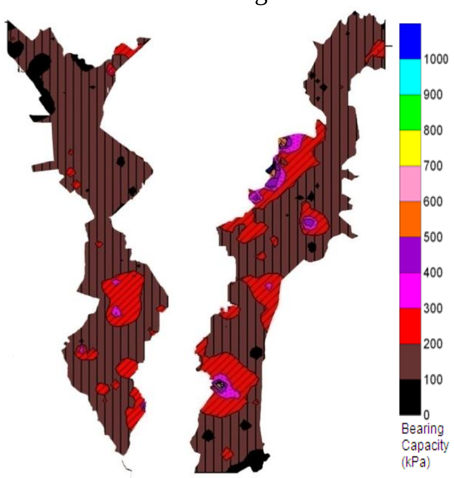


Fig. 10 Soil Bearing Capacity Contour Map of West and East Coast of Metro Manila (depth of 1m)

Since the surface geology of this area is reported as tuff, it can be generalized that the land is mostly made up of rocks. Comparing rocks to soil, rocks are generally stronger than soil. In accordance to this, the bearing capacities of the rocks should have high values compared to soils which is clearly noticeable in Figure 11. Calculations have shown that the bearing capacities of the area have a range of 200 to 300 kPa.

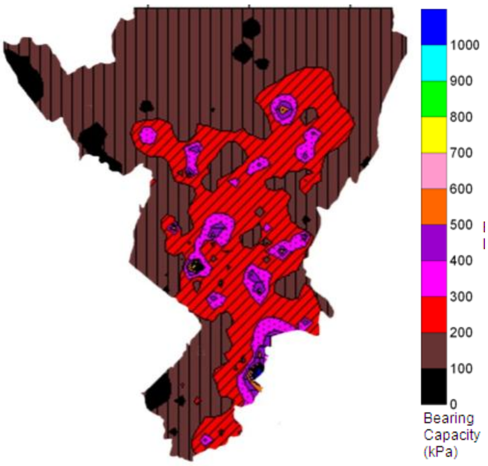


Fig. 11 Soil Bearing Capacity Contour Map of Central Area of Metro Manila at a depth of 1 meter

## CONCLUSION

Borehole logs were collected for a total of 486 locations all over Metro Manila, Philippines. Maps were also created in order to show the locations of the collected boreholes throughout Metro Manila.

Using a spreadsheet program, different geotechnical properties of the collected boreholes were computed. Some examples of this are the unit weight and the angle of internal friction. Also, using the same spreadsheet program, the soil bearing capacity of the 16 cities and 1 municipality were estimated and evaluated per meter depth until a depth of 5 meters. Contour maps of the allowable bearing capacities at each of the depths were also made and analyzed. Based on the results of the study, it was found out that several locations in Metro Manila were composed of soil with allowable bearing capacities suitable for shallow foundations.

Cities which are near the bodies of water, such as Manila, Navotas, and Marikina, have low bearing capacities. Thus, the use of shallow foundations on these areas is recommended only for structures that have lower design loads, such as residential houses. As the soil is not capable of carrying heavy loads, using shallow foundations for high rise buildings and other large structures should be avoided or a deep foundation is recommended. According to research [13], the western part of Metro Manila was once underwater. Due to this, some of the soils in the area contained seashells. Also, the surface geology of the western and eastern area is composed mostly of quarterly alluvium, a loose type of soil that is in its early ages. Also, it should be noted that the river system determines the direction of the sediments being washed out from its origins. Marikina River flows from north to south. Pasig River then carries the river water from Marikina River, splitting it into two: one in the west direction with the Manila Bay as its last stop, while the other in the east direction with the Laguna Bay as its endpoint. Because of this, sediments from high elevation areas were deposited by rivers and creeks into low lying areas along their paths. This happens because water slowly scours the soil and carries it to the areas where the slope is mild. Gravity then takes effect and sediments are left behind, resulting in a composition that is generally loose and soft for sands and clays.

Cities with rock formations beneath the surface, such as Quezon City, North Caloocan, and Muntinlupa, have soils with high bearing capacities at shallow depths. It is recommended to place the foundations on these refusal levels since it is more than capable of carrying loads that are suited for shallow foundations. Nevertheless, caution must be taken when placing structures in these areas, as the Valley Fault System is nearby, making the area prone to earthquakes.

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