*Maejo Int. J. Sci. Technol.* **2013**, *7*(02), 329-337

## *Maejo International Journal of Science and Technology*

**ISSN 1905-7873**
Available online at www.mijst.mju.ac.th

*Communication*

# Geotechnical maps for recommendation on bored pile capacity in Nakhon Ratchasima municipality, Thailand

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*Received: 7 September 2012 / Accepted: 15 August 2013 / Published: 16 August 2013*

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**Abstract:** This paper presents the development of geotechnical maps in Nakhon Ratchasima municipality, Nakhon Ratchasima province, Thailand based on the boring logs and in situ test results collected from public and private sector sources. The standard penetration number, $N$ was used to identify the soil type. The soil deposits in Nakhon Ratchasima municipality are divided into three layers: medium-to-stiff silty clay with $N <$ 30, first hard silty clay with $30 < N < 50$, and second hard silty clay with $N > 50$. The medium-to-stiff silty clay layer has a thickness varying from 1.8 to 7.5 metres and an average $N$ value of 14 with a relatively low standard deviation of 1.08. The first hard silty clay layer has a thickness varying from 1.2 to 3.0 metres and an average $N$ value of 42 with a standard deviation of 1.37. For a practical application in foundation engineering in which the pile tips of the bored piles are located in the second hard stratum with $N > 50$, eight pile tip zones with approximated load capacity are recommended for pile lengths of 3-10 metres.

**Keywords:** geotechnical map, Nakhon Ratchasima municipality, standard penetration number, bored pile.

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## INTRODUCTION

The infrastructure in the city of Nakhon Ratchasima, Nakhon Ratchasima province, Thailand has grown rapidly in recent years. Soil deposits in this area are generally silty clay, which is wind-blown and deposited over several decades. The top soil is problematic clay sensitive to changes in water content. Laboratory and field investigations on its collapsing behaviour due to wetting were conducted by Kohgo et al. [1] and Kohgo and Horpibulsuk [2]. Due to the moderate strength of the soil when dry, many low-rise and medium-rise buildings were constructed on shallow foundations. When soil moisture changed due to rain and waste water from the buildings, building movements occurred [3]. This movement may be either a settlement or a heave due to changes in effective stress [4-6].

To avoid this problem, piled foundations have been used to transfer the load of the super-structure to the hard soil stratum. The driven pile is not allowed in this area due to vibration problems. Dry-process bored piles have been commonly used instead because the ground water level is very deep and the soil deposit is cohesive, which can protect the borehole from collapse. A casing is therefore not required for construction. The pile tip and pile diameter are generally determined from shear-strength parameters, which are obtained from either laboratory or in situ tests. The standard penetration test (SPT) is suitable for stiff-to-hard clay. Soil samples can be obtained during the test to determine soil index properties. The standard penetration number, $N$, which is the number of blows per foot, is practically used to approximate the strength parameters and the pile load capacity. For clayey soils, the $N$ value is directly related to the undrained shear strength.

Available empirical relationships between undrained shear strength, $S_u$, and standard penetration number, $N$, are limited to $N < 30$ and dependent upon soil characteristics [7,8]. Soil with higher plasticity exhibits higher undrained shear strength for the same $N$ value. For a known clay characteristic, the available relationships are sufficient for designing a driven pile with a large section that cannot penetrate the hard clay ($N > 30$). The same is not true for a bored pile for which a borehole can be advanced by a boring machine. Horpibulsuk et al. [3] back-calculated the pile load test results for micro-piles in stiff-to-hard silty clay in the campus of Suranaree University of Technology, where the clay is of medium plasticity. They concluded that for a low $N$ (< 30), a linear relationship between $S_u$ and $N$ exists and is close to that proposed by Terzaghi and Peck [7]. The same relationship was also observed for $N > 30$. The relationship between $S_u$ and $N$ for $N < 68$ was proposed as follows [3]:

$$S_u = \frac{2}{3}N \tag{1}$$

where $S_u$ is expressed as ton/m$^2$ and $N$ is expressed as number of blows/ft.

The traditional method for approximating pile load capacity in Nakhon Ratchasima province is the use of a static formula. The designed load capacity of a single pile is then proved by the pile load test. The designed strength parameters are obtained from a standard penetration test. The soil profile in Nakhon Ratchaisma province varies significantly because the province is located in a mountainous area. Consequently, significant boring logs are generally required for appropriate design. Geological maps showing an overview of the soil profile in Nakhon Ratchasima province are considered as a necessary tool for economical and engineering purposes. This paper aims to collect boring logs and in situ test results in Nakhon Rachasima municipality to develop geotechnical maps. The recommended pile tip zones and approximated load capacity of bored piles for different locations are finally presented based on the developed contour maps. The pile tip zones are classified according to the depth of the hard clay stratum where the $N$ values are greater than 50. The ultimate loads for each zone are approximated using a static formula. The recommended pile tip zones and load capacity are useful for a rapid determination of the pile diameter required to attain the allowable load, and hence a cost estimate of the pile installation for contractors, designers and owners.

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**METHODOLOGY**

Geotechnical maps for bored pile designs in Nakhon Ratchasima municipality were developed using 139 boring logs collected from public and private sector sources. Most of the data were from Mr. Taveesak Wintachai, a professional engineer, and his team. They have performed several boring and in situ tests in Nakhon Ratchasima province and the pile foundations in many construction projects were designed based on their data. Soil layers were generally classified based on the undrained shear strength approximated from the *N* value. Standard penetration tests were performed according to the American Society for Testing and Materials (ASTM) standards. The groundwater table was measured in all boreholes after one day of boring. Generally, the groundwater table is not detected because the groundwater is very deep in this area. Figure 1 shows a boring log in Muang district, Nakhon Ratchasima. A typical soil profile in the studied area is summarised and shown in Figure 2. The soil profile consists of a medium-to-stiff silty clay layer and the first and second hard-clay layers. The raw data include the ground elevation above mean sea level and the thickness and soil properties of the medium-to-stiff clay layer and the first hard-clay layer. The thickness of the second hard-clay layer, with *N* values greater than 50, is not within the scope of this study because it is impossible to advance the borehole through this layer using dry boring technique (the pile tip being located in the second hard-clay layer). The Land Desktop 2006 was used to create two types of contour maps, which are maps of ground elevation and soil thickness. For the map of ground elevation, the input data are the northern (N) and eastern (E) coordinates and ground elevation (Z). The input data are (N, E) coordinates and thickness of each soil layer for the map of soil thickness.

Based on the geotechnical maps, the pile tip zones are recommended for a rapid estimation of the pile length and diameter to attain the required load capacity. The ultimate loads for each zone were approximated for 4 pile diameters (0.35, 0.40, 0.50 and 0.6 metres) based on static formulae. These four pile diameters correspond to the typical drilling head in Thailand. The ultimate load, $Q_u$, consists of skin friction, $Q_{su}$, and end bearing resistance, $Q_{bu}$, which can be estimated from the following equations [9,10].

$$Q_{su} = \alpha S_u pL \tag{2}$$

$$Q_{bu} = wN_c S_u A \tag{3}$$

where $\alpha$ is the adhesion factor, which is taken as 0.45 for a bored pile [11]; $p$ is the pile perimeter; $L$ is the length of the pile shaft; $N_c$ is the bearing capacity factor equal to 9.0 [12]; $A$ is the cross sectional area of the pile toe and $w$ is the reduction factor. The end bearing resistance is mainly controlled by the soil shear strength at the pile tip, where the disturbance during soil boring is commonly significant for a large pile diameter. It is thus recommended that the $w$ value decreases as the pile diameter increases. It is equal to 0.8 or 0.75 for pile diameters less or greater than 1.0 metre respectively [11]. The allowable load for the bored pile can be obtained using a safety factor of 2.5 to 3.0.

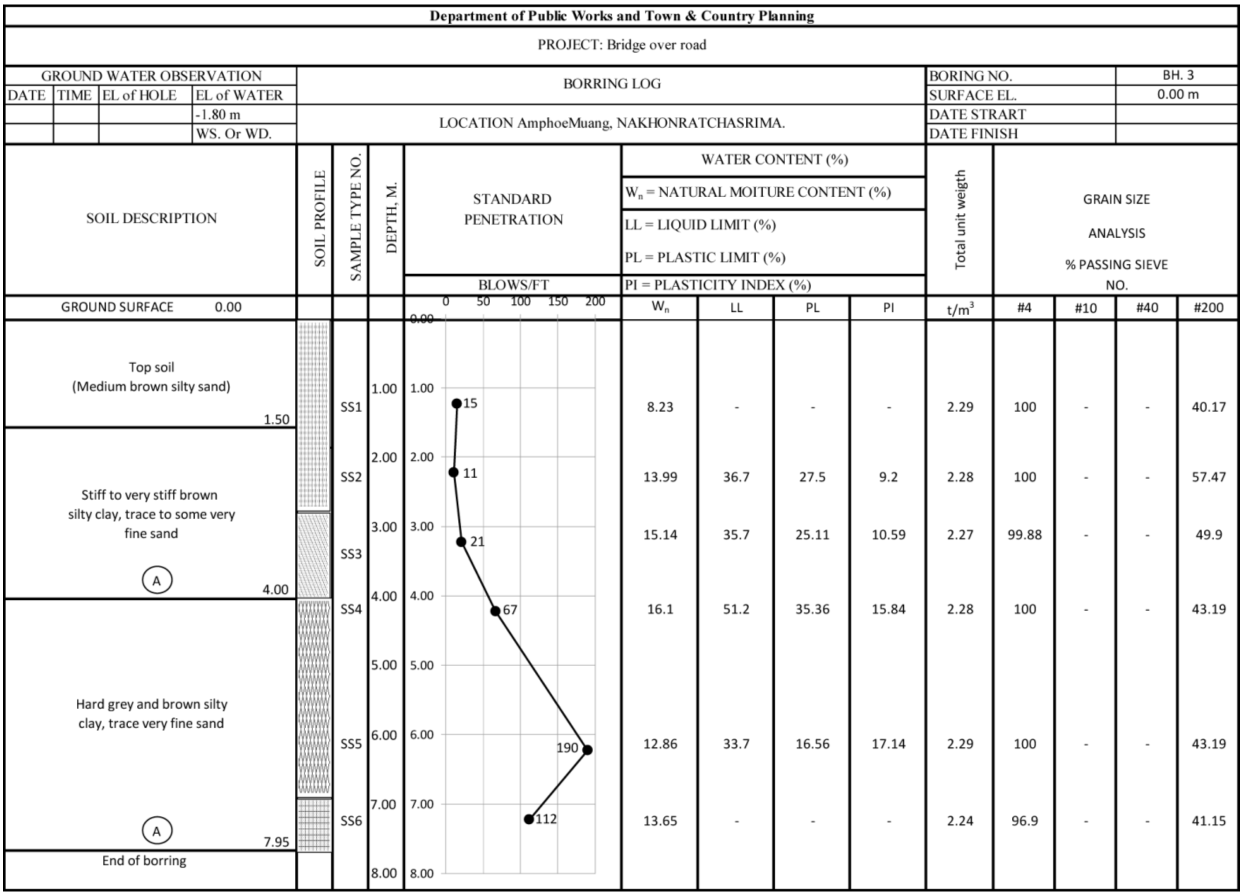


**Figure 1.** Boring log in Muang district, Nakhon Ratchasima (data from Department of Public Works and Town & Country Planning)

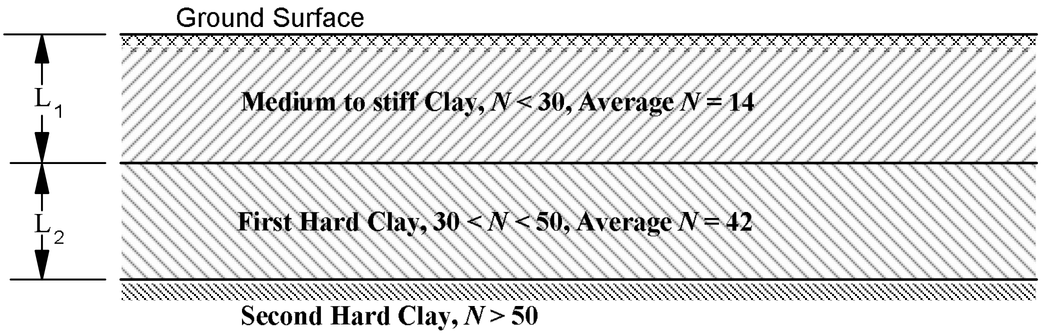


**Figure 2.** Typical soil profile in Nakhon Ratchasima municipality

## RESULTS AND DISCUSSION

From the boring logs, the soil deposit was determined to be silty clay (Figure 2), i.e. the medium-to-stiff clay layer with $N$ values less than 30, the first hard-clay layer with $30 < N < 50$ and the second hard-clay layer with $N$ values greater than 50. The average $N$ value of the medium-to-stiff silty clay layer is 14 with a very low standard deviation of 1.08, while that of the first hard-clay layer is 42 with a very low standard deviation of 1.37. Figure 3 shows the contour map of the ground elevation in Nakhon Ratchasima municipality, which varies from 169 to 216 m above mean sea level. This significant difference in ground elevation leads to a large difference in the thicknesses of the medium-to-stiff clay and hard-clay layers. The thickness of the medium-to-stiff clay layer, $L_1$, varies from 1.80 to 7.00 metres (Figure 4) and the thickness of the first hard-clay layer, $L_2$, is 1.20 to 3.00 metres (Figure 5). The thickness of the medium-to-stiff clay layer, $L_1$, in Figure 4 is the difference between the depth of medium-to-stiff clay layer and the ground level obtained from Figure 3. The thickness of the first hard-clay layer, $L_2$, in Figure 5 is the difference between the depth of first hard-clay layer and the depth of medium-to-stiff clay layer.

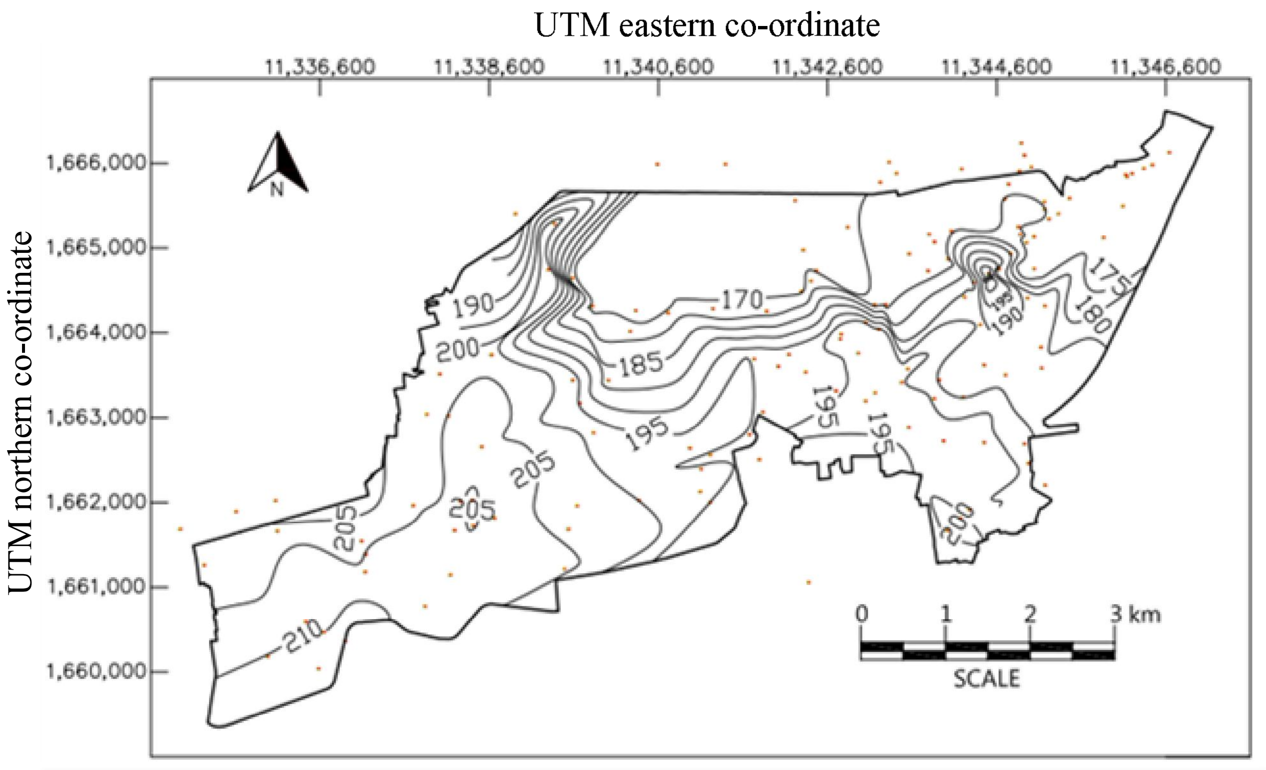


**Figure 3.** Contour map of ground elevation in Nakhon Ratchasima municipality. Red dots represent position of boring logs.

The minimum pile length must be greater than the sum of $L_1$ and $L_2$ to ensure that the pile tip of the bored pile is located in the second hard-clay layer. Due to a significant difference in the geotechnical profile in this area, the required pile length varies from 3 to 10 metres. Having obtained Figures 4 and 5, the average values of $L_1$ and $L_2$ were calculated and the area was zoned. For each zone, the mean standard deviation, SD, was less than 10% of the average value, showing that the value can be representative. The recommended pile tips in Figure 6 are the sum of $L_1$ and $L_2$. The approximated ultimate load for each zone is presented in Table 1. In the approximation, the $w$ value was 0.8 for all pile diameters and the average $N$ values of 14 and 42 were used for the medium-to-stiff clay and first hard-clay layers respectively. These $N$ values correspond to the undrained shear strength of 9.3 and 28 ton/m$^2$ respectively. The average thicknesses of the medium-to-stiff clay and first hard-clay layers used for the approximation of pile load capacity are $L_1 = 1.80 \pm 0.01$ m and $L_2 = 1.20 \pm 0.14$ m for zone 1, $L_1 = 2.5 \pm 0.20$ m and $L_2 = 1.5 \pm 0.06$ m for zone 2, $L_1 = 3.90 \pm 0.15$ m and $L_2 = 1.10 \pm 0.22$ m for zone 3, $L_1 = 4.40 \pm 0.23$ m and $L_2 = 1.60 \pm 0.32$ m for zone 4, $L_1 = 4.80 \pm 0.37$ m and $L_2 = 2.20 \pm 0.27$ m for zone 5, $L_1 = 5.50 \pm 0.45$ m and $L_2 = 2.50 \pm 0.25$ m for zone 6, $L_1 = 6.30 \pm 0.75$ m and $L_2 = 2.70 \pm 0.98$ m for zone 7, and $L_1 = 7.00 \pm 0.14$ m and $L_2 = 3.00 \pm 0.28$ m for zone 8.

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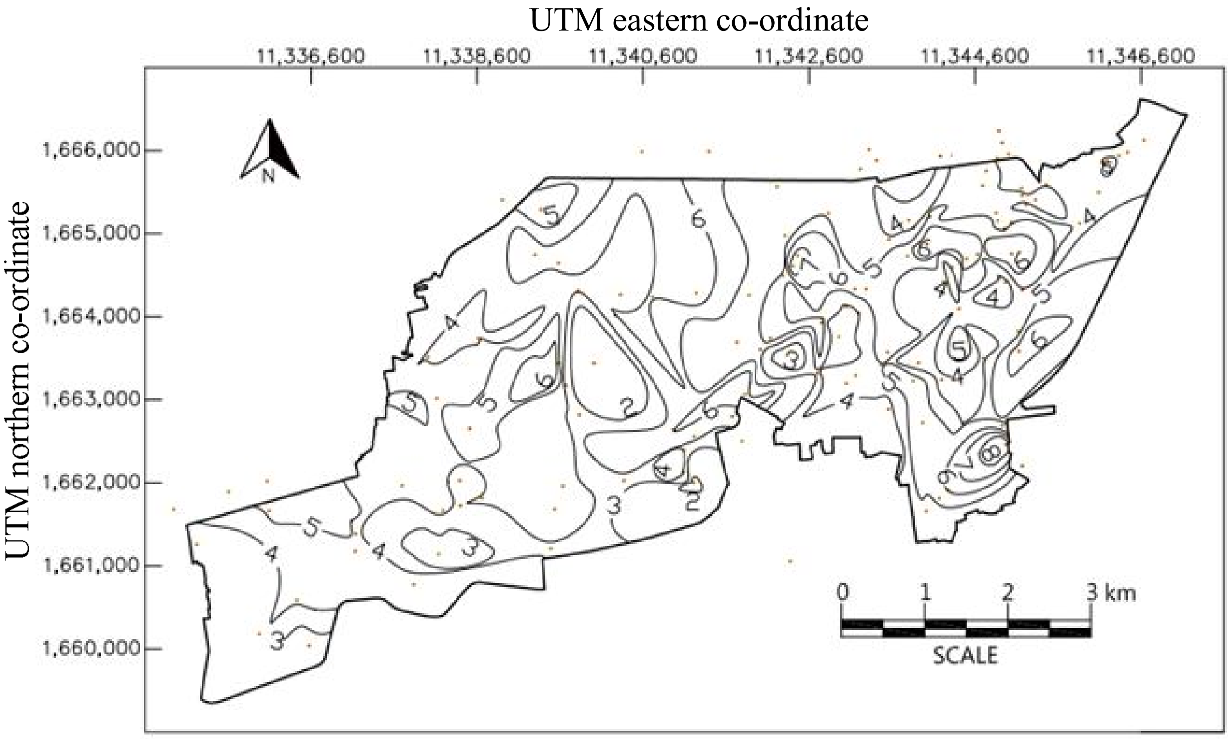


**Figure 4.** Contour map of the thickness of the medium-to-stiff clay layer ($N < 30$). Red dots represent position of boring logs.

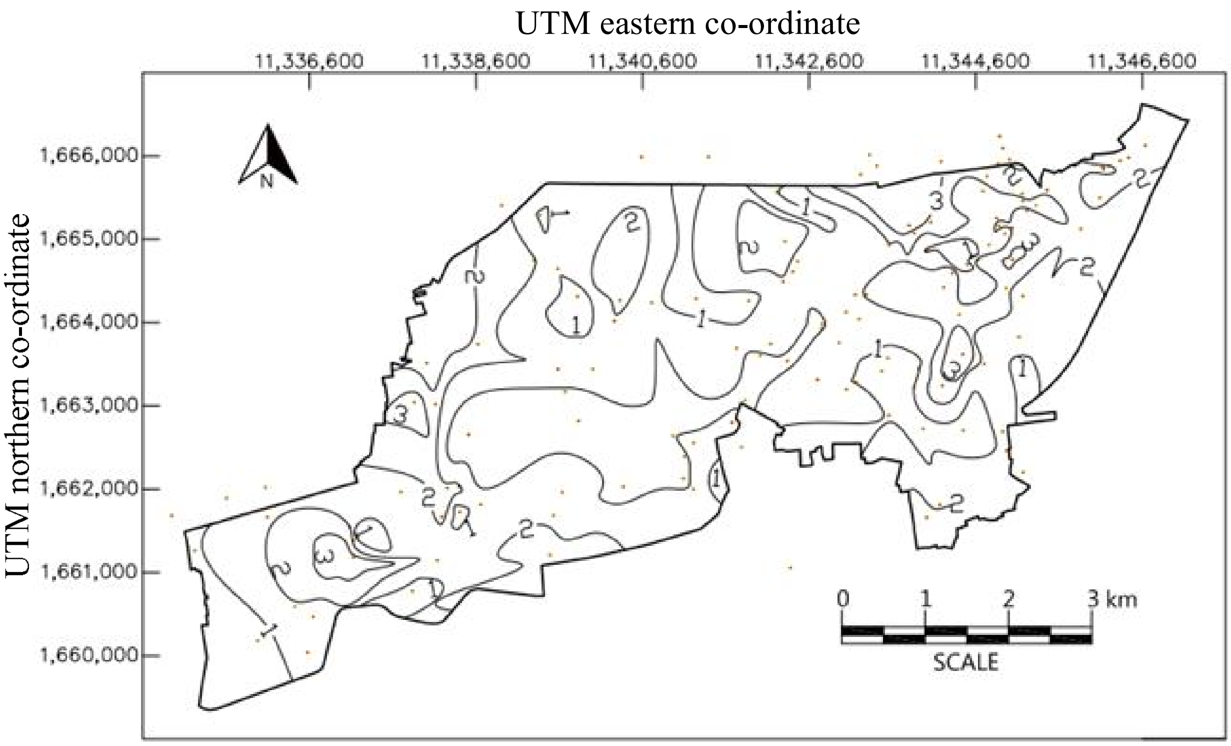


**Figure 5.** Contour map of the thickness of the first hard-clay layer ($30 < N < 50$). Red dots represent position of boring logs.

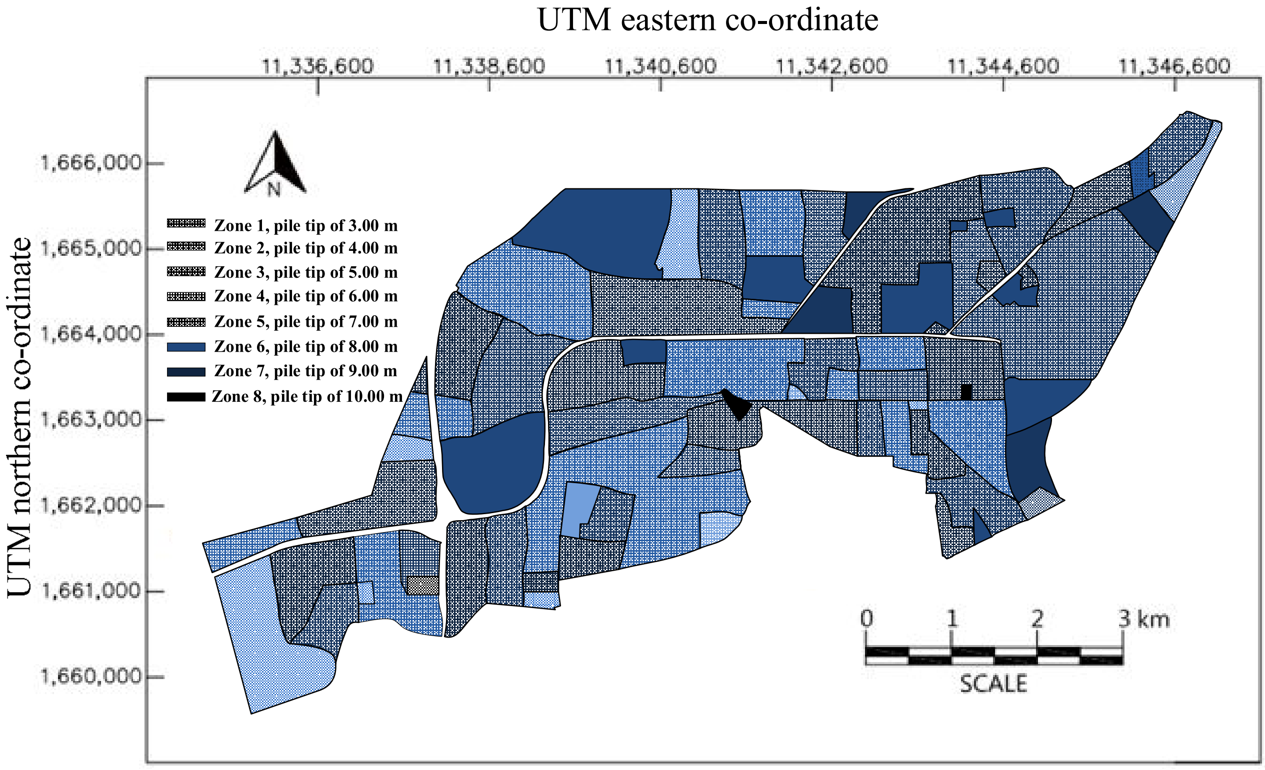


**Figure 6.** Recommended pile tips for eight zones in Nakhon Ratchasima municipality

**Table 1.** Approximated ultimate load of single pile for eight zones

| Pile diameter (m) | Approximated ultimate load (ton) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 | Zone 8 |
| 0.35 | 49.4 | 56.8 | 57.7 | 67.0 | 77.1 | 84.5 | 91.0 | 98.4 |
| 0.4 | 60.5 | 69.0 | 70.0 | 80.6 | 92.2 | 100.6 | 108.0 | 116.5 |
| 0.5 | 85.7 | 96.2 | 97.6 | 110.7 | 125.3 | 135.8 | 145.1 | 155.6 |
| 0.6 | 114.8 | 127.5 | 129.1 | 144.9 | 162.3 | 175.0 | 186.1 | 198.7 |

The following is an example of the estimation of bored pile capacity in Zone 1 for a pile diameter of 0.35 m. The average $L_1$ and $L_2$ are 1.8 and 1.2 metres and the corresponding undrained shear strength values are 9.3 and 28.0 ton/m$^2$ respectively. Using Eq. (2), $Q_{su}$ can be determined:

$$Q_{su1} = 0.45 \times 9.3 \times 1.10 \times 1.80 = 8.3 \text{ ton/m}^2$$

$$Q_{su2} = 0.45 \times 28 \times 1.10 \times 1.20 = 16.6 \text{ ton/m}^2$$

$$Q_{su} = Q_{su1} + Q_{su2} = 8.29 + 16.63 = 24.9 \text{ ton/m}^2$$

The end bearing resistance is approximated from Eq. (3) as follows:

$$Q_{sb} = 0.85 \times 9 \times 33.33 \times 0.0962 = 24.5 \text{ ton/m}^2.$$

Thus, the approximated load capacity is equal to 24.9 + 24.5 = 49.4 ton/m$^2$.

The proposed geotechnical maps and the approximated ultimate loads were determined from the available data and the empirical parameters ($\alpha$ and $w$). They are useful as a tool for a rapid estimation of the pile diameter and length as well as the installation cost. It must be stated that site investigation and pile load tests are still required prior to the installation of bored piles. For some areas where the adjacent areas require an abrupt change of pile length, a long pile is conservatively recommended at the boundary between the two areas.

## CONCLUSIONS

This paper deals with the development of geotechnical maps and the approximated ultimate load capacity in Nakhon Ratchasima municipality. The development is based on 139 boreholes which cover the studied area. The ground elevation in this area varies significantly with a maximum difference of 47 metres. The soil profile consists of 3 layers: the medium-to-stiff clay layer with average *N* value of 14, the first hard-clay layer with average *N* value of 42, and the second hard-clay layer with *N* value of greater than 50. The variation of the *N* value for each layer is considered as low with a standard deviation of less than 1.37. The contour of ground elevation and the thickness of the medium-to-stiff clay and the first hard-clay layers are introduced. The length of the bored pile varies between 3-10 metres in eight different zones. The zone map and the approximated load capacity are very useful as a practical tool for a rapid estimation of the pile diameter and length as well as the installation cost. However, the site investigation and pile load tests are still required prior to the installation of the bored piles.

## ACKNOWLEDGEMENTS

This work was supported by the Higher Education Research Promotion and National Research University Project of Thailand, Office of Higher Education Commission. The authors are grateful to Mr. Taveesak Wintachai for providing the boring logs.

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