COMPARISON OF MALAYSIAN PRACTICE WITH EC7 ON THE DESIGN OF DRIVEN PILE AND BORED PILE FOUNDATIONS UNDER AXIAL COMPRESSION LOAD

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ABSTRACT: This paper presents commonly used design methodologies for driven pile and bored pile foundation in Malaysia. In Malaysia, empirical equations to predict ultimate shaft resistance ($f_{su}$) and the ultimate base resistance ($f_{bu}$) are commonly correlated to Standard Penetration Tests (SPT) ’N’ values as they are extensively carried during subsurface investigation (S.I.) works at the site. Comparisons of the current Malaysian practice are made with EC7 methodologies with some suggested values of partial factors for development of EC7 Malaysian National Annex (MY-NA) for pile foundation under axial compression load, are presented. Finally results of pile load tests are also presented for verification of the suggested EC7 Malaysian National Annex values.

1.0 Introduction

Displacement driven piles, namely spun piles and RC square piles and cast-in-situ bored piles are commonly used in Malaysia as foundation to support for heavily loaded structures such as high-rise buildings and bridges in view of their flexibility of sizes to suit different loads, subsoil conditions and availability of many experienced foundation contractors to carry out the works. This paper presents commonly used design methodologies for driven pile and bored pile foundations in Malaysia. Comparisons are also made with the EC7 methodologies especially on the partial factors to be adopted together with some suggested values for development of EC7 Malaysian National Annex for pile foundations under axial compression loads. Finally results of pile load tests are also presented for verification of suggested EC7 Malaysian National Annex (MY-NA) values.
2.0 Malaysian Conventional Design Practice for Geotechnical Capacity of Piles

2.1 Factor of Safety

In Malaysia, the Factors of Safety (FOS) normally used in static calculation of pile geotechnical capacity are partial FOS on shaft \((F_s)\) and base \((F_b)\) respectively; and the global FOS \((F_g)\) on total capacity. The lower geotechnical capacity obtained from both methods using the following equations is adopted as allowable geotechnical capacity

\[
Q_{ag} = \frac{Q_{su}}{F_s} + \frac{Q_{bu}}{F_b} \quad \text{(eq.1)}
\]

\[
Q_{ag} = \frac{Q_{su}}{F_g} \quad \text{(eq.2)}
\]

Note: Use the lower of \(Q_{ag}\) obtained from eq. 1 and eq. 2 above.

Where:
\(Q_{ag}\) = Allowable geotechnical capacity
\(Q_{su}\) = Ultimate shaft capacity = \(\sum_i (f_{su} \times A_s)\)
\(i\) = Number of soil layers
\(Q_{bu}\) = Ultimate base capacity = \(f_{bu} A_b\)
\(f_s\) = Unit shaft resistance for each layer of embedded soil
\(f_b\) = Unit base resistance for the bearing layer of soil
\(A_s\) = Pile shaft area
\(A_b\) = Pile base area
\(F_s\) = Partial Factor of Safety for Shaft Resistance (generally 1.5)
\(F_b\) = Partial Factor of Safety for Base Resistance (generally 3.0)
\(F_g\) = Global Factor of Safety for Total Resistance (Base + Shaft) generally 2.0

For the general practice in Malaysia, contribution of base resistance in bored piles is ignored due to the difficulty of proper base cleaning especially in wet holes (with drilling fluid). The contribution of base resistance can only be used if it is constructed in shallow dry holes where proper inspection of the base can be carried out, or base grouting is implemented or with fully instrumented preliminary pile loaded to failure and ultimate base capacity verified on site. Therefore, special attention should be given when designing base resistance for bored piles.
2.2 Design of Geotechnical Capacity in Soil

The design of pile geotechnical capacity is divided into two major categories namely:

a) Semi-empirical Method
b) Simplified Soil Mechanics Method

2.2.1 Semi-empirical Method

Piles installed in tropical residual soils are generally complex in soil characteristics. The complexity of these founding mediums with significant changes in ground properties over short distance and the friable nature of the materials make undisturbed sampling and laboratory strength and stiffness testing of the material difficult. Furthermore current theoretically based formulae also do not consider the effect of soil disturbance, stress relief and partial reestablishment of ground stresses that occur during the construction of piles; therefore, the sophistication involved in using such formulae may not be necessary.

Semi-empirical correlations have been extensively developed relating both shaft resistance and base resistance of piles to N-values from Standard Penetration Tests (SPT’N’ values) (Tan & Chow, 2003). In the correlations established, the SPT’N’ values generally refer to uncorrected values before pile installation.

The commonly used correlations for piles are as follows:

\[ f_{su} = K_{su} \times SPT’N’ \text{ (in kPa)} \]
\[ f_{bu} = K_{bu} \times SPT’N’ \text{ (in kPa)} \]

Where:

- \( K_{su} \) = Ultimate shaft resistance factor
- \( K_{bu} \) = Ultimate base resistance factor
- SPT’N’ = Standard Penetration Tests blow counts (blows/300mm)

For shaft resistance of bored piles, Tan et al. (1998), used the results of 13 fully instrumented bored piles in residual soils, presented \( K_{su} \) of 2.6 but limiting the \( f_{su} \) values to 200kPa. Toh et al. (1989) also reported that the average \( K_{su} \) obtained varies from 5 at SPT’N’ 20 to as low as 1.5 at SPT’N’=220. Chang & Broms (1991) suggested \( K_{su} \) of 2 for bored piles in residual soils of Singapore with SPT’N’<150.
For base resistance, $K_{bu}$ values reported by many researchers vary significantly indicating difficulty in obtaining proper and consistent base cleaning during construction of bored piles. It is very dangerous if the base resistance is relied upon when the proper cleaning of the base cannot be assured. From back-analyses of test piles, Chang & Broms (1991) showed that $K_{bu}$ was 30 to 45 and Toh et al. (1989) reports that $K_{bu}$ ranged between 27 and 60 as obtained from the two piles that were tested to failure.

Lower values of $K_{bu}$ between 7 and 10 were reported by Tan et al. (1998). The relatively low $K_{bu}$ values are most probably due to the soft toe effect which is very much dependent on the type of soil, workmanship and pile geometry. This is even more significant in long pile. Furthermore, a relatively larger base movement is required to mobilise the maximum base resistance as compared to the displacement needed to fully mobilise shaft resistance. The base displacement of approximately 5% to 10% of the pile diameter is generally required to mobilise the ultimate base resistance provided that the base is properly cleaned. However in the last few years, there has been a trend of increasing base and shaft resistance factors due to the improvement of machinery used and shorter construction times for each pile.

In view of the large movement required to mobilise the base resistance of bored piles and the difficulty in base cleaning, the authors strongly recommend to ignore the base contribution in the bored pile design unless proper base cleaning can be assured and verified by load tests.

For driven piles, the ultimate shaft resistance factor, $K_{su}$ generally ranges from 2.0 to 3.0 depending on the size of piles, materials of pile, soil strength/stiffness (e.g. SPT’N’ values) and soil type. Commonly $K_{su}$ of 2.5 is used for preliminary design prior to load tests. Ultimate base resistance factors, $K_{bu}$ for driven piles are tabulated in Table 1.

### Table 1  Correlation between ultimate base resistance factor with soil type.

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>$K_{bu}$</th>
<th>REFERENCES</th>
</tr>
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<tbody>
<tr>
<td>Gravels</td>
<td>500 to 600</td>
<td>Authors local experiences</td>
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| Sand               | 400$^{(1)}$ to 450$^{(2)}$ | 1° Decourt (1982)  
2° Martin et al. (1987) |
| Silt, Sandy Silt   | 250$^{(1)}$ to 350$^{(2)}$ | 1° Decourt (1982) for residual sandy silts  
2° Martin et al. (1987) for silt & sandy silt  |
| Clayey Silt        | 200               | Decourt (1982) for residual clayey silt         |
| Clay               | 120$^{(1)}$ to 200$^{(2)}$ | 1° Decourt (1982)  
2° Martin et al. (1987) |

Note: $f_{bu} = K_{bu} \times \text{SPT'}N'$ (in kPa)