Since the implementation of the revised Malaysian Uniform Building By Laws (UBBL) in 2012, two (2) States in Malaysia have gazetted the use of Malaysian Standards on Eurocode (MS EN 1997-1:2012) in replacement of British Standards (BS). Hence, this paper presents the comparisons of the current Malaysian practice (i.e. with reference to BS) with EC7 methodologies, for pile foundation under axial compression load. This paper presents commonly used design methodologies for driven pile and bored pile foundations in Malaysia. In Malaysia, empirical equations to estimate ultimate shaft resistance (f_{su}) and ultimate base resistance (f_{bu}) of piles are commonly correlated to Standard Penetration Tests (SPT) 'N' values as they are extensively carried out during subsurface investigation (SI) works. Particular attention is made on the incorporation of partial safety factors published in the Malaysian National Annex (MY NA) in 2012. Case studies are also presented on the application of EC7 in Malaysian practices for foundation design, to showcase the expected impact of such newly introduced design codes in the Malaysian context.

COMPARISON OF MALAYSIAN PRACTICE (BS) VERSUS EC7 ON THE DESIGN OF DRIVEN PILE AND BORED PILE FOUNDATIONS UNDER AXIAL COMPRESSION LOAD

Shiao-Yun Wong, Shafina Sabaruddin and Yean-Chin Tan

INTRODUCTION

Displacement driven piles, namely spun piles and RC square piles as well as 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 made with EC7 methodologies based on partial factors published in the Malaysian National Annex (MS EN 1997-1:2012 (National Annex)) for pile foundations under axial compression loads.

MALAYSIAN CONVENTIONAL DESIGN PRACTICE FOR GEOTECHNICAL PILE CAPACITY

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 computed from both methods, is adopted as the allowable geotechnical pile capacity.

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 proper base cleaning can be carried out and proven with adequate sampling of drilling fluid at the base prior to concrete placement. Furthermore, it shall be subjected to fully instrumented preliminary pile test loaded to failure or at least up to three (3) times the pile capacity, for the verification of ultimate base resistance.

Design of Geotechnical Capacity in Soil

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

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

Semi-empirical Method

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 variable nature of the materials make characterising 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, 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 and 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' (in kPa) (1)

$f_{bu} = K_{bu} \times$ SPT'N' (in kPa) (2)

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. Meanwhile, Chang and Broms (1991) suggested K_{su} of 2 for bored piles in residual soils of Singapore with SPT'N'<150.

For base resistance of bored pile, 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 proper cleaning of the base cannot be assured. From back-analyses of test piles, Chang and Broms (1991) showed that K_{bu} was 30 to 45 and Toh et al. (1989) reported that K_{bu} ranged between 27 and 60 based on two piles tested to failure.

Meanwhile, 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. 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.

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.

Soil Type	K_{bu}	References
Gravels	500 - 600	Chow and Tan (2009)
Sand	400(1) - 450(2)	(1)Decourt (1982) (2)Martin et al. (1987)
Silt, Sandy Silt	250(1) - 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) - 200(2)	(1)Decourt (1982) (2)Martin et al.(1987)

Simplified Soil Mechanics Methods

Generally, the simplified soil mechanics methods for pile design can be classified into cohesive soils (e.g. clays, silts) and cohesionless soils (e.g. sands and gravels).

Cohesive Soils

The ultimate shaft resistance (f_{su}) of piles in cohesive soils can be estimated based on the undrained shear strength method as follows:

$$f_{su} = \alpha \times s_u \qquad (3)$$

where:

α = adhesion factor

s_u = undrained shear strength (kPa)

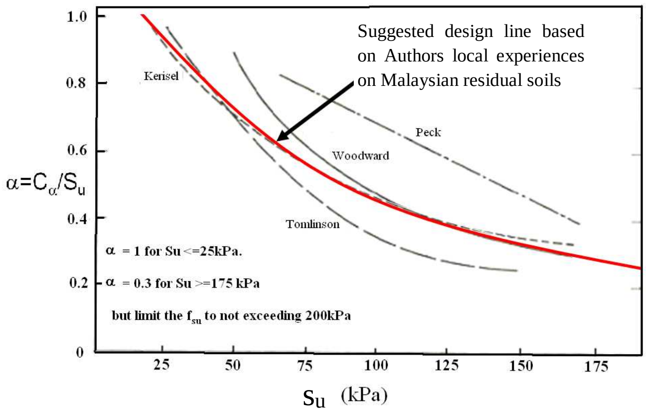
Whitaker and Cooke (1966) reported that the α value lies in the range of 0.3 to 0.6 for stiff over-consolidated clays, while Tomlinson (1994) and Reese and O'Neill (1988) reported α values in the range of 0.4 to 0.9. The α values for residual soils of Malaysia are also within this range as shown in Figure 1. Where soft clay is encountered, a preliminary α value of 0.8 to 1.0 is usually adopted together with the corrected undrained shear strength from the vane shear test (recommended by Bjerrum, 1972, 1973). This total stress α approach is useful if the piles are to be constructed on soft clay near rivers or at coastal areas. The value of α to be used should be verified by preliminary pile load test. Meanwhile, ultimate base resistance for piles in cohesive soil can be related to undrained shear strength as follows:

$$f_{bu} = N_c \times s_u \qquad (4)$$

where:

N_c = bearing capacity factor = 9

Figure 1. Adhesion factors for driven piles in clay (McClelland, 1974)



Cohesionless soils

The ultimate shaft resistance (f_{su}) of bored piles in cohesionless soils can be expressed in terms of effective stresses as follows:

$f_{su} = \beta \times \sigma_v'$ (5)

where:

β = shaft resistance factor for cohesionless soils.

The β values can be obtained from back-analyses of pile load tests. The typical β values of bored piles in loose sand and dense sand are 0.15 to 0.3 and 0.25 to 0.6 respectively, based on Davies and Chan (1981). Meanwhile, the theoretical ultimate base resistance for piles in cohesionless soil can be related to effective stresses as follows:

$f_{bu} = N_q \times \sigma_b'$ (6)

where:

N_q = bearing capacity factor

σ_b' = Effective overburden pressure at pile base (kPa)

Design of Geotechnical Capacity in Rock for Bored Piles

In Malaysia, bored pile design in rocks is mostly based on the semi-empirical method. Generally, the design rock socket friction is a function of surface roughness of a rock socket, unconfined compressive strength of intact rock, confining stiffness around the socket in relation to fractures of rock mass and socket diameter, and the geometry ratio of socket length-to-diameter. However, it is very complicated to quantify all these aspects in the design of rock socket pile. Therefore, based on the conservative approach and local experiences, some semi-empirical methods have evolved to facilitate quick rock socket design with consideration to all these aspects. Table 2 summarises the typical design rock socket friction values for various rock formations in Malaysia.

Table 2. Summary of Rock Socket Friction Design Values

Rock Formation	Working Rock Socket Friction	Source
Limestone	300kPa for RQD < 30% 400kPa for RQD = 30 – 40% 500kPa for RQD = 40 – 55% 600kPa for RQD = 55 – 70% 700kPa for RQD = 70 – 85% 800kPa for RQD > 85% The above design values are subject to 0.05× minimum of {q_{uc}, f_{cu}} whichever is smaller.	Tan & Chow (2009)
Limestone	300kPa for RQD < 25% 600kPa for RQD = 25 – 70% 1000kPa for RQD > 70% The above design values are subject to 0.05× minimum of {q_{uc}, f_{cu}} whichever is smaller.	Neoh (1998)
Sandstone	$0.10 \times q_{uc}$	Thorne (1977)
Shale	$0.05 \times q_{uc}$	Thorne (1977)
Granite	1000 – 1500kPa for q_{uc} > 30N/mm^2	Tan & Chow (2003)

where:

RQD = Rock Quality Designation

q_{uc} = Unconfined Compressive Strength of rock

f_{cu} = Concrete grade

When proper base cleaning and inspection for bored piles can be carried out with verification from instrumented pile tests, base resistance can be considered. The assessment of ultimate end bearing capacity of bored piles in rock can be carried out using the following expression:

$$Q_{ub} = cN_c + \gamma BN_\gamma/2 + \gamma DN_q \quad (7)$$

where:

c	=	Cohesion
B	=	Pile diameter
D	=	Depth of pile base below rock surface
γ	=	Effective density of rock mass
N_c, N_γ & N_q	=	Bearing capacity factors related to friction angle, ϕ (Table 3; for circular case, multipliers of 1.2 & 0.7 shall be applied to N_c & N_γ respectively)
N_c	=	$2N_\phi^{1/2}(N_\phi+1)$ (8)
N_γ	=	$N_\phi^{1/2}(N_\phi^2-1)$ (9)
N_q	=	N_ϕ^2 (10)
N_ϕ	=	$Tan^2(45°+\phi/2)$ (11)

Table 3. Typical Friction Angle for Intact Rock (Wyllie, 1991)

Classification	Type	Friction Angle
Low Friction	Schist (with high mica content), Shale	20° - 27°
Medium Friction	Sandstone, Siltstone, Gneiss	27° - 34°
High Friction	Granite	34° - 40°

Alternatively, the allowable rock bearing pressure can be estimated from the empirical correlation recommended by the Canadian Foundation Engineering Manual (Canadian Geotechnical Society, 1992):

$$q_a = K_{sp} \times q_{u\text{-}core} \quad (12)$$

where

q_a	=	Allowable bearing pressure
$q_{u\text{-}core}$	=	Average unconfined compressive strength of rock
K_{sp}	=	Empirical coefficient, which includes a factor of 3 and ranges from 0.1 to 0.4 (Table 4 for K_{sp} value at respective spacing of discontinuities)

Table 4. Coefficients of Discontinuity Spacing (Canadian Geotechnical Society, 1992)

Spacing of Discontinuities	Spacing Width (m)	K_{sp}
Moderately close	0.3 - 1	0.1
Wide	1 - 3	0.25
Very wide	> 3	0.4

If the pile length is significant (i.e. when pile length exceeding 30m), the contribution of the shaft resistance in the soil embedment above the rock socket should also be considered in the overall pile resistance assessment.

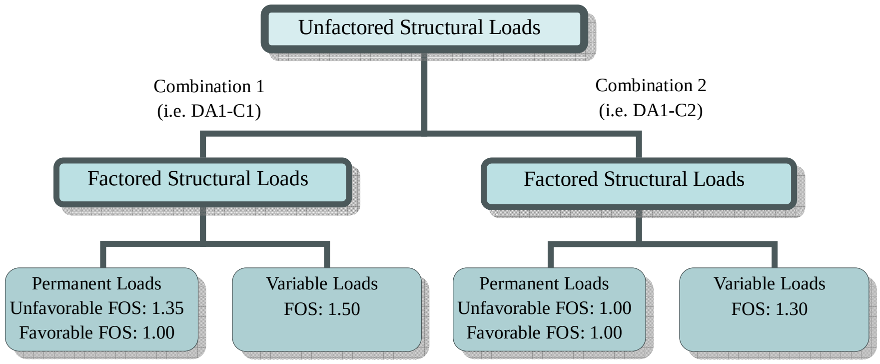
EC7 DESIGN METHODOLOGY FOR GEOTECHNICAL DESIGN OF PILE FOUNDATION UNDER COMPRESSION LOAD IN MALAYSIA

The usage of EC7 in Malaysia for geotechnical design has been introduced in 2012, followed by the publication of Malaysian National Annex in the same year. The following references shall be referred to for detail understanding and application of the newly introduced EC7 methodologies in the Malaysian context:

- BS EN 1997-1:2004, Eurocode 7: Geotechnical design – Part 1: General Rules (Section 7) – (BS EN)
- MS EN 1997-1:2012, Eurocode 7: Geotechnical design – Part 1: General Rules (MS EN)
- Malaysia National Annex to Eurocode 7: Geotechnical design – Part 1: General Rules (MY NA)

EC7 has recommended three (3) Design Approaches (outlined in Cl. 2.4.7.3.4), i.e. Design Approach 1 to 3. The approaches are different in the way they distribute partial factors between actions, effects of actions, material properties and resistances and its selection shall be at individual country's discretion. Malaysia has adopted Design Approach 1 only, i.e. including Combination 1 and 2. The flow chart shows in Figure 2 illustrates the design methodologies in EC7 based on unfactored structural loads.

Figure 2. Flow chart on EC7 design methodology based on unfactored structural loads.



As stated in Cl. 7.4.1 of MS EN, the design of piles shall be based on one of the following methods:

i) the **results of static load tests**, which have been demonstrated, by means of calculations or otherwise, to be consistent with other relevant experience;

ii) **empirical or analytical calculation methods** whose validity has been demonstrated by static load tests in comparable situations;

iii) the **results of dynamic load tests** whose validity has been demonstrated by static load tests in comparable situations;

iv) the **observed performance of a comparable pile foundation**, provided that this approach is supported by the results of site investigation and ground testing.

The most commonly adopted methods in Malaysian practice is by using the empirical or analytical calculation methods, and will be discussed in detail in this paper. The remaining methods will not be covered in this paper and will have to be addressed separately in the future.

Concept of Partial Factors of Safety for Shaft and Base

Complying with the methodology as stated in MS EN, Cl. 7.6.2.3(8), the characteristic values may be obtained by calculating:

$$R_{b;k} = A_b q_{b;k} \quad and \quad R_{s;k} = \sum_i A_{s;i} \bullet q_{s;i;k} \qquad (13)$$

where $q_{b;k}$ and $q_{s;i;k}$ are characteristic values (in kPa) of base resistance and shaft friction in various strata, obtained from values of soil/rock parameters. $R_{b;k}$ and $R_{s;k}$ are characteristic base and cumulative shaft capacity (in kN). The partial factors for base (γ_b) and shaft (γ_s) resistances tabulated in Table 5 should be adopted, while the total/combined partial factor is not applicable, as it is used only when the design pile resistance is obtained from load tests, as stated in Cl. 7.6.2.2, 7.6.2.4, 7.6.2.5 and 7.6.2.6 of MS EN. The summation of $R_{b;k}$ and $R_{s;k}$ would be the final design pile resistance.

In addition to the partial factors adopted for actions, effects of actions, material properties and resistances, a model factor shall be applied to the shaft and base resistance calculated using characteristic values of soil properties. As stated in the MY NA, model factor of either 1.4 or 1.2 shall be applied, in which model factor of 1.2 is only applied if the resistance has been verified by a preliminary (sacrificial) pile subjected to maintained load test, tested to the calculated unfactored ultimate resistance. In other words, when such test is not carried out, model factor of 1.4 shall be applied prior to the application of partial factors for resistance such as base (γ_b) and shaft (γ_s) stated in Table 5.

In order to adopt model factor of 1.2, a maintained load test shall be carried out on a preliminary pile (also known as trial pile in EC7), the requirements as spelt out in Cl. 7.5.1 and 7.5.2 of MS EN shall be adhere to. However, there are no explicit number of test or test load being specified. Therefore, Tan et al. (2010) has recommended a preliminary pile to be load to at least 2.5 times the design load or to failure of the pile, to try to obtain the ultimate resistance of pile for shaft and base, and instrumentation is encouraged to allow proper verification of load-settlement behaviour in shaft and base.

Concept of Pile Verification Under Serviceability Limit State

As shown in Table 5, the recommended partial factor for resistance (i.e. R4 values) in Design Approach 1 Combination 2 has also been differentiated based on the condition of WITH or WITHOUT explicit verification of serviceability limit state (SLS). As recommended by MY NA, explicit verification of SLS could be considered under the following conditions:

(a) if serviceability is verified by static load tests (preliminary and/or working) carried out on more than 1% of the constructed piles to loads not less than 1.5 times the representative load for which they are designed, OR
(b) if settlement is explicitly predicted by a means no less reliable than in (a), OR
(c) if settlement at the serviceability limit state is of no concern.

In addition to the above, MY NA also recommended to refer to ICE (2007) for pile testing strategy based on the characteristics of piling works and the expected risk level. The extracted information from the said ICE publication are shown in Table 6.

Table 5. Summary of Partial Factors for Actions, Soil Materials and Resistance (extracted from MY NA)

			Design Approach 1								
			Combination 1			Combination 2 – piles and anchors					
						WITHOUT explicit verification of SLS			WITH explicit verification of SLS		
			A1	M1	R1	A2	M1	R4	A2	M1	R4
Actions	Permanent	Unfav	1.35			1.00			1.00		
		Fav	1.00			1.00			1.00		
	Variable	Unfav	1.50			1.30			1.30		
Soil	tan ϕ'			1.00			1.00			1.00	
	Effective cohesion			1.00			1.00			1.00	
	Undrained strength			1.00			1.00			1.00	
	Unconfined strength			1.00			1.00			1.00	
	Weight density			1.00			1.00			1.00	
Driven piles	Base				1.0			1.87			1.65
	Shaft (compression)				1.0			1.65			1.43
	Total/combined *(only for pile resistance from load tests)*				1.0			1.87			1.65
Bored piles	Base				1.0			2.20			1.87
	Shaft (compression)				1.0			1.76			1.54
	Total/combined *(only for pile resistance from load tests)*				1.0			2.20			1.87

Table 6. Typical Pile Testing Strategy Based on Risk Levels (extracted from ICE, 2007)

Characteristic of the Piling Works	Risk Level	Pile Testing Strategy
• Complex or unknown ground conditions • No previous pile test data • New piling technique or very limited relevant experience	High	• Both preliminary and working pile tests essential • 1 preliminary pile test per 250 piles • 1 working pile test per 100 piles
• Consistent ground conditions • No previous pile test data • limited experience of piling in similar ground	Medium	• Pile tests essential • Either preliminary and/or working pile tests can be used • 1 preliminary pile test per 500 piles • 1 working pile test per 100 piles
• Previous pile test data is available • Extensive experience of piling in similar ground	Low	• Pile tests essential • If using pile tests either preliminary and/or working pile tests can be used • 1 preliminary pile test per 500 piles • 1 working pile test per 100 piles

Based on the above recommendations and the experiences gained in local practice, Tan et al (2010) has proposed the testing criteria for piles to satisfy items (1) and (2) as stated below, and as summarised in Table 7:

1) Static Load Test (SLT) on Working Piles:

- Load to 1.5 times design load. Acceptable settlement at pile cut-off level should be less than 10% of the pile diameter.(I)
- Acceptable settlement at pile cut-off-level should not exceed 12mm(II) at 1.0 time representative load.
- Acceptable residual settlement at pile cut-off-level should not exceed 6mm(II) after full unloading from 1.0 time representative load.
- To fulfil criteria "***WITH*** explicit verification of SLS", the suggested percentage of constructed piles are listed in Table 7.

Note:

(I) "Failure" criterion adopted in Cl. 7.6.1.1 (3) of MS EN. However, for very long piles, elastic shortening will need to be taken into account as the elastic shortening of the long pile itself may reach 10% of the pile diameter and this scenario, the acceptable

pile settlement shall be defined by the Engineer taking into consideration the intended usage of the structure.
[II] The values are indicated as preliminary guide by Tan et al. (2010). Geotechnical engineers and Structural engineers shall specify the project specific allowable building distortion to suit the intended usage of the structure.

2) (A) High Strain Dynamic Load Test (DLT) on Piles:

- To fulfil criteria "***WITH*** explicit verification of SLS", the suggested percentage of constructed piles subjected to DLT are listed in Table 7[III]

  Note :

  [III] DLT can be omitted if it is technically not suitable to carrying out DLT on the pile (e.g. bored pile solely relies on rock socket, etc). Then more SLT shall be carried out.

  OR

  (B) Statnamic Load Test (sNLT) on Pile :

- To fulfil criteria "***WITH*** explicit verification of SLS", the suggested percentage of constructed piles subjected to sNLT are listed in Table 7[IV]

  Note :

  [IV] sNLT can be omitted if it is technically not suitable to carrying out sNLT on the pile (e.g. bored pile solely rely on rock socket, etc). Then more SLT shall be carried out.

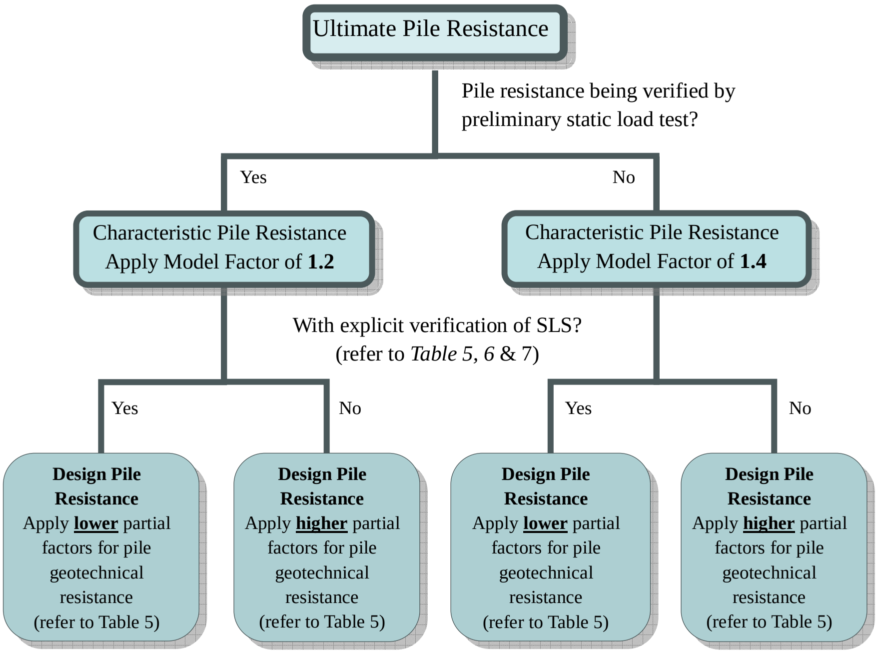
In the event where the percentage of SLT has to be increased or reduced due to the type of foundation system selected or the individual project nature, the required percentage of DLT shall be adjusted accordingly. Table 7 lists the recommended percentage of testing to be carried out on the constructed piles to fulfil the criteria "WITH explicit verification of SLS". The Authors also cross-checked the suggested percentage with 16 project sites that had been successfully completed and randomly selected by the Authors to verified that the recommended percentage is in order.

Table 7. Suggested Percentage (%) of Constructed Piles to be Tested to Fulfil Criteria of "WITH explicit verification of SLS" (Tan et al., 2010)

Options	Percentage (%) of Constructed Piles to be Tested to Fulfil Criteria of "*WITH* explicit verification of SLS"				
	Must Include		Either		Either
	SLT		DLT		sNLT
1	> 0.2%	AND	> 1.0%	OR	≥ 0.5%
2	> 0.1%		> 2.5%		≥ 1.2%
3	> 0.05%		> 5.0%		≥ 2.5%
4 (Especially for bored/barrette pile where its capacity is mainly derived from rock socket friction)	> 0.3%		NIL		NIL
Note: In all cases, the following minimum numbers of SLT shall be carried out: 1. Minimum one (1) number for total piles < 500 numbers. 2. Minimum two (2) numbers for 500 ≤ total piles < 1000 numbers. 3. Minimum three (3) numbers for total piles ≥ 1000 numbers.					

The above EC7 design methodologies has been summarised in a form of flow chart and are shown in Figure 3.

Figure 3. Overall EC7 design methodology in computing design pile resistance.



CASE STUDY ON DRIVEN PILES

Based on the above description on the conversion from existing Malaysian Practice (with reference to British Standard) to the newly implemented EC7 design methodologies, with the latest publication of Malaysian National Annex (MY NA) in 2012, a case study is presented in this paper to demonstrate the potential impact to the current Malaysian Practice in driven pile design. The selected case study is a proposed Neighbourhood Centre consists of retails, sport centre, show gallery and function hall (total building height of 16m) situated at the Johor State in Malaysia, under the Jurong Geological Formation. The adopted pile type is driven reinforced concrete (RC) square pile of 350mm × 350mm.

As shown in the borelog in Figure 4, the subsoil materials consist mainly of sandy/silty CLAY material overlying GRAVELLY material as a thick layer of subsoil with SPT 'N' value more than 50 (i.e. hard layer). Semi-empirical method was used in current driven pile design where the ultimate shaft resistance factor (K_{su}) adopted was 2.5 and the ultimate base resistance factor (K_{bu}) adopted was 250. With that, the actual computation of the cumulative ultimate shaft resistance and cumulative base resistance are shown in Figure 4, where the details on the adopted formulae are shown in Eq. 1 and 2 of this paper.

Comparisons of the equivalent design pile resistance are shown in Table 8, where six (6) possible combinations of partial factors (for load and resistance) and model factors (either 1.2 or 1.4) are clearly listed, for preliminary design purposes. Such summary table facilitates obvious comparisons of the computed Design Pile Resistance based on the existing Malaysian Practice and the newly implemented EC7 design methodologies.

For the purpose of this case study, the ratio of structural permanent load and variable load is assumed as 80:20 distribution, which represents the load distribution in most of the residential and commercial buildings. In the event with the structure is constructed for special usage, where the load distribution is not 80:20, separate assessment and comparisons shall be carried out to reflect the actual impact.

As shown in Table 8, the benefit of conducting a preliminary (sacrificial) test pile with maintained load test is very obvious, where model factor can be reduced from 1.4 to 1.2, and the computed equivalent design pile resistance would increase. Furthermore, if sufficient working piles were tested (i.e. compliance with the recommended frequency of testing in MY NA, Tables 6 and 7), the equivalent design pile resistance would increase by up to 29% as compared to the design pile resistance calculated based on the current Malaysian Practice. Such significant increase in design pile resistance would provide more cost effective foundation system while pile performance could also be verified with the recommended numbers of preliminary and working test piles. On the other hand, in the event where no preliminary test pile (i.e. model factor 1.4) are conducted and insufficient working test piles are carried out, the equivalent design pile resistance would reduce by at least 3%, as compared to the design pile resistance calculated based on the current Malaysian Practice. In other words, EC7 design methodology emphasises on the importance of design verification which is generally known as good engineering practice and allows optimisation in design when adequate verification are carried out. Such approach not only provides a more cost effective design but also encourage more prudent engineering design.

Figure 4. Subsoil borelog and computation of ultimate shaft and base resistance for driven pile case study.

Pile No/Group	**BH3**		
Pile Type	**Square**		
Pile Size	**0.35 m**		
f_s factor (for SPT)	**2.50**		
Limiting Friction, f_{slim}	**150 kN/m^2**		
Pile Working Load	945.0 kN	Reduced Level of Pile Toe(m)	
Total Pile Penetration	13.60 m	-3.70 m	
	44.62 ft		

SUBSURFACE INFORMATION AND SHAFT FRICTION CALCULATION

RL (m)	Thickness t (m)	SPT N_{ave}	S_u	α	Friction $f_{s(kPa)}$	Perimeter P (m)	+/-	$Q_s=f_s*P*t$ (kN) Positive	Negative
9.9	◄ Piling Platform Level							**Positive**	**Negative**
	2.9 *	8			20.0	1.40	+	**81.2**	
7									
	5.0	1			2.5	1.40	+	**17.5**	
2									
	1.0	1			2.5	1.40	+	**3.5**	
1									
	1.5	4			10.0	1.40	+	**21.0**	
-0.5									
	1.5	8			20.0	1.40	+	**42.0**	
-2									
	1.5	24			60.0	1.40	+	**126.0**	
-3.5									
	0.2	115			150.0	1.40	+	**42.0**	
-6.5									
						Total Ultimate Shaft Friction :		**333.2 kN**	**.0 kN**

*Note: Well compacted backfill layer from RL9.9 - RL7

Base Capacity

Limiting Base, f_{blim}	17,500 kN/m^2
SPT N of Pile Toe	115
Pile Toe Area	0.122500 m^2
Base Resistance Factor	250
Ultimate Base Resistance	**2,143.8 kN**

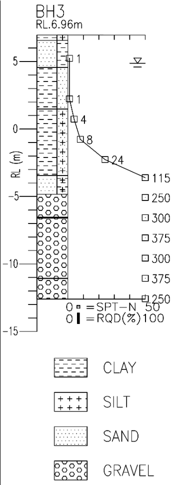


Table 8: Comparisons of EC7 Design Methodologies and Malaysian Practice for driven pile case study.

	Based on MS EN and MY NA						**Based on Current Malaysian Practice**
	Design Approach 1						
	Combination 1		Combination 2				
			WITHOUT explicit verification of SLS		WITH explicit verification of SLS		
Model Factor	1.20	1.40	1.20	1.40	1.20	1.40	-
Characteristic Shaft Resistance (kN)	277.7	238.0	277.7	238.0	277.7	238.0	-
Characteristic Base Resistance (kN)	1786.5	1531.3	1786.5	1531.3	1786.5	1531.3	-
Partial FOS for Shaft Friction, FOS_{PS}	1.00	1.00	1.65	1.65	1.43	1.43	1.5
Partial FOS for Pile Base, FOS_{PB}	1.00	1.00	1.87	1.87	1.65	1.65	3.0
Global FOS, FOS_{GLOBAL}	1.00	1.00	1.87	1.87	1.65	1.65	2.0
Design Pile Resistance (kN)	2064.1	1769.3	1123.6	963.1	1276.9	1094.5	936.7
Permanent Load Factor	1.35	1.35	1.00	1.00	1.00	1.00	1.00
Variable Load Factor	1.50	1.50	1.30	1.30	1.30	1.30	1.00
Structural Dead Load Ratio	0.80	0.80	0.80	0.80	0.80	0.80	-
Structural Live Load Ratio	0.20	0.20	0.20	0.20	0.20	0.20	-

Additional FOS due to Load Factor	1.38	1.38	1.06	1.06	1.06	1.06	-
Equivalent Design Pile Resistance (kN)	**1495.7**	**1282.1**	**1060.0**	**908.6**	**1204.6**	**1032.5**	**936.7**
Ratio over Conventional Method	1.60	1.37	1.13	0.97	1.29	1.10	-

CASE STUDY ON BORED PILES

Similar to driven piles the comparison of Design Pile Resistance for bored piles are also presented in this paper to demonstrate the potential impact to the current Malaysian Practice in bored pile design. The selected case study is a proposed 33-storey commercial building situated in Kuala Lumpur under the Hawthornden Geological Formation. The adopted pile type is 1200mm diameter bored pile.

As shown in the borelog in Figure 5, the subsoil material consist mainly of sandy SILT material. Semi-empirical method was used in current driven pile design where the ultimate shaft resistance factor (K_{su}) adopted was 2.0 and the ultimate base resistance factor (K_{bu}) adopted was 40, with SPT 'N' value at base being limited to 50. The detail computation of the cumulative ultimate shaft resistance and base resistance are shown in Figure 5.

Figure 5. Subsoil borelog and computation of Ultimate Shaft and Base Resistance for Bored Pile Case Study.

Pile No/Group	**BH3**	
Pile Type	**Circular**	
Pile Size	**1.20 m**	
f_s factor (for SPT)	**2.00**	
Limiting Friction, f_{slim}	**250 kN/m^2**	
Pile Working Load	11,000.0 kN	Reduced Level of Pile Toe(m)
Total Pile Penetration	36.00 m	58.00 m
	118.11 ft	

SUBSURFACE INFORMATION AND SHAFT FRICTION CALCULATION

RL (m)	Thickness t (m)	SPT N_{ave}	S_u	α	Friction $f_{s(kPa)}$	Perimeter P (m)	+/-	$Q_s=f_s*P*t$ (kN) Positive	Negative
94	◄ Piling Platform Level							Positive	Negative
	4.5	7			14.0	3.77	+	237.5	
89.5									
	1.5	18			36.0	3.77	+	203.6	
88									
	3.0	100			200.0	3.77	+	2,261.9	
85									
	4.5	75			150.0	3.77	+	2,544.7	
80.5									
	22.5	105			210.0	3.77	+	17,812.8	
54									
					Total Ultimate Shaft Friction :			23,060.5 kN	.0 kN

Base Capacity	
Limiting Base, f_{blim}	17,500 kN/m^2
SPT N of Pile Toe	50
Pile Toe Area	1.130973m^2
Base Resistance Factor	40
Ultimate Base Resistance	**2,261.9 kN**

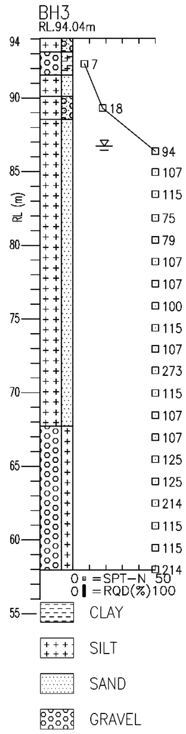


Table 9: Comparisons of EC7 Design Methodologies and Malaysian Practice for Bored Pile Case Study

	Based on MS EN and MY NA						**Based on Current Malaysian Practice**
	Design Approach 1						
	Combination 1		Combination 2				
			WITHOUT explicit verification of SLS		WITH explicit verification of SLS		
Model Factor	1.20	1.40	1.20	1.40	1.20	1.40	-
Characteristic Shaft Resistance (kN)	19,217.1	16,471.8	19,217.1	16,471.8	19,217.1	16,471.8	-
Characteristic Base Resistance (kN)	1,885	1,615.7	1,885	1,615.7	1,885	1,615.7	-
Partial FOS for Shaft Friction, FOS_{PS}	1.00	1.00	1.76	1.76	1.54	1.54	1.5
Partial FOS for Pile Base, FOS_{PB}	1.00	1.00	2.20	2.20	1.87	1.87	3.0
Global FOS, FOS_{GLOBAL}	1.00	1.00	2.20	2.20	1.87	1.87	2.0
Design Pile Resistance (kN)	21,102.1	18,087.5	11,775.6	10,093.4	13,486.6	11,560.0	12,661.2
Permanent Load Factor	1.35	1.35	1.00	1.00	1.00	1.00	1.00
Variable Load Factor	1.50	1.50	1.30	1.30	1.30	1.30	1.00
Structural Dead Load Ratio	0.80	0.80	0.80	0.80	0.80	0.80	-
Structural Live Load Ratio	0.20	0.20	0.20	0.20	0.20	0.20	-
Additional FOS due to Load Factor	1.38	1.38	1.06	1.06	1.06	1.06	-
Equivalent Design Pile Resistance (kN)	**15,291.4**	**13,106.9**	**11,109.1**	**9,522.1**	**12,723.2**	**10,905.7**	**12,661.2**
Ratio over Conventional Method	1.208	1.035	0.88	0.75	1.005	0.86	-

Comparisons of the equivalent design pile resistance between the existing Malaysian Practice and the newly implemented EC7 design methodologies are shown in Table 9. As shown in Table 9, the computed equivalent design pile resistance would obviously increase when model factor reduces from 1.4 to 1.2, i.e. when preliminary test piles were conducted. However, due to high partial factors recommended for bored piles in MY NA, the equivalent design pile resistance based on EC7 design methodologies would be reduced by 12% - 25%, as compared to the design pile resistance calculated based on the current Malaysian Practice, especially when inadequate working piles are tested. Meanwhile, if both preliminary pile and sufficient working piles were tested, the equivalent design pile resistance would be similar to that derived based on the current Malaysian Practice. Similar observations were made in Balakrishnan (2014). Hence, similar to driven piles, EC7 design methodology for bored piles emphasise on the importance of design verification as well.

However, it is in the opinion of the Authors that there are still room for improvement in the current recommended partial factors in the MY NA and more preliminary and working pile tests should be conducted to further rationalise the recommended FOS in the current MY NA for bored pile design. This is to encourage the implementation of either preliminary test pile or adequate working test piles as a form of design verification, while controlling increase in foundation cost which might lead to increase in material wastage.

CONCLUSIONS

This paper presents the Malaysian design methodologies for driven pile and bored pile foundations and the conversion to EC7 design methodologies. When preliminary test piles were conducted, coupled with sufficient working test piles, the design pile resistance would increase by 29% for the selected case study on driven piles, and increase by 0.5% for the selected case study on bored piles, as compared to the design pile resistance calculated based on the current Malaysian Practice. In other words, EC7 design methodology emphasises on the importance of design verification and allows optimisation in design when adequate verifications are carried out. Such approach not only provides a more cost effective design but also encourages more prudent engineering design.

However, due to high partial factors recommended for bored piles in MY NA, the equivalent design pile resistance based on EC7 design methodologies would be reduced, as compared to the design pile resistance calculated based on the current Malaysian Practice, when no adequate working piles are tests. It is in the opinion of the Authors that there are still room for improvement in the current recommended partial factors in the MY NA and more preliminary and working pile tests should be conducted to further rationalise the recommended FOS in the current MY NA for bored pile design. This is to encourage the implementation of either preliminary test pile or adequate working test piles as a form of design verification, while controlling increase in foundation cost which might lead to increase in material wastage.

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