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

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- Introduction
- Malaysian Practice for Pile Geotechnical Design
- EC7 Design Methodology for Geotechnical Design of Pile Foundation Under Compression Load in Malaysia
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INTRODUCTION

INTRODUCTION

PETRONAS TWIN TOWER-BORED PILE

PLATINUM PARK – BORED PILE

PENANG BRIDGE-DRIVEN PILE

INTRODUCTION

- Displacement driven pile and bored pile commonly used in Malaysia due to:
  - Flexibility of sizes to suit the load
  - Subsoil conditions
  - Availability of many experienced foundation contractor

INTRODUCTION

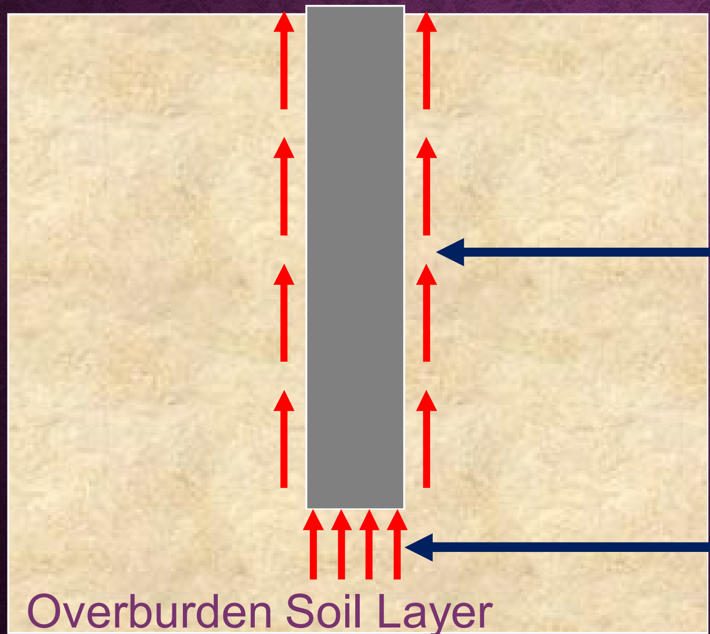
This paper presents:

- Commonly used design methodologies for bored pile and driven pile in Malaysian context (British Standard, BS)
- EC7 method, based on partial factors published in the Malaysian National Annex, MY NA (MS EN 1997-1:2012 (National Annex))
- Comparison between the commonly used Malaysian (BS) approach and EC7
- Pile foundations design under Axial Load only

MALAYSIAN PRACTICE FOR PILE GEOTECHNICAL DESIGN

PILE GEOTECHNICAL CAPACITY

$$Q_u = Q_{su} + Q_{bu}$$



Q_u = ultimate bearing capacity

Q_{su} = shaft friction

Q_{bu} = end bearing

PILE GEOTECHNICAL CAPACITY

$$Q_u = \underbrace{f_{su}.A_s}_{Q_{su}} + \underbrace{f_{bu}.A_b}_{Q_{bu}}$$

Q_u = Ultimate bearing capacity of the pile

f_{su} = shaft resistance

A_s = surface area of shaft

f_{bu} = base resistance

A_b = cross sectional area of pile base

FACTOR OF SAFETY (FOS)

- Partial FOS on Shaft (F_s) and Base (F_b)
- Global FOS (F_g) on total capacity
- The lower allowable geotechnical capacity from above will be adopted

PARTIAL FOS

Partial FOS for shaft & base capacities respectively

- For shaft, use 1.5 (typical)
- For base, use 3.0 (typical)
- $$Q_{all} = \frac{\Sigma Q_{su}}{1.5} + \frac{Q_{bu}}{3.0}$$

GLOBAL FOS

Global FOS for total ultimate capacity

- Use 2.0 (typical)
- $$Q_{all} = \frac{\Sigma Q_{su} + Q_{bu}}{2.0}$$

PILE GOTECHNICAL DESIGN

Calculate ultimate pile geotechnical resistance (Qsu, Qbu) using

a) semi-empirical method

or

b) simplified soil mechanics method

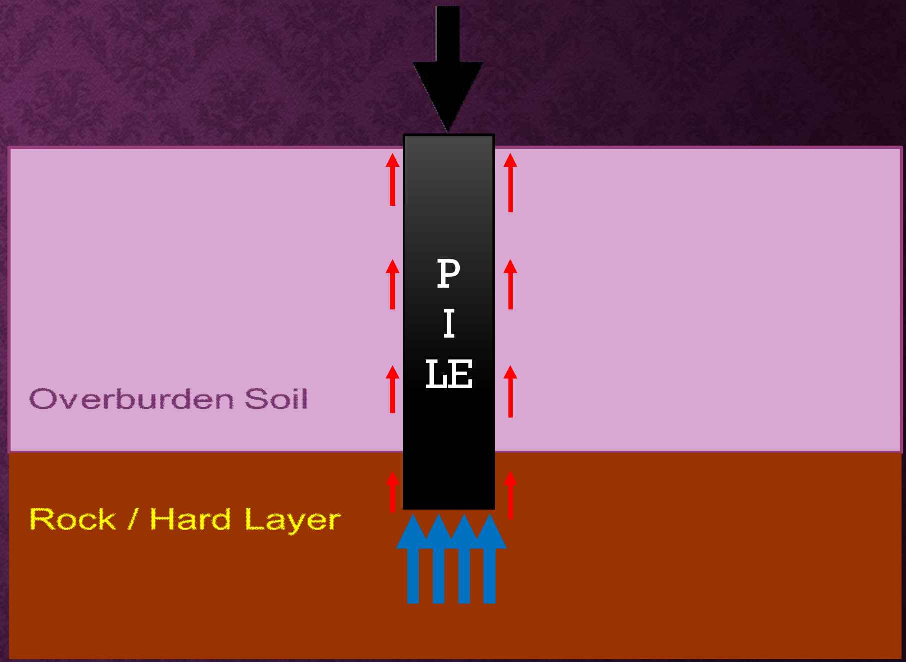
(i.e. effective stress method)

a) Semi Empirical Method

a) Semi-empirical Method

- Extensively developed for:
  1. Shaft Resistance
  2. Base Resistance

- Relating to SPT N values from Standard Penetration Test



Semi-empirical Method - Shaft resistance

- Shaft Resistance, $f_{su} = K_{su}$ x SPT 'N' (in kPa)

Where,

K_{su} = Ultimate Shaft resistance factor

SPT 'N' = Standard Penetration Test blow counts (blows/300mm)

Semi-empirical Method - Shaft resistance

<u>Driven Piles</u>

- K_{su} ranges from 2.0 to 3.0

(depending on the size of piles, materials of piles, soil strength/stiffness (eg. SPT 'N' values) and soil types)

- Commonly 2.5 is used before load tests

a)Semi-empirical Method - Shaft resistance

Bored Piles

- Tan et al. (1998) K_{su} = 2.6 but limited to 200kPa
- Toh et al. (1989) K_{su} = from 5 at SPT 'N'=20

  K_{su} = as low as 1.5 at SPT 'N' = 220
- Chang and Broms (1991) K_{su} = 2 for SPT 'N' < 150 for residual soils of Singapore

a) Semi-empirical Method - Base Resistance

- Base Resistance, $f_{bu} = K_{bu}$ x SPT 'N' (in kPa)

Where,

K_{bu} = Ultimate Base resistance factor

SPT 'N' = Standard Penetration Test blow counts (blows/300mm)

a) Semi-empirical Method-Base Resistance

Driven Piles

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)

a) Semi-empirical Method - Base resistance

Bored Piles

- Vary significantly due to difficulty in ensuring proper and consistent base cleaning during construction

- Dangerous if rely on base resistance while proper cleaning cannot be assured

a) Semi-empirical Method - Base resistance

Bored Piles

- Tan et. Al (1998) K_{bu} = between 7 and 10
- Toh et. Al (1989) K_{bu} = between 27 and 60
- Chang and Broms (1991) K_{bu} = 30 to 45

a) Semi-empirical Method – Bored Pile in Rock

- Rock socket friction is a function of:

1. Surface roughness of rock socket
2. Unconfined compressive strength of intact rock
3. Confining stiffness around the socket
4. Geometry ratio of socket length-to-diameter

- However, semi-empirical methods has evolved to facilitate quick rock socket design, based on local experience

a) Semi-empirical Method – Bored Pile in Rock

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)**

a) Semi-empirical Method – Bored Pile in Rock

Where,

- RQD = Rock Quality Designation
- q_{uc} = Unconfined Compressive Strength of Rock
- f_{cu} = Concrete grade

a) Semi-empirical Method – Bored Pile in Rock

- Base resistance can be considered if:

a) proper base cleaning and inspection for bored pile can be carried

b) verification from instrumented test pile

a) Semi-empirical Method – Bored Pile in Rock

- Allowable rock bearing pressure by Canadian Foundation Engineering Manual (Canadian Geotechnical Society, 1992)
  - $q_a = K_{sp} \times q_{u\text{-}core}$

where

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

a) Semi-empirical Method – Bored Pile in Rock

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**

a) Semi-empirical Method – Bored Pile in Rock

- For long pile, contribution of shaft resistance in the soil above the rock socket should be considered

b) Simplified Soil Mechanics Method

b) Simplified Soil Mechanics Method

- Classified into:

a) Cohesive Soils (eg. CLAY, SILT)

b) Cohesionless Soil (SAND, GRAVEL)

b) Simplified Soil Mechanics Method - Cohesive Soil

<u>Ultimate Shaft Resistance</u>

$$f_{su} = \alpha \text{ x } s_u$$

Where,

α = adhesion factor

s_u = undrained shear strength (kPa)

b) Simplified Soil Mechanics Method - Cohesive Soil

- Whitaker and Cooke (1966) , α lies between 0.3 to 0.6

(for stiff over-consolidated clay)

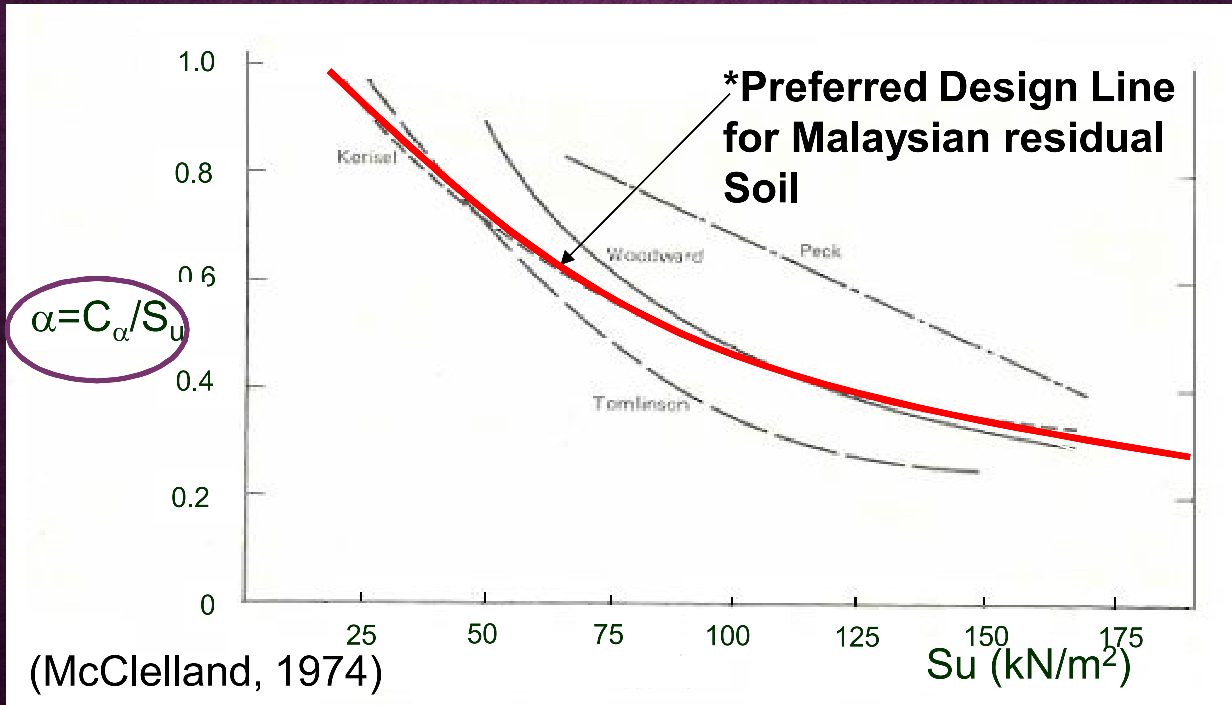
- Tomlinson (1994), Reese and O'Neill (1988) , α in the range of 0.4 to 0.9

- Bjerrum (1972, 1973) , α between 0.8 to 1.0

(used with the corrected undrained shear strength from the vane shear test)

b) Simplified Soil Mechanics Method - Cohesive Soil

Adhesion factor (α) for driven piles



*Tan et al. (2009)

b) Simplified Soil Mechanics Method - Cohesive Soil

Ultimate Base Resistance

$$f_{bu} = N_c \text{ x } s_u$$

Where,

N_c = bearing capacity factor = 9

s_u = undrained shear strength (kPa)

b) Simplified Soil Mechanics Method - Cohesionless Soil

Ultimate Shaft Resistance

$$f_{su} = \beta \times \sigma_v'$$

Where,

β = shaft resistance factor

σ_v' = effective stress (kPa)

b) Simplified Soil Mechanics Method - Cohesionless Soil

Ultimate Shaft Resistance

- β values can be obtained from back-analysed pile load test

- Typical values for bored piles (Davies and Chan (1981)):

  Loose sand, 0.15 to 0.3

  Dense sand, 0.25 to 0.6

b) Simplified Soil Mechanics Method - Cohesionless Soil

<u>Ultimate Base Resistance</u>

$$f_{bu} = N_q \times \sigma_b'$$

Where,

N_q = bearing capacity factor

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

b) Simplified Soil Mechanics Method – Bored Pile in Rock

- Bearing capacity of bored piles in rock:

$$Q_{ub} = cN_c + \gamma BN_\gamma/2 + \gamma DN_q$$

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

b) Simplified Soil Mechanics Method – Bored Pile in Rock

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°**

b) Simplified Soil Mechanics Method – Bored Pile in Rock

- N_c = $2N_\phi^{1/2}(N_\phi+1)$
- N_γ = $N_\phi^{1/2}(N_\phi^2-1)$
- N_q = N_ϕ^2
- N_ϕ = $Tan^2(45^\circ+\phi/2)$

Note: For circular case, multiplier of 1.2 shall be applied to N_c
multiplier of 0.7 shall be applied to N_γ

Commonly…

- Based on Semi Empirical Method

$$Q_{all} = \frac{\Sigma Q_{su}}{1.5} + \frac{Q_{bu}}{3.0}$$

$$Q_{all} = \frac{\Sigma Q_{su} + Q_{bu}}{2.0}$$

Whichever is LOWER

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

EC7 DESIGN METHODOLOGY

Introduced in 2012 with publication of Malaysian National Annex

Reference:

- 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 DESIGN METHODOLOGY

- EC7 recommends 3 Design Approaches

- Approaches different in partial factors between :

a) Actions

b) Material properties

c) Resistance

- Selection is at Country's Discretion

EC7 DESIGN METHODOLOGY

Malaysia has adopted Design Approach 1 (DA1) only:

- Combination 1 (C1)
- Combination 2 (C2)

EC7 DESIGN METHODOLOGY

Unfactored Structural Loading

- Combination 1 (i.e. DA1-C1)
  - **Factored Structural Loading**
    - Permanent Load
      - Unfavorable FOS: 1.35
      - Favorable FOS: 1.00
    - Variable Load
      - FOS: 1.50
- Combination 2 (i.e. DA1-C2)
  - **Factored Structural Loading**
    - Permanent Load
      - Unfavorable FOS: 1.00
      - Favorable FOS: 1.00
    - Variable Load
      - FOS: 1.30

EC7 DESIGN METHODOLOGY

Cl. 7.4.1 of MS EN, design based on one of the following methods:

- the **results of static load tests,** which have been demonstrated, by means of calculations or otherwise, to be consistent with other relevant experience;
- **empirical or analytical calculation methods** whose validity has been demonstrated by static load tests in comparable situations;
- the **results of dynamic load tests** whose validity has been demonstrated by static load tests in comparable situations;
- the **observed performance of a comparable pile foundation**, provided that this approach is supported by the results of site investigation and ground testing.

Concept Of Partial Factors Of Safety For Shaft And Base

- Based on MS EN, Cl. 7.6.2.3(8), the characteristic values :

$$R_{b;k} = A_b q_{b;k} \text{ and } R_{s;k} = \sum A_{s;i} \,.\, q_{s;i;k}$$

where

$q_{\mathrm{b;k}}$,$q_{\mathrm{s};i;\mathrm{k}}$ = characteristic values (in kPa) of base resistance and shaft friction

A_b , $A_{s;i}$ = base area under pile and pile shaft surface area in layer *i*

$R_{\mathrm{b;k}}$,$R_{\mathrm{s;k}}$ = characteristic base and cumulative shaft capacity (in kN).

Concept Of Partial Factors Of Safety For Shaft And Base

- Based on MS EN, Cl. 7.6.2.3(3), the design compressive resistance of pile,

$$R_{c;d} = R_{b;d} + R_{s;d}$$

where

$R_{b;d} = R_{b;k} / \gamma_b$

$R_{s;d} = R_{s;k} / \gamma_s$

γ_b , γ_s = Partial factor for base and shaft (refer to Table 5)

Concept Of Partial Factors Of Safety For Shaft And Base

- total/combined partial factor is not applicable

- 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.

TABLE 5 SUMMARY OF PARTIAL FACTORS FOR ACTION (A), SOIL MATERIALS (M) AND RESISTANCE (R) 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

Concept Of Partial Factors Of Safety For Shaft And Base

- MODEL FACTOR to be applied to SHAFT and BASE in addition to the partial factors
- Based on MY NA , Model Factor =1.2 or 1.4
- If resistance is verified by:

1.preliminary/trial (sacrificial) pile subjected to maintained load test

2.tested to the calculated unfactored ultimate resistance

Model Factor 1.2

- If no such test carried out

Model Factor 1.4

Concept Of Partial Factors Of Safety For Shaft And Base

- No explicit number of test and tested load been specified
- Tan et al. (2010) has recommended the trial pile to be loaded at least 2.5 x design load, or to failure
- Tan et al. (2010) recommended to try to obtain ultimate pile resistance of pile for shaft and base
- Instrumentation is encourages for proper verification of load-settlement behavior

Concept Of Pile Verification Under Serviceability Limit State (SLS)

- Recommended partial factor for resistance in DA1CA2 has been differentiated between WITH and WITHOUT explicit verification of SLS

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		Fav	1.00			1.00			1.00		
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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	
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Concept Of Pile Verification Under Serviceability Limit State (SLS)

Explicit SLS could be considered :

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.

Concept Of Pile Verification Under Serviceability Limit State (SLS)

- MY NA refer to ICE (2007) for pile test strategy based on risk level

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

Concept Of Pile Verification Under Serviceability Limit State (SLS)

Tan et al. (2010) proposed testing criteria to satisfy Item 1) and 2) below:

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

- Load to 1.5 times design load. Acceptable settlement should ⩽10% of the pile diameter.(I)
- Acceptable settlement ⩽12mm(II) at 1.0 time representative load.
- Acceptable residual settlement ⩽ 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.

Concept Of Pile Verification Under Serviceability Limit State (SLS)

- (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.

Concept Of Pile Verification Under Serviceability Limit State (SLS)

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

- To fulfil criteria "***<u>WITH</u>*** 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

Concept Of Pile Verification Under Serviceability Limit State (SLS)

2) (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 (e.g. bored pile solely rely on rock socket, etc). Then more SLT shall be carried out.

Concept Of Pile Verification Under Serviceability Limit State (SLS)

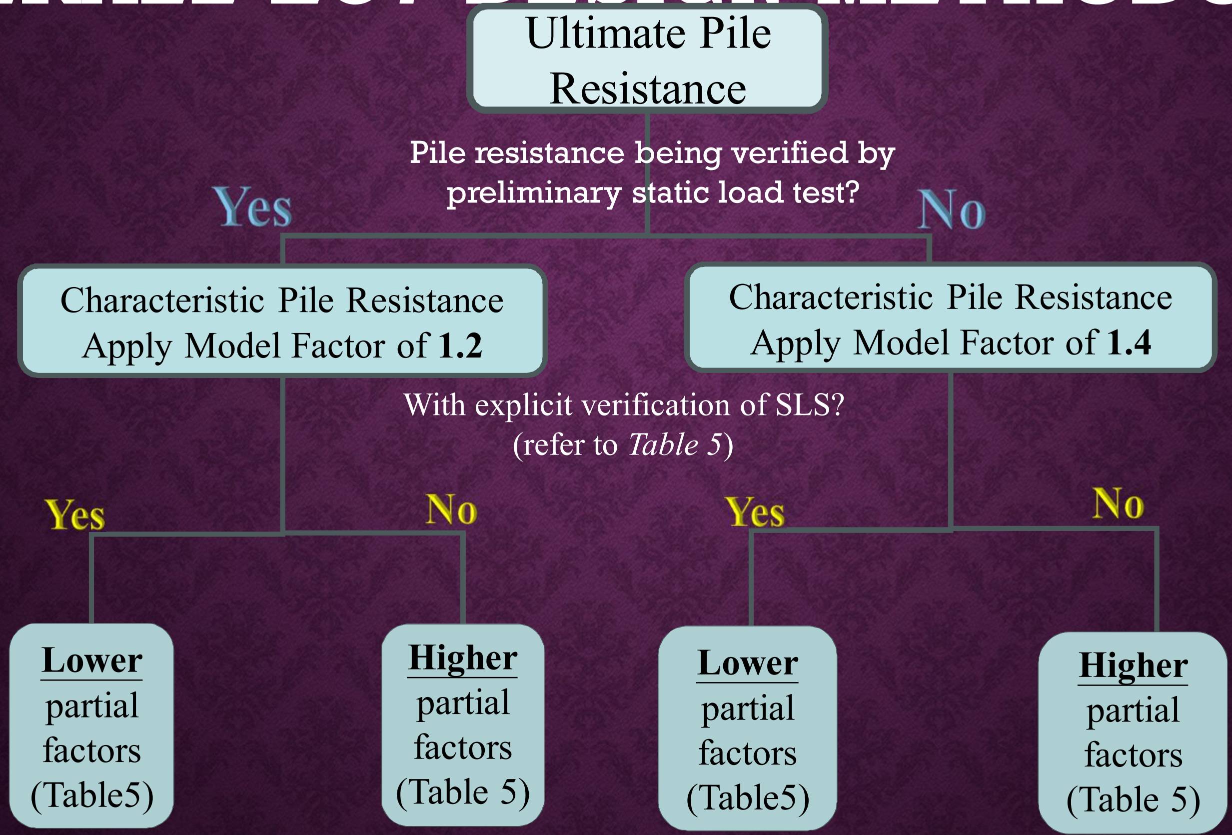
TABLE 7 Options	Percentage (%) of Constructed Piles to be Tested to Fulfil Criteria of "*WITH* explicit verification of SLS"				
	Must Include		Either		Either
	SLT		DLT		sNLT
1	> 0.2%	AND	> 1.0%	OR	≥ 0.5%
2	> 0.1%		> 2.5%		≥ 1.2%
3	> 0.05%		> 5.0%		≥ 2.5%
4 (Especially for bored/barrette pile where its 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.

(Tan et al.,2010)

OVERALL EC7 DESIGN METHODOLOGY



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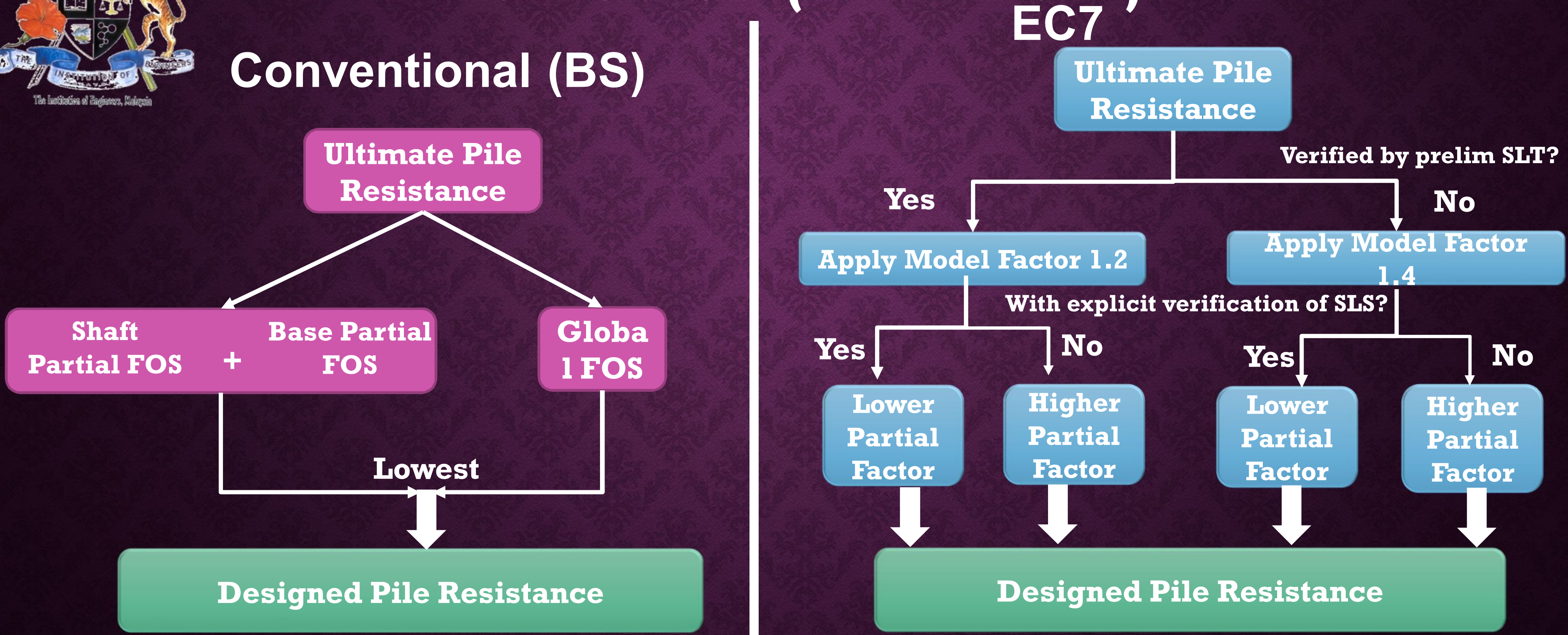
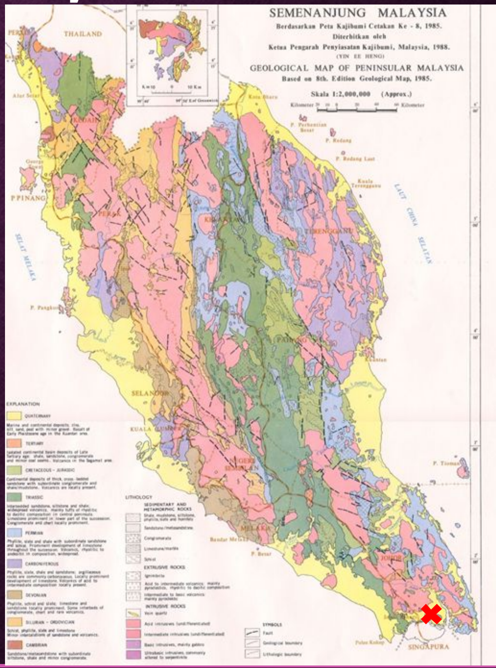
BS VS EC7 (MALAYSIA)



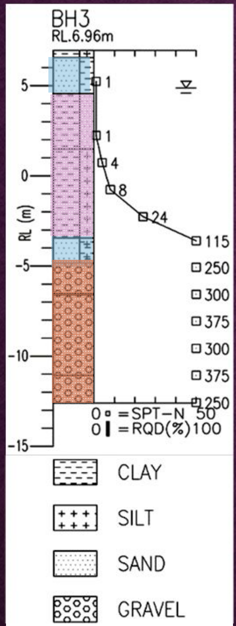
CASE STUDY ON DRIVEN PILE

CASE STUDY ON DRIVEN PILE

- Proposed Neighbourhood Center (retails, sport center, show gallery and function hall), Johor, Malaysia
- Total building height 16m
- Geological Formation : Jurong Fomation (sedimentary)
- Pile type: Reinforced Concrete (RC) Square Pile
- Pile size : 350mm x 350mm



CASE STUDY ON DRIVEN PILE



Pile No/Group	BH3
Pile Type	Square
Pile Size	0.35 m
f_s factor (for SPT)	2.50
Limiting Friction, f_{slim}	150.0 kN/m2
Pile Working Load	945.0 kN
Total Pile Penetration	13.60 m
	44.62 ft
Reduced Level of Pile Toe(m)	-3.70 m
Net Allowable Geotechn Pile Capacity (EC7)	1,251.0 kN

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								
	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

Base Capacity	
Limiting Base, f_{blim}	17,500 kN/m2
SPT N of Pile Toe	115
Pile Toe Area	0.122500 m2
Base Resistance Factor	250
Ultimate Base Resistance	2,143.8 kN

Ultimate Skin Friction, Q_{su} = 333.2kN

Ultimate Base Resistance, Q_{bu} = 2,143.8kN

CASE STUDY ON DRIVEN PILE

Q_{su} = 333.2kN

Q_{bu} = 2,143.8kN

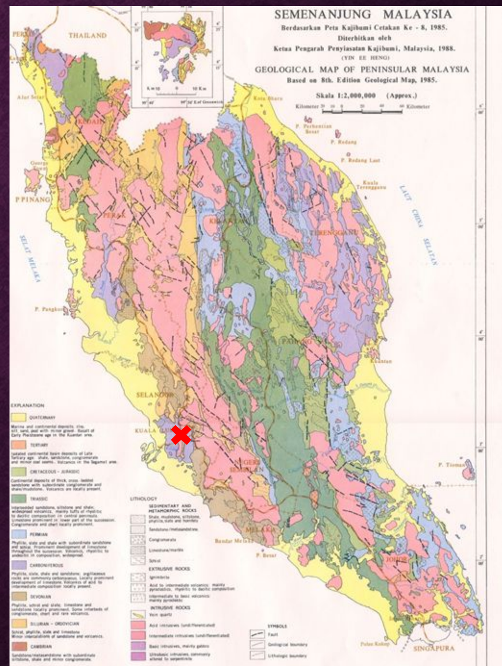
	Based on MS EN and MY NA						Based on Current Malaysian Practice
	Design Approach 1						
	Combination 1		Combination 2				
			WITHOUT explicit verification of SLS		WITH explicit verification of SLS		
Model Factor	1.20	1.40	1.20	1.40	1.20	1.40	-
Characteristic Shaft Resistance (kN)	277.7	238.0	277.7	238.0	277.7	238.0	-
Characteristic Base R[illegible] (kN)	1786.5	1531.3	1786.5	1531.3	1786.5	1531.3	-
Partial FOS fo[illegible]	1.00	1.00	1.65	1.65	1.43	1.43	1.5
Partial FO[illegible]	1.00	1.00	1.87	1.87	1.65	1.65	3.0
Glob[illegible]	NOT CONSIDERED AS DESIGN IS BASED ON GROUND TEST RESULT						2.0
Design P[illegible]	2064.1	1769.3	1123.6	963.1	1276.9	1094.5	936.7
Permanen[illegible]	1.35	1.35	1.00	1.00	1.00	1.00	1.00
Variable Load [illegible]	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	-

80: 20 is common load distribution for commercial and residential

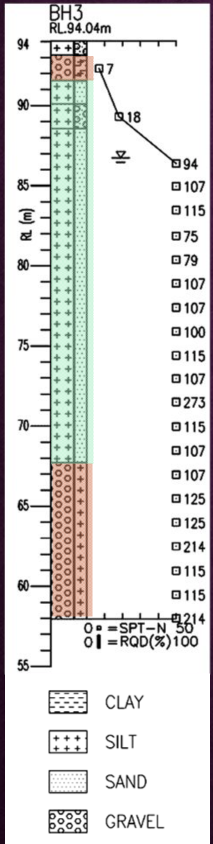
CASE STUDY ON BORED PILE

CASE STUDY ON BORED PILE

- Proposed commercial building, Kuala Lumpur, Malaysia
- 33-storey building
- Geological Formation : Hawthornden
- Pile type: Bored Pile
- Pile size : 1200mm diameter



CASE STUDY ON BORED PILE



Pile No/Group	BH3		
Pile Type	Circular		
Pile Size	1.20 m		
f_s factor (for SPT)	2.00		
Limiting Friction, f_{slim}	300.0 kN/m2		
			Net Allowable Geotechnic Pile Capacity (EC7)
Pile Working Load	11,000.0 kN	Reduced Level of Pile Toe(m)	
Total Pile Penetration	36.00 m	58.00 m	11,284.5 kN
	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								
	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/m2
SPT N of Pile Toe	50
Pile Toe Area	1.130973 m2
Base Resistance Factor	40
Ultimate Base Resistance	2,261.9 kN

Ultimate Skin Friction, Q_{su} = 23,060.5kN

Ultimate Base Resistance, Q_{bu} = 2,261.9kN

CASE STUDY ON BORED PILE

Q_{su} = 23,060.5kN

Q_{bu} = 2,261.9kN

	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	[illegible]	[illegible]	[illegible]	-
Characteristic Base Resistance (kN)	1,885	1,615.7	1,885	[illegible]	[illegible]	[illegible]	-
Partial FOS for Shaft Friction, FOS_{PS}	1.00	1.00	1.76	[illegible]	[illegible]	[illegible]	1.5
Partial FOS for Pile Base, FOS_{PB}	1.00	1.00	2.20	2.20	[illegible]	1.87	3.0
Global FOS, FOS_{GLOBAL}	NOT CONSIDERED AS DESIGN IS BASED ON GROUND [illegible]						2.0
Design Pile Resistance (kN)	21,102.1	18,087.5	11,775.6	10,093.4	[illegible]	[illegible]	12,661.2
Permanent Load Factor	1.35	1.35	1.00	1.00	[illegible]	[illegible]	1.00
Variable Load Factor	1.50	1.50	1.30	1.30	[illegible]	[illegible]	1.00
Structural Dead Load Ratio	0.80	0.80	0.80	0.80	[illegible]	[illegible]	-
Structural Live Load Ratio	0.20	0.20	0.20	0.20	[illegible]	0.20	-
Additional FOS due to Load Factor	1.38	1.38	1.06	1.06	[illegible]	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	-

Similar if both with preliminary and sufficient working pile tests

CONCLUSION

CONCLUSION - DRIVEN PILE

- Design methodology based on BS vs EC7 for driven and bored piles are presented
- Based on case study ,with prelim test and sufficient working pile test :

Driven piles, design pile resistance 29% with EC7 compared to conventional

Bored piles, design pile resistance 0.5% with EC7

CONCLUSION - BORED PILE

- Due to high partial factors recommended by MY NA, equivalent design pile resistance based on EC7 when no adequate working piles are tested compared to current Malaysian Practice.
- Still room for improvement on the partial factors recommended in the MY NA
- More prelim test and working pile tests to be conducted to rationalize the recommended FOS in the MY NA
- Encourage the prelim pile test or adequate working pile tests as a form of design verification
- To manage increase in foundation cost which may lead to increase in material wastage

CONCLUSION

- EC7 emphasize on importance of design verification
- EC7 allows optimization in design when adequate verification is carried out
- Cost effective
- Encourage more prudent engineering design

THANK YOU

QUESTION AND ANSWER