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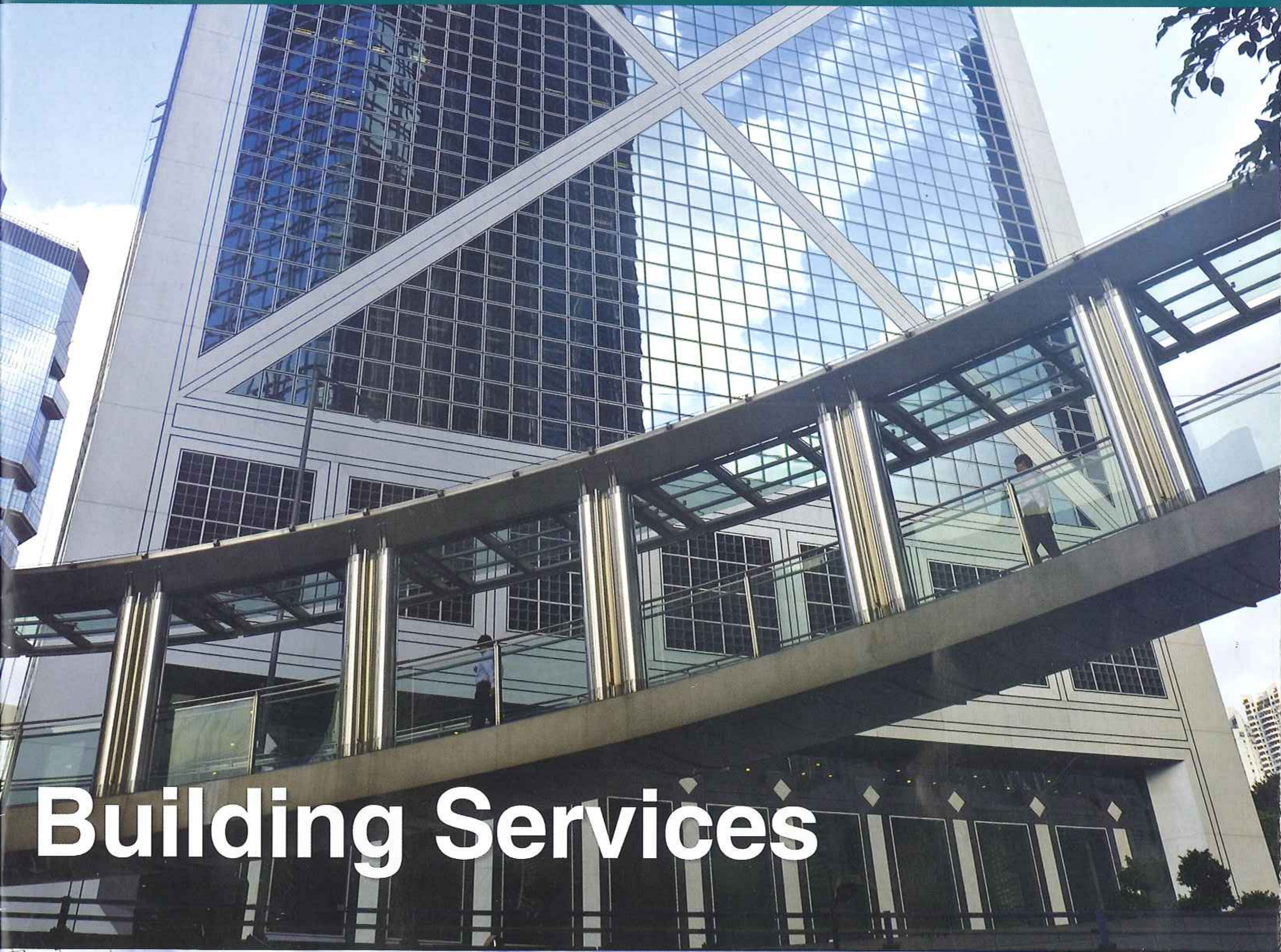

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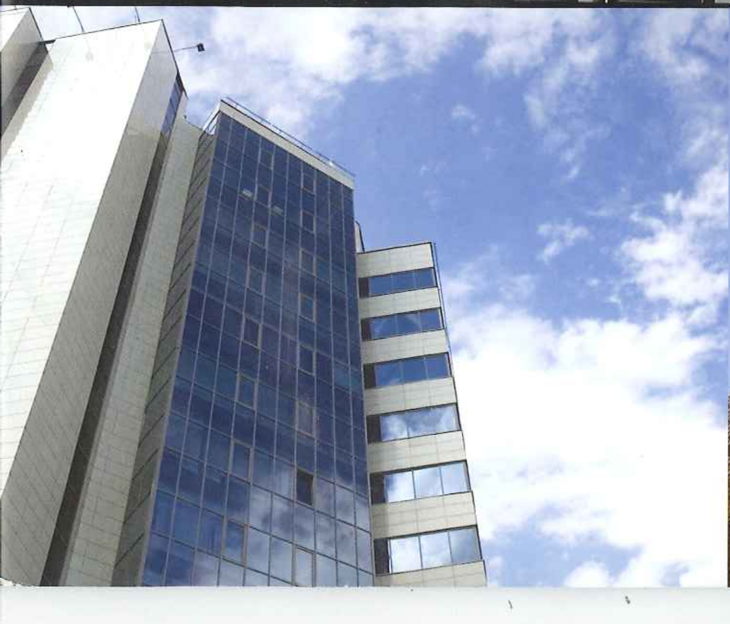

Development of EC7 Malaysian Annex on the Design of Pile Foundations Under Axial Compression Load

by *Ir. Tan Yean Chin*

ABSTRACT: *Conventional geotechnical design of pile foundations under axial compression load had generally been successfully implemented in Malaysia for the last 50 years due to intrinsic conservatism in the practice that ensure safety. Despite its success, there are still room for improvement especially on the specific requirements on testing (e.g. type of tests, % of tests, test load etc), factor of safety on shaft and base, serviceability requirements of the pile (e.g. pile displacement under working load, etc). Taking advantage of the development of pile analysis and design methodologies together with improvements in construction and testing technologies, further refinement to the pile design should be carried out which fulfil the following in priority : public safety, construction friendly, cost effectiveness, and less wasteful in line with sustainable development. The introduction of EN1997 Eurocode 7: Geotechnical Design (EC7) has presented a framework for geotechnical design based on limit state principles. Malaysia design codes which rely on mainly on British design codes will be affected after withdrawal of some of the British design codes. As such, Malaysia has to formulate appropriate National Annex which suits Malaysian local conditions when applying EC7. In view of the need to formulate Malaysian National Annex (MY-NA), it is very important that proper processes shall be carried out when drafting the MY-NA to incorporate necessary refinements to the pile design and testing requirements so that our practice is in line with good local and international practice. In this paper, suggestions on partial factors and model factors for MY-NA to be used in conjunction with EC7 for the pile design under axial compression loads based on current Malaysian experiences are presented together with recommendations for further refinements on the design and testing of pile.*

1. INTRODUCTION

Geotechnical design of pile foundations in Malaysia is traditionally based on working state principles with estimation of pile allowable capacity based on semi-empirical method. The factors of safety (FOS) normally used in static calculation of allowable pile geotechnical capacity are partial FOS on shaft (F_s) and base (F_b) respectively, and global FOS (F_g) on total capacity. The lower geotechnical capacity obtained from both methods using the following equations is adopted as the allowable pile geotechnical capacity:

$$Q_{ag} = \frac{Q_{su}}{F_s} + \frac{Q_{bu}}{F_b} \qquad (1)$$

$$Q_{ag} = \frac{Q_{su} + Q_{bu}}{F_g} \qquad (2)$$

Note: Malaysian practice use the lower of Q_{ag} obtained from Equation 1 and Equation 2 above. However in EC7, the designer is allowed to choose either one of the equations 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 = $f_{bu} \times A_b$
f_{su} = Unit shaft resistance for each layer of embedded soil
f_{bu} = 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

The evaluation of shaft resistance and base resistance is commonly based on semi-empirical method based on correlations to N-values from Standard Penetration Tests (SPT 'N' values):

f_{su} = K_{su} x SPT'N' (in kPa)
f_{bu} = K_{bu} x SPT'N' (in kPa)

Tan & Chow, 2003, Tan *et al.*, 2009 and Chow & Tan, 2009 discuss some of the commonly adopted design approaches in Malaysia.

Despite the conventional geotechnical design of pile foundations under axial compression load had generally been successfully implemented in Malaysia for the last 50 years due to intrinsic conservatism in the practice (*e.g.* sometimes applying higher Factor of Safety) to ensure safety, there are still room for improvement especially on the specific requirements on testing (*e.g.* type of tests, % of tests, test load *etc*), factor of safety on shaft and base, serviceability requirements of the pile (*e.g.* pile displacement under working load, *etc*). Taking advantage of the development of pile analysis and design methodologies together with improvements in construction and testing technologies, further refinement to the pile design should be carried out which fulfil the following in priority : public safety, construction friendly, cost effectiveness, and less wasteful in line with sustainable development. The introduction of EN1997 Eurocode 7: Geotechnical Design (EC7) has presented a framework for geotechnical design based on limit state principles. Malaysia design codes which rely on British design codes will be affected after withdrawal of some of the British design codes. As such, Malaysia has to formulate appropriate National Annex which suits Malaysian local conditions when applying EC7. In view of the need to formulate Malaysia National Annex (MY-NA), it is very important that proper processes shall be carried out when drafting the MY-NA to incorporate necessary refinements to the pile design and testing requirements so that our practice is in line with good local and international practice. In this paper, suggestions on partial, correlation and model factors used in conjunction with Design Approach 1 of "alternative procedure" as per Clause 7.6.2.3 (8) of EC7 for the pile design under axial compression loads based on current Malaysian experience are presented together with recommendations for further refinements on the design and testing of pile.

2. CONCEPT FOR APPLICATION OF EC7 TO LOCAL PRACTICE

2.1 General Approach

The application of EC7 to local practice should take into consideration the following aspects:

a) Comparison with local practice on adopted factors of safety (FOS). The National Annex based on principles of EC7 should be calibrated with local practice to ensure smooth transition to EC7.
b) Adopt the EC7 concept of encouraging pile tests at site to verify and calibrate design value instead of relying only on high FOS in the design. This is safer and less wasteful (sustainable development).
c) Review of current local practice on pile testing requirements and compare with pile testing requirements of EC7 to ensure consistency. Incorporate the development and improvement on pile design such as serviceability limit state check (*e.g.* pile displacement prediction and verification, *etc*)
d) Clear distinction between partial factors on resistance for shaft and base which are mobilised at different magnitudes of displacement respectively.
e) Calibration of partial factors with actual case histories/ load test results.

2.2 Suggested Approach for Development of Malaysian Annex

To ensure smooth transition to EC7, the followings are the main criteria that require rationalisation and harmonisation for application of EC7 in Malaysia for geotechnical design of pile foundations under compression load (Tan *et al.*, 2009):

a) Sufficient actual projects data (*e.g.* design vs actual pile tests results, % of different pile tests carried out vs total numbers of working piles constructed, *etc.*) shall be collected and reviewed before finalising the values in the National Annex.
b) In EC7, if more piles are tested at site, it is allowed to use slightly lower partial factors or model factors in design (which lead to slightly lower design FOS). This approach still ensures public safety through actual pile tests at site to verify the design values.
c) The partial factors should be in line with current partial factor of safety (FOS) on shaft (F_s), base (F_b) and global FOS (F_g) on total capacity that are extensively accepted and used in Malaysia.
d) There should be a clear distinction between the partial factor of safety for shaft and base which are mobilised at different magnitude of displacement.
e) Requirements for pile testing especially static and dynamic load tests on preliminary piles (sacrificial piles) to be loaded to failure and also working piles to be loaded to a designed test load.
f) The adoption of the similar range of Model Factor as in United Kingdom's National Annex (UK-NA).
g) The suggested partial factors need to be verified with actual case histories to review the reliability of the sug-

gested values. More case histories are needed before the values of partial factors for Malaysian National Annex is finalised.

h) Complying to methodology outlines in EN1997-1, 7.6.2.3(8) where the characteristic values may be obtained by:

$$R_{b;k} = A_b \, q_{b;k} \text{ and } R_{s;k} = \sum_i A_{s;i} \cdot q_{s;i;k} \qquad (3)$$

where

$q_{b;k}$ and $q_{s;l;k}$ are characteristic values (in kPa) of base resistance and shaft friction in the various strata, obtained from values of soil/rock parameters. $R_{b;k}$ and $R_{s;k}$ are characteristic base and cumulative shaft resistance (in kN).

Note: In order to apply this procedure, the values of the partial factors for resistance such as base (γ_b), shaft (γ_s) and combined (γ_t) may need to be corrected by a model factor in which UK-NA recommends a value of 1.4, except that it may be reduced to 1.2 if the resistance is verified by a maintained load test taken to the calculated, unfactored ultimate resistance (*e.g.* calculated failure load). The concept of allowing two values for model factor in UK-NA shall be incorporated into Malaysian Annex if we were to use the same methodology so that it complies to the fundamental concept of UK-NA which encourages preliminary pile test at site.

EC7 also covers other methodologies as follows:

- 7.6.2.2: Ultimate compressive resistance from static load tests.
- 7.6.2.3: Ultimate compressive resistance from ground test results (except 7.6.2.3(8)).
- 7.6.2.4: Ultimate compressive resistance from dynamic impact tests.
- 7.6.2.5: Ultimate compressive resistance by applying pile driving formulae.

These methodologies had not been used in Malaysia and will not be discussed in this paper. The Author does not rule out the application of these methodologies in Malaysia in the future, however when drafting MY-NA, careful evaluation shall be carried out to and compare with statistics of current practice.

Based on the above concepts, different sets of partial factors are suggested for driven pile, bored pile and jack-in pile. Even though jack-in pile can be categorised as displacement pile which is the same as driven pile, there is notable differences in the behaviour of jack-in pile compared to traditional driven pile which warrants a separate sets of partial factors. Chow & Tan (2009 and 2010) discuss some of the observed behaviour of jack-in pile and its effect to pile design.

3. SUGGESTED PARTIAL FACTORS FOR MALAYSIAN NATIONAL ANNEX OF EC7 FOR PILE FOUNDATIONS UNDER COMPRESSION LOAD

Based on the general concept outlined, Table 1 summarises the partial factors for actions, soil materials and resistance suggested for Malaysian National Annex (MY-NA) to EC7 for driven piles, bored piles and jack-in piles (Tan *et. al.*, 2009). Tables 2 and 3 list the partial factors on resistance from EC7 Annex A and UK-NA respectively for easy comparison of the readers.

Generally, partial factors for actions and soil materials suggested for Malaysian National Annex (MY-NA) follow the UK National Annex. The only suggested changes are on the partial factors for resistance. The partial factors suggested for resistance will be in line conceptually with the Malaysian's conventional Factor of Safety (FOS) on shaft (F_s) and base (F_b) and the global FOS (F_g) on total capacity. It is also suggested that model factor values of 1.4 and 1.2 same as UK-NA are to be used as this is an improvement to current practice as it encourages preliminary test pile at site.

In line with EC7 UK-NA, if design and testing fulfil the requirement of "WITH explicit verification of SLS" (further discussion in Section 4), lower partial factors

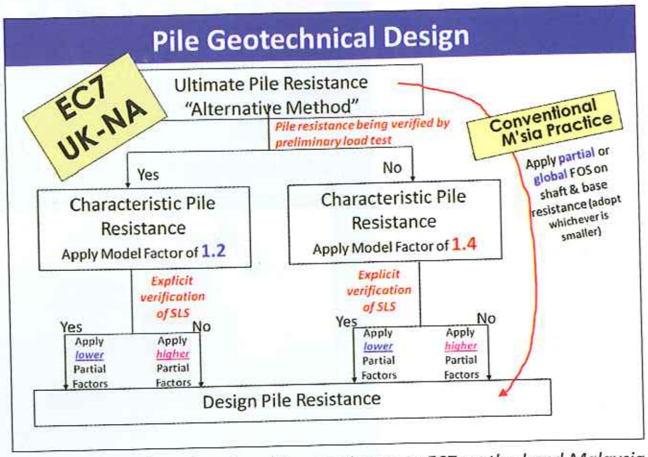

Figure 1: Flow chart showing difference between EC7 method and Malaysia conventional method

can be adopted. In summary, this is in line with good engineering practice and concept of EC7 allowing slightly lower partial factors and model factors with more pile load tests at site.

A simplified flow chart is shown in Figure 1 to show the difference in design methodology between EN1997-1 Cl.7.6.2.3(8) UK-NA and conventional Malaysian practice.

The partial factors for driven piles and jack-in piles are essentially the same as in Table 1. The main difference between driven piles and jack-in piles is in the suggested model factor. For jack-in pile, the model factor suggested is generally lower with value of 1.3 and 1.1 if the resistance is verified by static load tests taken to the ultimate resistance. The main rationale behind the lower model factor is based on EC7's principles which allow lower partial factors if testing on preliminary piles to ultimate resistance is carried out on site to verify the load capacity. This is evident from the reduction of model factor from 1.4 to 1.2 if there is a preliminary pile static load test which is loaded to unfactored ultimate resistance (*e.g.* failure load).

As such, lower model factor for jack-in piles are suggested for MY-NA based on the following considerations :-

a) Every jack-in pile during installation is jacked (loaded) to two (2) times the design load or more, and held for 30 seconds to record settlement for at least two (2) cycles and this is similar to carrying out a "static" load test in a very short holding time. Despite it being not exactly the same as a static load test, the quality control and verification of load capacities for jack-in piles is more rigorous and more assured compared to other pile types (*e.g.* driven piles, bored piles and micropile) which are not "test loaded" during installation. Therefore, the suggested model factor value should be smaller than that of driven piles and bored piles in line with the concept of EC7 allowing lower model factors with more testing.

b) For consistency in design, it is suggested that the partial factors for resistance (shaft, base and combined) in jack-in piles should follow those of driven piles when adopting design approach outlined in EN1997-1, 7.6.2.3(8). This is because both driven and jack-in piles are generally

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Table 1: Summary of partial factors for actions, soil materials and resistance suggested for Malaysian National Annex (MY-NA) EN1997-1:2004

			Design Approach 1								
			Combination 1			Combination 2 – Piles					
						WITHOUT explicit verification of Serviceability Limit State (SLS)[A)]			WITH explicit verification of Serviceability Limit State (SLS)[A)]		
			A1	M1	R1	A2	M1	R4	A1	M1	R4
Actions	Permanent	Unfavorable	1.35			1.00 standard for Project			1.00		
		Favorable	1.00			1.00			1.00		
	Variable	Unfavorable	1.50			1.30			1.30		
Soil	tan ϕ'			1.50			1.00			1.00	
	Effective cohesion			1.50			1.00			1.00	
	Undrained strength			1.50			1.00			1.00	
	Unconfined strength			1.50			1.00			1.00	
	Weight density			1.50			1.00			1.00	
Driven piles or Jack-in piles[B)]	Base				1.10			1.9			1.8
	Shaft (compression)				1.0			1.5			1.0
	Total / combined				1.05			1.6			1.3
Bored piles	Base				1.2*			2.2*			1.8*
	Shaft (compression)				1.0			1.5			1.1
	Total / combined				1.1			1.6			1.4(1.3)**

[A)] The lower partial factor of safety in R4 may be adopted
- a) if serviceability is verified by static load tests (preliminary and/or working) carried out on in accordance with the pile testing criteria listed in Table 4, 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

A ***model factor*** should be applied to the shaft and base resistance calculated using characteristic values of soil properties by a method complying with EN1997-1, 2.4.1(6). The value of the ***model factor*** should be 1.4, except that it may be reduced to 1.2 if the resistance is verified by a static load test taken to the calculated, unfactored ultimate resistance. (To follow NA to BS EN 1997-1:2004)

* For bored pile design, the base resistance is ignored (not included in calculation) unless for bored pile constructed in dry hole, or with base grouting, or with fully instrumented preliminary pile loaded to failure and ultimate base capacity verified on site.

** Partial factors for Total/Combined capacity of bored pile can be reduced to 1.3 if base is ignored in the calculation of the total/combined capacity.

[B)] For Jack-in Piles, model factor should be applied to shaft and base resistance calculated using characteristic values of soil properties by a method complying with EN1997-1, 2.4.1(6). The value of the model factor should be 1.3, except that it may be reduced to 1.1 if the resistance is verified by static load tests taken to the calculated, unfactored ultimate resistance.

In order to qualify using a lower model factor of 1.2 and 1.1 for driven and jack-in piles respectively, a preliminary (sacrificial) pile should be subjected to a static load test (SLT) taken to the calculated, unfactored ultimate resistance as follows:
- a) Load to at least 2.5 times the design load or to the failure of the pile to try to obtain ultimate resistance of pile for shaft and base and to determine settlement characteristic of the pile.
- b) Instrumentation is encouraged to allow proper verification of load-settlement behaviour in shaft and also base.
- c) Without SLT on preliminary pile to verify ultimate resistance, a Model Factor of 1.4 and 1.3 for driven and jack-in piles should be used instead.

Irrespective of design approach, proper and sufficient pile load verification tests should be carried out such as static load tests, dynamic load tests and sonic logging (for bored piles) to verify the acceptance of the pile.

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displacement type of pile foundations and base capacity will not be reduced due to disturbance as in bored piles. However, the ultimate shaft resistance and base capacity for jack-in piles are often higher compared to driven piles (Chow & Tan, 2010).

Irrespective of which design approach is adopted in the design of piles, sufficient and properly planned subsurface investigation (S.I.), including field and laboratory tests, should be carried out to obtain representative subsoil conditions and parameters. Proper full time supervision of S.I. is also important to increase confidence levels in the information obtained. The Board of Engineers Malaysia (BEM) has issued a circular titled "Engineer's Responsibility for Subsurface Investigation" in 2005 which reminded all professional engineers that they are responsible for planning and supervision of the S.I. to be used in their design (in which they act as Submitting Engineer). Failure to do so contravenes the Part IV, Code of Professional Conduct of the Registration of Engineers Regulation (1990) (Amendment 2003) and calls for disciplinary action under the Registration of Engineers Act, Malaysia.

3. PILE TESTING REQUIREMENTS AND ITS INFLUENCE ON DESIGN IN EC7

EC7 in principal encourages verification of designed value (*e.g.* analysed and calculated working load, failure load) with pile load tests. Generally if more pile tests are being carried out at site, EC7 allows slightly lower partial factors or model factors in design (which lead to slightly lower design FOS but verified through actual testing at site which ensures safety).

The major differences between Annex A in EC7 and UK-NA are the partial factors used for shaft, base and also total/combined resistance (capacity). UK-NA introduces lower partial factors if there is *"With explicit verification of Serviceability Limit State (SLS)"* with the following requirements:

a) if serviceability is verified by 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 UK-NA, there is a condition in Tables A.NA.6 to A.NA.8 "Set R4" which listed different partial factors on resistance for "With explicit verification of SLS" and "Without explicit verification of SLS".

After reviewing the requirements stated in "With explicit verification of SLS" of UK-NA, the comments by Author are as follows :

a) Requirements to carry out load tests on more than 1% of the constructed piles are generally on the high side

Table 2: Summary of partial factors for actions, soil materials and resistance extracted from EN1997-1:2004 Annex A

		Design Approach 1						
		Combination 1			Combination 2 – Piles			
		A1	M1	R1	A2	M1 or	M2	R4
Driven piles	Base			1.00				1.30
	Shaft (compression)			1.00				1.30
	Total / combined			1.00				1.30
Bored piles	Base			1.25				1.60
	Shaft (compression)			1.00				1.30
	Total / combined			1.15				1.50

A ***model factor*** should be applied to the shaft and base resistance calculated using characteristic values of soil properties by a method complying with EN1997-1, 2.4.1(6). The value of the ***model factor*** should be 1.4, except that it may be reduced to 1.2 if the resistance is verified by a static load test taken to the calculated, unfactored ultimate resistance. (extracted from NA to BS EN 1997-1:2004 page 11)

Table 3: Summary of partial factors for actions, soil materials and resistance extracted from UK National Annex EN1997-1:2004 (UK-NA)

		Design Approach 1 UK-NA								
		Combination 1			Combination 2 – Piles and anchors					
					WITHOUT explicit verification of SLS[A)]			WITHOUT explicit verification of SLS[A)]		
		A1	M1	R1	A2	M1	R4	A1	M1	R4
Driven piles	Base			1.00			1.70			1.50
	Shaft (compression)			1.00			1.50			1.30
	Total / combined			1.00			1.70			1.50
Bored piles	Base			1.25			2.00			1.70
	Shaft (compression)			1.00			1.60			1.40
	Total / combined			1.15			2.00			1.70

[A)] The lower partial factor of safety in R4 may be adopted
a) if serviceability is verified by 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

A ***model factor*** should be applied to the shaft and base resistance calculated using characteristic values of soil properties by a method complying with EN1997-1, 2.4.1(6). The value of the ***model factor*** should be 1.4, except that it may be reduced to 1.2 if the resistance is verified by a static load test taken to the calculated, unfactored ultimate resistance. (extracted from NA to BS EN 1997-1:2004 page 11)

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for commercial and residential buildings constructed in Malaysia based on Author's experience. This percentage may be applicable to bridges and viaducts foundation (*e.g.* linear type project where the ground likely to vary along the alignment).

b) The proposed test load of 1.5 times the representative load (*e.g.* working load) stated in UK-NA instead of 2.0 times commonly practiced in Malaysia is technically better. This is because if the pile is designed to FOS of 2.0, by test loading the pile to 2.0 times the working load is like loading the pile to designed failure load (which theoretically should fail the pile if prediction is correct causing the pile not usable anymore). In the development of pile design, serviceability limit state (SLS) is being emphasised thus it is important to control the displacement of the pile under one working load and residual settlement other than knowing the failure load. Load the pile to 1.5 times working load should be sufficient to ensure safety if the SLS requirements are complied. However, engineer should be allowed to specify higher test load for working pile to suit their design and site conditions.

c) In MY-NA, it is also important to provide guidelines on the acceptable displacement for working load, residual displacement after unloading, displacement to be considered to have reached failure load, etc. However, flexibility should be given to the project specific requirements on the displacement of the pile under different loading conditions.

The recommended MY-NA requirements to fulfil "WITH explicit verification of SLS" for piles under compression load should satisfy items (1) and (2) stated below

1) **Static Load Test (SLT) on Working Pile:**
   a) Load to 1.5 times design load. Acceptable settlement at pile cut-off level should be less than 10% of the pile diameter.(I)
   b) Acceptable settlement at pile cut-off level should not exceed 12.5mm(II) at 1.0 times the representative load.
   c) Acceptable residual settlement at pile cut-off level should not exceed 6.5mm(II) after full unloading from 1.0 times the representative load.
   d) To fulfil criteria "With explicit verification of SLS" (as described in Table 1), the percentage (%) of constructed piles listed in Table 4 should be subjected to SLT (minimum one (1) pile).

Note:
(I) EC7, 7.6.1.1 (3) states "For piles in compression it is often difficult to define an ultimate limit state from a load settlement plot showing a continuous curvature. In these cases, settlement of the pile top equal to 10% of the pile base diameter can be adopted as the "failure" criterion". 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 in this scenario, the ultimate load should be defined by the Engineer taking into consideration the intended usage of the structure.

(II) The values indicated serve as a preliminary guide. Geotechnical Engineer and Structural Engineer should specify the project-specific allowable settlement at 1.0*Working Load (WL) and residual settlement to suit the buildings and structures to be supported by the pile.

2) **(A) High Strain Dynamic Load Test (DLT) on Pile:**
   a) To fulfil the criterion "With explicit verification of SLS", a minimum percentage (%) of constructed piles listed in Table 4 should be subjected to DLT.(III)

Note:
(III) DLT can be omitted if it is technically not suitable to carry out DLT on the pile (e.g. bored pile with capacity solely relying on rock socket, etc.). Then, more SLT should be carried out instead.

OR

(B) Statnamic Load Test (sNLT) on Pile:
   a) To fulfil the criterion "With explicit verification of SLS", a minimum percentage (%) of constructed piles listed in Table 4 should be subjected to sNLT.(IV)

Note:
(IV) sNLT can be omitted if it is technically not suitable to carry out sNLT on the pile (*e.g.* bored pile with capacity solely relying on rock socket, *etc.*). Then, more SLT should be carried out instead. Since the reliability of test results using sNLT lies between SLT and DLT, a higher percentage of tests are need compared to SLT but a lower percentage compared to DLT.

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 % of DLT shall be adjusted accordingly. Table 4 lists the recommended percentage (%) of testing to be carried out on the constructed piles to fulfil the criteria "WITH explicit verification of SLS". The recommended values have been verified with more than 10 project sites that had been successfully completed. Further data of actual % of tests from projects successfully carried out in Malaysia should be collected before the final values are specified in MY-NA.

4. COMPARISON OF RECOMMENDED MY-NA TO EQUIVALENT FACTOR OF SAFETY (FOS)

Based on the suggested partial factors in Table 1, comparisons are made to conventional factors of safety (FOS) adopted in current Malaysian practice. The comparison is made

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Table 4: Recommended percentage of piles to be tested

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*	>0.3%		NIL		NIL

The following minimum numbers of SLTs should be carried out:
1) Minimum one (1) for total piles < 500.
2) Minimum two (2) for 500 ≤ total piles < 1000.
3) Minimum three (3) for total piles ≥ 1000.

*Especially for bored/barrette piles with capacity mainly derived from rock socket friction.

Table 5: Summary of "Equivalent" Factors of Safety (FOS) based on suggested Malaysian National Annex (MY-NA) for EN1997-1:2004

Table of "Equivalent" Factor of Safety (FOS)		DA1-C1 MY-NA	DA1-C2 MY-NA WITHOUT explicit verification of SLS	DA1-C2 MY-NA WITH explicit verification of SLS
Model Factor = 1.4				
Bored Pile	Base	2.32*	3.26*	2.67*
	Shaft	1.93	2.23	1.63
	Total	2.13	2.37	2.08 (1.93**)
Driven Pile	Base	2.13	2.82	2.67
	Shaft	1.93	2.23	1.48
	Total	2.03	2.37	1.93
Model Factor = 1.3				
Jack-in Pile	Base	1.97	2.62	2.48
	Shaft	1.79	2.07	1.38
	Total	1.88	2.20	1.79
Model Factor = 1.2				
Bored Pile	Base	1.99*	2.80*	2.29*
	Shaft	1.66	1.91	1.4
	Total	1.82	2.04	1.78 (1.65**)
Driven Pile	Base	1.82	2.41	2.29
	Shaft	1.66	1.91	1.27
	Total	1.74	2.03	1.65
Model Factor = 1.1				
Jack-in Pile	Base	1.67	2.21	2.10
	Shaft	1.52	1.75	1.17
	Total	1.59	1.86	1.52

For bored pile design, the base resistance is ignored (not included) unless for bored pile constructed in dry holes, or with base grouting, or with fully instrumented preliminary pile loaded to failure and ultimate base capacity verified on site.
** = Partial factors for Total/Combined capacity of bored pile can be reduced to 1.3 if base is ignored in the calculation of the total/combined capacity.

by combining the various partial factors of safety suggested for MY-NA to an "equivalent" FOS. The ratio of permanent load (*e.g.* dead load) to variable load (*e.g.* life load, *etc.*) is taken as 8:2 when calculating the "equivalent" FOS. Table 5 summarises the "equivalent" factors of safety based on suggested Malaysian National Annex for EN1997-1:2004 for driven piles and jack-in piles.

From Table 5, it can be observed that the suggested partial factors for MY-NA will produce "equivalent" FOS which ranges from 1.52 to 2.37 for total/combined capacity compared to current Malaysian practice of 2.0. The "equivalent" FOS for shaft capacity ranges from 1.17 to 2.23 while the "equivalent" FOS for base capacity ranges from 1.67 to 2.82. The suggested partial factors of safety is also found to be conservative based on actual load test results compiled by Tan *et al.*, 2009, 2010 and Chow & Tan, 2009. It is very important to compare the design value with actual pile test results as conventional pile design usually yield higher FOS from actual pile test compared to its designed FOS thus conservative.

In recommended MY-NA, higher "equivalent" FOS is intended (more conservative of up to 44% addition in FOS) if there is no preliminary pile test (thus need to use Model Factor of 1.4) and "Without explicit verification of SLS" (less pile tests on working pile, thus use higher partial factors on resistance). This is in line with EC7 concept of encouraging more pile tests to verify capacity of the pile at site (ensure safety) instead of relying solely on using high FOS in design which is relatively less reliable compared to actual pile test.

Table 6: Summary of "Equivalent" Factors of Safety (FOS) based on EN1997-1:2004 Annex A and UK National Annex (UK-NA)

Table of "Equivalent" Factor of Safety (FOS)		EC7	UK-NA	
		DA1-C2 ANNEX A	DA1-C2 UK-NA WITHOUT explicit verification of SLS	DA1-C2 UK-NA WITH explicit verification of SLS
Model Factor = 1.4				
Bored Pile	Base	2.42	2.97	2.52
	Shaft	1.93	2.37	2.08
	Total	2.22	2.97	2.52
Driven Pile	Base	1.93	2.52	2.23
	Shaft	1.93	2.23	1.93
	Total	1.93	2.52	2.23
Model Factor = 1.2				
Bored Pile	Base	2.07	2.54	2.16
	Shaft	1.66	2.04	1.78
	Total	1.90	2.54	2.16
Driven Pile	Base	1.66	2.16	1.91
	Shaft	1.66	1.91	1.65
	Total	1.66	2.16	1.91

EC7 Annex A and UK-NA had not covered partial factors for Jack-In Pile

(To be continued on page 34)

For completeness, it is also important to compare the "equivalent" FOS obtained from recommended MY-NA with those obtained from EC7 Annex A and UK-NA as shown in Table 6. The "equivalent" FOS total/combined capacity for driven pile obtained from EC7 Annex A ranges from 1.66 to 1.93 while for bored pile the value ranges from 1.90 to 2.22. While the "equivalent" FOS obtained from UK-NA on total/combined capacity for driven pile ranges from 1.91 to 2.52 while for bored pile the value ranges from 2.16 to 2.97. Therefore, UK-NA is more conservative than EC7 Annex A by 14% to 35%. UK-NA is also more conservative than recommended MY-NA by 6% to 25%. In summary, the "equivalent FOS" obtained from recommended MY-NA falls between EC7 Annex A and UK-NA.

5. CONCLUSION

The recommended MY-NA for pile foundations under axial compression load in this paper should be adequate to ensure public safety through proper selection of parameters, analysis, design and equally important pile testing requirements discussed in Section 3. As a developing country especially for less developed states, Malaysia still needs a lot of infrastructures and buildings to be constructed. The code to be introduced while ensuring public safety, should not be overly conservative as it will lead to unnecessary higher construction cost thus directly hinder development of the nation. It is the responsibility of the engineers drafting the MY-NA to bear in mind these two key factors to have a more balanced view for the betterment of the country and the engineering fraternity. ■

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