Transportation Engineering

Development of EC7 Malaysia National Annex for the Design of Embankment Stability on Soft Ground (Part 1 of 2)

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This article is the first of two parts. Part two of the article would be published in the October 2010 issue.

1. INTRODUCTION

The construction of embankments over very soft to soft fine grained subsoil at the coastal alluvium area for highways, railways or other infrastructures is increasing in Malaysia. Figure 1 presents an overview of the quaternary sediments in Peninsular Malaysia. For the past 50 years, a comprehensive design methodology, especially on embankment stability, has been established, used and improved by practising engineers in Malaysia to prevent the failure of embankments.
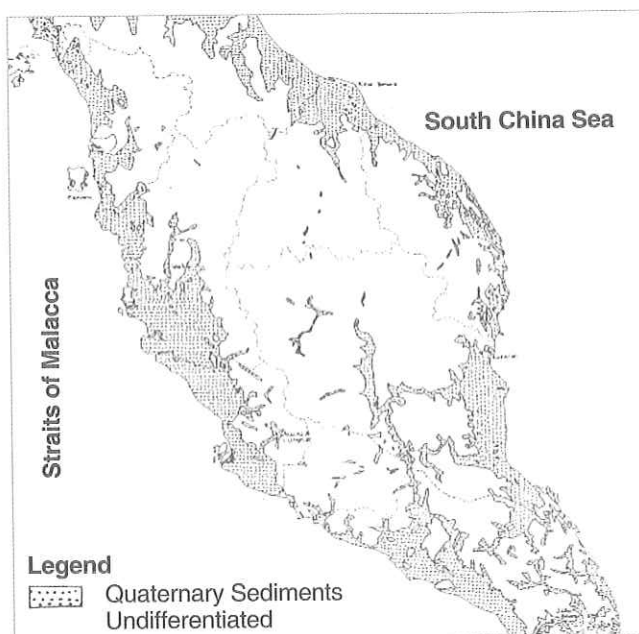

Figure 1: Quaternary Sediments in Peninsular Malaysia

The introduction of EN1997 Eurocode 7: Geotechnical Design (EC7) has presented a framework for geotechnical design based on limit state principles. The Malaysian design codes, which were developed from the British design codes, will be affected after the withdrawal of some of the latter. As such, Malaysia has to formulate an appropriate National Annex which suits the local conditions when applying EC7. In view of the need to formulate the Malaysia National Annex (MY-NA), it is very important that proper processes are carried out when drafting the MY-NA to incorporate the practice of engineers in Malaysia for both private and government projects. Therefore, the rationalisation between the private practice and the requirements of the Public Works Department (Jabatan Kerja Raya, Malaysia or JKR) that governs most of the government projects is to have a more uniform practice when developing the MY-NA. The adoption of EC7 in Malaysia will also affect many practising engineers who are more familiar and experienced in conventional methods of geotechnical design (*e.g.* global factor of safety, *etc*) thus further calibration and familiarisation of the conventional practice to EC7 shall also be allowed before finalising the MY-NA.

This paper presents case studies to rationalise the Malaysian conventional design practice to EC7 for the stability of embankment on soft fine grained subsoil. Suggestions on partial factors on actions (γ_F), soil (γ_M) and earth resistance (γ_R) to be used in conjunction with different design approaches in EC7 are presented. This paper only addresses ultimate limit stage (ULS) (*e.g.* failure) of embankment. It is important to note that serviceability limit state (SLS) (*e.g.* settlement with time, lateral deformation of the subsoil, *etc*) is equally if not more important than ULS, but will not be discussed in this paper.

2. MALAYSIAN CONVENTIONAL PRACTICE FOR EMBANKMENT ANALYSES AND DESIGNS

In conventional practice, the stability of an embankment is commonly assessed using limit equilibrium analysis. Different potential failure surfaces, circular and non-circular as shown in Figure 2, are considered in order to yield the lowest factor of safety (FOS) of the analysed embankment. The FOS against failure is usually defined as the ratio of average shear strength available along the failure surface to the average shear stress applied along the failure surface.
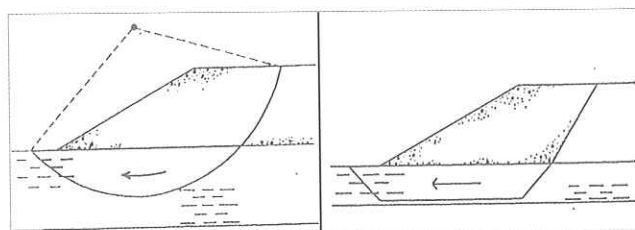

Figure 2: Circular and Non-Circular Failure Surfaces

The stability of an embankment on soft fine grained subsoil is analysed based on total stress analysis, which is most commonly used in the analyses of short term stability (which is the most critical as shown in Figure 3) and design of staged construction which considers gain in strength in the subsoil. In total stress analysis, the stability of embankment is commonly analysed based on the in-situ undrained shear strength of the subsoil prior to the commencement of construction (filling). In an analysis, a surcharge of 10kPa is normally applied as the machinery load in the short term stability analyses (Tan, 2005). The FOS of embankment against slip failure in total stress or undrained strength analyses during construction is usually taken as between 1.2 to 1.3 depending on the consequences of a
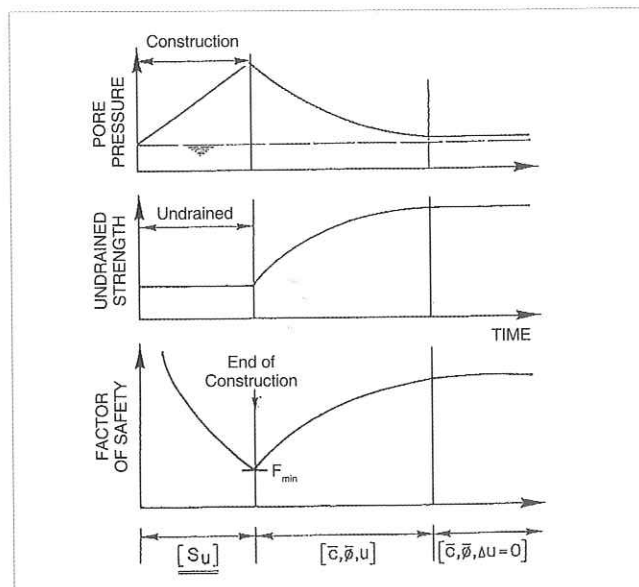
Figure 3: Change in FOS under an embankment built rapidly on soft clay (Bishop and Bjerrum, 1960)

failure and also adjacent conditions (*e.g.* any nearby buildings, services, *etc*). A FOS of 1.4 is normally adopted in effective stress analyses of embankment for permanent stage (long term) using moderately conservative effective shear strength soil parameters (characteristics values). Usually a higher FOS (*e.g.* 1.4) is adopted for the long term (under drained condition) as, in this condition, it is similar to cut slopes in the long term in which the stability is mainly affected by the groundwater level and also the effective stress strength parameters (c' & ϕ') of the subsoil. In JKR's recommendations, the FOS for short term and long term are 1.3 and 1.2 respectively.

For the design of embankment stability, the testing methods used (field and laboratory tests) and the selection of soil parameters, especially undrained shear strength (s_u) of the fine grained soil, the groundwater level and unit weight of the subsoil and fill materials are very important. Other important detailed information for embankment stability analysis are the geometry of the embankment and surrounding ground (*e.g.* any channel along the embankment, depression, water logged area, *etc*), the total fill thickness of the embankment which has to include the settlement that took place during filling and temporary surcharge fill, filling rate and ground treatment (if any) to be used. All theses parameters and information shall be carefully selected and checked to ensure that only the correct input parameters are to be used for the analysis and design of an embankment.

In the selection of undrained shear strength of the soft soil, normally field tests such as penetrating vane shear tests, mackintosh/JKR probes, piezocones and boreholes are used in combination to obtain the most representative subsoil strength profile. The details of planning and interpretation of the site investigation and interpretation can be obtained from papers by Gue and Tan (2000), Neoh (1999) and Tan (1999). The undrained shear strength selected shall be of "moderately conservative" or "characteristic" which is defined in EC7 as "cautious estimate of the value affecting the occurrence of limit state". If statistical methods, which is not common and seldom used in Malaysia, are used for the selection of geotechnical

data, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5%. Therefore, with this conservatism and good practice, the risk of failure had been reduced significantly during the proper selection of soil strength for design.

The current trend in the design of expressways or rail embankments over soft ground has also placed emphasis on value engineering and long term serviceability of the ground treatment options (Tan and Chow, 2009) while ensuring stability during construction (prevent failure during construction). As shown in Figure 3, if an embankment is stable after reaching its final level (final thickness of fill which is the highest load acting on the subsoil), then the FOS will increase with time with the dissipation of excess pore water pressure. Thus, the ground treatment implemented to ensure stability during construction only (*e.g.* high strength geotextile, soft soil replacement, *etc*) will have less function and become redundant in the long term. This is the reason why during the construction of embankment (during filling), the FOS adopted in design shall be sufficient to prevent failure but not too conservative to cause the wastage of materials which is non-sustainable for the earth.

Conventional ground treatment methods such as surcharging, partial soft soil replacement, prefabricated vertical drains with surcharge, stone columns, dynamic replacement, piled embankment with reinforced concrete slabs, or combinations of these techniques are widely used in Malaysia. The experience of various ground treatment techniques has been accumulated over the years through projects such as the Kuala Lumpur International Airport where extensive peat deposits were encountered and also from findings such as the Trial Embankments on Malaysian Marine Clays carried out by the Malaysian Highway Authority (1989). Emphasis is also placed on controlling differential settlement between piled structures (viaducts and bridges) and approach embankments (usually unpiled). The techniques commonly used in Malaysia are transition piled embankments, expanded polystyrene (EPS), oversized culverts, etc. (Gue, *et al.*, 2002). Lately, foam (light weight) concrete has been introduced to Malaysia as one of the options to replace EPS in view of its inertness to fire.

3. DESIGN PRACTICE PROPOSED IN EC7

The design of embankment using EC7 is based on limit states principle where partial factors are introduced for actions, soil materials and resistance. Three design approaches have been outlined in the EC7 Annex A (normative), namely, Design Approach 1, Design Approach 2 and Design Approach 3. The difference between the Design Approaches is the way partial factors are distributed between the actions, the effect of actions, material properties and resistances. Table 1 summarises the partial factors for different design approaches.

As shown in Table 1, the proposed partial factors on actions for slope ranges from 1.35 to 1.50, and there is no specific provision of partial factors specifically for embankment stability. EC7 only addresses embankments which are similar to slopes. As explained previously, the behaviour (*e.g.* pore pressure response, shear strength, *etc.*) of a cut slope is totally different from that of an embankment over soft fine grained subsoil. This is because the stability of the embankment is most critical during and at the end of construction (short term)

Table 1: Summary of Partial Factors for Actions, Soil Materials and Resistance Extracted from EN1997-1:2004 Annex

			Design Approach 1						Design Approach 2				Design Approach 3			
			Combination 1			Combination 2			Combination 1			Slopes					
			A1	M1	R1	A2	M2	R2	A1	M1	R2	A1	M=R2	A1	A2	M2	R3
Actions	Permanent	Unfav	1.35			1.00			1.35			1.35		1.35	1.00		
		Fav	1.00			1.00			1.00			1.00		1.00	1.00		
	Variable	Unfav	1.50			1.30			1.50			1.50		1.50	1.30		
Soil	$\tan\phi'$			1.00			1.25			1.00				Struct	Geotech	1.25	
	Effective cohesion			1.00			1.25			1.00				Actions	Actions	1.25	
	Undrained strength			1.00			1.40			1.00						1.40	
	Unconfined strength			1.00			1.40			1.00						1.40	
	Weight density			1.00			1.00			1.00						1.00	
Slopes	Earth resistance				1.00			1.00				1.10					1.00

as shown in Figure 3 and it is commonly analysed based on total stress analysis using undrained shear strength for fine grained subsoil. The most critical condition of a cut slope is the long term stability, in which the induced negative pore pressures during cutting dissipate with time leading to a reduction in shear strength and FOS with time. Therefore, it is not appropriate to lump them together as this violates the fundamental understanding of soil mechanics.

Malaysia will likely adopt Design Approach 1 which is used by the British as previous Malaysian standards were also developed from the British standards. Therefore, for embankment stability analysis, Design Approach 1 – Combination 2 (DA1-C2) will be focused on as it is used to check for Geotechnical Limit State while Design Approach 1 – Combination 1 (DA1-C1) focuses on Structural Limit State. Design Approach 2 – Slopes (DA2-Slopes) will also be discussed as it is easy to relate it to the Malaysian conventional design practice.

As shown in Table 1 DA1-C2 and DA3, there is a distinct difference in the value of partial factors on soil parameters (γ_M). In EC7, higher partial factors are imposed on undrained shear strength (γ_{cu} & γ_{qu} = 1.4) compared to drained shear strength (γ_ϕ' & γ_c' = 1.25) as influenced by the confidence level placed on these soil parameters (using higher partial factors if confidence level is lower), possible variation at site and soil behaviour. However, it is also important to note that with properly planned and executed field and laboratory tests, coupled with the correct interpretation and selection of parameters by the engineers, this problem can be overcome.

4. CASE STUDY ON EMBANKMENT STABILITY ANALYSES
4.1 Methodology
Embankment stability analyses were carried out using a limit equilibrium commercial software to study the embankment height (thickness of fill) that can be constructed over soft fine grained subsoil in order to comply with the FOS based on the Malaysian current conventional practice and partial factors recommended by EC7 Annex A (normative). The stability analyses were carried out based on the undrained shear strength profile of the Muar Test Embankment (Brand, E.W. & Premchitt, J, 1989) in Johor, Malaysia as shown in Figure 4 so that a direct

comparison on the allowable embankment height (with adequate FOS as per the Malaysian current practice and EC7 recommendation) can be made as the Muar Test Embankment was constructed to failure. The test embankment was filled (loaded) until failure without a rest period, thus there was an insignificant gain in strength in the low permeability fine grained subsoil. The filling (loading) process is quite similar to the condition of the total stress analysis without the gain in strength in the subsoil. Therefore, it should yield a lower height of embankment at failure compared to a normal embankment constructed which is usually filled slowly (controlled filling) with ground treatment (e.g. prefabricated vertical drains to expedite consolidation) which leads to gain in strength in the subsoil. In summary, the Muar Test Embankment represents the most critical condition of loading an embankment would experience compared to an embankment which is built with a controlled rate of filling. The cross section of the Muar Test Embankment is shown in Figure 5 while Figure 6 shows the picture of the embankment after failure.

The following procedures were adopted in the stability analyses in line with EC7 as per suggestions by Prof. Roger Frank (2004):

a) Although not explicitly stated in EC7, Design Approach-1 Combination 2 (DA1-C2) is normally the recommended method for overall stability checking for problems where the ground is the main element providing resistance (i.e. in mainly geotechnical (GEO) type limit states); in such cases, Combination 1 is not relevant.

b) Partial factors for all permanent actions (favourable and unfavourable), both structural and geotechnical, including gravity loads due to ground and water are set to unity instead of $\gamma_G = 1.35$. This partial factor is later accounted for at the end of the stability analyses.
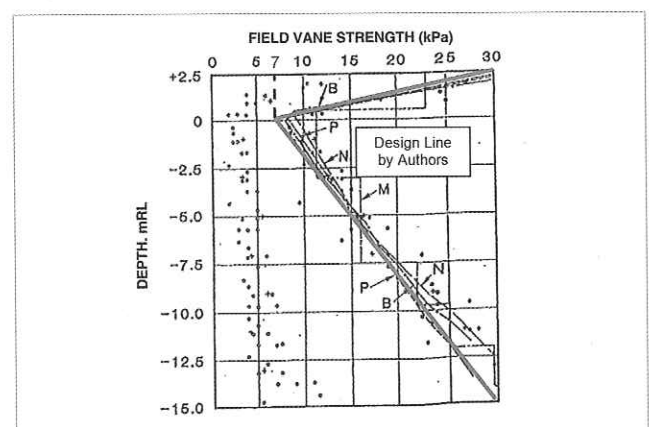

Figure 4: Undrained Shear Strength Profile of Muar Test Embankment, Johor, Malaysia (Brand, E.W and Premchitt, J., 1999)
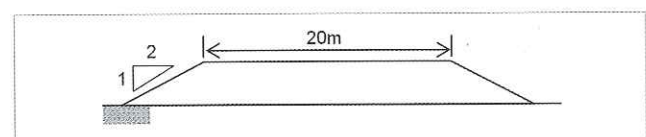

Figure 5: Typical Cross Section of Muar Test Embankment, Johor, Malaysia

c) The partial factor for variable unfavourable action is set to $\gamma_Q = 1.30/1.00 = 1.30$ and $\gamma_Q = 1.50/1.35 = 1.11$ for DA-1 Combination 2 and DA-2 & DA-3 respectively.

Figure 6: The Muar Test Embankment after Failure (from Malaysian Highway Authority (1989))

Subsequently, the allowable embankment heights obtained from stability analyses based on partial factors in line with EC7 were used to carry out stability analyses based on the Malaysian current practice. This is to obtain the equivalent FOS against embankment instability based on the Malaysian current practice in order to provide a direct comparison in the form of conventional FOS. This comparison is important so that Malaysian engineers can relate the partial factors used in EC7 to equivalent FOS using the conventional method of analysis which they are familiar with.

4.2 Results and Findings

Figure 7 presents the embankment height that can be safely constructed over the soft fine grained subsoil profile shown in Figure 4 in order to compare the FOS based on the Malaysian current conventional practice and partial factors recommended by EC7 Annex A (normative). Figure 8 shows the equivalent FOS of the embankment based on the height of the embankment obtained from various methods.

Based on the results, the following findings can be deduced:

a) Based on partial factors recommended by EC7 Annex A, the allowable embankment height obtained is 2m to 2.1m, which is about 24% to 28% lower than the embankment height of 2.75m obtained from the Malaysian practice. The results indicate that EC7 is relatively more conservative than the Malaysian practice on the design of embankment stability.

b) The stability analyses indicated that the subsoil can support a 3.4m thick embankment prior to failure, in which FOS = 1.0 based on the Malaysian current practice. This is lower than the actual failure thickness of 5.4m. Thus, there is some conservatism (safe side) in the Malaysian approach which did not take into account of the gain in strength of the subsoil with time.

c) The allowable embankment height of 2m based on partial factors recommended by EC7 Annex A (DA1-C2) is only 38% of the actual failure thickness of 5.4m. This is very conservative.

d) Whilst the allowable embankment height of 2.75m based on the Malaysian current practice is about 81% and 51% of the embankment thickness of 3.4m (FOS = 1.0) and actual failure thickness of 5.4m respectively. These results show that the Malaysian current practice is actually conservative despite using a FOS of only 1.2. This is strong evidence for not needing a higher FOS in the design of embankment stability during construction. Instead, using proper tests, correct interpretation, selecting representative "characteristic" values and proper methods of analysis are the right approaches to ensure the safety of an embankment instead of relying on a higher FOS.
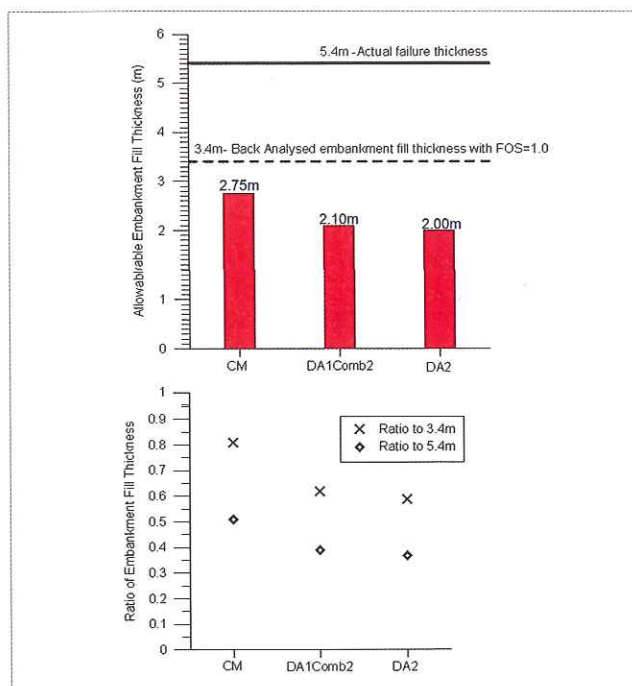

Figure 7: Allowable Fill Thickness based on conventional method & EC7 and Ratio of Embankment Fill Thickness to actual failure thickness and back analysed embankment thickness
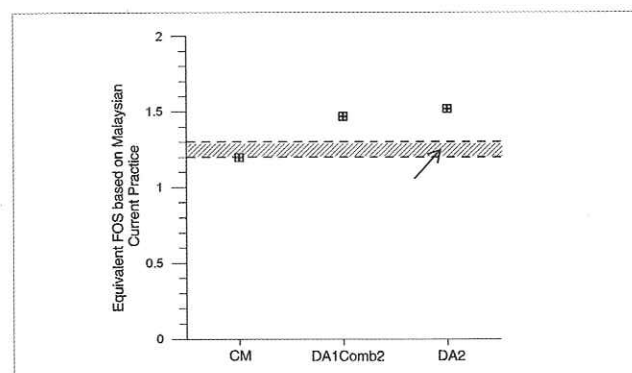

Figure 8: Equivalent FOS obtained from analyses based on Malaysian Current Practice using allowable embankment height based on EC7

e) Relatively intensive ground treatment will be required in order to achieve the sufficient FOS against embankment instability if embankment stability analyses are carried out based on EC7 partial factors listed in Table 1. This will lead to a much higher construction cost than what is actually needed, which is bad for the development of the nation. The impact will be significant if the subsoil is very soft and soft which is commonly found in Malaysia compared to stiffer materials commonly found in Europe.

f) The equivalent FOS based on the Malaysian current practice for allowable embankment height obtained from DA1-C2 and DA2 is 1.47 and 1.52 respectively as shown in Figure 8. This equivalent FOS is much higher than the current required FOS of 1.20 commonly used in Malaysia which is already sufficient and safe. If there is a higher risk to life or economical risk to structures/services to be built beside the embankment, then the FOS can be raised to 1.3. ■
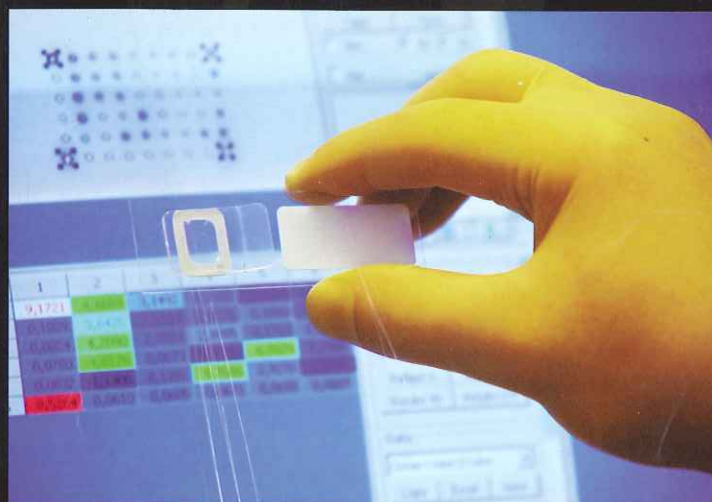
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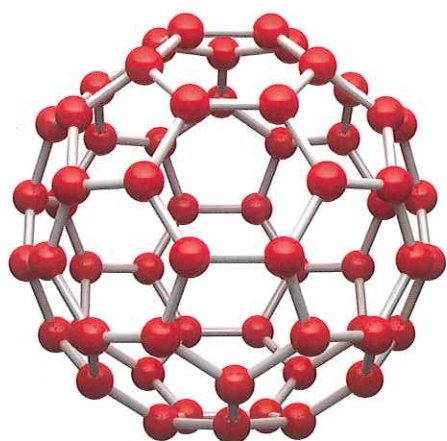
Advanced Material and Nanotechnology

Development of EC7 Malaysia National Annex for the Design of Embankment Stability on Soft Ground (Part 2 of 2)

by **Ir. Tan Yean Chin**

5. DEVELOPMENT OF THE MALAYSIA NATIONAL ANNEX (MY-NA) FOR THE DESIGN OF EMBANKMENT STABILITY

It is important that the MY-NA does not combine both Cut Slopes and Embankment into the same category to prevent making a fundamental mismatch of the loading mechanism and soil behaviour. A very clear distinction between the two can be found in past Malaysian practice, which is still being practised by adopting a factor of safety (FOS) of 1.2 to 1.3 for embankment during construction (*e.g.* total stress analysis), while for cut slopes, the FOS is 1.4 to 1.5 (*e.g.* effective stress analysis). The Malaysian practice is fundamentally correct and should be incorporated into the MY-NA by separating Embankment from Cut Slopes. We should also understand that in EC7, the fine grained subsoil materials the British are facing are mainly medium to stiff clay (*e.g.* London Clay), thus they are different from Malaysia and other ASEAN countries (*e.g.* Thailand and Indonesia) with many coastal areas underlain by very soft to soft alluvium clay. Therefore, the problems we face are different from that of the British especially in constructing embankment on very soft ground.

It is time for Malaysia to produce a code that truly reflects the engineering progress and development that we have achieved for the last 50 years instead of following the British National Annex (UK-NA), which is good in general, but in some situations, is not suitable for our country due to differences in geology, subsoil condition, requirements on infrastructure developments, practice and economy affordability, *etc*. The MY-NA to be used will have a great impact on the overall development of the nation as a conservative code will cause the cost to escalate (make many potential projects not viable thus hinder the infrastructure development of the country), while an optimistic code may trigger failures or even fatalities. Therefore, a balanced code that suits Malaysia's condition shall be formulated carefully and with proper processes including getting feedback from the various stakeholders, namely, the government, developers, contractors, engineering consultants, academics, etc, during the development of MY-NA. Malaysian practicing engineers should start to calibrate their conventional Malaysian practice with EC7 Annex A and with UK-NA so that they will be familiar with EC7 when imposed in Malaysia. Through calibration then only Malaysian engineers will understand and have

Table 2: Suggested Partial Factors for Actions, Soil Materials and Resistance in the MY-NA for Embankment

			Design Approach 1			Design Approach 2	
			Combination 2 - Embankment			Embankment	
			A1	M1	R2	A1	M=R2
Actions	Permanent	Unfav	1.00			1.00 ~ 1.20*	
		Fav	1.00			1.00	
	Variable	Unfav	1.00~ 1.30*			1.00 ~ 1.30*	
Soil	tan φ'				1.20		
	Effective cohesion				1.20		
	Undrained strength				1.20		
	Unconfined strength				1.20		
	Weight density				1.00		
Embankment	Earth Resistance (Short Term/Construction)				1.00 ~ 1.10*		1.20~ 1.30*
	Earth Resistance (Long Term / Drained Condition)				1.15		1.40

Notes * :

1. *Permanent* Actions (Unfavourable) (For Design Approach 2 : Embankment) :-
   = 1.00 if proper monitoring and control of filling <u>can</u> be executed effectively at site with instrumentation.
   = 1.20 if proper monitoring and control of filling <u>cannot</u> be effectively executed at site.
2. *Variable* Actions (Unfavourable) (For both Design Approach 1 and Design Approach 2) :-
   = 1.00 if proper control of variable load imposed on embankment <u>can</u> be executed effectively at site
   = 1.30 if proper control of variable load imposed on embankment <u>cannot</u> be executed effectively at site.
3. *Earth Resistance (Short Term / Construction)* (For both Design Approach 1 and Design Approach 2)
   = 1.00 (DA1-C2 Embankment) and 1.20 (DA2-Embankment) : For low risk to life (not likely to affect public safety) or not like to cause damages to adjacent important structures/services.
   = 1.10 (DA1-C2 Embankment) and 1.30 (DA2-Embankment) :For high risk to life (could affect public safety) or could caused damages to adjacent important structures/services.

Application of Earth Resistance :

1. To be applied to the Factor of Safety obtained from the stability analysis.

the necessary engineering judgement on the implication of the potential values set in the MY-NA affecting their design in terms of safety and cost. In Europe, the practicing engineers there are just starting to use EC7 for design. It is also expected that further refinements of EC7 will surface within three to four years due to the problems faced by European engineers when using EC7 which, in the author's opinion, has to rely more on local practice, geological
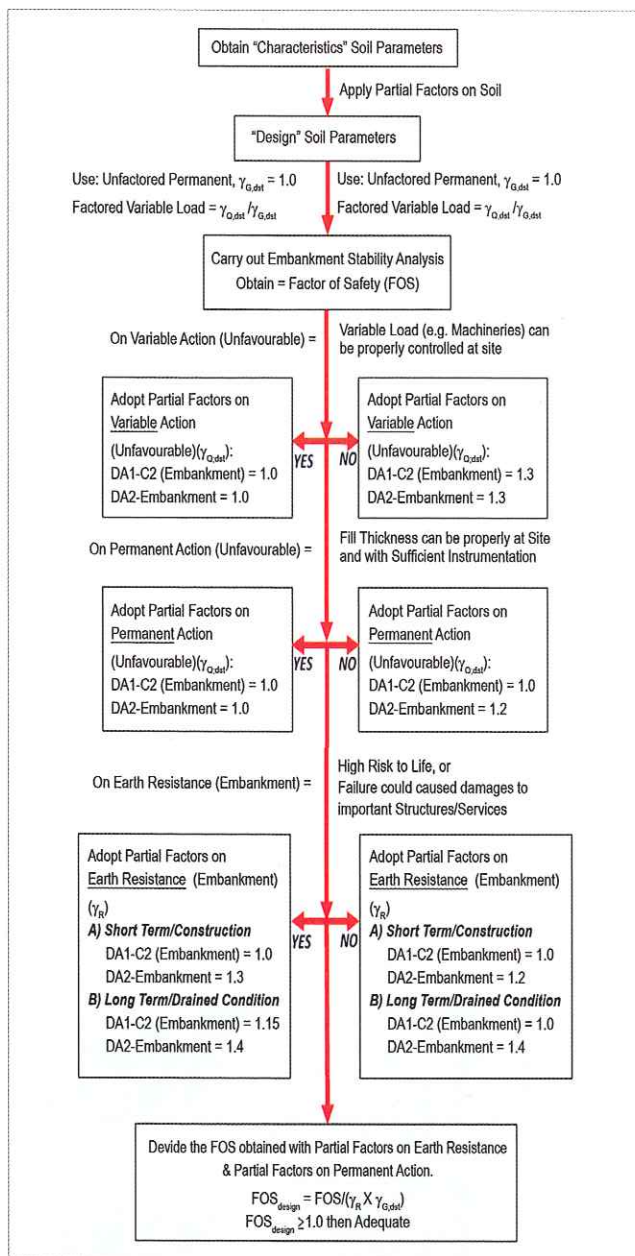
Figure 9: Simplified Flowchart for Stability Analysis of Embankment in EC7 using Suggested MY-NA

conditions, construction practice, history, etc, compared to EC1 to EC6 for structures.

It is also important that the MY-NA drafted should not use increased FOS values (*e.g.* increased partial factors values in EC7) as a way to compensate for the lack of proper engineering education, a systematic and proper on-the-job training, good engineering design and judgement, proper supervision and workmanship. If Malaysia were to fall into this trap of trying to increase the FOS due to the lack of confidence in the engineer's design, supervision and being afraid that the contractor will cheat, then we are definitely on the wrong track and this will hinder Malaysia from becoming a developed country in the future. The problems that the construction industry face shall be addressed

separately by going into the root causes and finding relevant solutions that resolve the problems encountered. FOS is not a solution for most of the problems highlighted above, instead, it causes wastage of materials and unnecessary increase in cost without real safety or benefit.

EN1997-1:2004 (EC7) Section 2 - Basis of Geotechnical Design Section 2.4.7 Clause 2.4.7.1(4) stated that, "More severe values than those recommended in Annex A should be used in cases of abnormal risk or unusual or exceptionally difficult ground or loading conditions", while Clause 2.4.7.1(5) stated that, "Less severe values than those recommended in Annex A may be used for temporary structures or transient design situations, where the likely consequences justify it". Despite the freedom stated in the two clauses, it is recommended that the MY-NA be more specific to help practicing engineers. Therefore, in suggested MY-NA values listed in Table 2, specific differentiation between risk to life or possible damages to adjacent important structures/services are stated when selecting the partial factors for earth resistance.

In summary, the application of EC7 for embankment stability analyses needs rationalisation and harmonisation with currently established local practices that have been successfully adopted in the construction industry. The following are the main criteria that require rationalisation and harmonisation for the application of EC7 in Malaysia for the stability analyses of embankment over soft fine grained subsoil:

a) An understanding of the indirect comparison of load factors and partial factors adopted in EC7 with conventional FOS which local engineers are familiar with. The transformation of currently adopted overall FOS against embankment instability to partial factors used in the MY-NA of EC7 needs calibration.

b) For stability analyses of embankment over soft fine grained subsoil, the partial factor for permanent action (unfavourable), γ_G, which is referred to as the weight of the embankment (thickness of fill), shall be set equal to unity (1.0) in the MY-NA instead of 1.35 in the UK-NA. This is because the actual embankment weight and thickness of fill can be controlled at site as the filling works are carried out in layers. In addition, the filled height can be closely captured by settlement gauges, which are adopted for monitoring purposes. Therefore, the chances of overfill is unlikely and the uncertainties of the embankment weight is under control with proper monitoring and supervision.

c) It is recommended to set the partial factor for variable load equals to unity (1.0) in the MY-NA. Again, this is because the machineries loads are fairly consistent and controllable in earthwork constructions. Hence, the risk on the inconsistent variable load would not arise. Should there be no proper control, the partial factor for variable load could be applied.

d) As mentioned earlier, the stability of the embankment is most critical at the end of construction when the

embankment height is the highest (short term) and the undrained shear strength will gain in strength with time due to the dissipation of excess pore pressure. In view of this, it is impractical to apply a high partial factor of 1.4 on the undrained shear strength during stability analyses of the embankment over soft fine grained subsoil. In addition, currently available methods to obtain the in-situ undrained shear strength are generally reliable enough to be used in total stress analyses of an embankment. Therefore, the author recommends a partial factor of 1.2 to be adopted on undrained shear strength.

e) For suggested MY-NA, higher partial factors on earth resistance (embankment) (γ_R) are proposed if any failure of the embankment is high risk to life (*e.g.* fatalities and affects public safety) or causes damages to important structures/services. Using different partial factors on earth resistance is a rational way to differentiate the risk associated with embankment stability in different site conditions.

The suggested partial factors in the MY-NA for the design of embankment stability are listed in Table 2 for easy reference. Since DA1-C2 is likely to be adopted in Malaysia, the steps for embankment stability analysis following this approach are illustrated using the suggested partial factors of the MY-NA in Table 2:

1) Obtain the correct geometry of the embankment (including settlement magnitude), groundwater level, surrounding ground profile (*e.g.* any depression, channel or drains beside the embankment).

2) Select representative layers of "Characteristic" soil parameters of shear strength (*e.g.* undrained shear strength for fine grained soil [clayey materials] and effective shear strength parameters for coarse grained soil [sandy/gravelly materials])

3) Divide the "Characteristic" soil strength with the partial factors of soil strength (γ_M soil from Table 2 of suggested MY-NA) to obtain the "Design" soil strength.

4) Use "Characteristics" bulk unit weight of fill and subsoil materials that are classified as permanent actions (either favourable or unfavourable). In this step, the partial factors for all permanent actions (γ_G) (favourable and unfavourable) are set to unity (1.0). Thus the "Design" permanent action is the same as the "Characteristics" value.

5) On Variable Unfavourable Action (*e.g.* load from Machineries), it shall be multiplied by the ratio of partial factors on actions of ($\gamma_Q;dst/\gamma_G;dst$). Following DA1-C2 of Table 2, the value is either (a) or (b):
   (a) Able to control machineries load at site, use ($\gamma_Q;dst/\gamma_G;dst$)= (1.0/1.0) = 1.0
   (b) Unable to control machineries load at site, use ($\gamma_Q;dst/\gamma_G;dst$)= (1.3/1.0) = 1.3

6) Carry out stability analysis to obtain the FOS using parameters obtained from Steps 1 to 5 for both Short Term/Construction and Long Term/Drained Condition.

7) Select the Partial Factors of Earth Resistance (γ_R) for Short Term/Construction from Table 2 based on either (a) or (b) from DA1-C2:

   (a) With low risk to life (not likely to affect public safety) or not likely to cause damages to adjacent important structures/services; use $\gamma_R = 1.00$

   (b) With high risk to life (could affect public safety) or could cause damages to adjacent important structures/services; use $\gamma_R = 1.10$

8) For Long Term/Drained Condition, the Partial Factors of Earth Resistance (γ_R) from Table 2 based on DA1-C2 is 1.15.

9) Obtain the "Design" FOS by dividing the FOS of Step 6 by both Partial Factors of Earth Resistance (γ_R) and Permanent Unfavourable Actions (γ_G;dst).

$$FOS_{design} = FOS / (\gamma_R \cdot \gamma_G;dst)$$

10) If the $FOS_{design} \geq 1.0$ for both Short Term/Construction and Long Term/Drained Condition, then it is adequate and acceptable.

A simplified flowchart is shown in Figure 9.

6. CONCLUSION

This paper presents the Malaysian design methodology for embankment stability on soft fine grained subsoil and the way forward in converting to EC7. As there is no provision of partial factors specifically for embankment stability over soft fine grained subsoil in EC7 and the behaviour (*e.g.* pore pressure response, shear strength, *etc.*) of a cut slope is totally different from an embankment over soft fine grained subsoil, this paper presents the EC7 methodology with a suggested approach and value of partial factors for the development of the MY-NA.

From the case study of the Muar Test Embankment (which was constructed to failure in 1989), the allowable embankment height based on partial factors recommended by EC7 is about 24% to 28% lower than the current Malaysian practice. This implies that EC7 is too conservative in stability analyses of embankment over soft fine grained subsoil. Since currently adopted Malaysian practice on embankment stability has been successfully implemented, the suggested partial factors on embankment stability over soft fine grained subsoil for the MY-NA in the application of EC7 should rely on local experience. ∎

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