Rationalisation of Conventional Geotechnical Practice to EC7 on the Stability of Embankment on Soft Fine Grained Subsoil

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ABSTRACT: Conventional geotechnical practice for the design of embankment on soft fine grained subsoil generally concentrates on stability of the embankment during construction (most critical condition) and control of long term settlement after construction. For embankment on soft fine grained subsoil, the factor of safety (FOS) of embankment against slip failure in total stress or undrained strength analyses during construction (filling) stage is usually taken as between 1.2 to 1.3 in Malaysia depending on the consequences of failure and also adjacent conditions (e.g. houses, services, etc). FOS of 1.4 is normally adopted in effective stress analyses of embankment for permanent stage (long term) using moderately conservative soil parameters (characteristics value). With the introduction of EN1997 Eurocode 7: Geotechnical Design (EC7), it presents a framework for geotechnical design based on limit state principles and many Asian countries which rely on European design codes (e.g. British, German, French, etc.) will be affected after withdrawal of the respective countries' design codes. As such, it is important for the affected countries to formulate appropriate National Annex for application in their own countries based on their own local experiences. In this paper, suggestions on partial and model factors used in conjunction with EC7 based on a Malaysian experience are presented to ensure smooth transition from current practice to EC7. The methodology presented in this paper could be adopted by other countries in formulation of their respective National Annex based on their own local experience for embankment on soft fine grained subsoil.

1. INTRODUCTION

The construction of embankment over soft to very soft fine grained subsoil at the coastal alluvium area is increasing in Malaysia for highway or other infrastructures. Figure 1 presents the areas of the soft quaternary sediments in Peninsular Malaysia. The comprehensive design methodology especially on embankment stability has long been established in Malaysia to prevent failure. However, the introduction of EN1997 Eurocode 7: Geotechnical Design (EC7) presents a framework for geotechnical design based on limit state principles and many Asian countries which rely on European design codes (e.g. British, German, French, etc.) will be affected after withdrawal of the respective countries' design codes. Hence, it is important to formulate an appropriate National Annex for application of EC7 in Malaysia based on local experiences. In line with this, case studies have been carried in order to rationalize the conventional design practise to EC7 for the stability of embankment on soft fine grained subsoil.

2. MALAYSIAN CONVENTIONAL PRACTICE FOR EMBANKMENT ANALYSES AND DESIGN

In conventional practice, stability of 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 ratio of average shear strength available along the failure surface to average shear stress applied along the failure surface.

The stability of the 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. In total stress analysis, the stability of embankment is commonly analysed based on the in-situ undrained shear strength of the subsoil prior to commencement of construction (filling). The factor of safety (FOS) of embankment against slip failure in total stress or undrained strength analyses during this stage is usually taken as between 1.2 to 1.3 depending on the consequences of failure and also adjacent conditions (e.g. any nearby buildings, services, etc). FOS of 1.4 is normally adopted in effective stress analyses of embankment for permanent stage (long term) using moderately conservative soil parameters (characteristic values). In addition, surcharge of 10kPa is normally applied as the machinery load in the short term stability analyses.

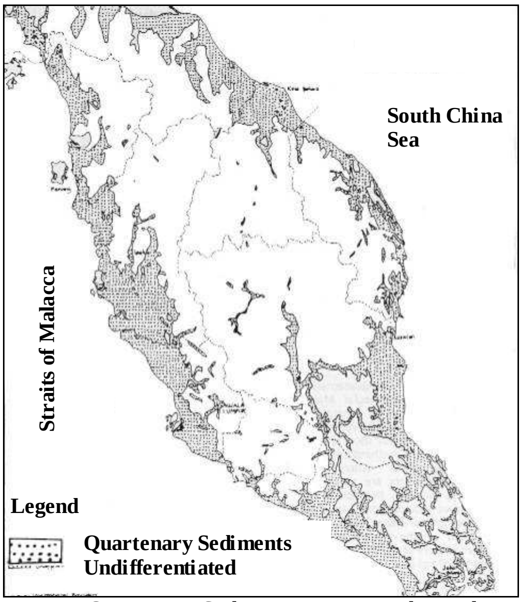

Figure 1 Quaternary Sediments in Peninsular Malaysia

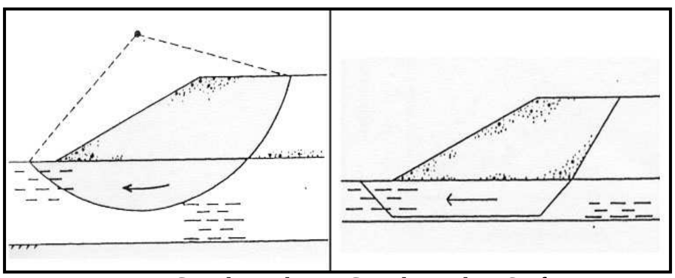

Figure 2 Circular and Non-Circular Failure Surfaces

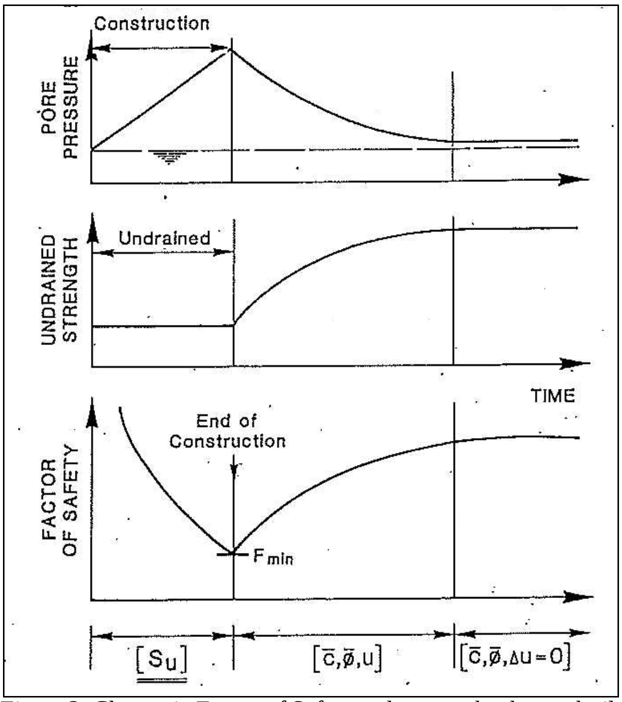

Figure 3 Change in Factor of Safety under an embankment built rapidly on soft clay (Bishop & Bjerrum, 1960)

3. DESIGN PRACTICE PROPOSED IN CURRENT EC7

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

As shown in Table 1, the proposed partial factors for slope analyses generally ranges from 1.35 to 1.50 and there is no provision of partial factors specifically for embankment stability. 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) as shown in Figure 3 and it is commonly analysed based on total stress analysis. Whilst, 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 factor of safety with time.

Table 1 Summary of Partial factors for Actions, Soil Materials and resistance extracted from EN1997-1:2004 Annex A

			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 ϕ'			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

A1, A2 –Set of partial factors for actions
R1, R2 and R3 –Set of partial factors for resistance
M1, M2 –Set of partial factors for soil materials

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 to the FOS based on 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 Malaysian current practice and EC7 recommendations) can be made as the Muar Test Embankment was constructed to failure. The cross section of the embankment is shown in Figure 5.

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 EN 1997-1, in DA-1 combination 2 (DA-1Comb2) is normally the recommended method for overall stability checking in problems where ground is the main element providing resistance (i.e in mainly GEO-type limit states); in such cases, combination 1 is not relevant.
b) Partial factors for all permanent actions (favourable and unfavourable), γ_G, both structural and geotechnical, including gravity loads due to ground and water are set to unity instead of γ_G=1.35. This partial factor is later accounted for at the end of the stability analyses
c) The partial factor for variable unfavourable action, γ_Q, is set to γ_Q=1.30/1.00=1.30 and γ_Q=1.50/1.35=1.11 for DA-1Comb2 and DA-2 & DA-3 respectively.

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 Malaysian current practice. This is to obtain the equivalent FOS against embankment instability based on Malaysian current practice in order to provide a direct comparison in the form of conventional FOS.

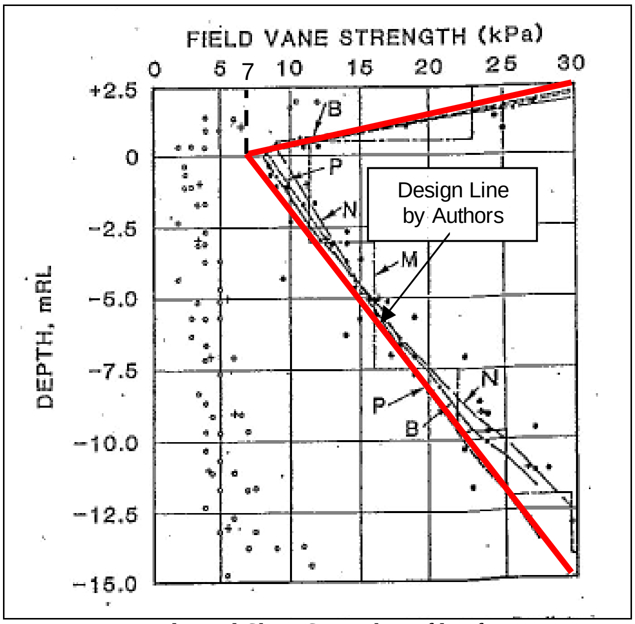

Figure 4 Undrained Shear Strength profile of Muar Test Embankment, Johor, Malaysia (Brand, E.W & Premchitt, J., 1999)

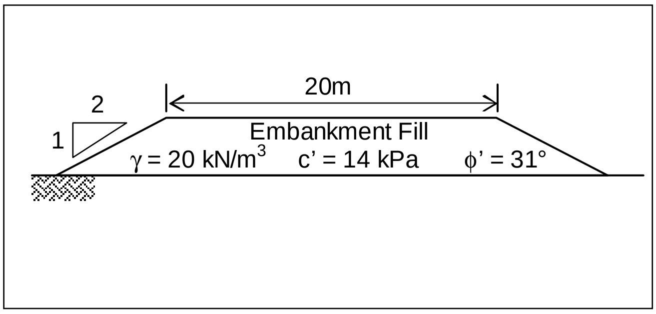

Figure 5 Typical Cross Section of Muar Test Embankment, Johor, Malaysia

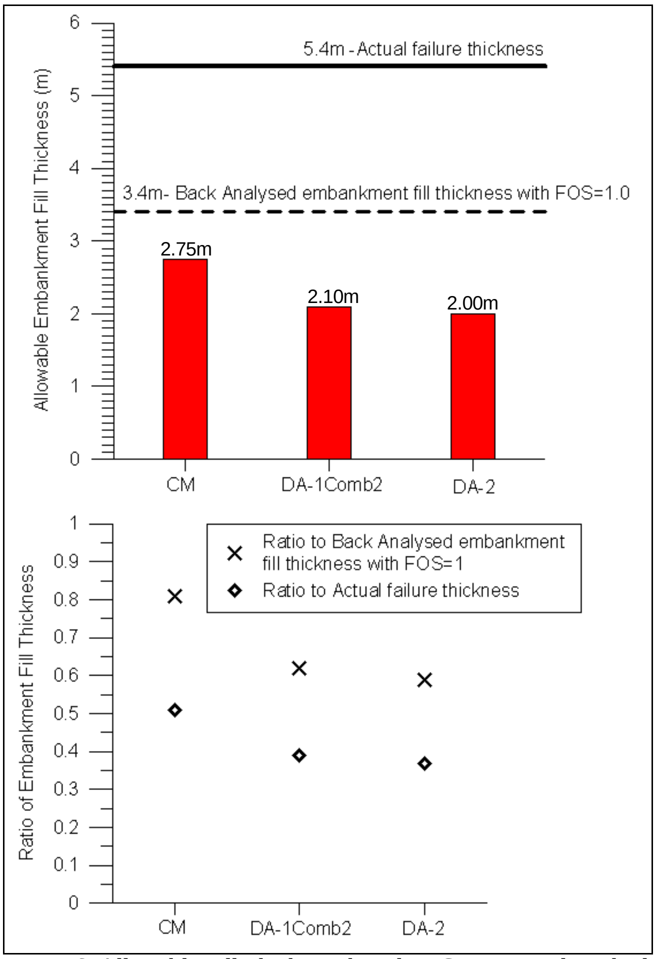

Figure 6 Allowable Fill Thickness based on Conventional Method (CM) & EC7 and Ratio of Embankment Fill Thickness to actual failure thickness and back analysed embankment thickness

4.2 Results and Findings

Figure 6 presents the embankment height that can be safely constructed over soft fine grained subsoil profile shown in Figure 4 in order to comply the FOS based on Malaysian current conventional practice and partial factors recommended by EC7 Annex A (normative). Based on the results, the following findings can be deduced:

a) The stability analyses indicate that the subsoil can support 3.4m thick embankment prior to failure, in which FOS = 1.0 based on Malaysia current practice. This is lower than the actual failure thickness of 5.4m. Thus, there is some conservatism in this approach which did not take into consideration of gain in strength of the subsoil with time during filling.

b) Based on partial factors recommended by EC7 Annex A, the allowable embankment height is about 24% to 28% lower than the Malaysian current practice.

c) The allowable embankment height based on partial factor recommended by EC7 Annex A is about 60% and 38% of embankment thickness of 3.4m (FOS=1.0) and actual failure thickness of 5.4m respectively. This is too conservative.

d) Whilst, the allowable embankment height based on Malaysian current practice is about 81% and 51% of embankment thickness of 3.4m (FOS=1.0) and actual failure thickness of 5.4m respectively.

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 recommendation. This will lead to much higher construction cost than what is necessary, thus bad for the nation.

f) The equivalent FOS based on Malaysian current practice for allowable embankment height obtained from DA-1Comb2 and DA-2 is 1.47 and 1.52 respectively as shown in Figure 7, which is much higher than the current required FOS of 1.20 commonly used in Malaysia.

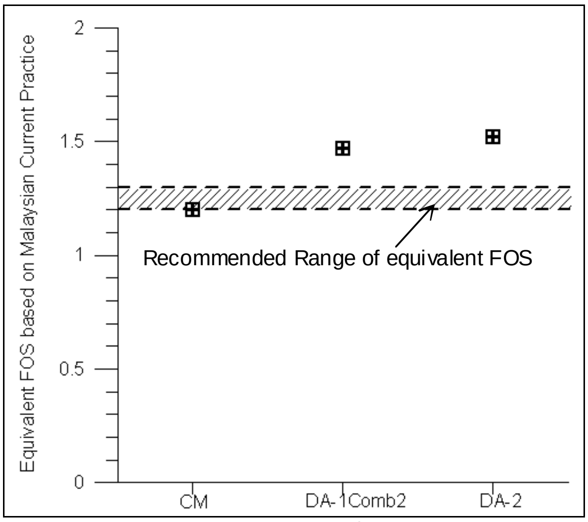

Figure 7 Equivalent FOS obtained from analyses based on Malaysian Current Practice using allowable embankment height based on EC7

5. PROPOSED CONCEPT FOR THE APPLICATION OF EC7 FOR EMBANKMENT STABILITY ANALYSES IN MALAYSIA

The application of EC7 for embankment stability analyses need rationalization and harmonization with current established local practices that have been successfully adopted in the construction industry.

Following are the main criteria that require rationalization and harmonization for 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 Factor of Safety (FOS) which local engineers are familiar with.

The transformation of current adopted overall FOS against embankment instability to partial factors or model factors (if any) used in the Malaysian Annex of EC7 will need 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 the weight of embankment (height) shall be set equal to unity (1.0) instead of 1.35. 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 on the embankment weight is under control with proper monitoring and supervision.

c) The Authors also recommend to set the partial factor for variable load equal to unity. Again, this is because the machineries loads are fairly consistent and controllable in earthwork constructions. Hence, the risk on the inconsistence variable load would not arise. Unless there is no proper control then, the partial factor for variable load could be applied.

d) As mentioned in earlier section, 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 as the dissipation of excess pore pressure with time. 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 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 embankment. Therefore, the Authors recommend partial factor of 1.20 to 1.30 shall be adopted on undrained shear strength depending on the consequences of failure and also adjacent conditions (e.g. nearby buildings, services, etc).

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 provisional 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 suggested approach and value of partial factors for the development of Malaysian National Annex (MY-NA).

Based on case study of 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 Malaysian current practice. This implies that EC7 appears to be too conservative in stability analyses of embankment over soft fine grained subsoil as current adopted methodology on embankment stability has been successfully implemented. Therefore, partial factors on embankment stability over soft fine grained subsoil for the development of Malaysian National Annex in the application of EC7 are proposed by the authors based on local experience.

4. REFERENCES

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