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CONCLUSIONS AND COMMENTS FROM SEISMIC ANALYSIS OF EMBANKMENTS ACCORDING TO GREEK SEISMIC CODE

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ABSTRACT

The stability of embankments with heights less than 15m and resting on almost non deformable soils under seismic loading has been examined, according to the provisions of the Greek Seismic Code. In the analyses the factors of safety of embankments with the commonly used in practice side inclinations 1:1.5 and 1:2 (V: H) were calculated taking into consideration typical design strength parameters, for various seismicity regions in the country. From the results of the parametric analysis it was concluded that the provisions posed from the Code are useless since in almost all the cases the obtained factors of safety were satisfactory (> 1.0) and therefore the need of a thorough reappraisal of the relevant provisions is urgent.

Keywords: Slope stability analysis, Seismic Codes

INTRODUCTION

The construction of relatively low height embankments (H < 15m) resting on almost non deformable soils (e.g. rock, gravel, overconsolidated clay etc.) is a very common case in practice. Usually these embankments are constructed with relatively steep side inclination 1:2 to 1:1.5 (V: H). The main subject of the design is to calculate their safe side inclination using slope stability analysis methods, since the almost non deformable soil material in the base does not post any settlement or bearing capacity problems.

The aim of the present paper is to present some very interesting conclusions and comments that arised from a systematic examination of the seismic slope stability analysis of such embankments, using the methodology provided by the Greek Seismic Code (EAK2000). According to this code the proposed methodology is valid for embankments up to 15m in height.

STATIC CASE ANALYSIS - SOIL STRENGTH DESIGN PARAMETERS

The required factor of safety of slopes for road embankments in Greece is equal to 1.4 (Design Recommendations of Greek Ministry of Public Works 1998, Design Manual of Egnatia Odos S.A. 1997). Taking into consideration that according to common practice these embankments are constructed with side inclination 1:2 to 1:1.5 (V: H) and having in mind that they are constructed from a very well compacted non cohesive material (sand and gravel) following strict specifications, we can calculate that for a slope inclination 1:1.5 the required angle of friction is equal to :

$$\varphi = \arctan\left(1.4 * \frac{1}{1.5}\right) = 43^\circ \tag{1}$$

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which is quite impossible to be obtained using the commonly used for embankment construction soil materials. For a slope inclination 1:2 the required angle of friction is equal to:

$$\varphi = \arctan\left(1.4 * \frac{1}{2}\right) = 35° \quad (2)$$

From the above considerations it has been accepted in current design practice to use in the slope stability analysis the values $\varphi' = 35^o$ and $c' = 10KPa$ for the soil strength design parameters.

IMPOSED BY EAK 2000 PROCEDURE FOR SEISMIC ANALYSIS

According to the provisions of the Greek Seismic Code (EAK2000), the procedure for the slope stability analysis of the road embankments with heights less than 15m is the following:

1. Estimation of the shear waves velocity Vs in the embankment material (a typical value of 500m/sec has been accepted for use in the practice, due to the good quality of the material and its controlled compaction).

2. Calculation of the embankment period T

$$T = 2.5 * \frac{H}{Vs} \quad (3)$$

   where H is the height of the embankment

3. Determination of the category of the soil on which the embankment will be constructed. For the good quality soils (from a seismic performance perspective), the categories A (rocky) and B (dense and very hard soils) are relevant.

4. Estimation of the spectral amplification β(T) from the proposed graph of the EAK2000 (shown in Figure 1) according to the considered soil category (A, B, C, D, X) and the calculated period T.

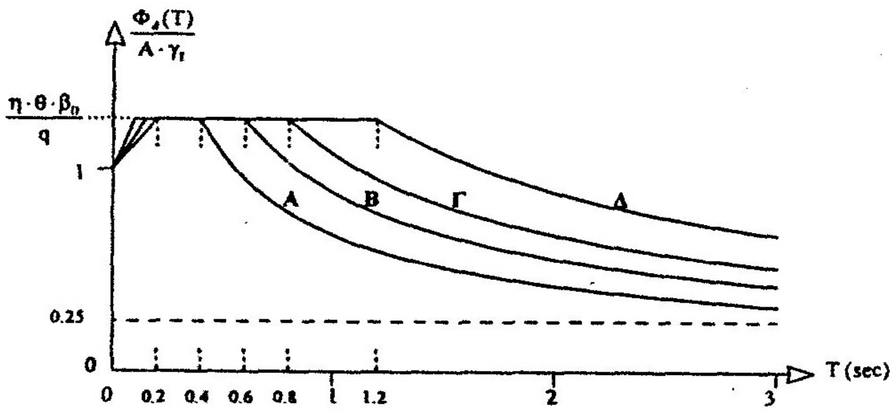

Figure 1. Design Spectrum according to EAK2000

5. Determination of design acceleration α at the examined site according to EAK2000 regulations for the three regions of seismicity of the country (equal to 0.16g for region I, 0.24g for region II and 0.36g for region III).

6. Determination of the design horizontal acceleration α_b at the base of the embankment and at the top of the embankment α_t, where

$$\alpha_b = 0.5 * \alpha \tag{4}$$

$$\alpha_t = 0.5 * \alpha * \beta(T) \tag{5}$$

7. In order to take efficiently into account these accelerations when using the currently existed software packages it has been accepted to use a mean horizontal acceleration for the whole embankment equal to α_h, where

$$\alpha_h = \frac{\alpha_b + \alpha_t}{2} \tag{6}$$

8. A simultaneous vertical acceleration α_v must be considered equal to

$$\alpha_v = \pm \frac{\alpha_h}{2} \tag{7}$$

(two cases, + for upwards, - for downwards)

9. The stability of the embankment must be checked for these accelerations and the calculated factor of safety must be at least equal to 1.00. The effect of seismic accelerations on a typical embankment is shown in Figure 2.

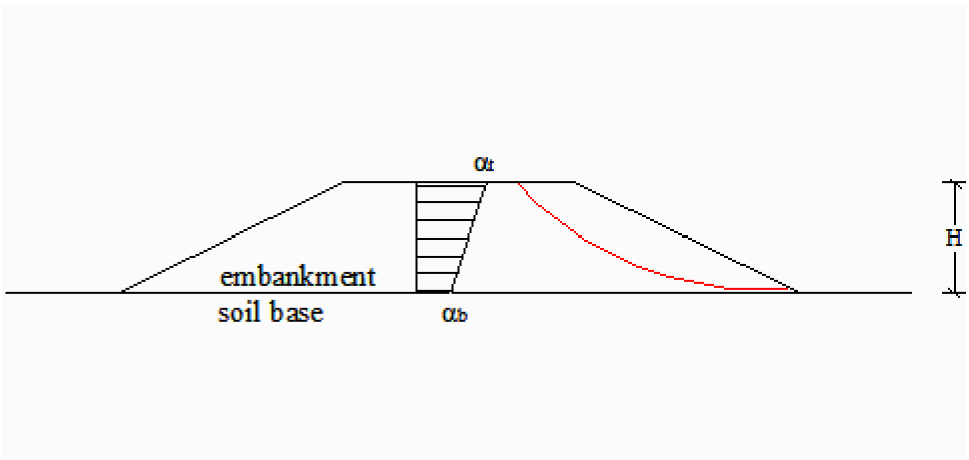

Figure 2. Distribution of horizontal seismic acceleration in the body of a typical embankment according to EAK2000

PROCEDURE FOLLOWED IN THE PRESENT STUDY

In this study the factors of safety (FOS) for embankments with height less than 15m and side inclination 1:1.5 and 1:2 resting on almost non deformable soils have been calculated for the three seismicity regions (I, II, III) of the country, using the imposed by EAK2000 procedure.

For the almost non deformable soils of the embankment base it has been accepted that they fall in category B; for these which fall in category A the spectral amplifications are lower and thus the considered accelerations lower, therefore we will be at the safe side.

Three embankment heights have been considered: H = 5, 10, 15m. The embankment material design parameters that have been accepted are shown in Table 1:

Table 1. Design parameters considered for the embankment material

Angle of friction φ (^{o})	35
Cohesion intercept c (KPa)	10
Unit weight γ (KN/m^3)	20
Shear wave velocity Vs (m/s)	50 0

SOFTWARE USED IN THE ANALYSIS

For the slope stability analyses necessary for this study the limit equilibrium method has been accepted and they have been performed by the software ANNA. This software uses for searching and solving purposes the well known PCSTABL engine. For the pre-process of the data and the meta-process of the results a special code has been developed. This code allows for the easy, dialog type, entry of the slope data and for the quick and easy visual control. It also allows for a well organized tabulate results and moreover for their easy visualization. In this way the user can see and check very easily the geometry of the slope, the critical surface, the most critical surfaces, the imposed limitations for the searching etc., as shown in Figure 3.

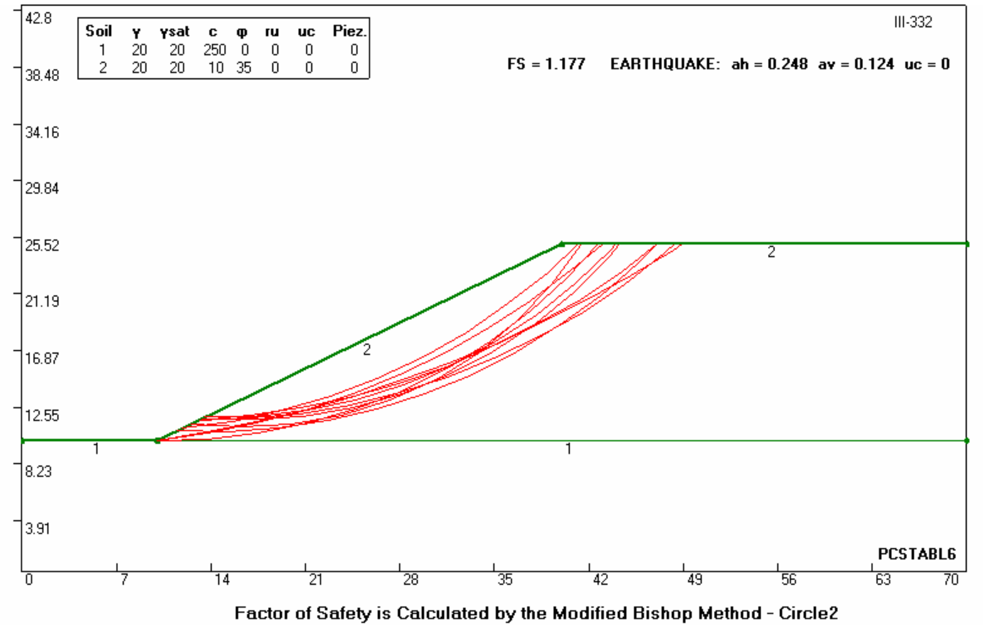

Figure 3. Demonstration of the slope stability analysis results using the software ANNA

RESULTS OF THE ANALYSIS

The calculated factors of safety for inclination 1:1.5 (V: H) for embankment slopes are presented in Table 2.

Table 2. Factors of safety for embankments with slope inclination 1:1.5 and Vs = 500m/s

Seismicity regions	Height (m)	Cohesion intercept c = 10 KPa			Cohesion intercept c = 5 KPa		
		Static case	Seismic Loading		Static case	Seismic Loading	
			α_v+	α_v-		α_v+	α_v-
I α=0.16g	5	2.25	1.94	1.90	1.79	1.53	1.51
	10	1.79	1.50	1.48	1.51	1.26	1.25
	15	1.61	1.31	1.31	1.40	1.14	1.14
II α=0.24g	5	2.25	1.81	1.76	1.79	1.41	1.40
	10	1.79	1.38	1.36	1.51	1.15	1.16
	15	1.661	1.19	1.20	1.40	1.02	1.04
III α=0.36g	5	2.25	1.61	1.59	1.79	1.25	1.26
	10	1.79	1.21	1.22	1.51	1.00	1.03
	15	1.61	1.02	1.06	1.40	0.87	0.92

It becomes obvious from the above results that the factors of safety, in all cases, are greater than 1.0, implying that for the examined cases and for those with intermediate height as well, there is no reason for the designers to perform seismic analysis anymore.

In order to study the variability of the results due to variance in soil properties, the results for a value cohesion intercept equal to c = 5 KPa, (for which a static FOS equal to the minimum required 1.40 for a height H=15m has been calculated) are presented in the same table (Table 2). As it can be seen, even in this case, the calculated factors of safety are lower than 1.0 only for the case of embankments higher than 10m in seismic region III.

The obtained results, when for the shear wave velocity a slightly lower value of 400m/s is accepted, are presented at Table 3.

Table 3. Factors of safety for embankments with slope inclination 1:1.5 and Vs = 400m/s

Seismicity regions	Height (m)	Cohesion intercept c = 10 KPa			Cohesion intercept c = 5 KPa		
		Static case	Seismic Loading		Static case	Seismic Loading	
			α_v+	α_v-		α_v+	α_v-
I α=0.16g	5	2.25	1.93	1.89	1.79	1.52	1.50
	10	1.79	1.49	1.47	1.51	1.25	1.24
	15	1.61	1.29	1.29	1.40	1.12	1.12
II α=0.24g	5	2.25	1.80	1.75	1.79	1.40	1.39
	10	1.79	1.36	1.35	1.51	1.13	1.14
	15	1.61	1.16	1.18	1.40	1.00	1.02
III α=0.36g	5	2.25	1.59	1.58	1.79	1.24	1.25
	10	1.79	1.19	1.20	1.51	0.98	1.02
	15	1.61	1.00	1.03	1.40	0.84	0.90

As it can be seen, even in the worst credible case with Vs = 400m/s and c = 5 KPa, the calculated factors of safety are lower than 1.0 only for embankments with heights greater than 10m and located in areas with seismicity class III.

The same procedure has been repeated for a more gentle embankment slope inclination 1:2 (V: H) which is also used in practice. The results are presented at Table 4 and Table 5 for shear waves velocity 500m/s and 400m/s respectively.

Table 4. Factors of safety for embankments with slope inclination 1:2 and Vs = 500m/s

Seismicity regions	Height (m)	Cohesion intercept c = 10 KPa			Cohesion intercept c = 5 KPa		
		Static case	Seismic Loading		Static case	Seismic Loading	
			α_v+	α_v-		α_v+	α_v-
I α=0.16	5	2.70	2.14	2.21	2.19	1.81	1.80
	10	2.19	1.77	1.76	1.89	1.51	1.52
	15	2.00	1.56	1.57	1.78	1.38	1.40
II α=0.24	5	2.70	2.04	2.02	2.19	1.65	1.65
	10	2.19	1.60	1.60	1.89	1.36	1.38
	15	2.00	1.39	1.42	1.78	1.23	1.26
III α=0.36	5	2.70	1.79	1.79	2.19	1.44	1.47
	10	2.19	1.38	1.42	1.89	1.16	1.22
	15	2.00	1.18	1.24	1.78	1.03	1.10

Table 5. Factors of safety for embankments with slope inclination 1:2 and Vs = 400m/s

Seismicity regions	Height (m)	Cohesion intercept c = 10 KPa			Cohesion intercept c = 5 KPa		
		Static case	Seismic Loading		Static case	Seismic Loading	
			α_v+	α_v-		α_v+	α_v-
I α=0.16	5	2.70	2.23	2.19	2.19	1.80	1.79
	10	2.19	1.75	1.74	1.89	1.50	1.50
	15	2.00	1.54	1.50	1.78	1.36	1.38
II α=0.24	5	2.70	2.03	2.00	2.19	1.64	1.64
	10	2.19	1.57	1.58	1.89	1.34	1.36
	15	2.00	1.36	1.39	1.78	1.20	1.24
III α=0.36	5	2.70	1.77	1.77	2.19	1.42	1.46
	10	2.19	1.35	1.39	1.89	1.14	1.20
	15	2.00	1.14	1.21	1.78	1.00	1.08

DISCUSSION

Considering the above presented results the following remarks can be made:

1. For the relatively gentle slope inclination 1:2 it can be concluded that the factors of safety are greater than 1.0, implying that for any considered height and parameter combination there is no problem. Therefore embankments with heights until 15m and side inclination 1:2 (V: H) can be considered safe for all the seismic regions of the country.

2. For the steeper inclination 1:1.5 and for the typical values of embankment material soil parameters, currently accepted in the design, the same conclusion holds.

3. Marginal problems are presented for slope inclination 1:1.5 when the strength parameters touch the lower acceptable values for strength properties of the soil material used for embankment construction. The safety problems were presented for embankments located in seismicity region III, with heights greater than 10m, when values of c = 5KPa and Vs = 400m/s were considered for the embankment material.

Moreover, from the analysis of the results, it has be concluded that for high embankments (H = 15m), critical was the upward direction of considered vertical acceleration, whereas for the lower embankments (H = 5m) critical was the combination with the downward direction of the considered acceleration α_v.

The stability of the slopes has also been examined without considering the vertical acceleration component. From the comparison of the results, which are not presented here due to lack of space, it can be concluded that the maximum difference in FOS is ± 3% for heights of 15m, ± 1.5% for heights of 10m and ± 1% for heights of 5m.

CONCLUSIONS

From the above presented results and discussion the following conclusions can be arisen:

1. The seismic slope stability analysis procedure imposed by EAK2000 for embankments with heights until 15m and with side inclinations until 1:1.5 (V: H), as usually happened in practice, has no meaning at all, at least for the case of embankments resting on a almost non deformable soil. When they are designed with static factor of safety equal to 1.40 the calculated factors of safety for seismic loading in all cases are greater than 1.00.

2. Minor problems are expected when it is suspected that mechanical properties of the embankment material are lower than the ones used in current analysis practice. This concerns embankments higher than 10m and located in seismic region III.

3. For reasons of respect to the common sense the relevant provisions of the Greek Seismic Code must be thoroughly reexamined, otherwise the designers should be informed that seismic analysis for these cases is not necessary.

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