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Road and Rail Infrastructure III

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POSSIBLE IMPACT OF EUROCODE 7 ON SLOPE DESIGN FOR ROADS AND RAILWAYS

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Abstract

Eurocode 7-1 covers the geotechnical design, among which is slope stability. As they are normally and routinely present in designing roads and railways, either as embankments or excavations, the necessity for actualization of Eurocode 7 through the prism of traffic infrastructures is understood. Most of the European countries have selected Design Approach 3 as appropriate for designing slopes according to Eurocode 7. Moreover, it was also found appropriate for Western Balkan countries, but in order to establish relation between the "old" and the "new" way of design, theoretical and numerical analyses were conducted. With them, direct relation between the global safety factor and prospective material partial factors has been adjusted, respecting both Eurocode 7 and former design tradition which has produced many stable and safe road/railway geotechnical structures. The results from research have shown that the material partial factor offered in Annex A of Eurocode 7-1 can not be directly applied if it is not absolutely clear in which circumstances i.e. load case, structure type, step of execution, reliability of parameters etc. it should be applied. This looks after enlarging the range of partial factors from the only single one as offered in Eurocode 7-1, since that keeping the single will push the roads and railways in the group of unsafe structures, unlike now. The methodology and findings are discussed further in the paper.

Keywords: Eurocode 7, slope stability, roads/railways, design tradition, relation

1 Introduction

Following the activities in the field of designing structures asks for accepting and application of Eurocodes (EC). In them, main news is limit state design, unlike hitherto working state design. There has been intensive work on the 10 parts of EC in the past decade, starting with their translation up to the most important part – preparation of National Annex. From that aspect, it seems that one of the most demanding was Eurocode 7 (EC7) which covers geotechnical works and it consists of two parts. The first one (EC 7-1) regulates the general rules for geotechnical design of foundations, retaining structures, embankments, their overall stability or hydraulic heave, while the second part (EC 7-2) is related to planning of terrain investigation, field and laboratory tests etc.

Slopes and their stability are part of EC7-1, and as slopes are commonly present in roads and railways, either through excavations or embankments, the necessity for actualization of EC7 through the prism of traffic infrastructure is understood. One of the specifics is that EC7 offers only single one material partial factor for determination of slope stability, suggesting its usage both in permanent and transient load cases, neglecting also the material and structure type. This differs drastically from the previous analyses and thus asks for careful calculation of slope stability in order to avoid endangering safety of traffic structures.

2 Slope design

2.1 Recent regulation

The factor of safety (FS) is defined as a ratio between the available shear strength and average mobilized shear strength needed to keep in equilibrium the hypotetic sliding body. It is calculated as a constant average relation of same value at all points of the sliding surface, although it does not have to be same for cohesion and tangent of angle of friction. The value of smallest allowable FS is determined in relation to the nature of an action, extent of investigations conducted on material properties etc. The standards [5] also specify that the FS increases with the lack of such conducted investigations. The determination of the FS may be regulated only locally, as it also depends on the environment (climate, type of ground, water, etc.)
Depending on the type of slope and material upon which it is performed, values shown in Table 1 are used as common design values for minimal FS, when highly reliable geomechanical parameters are available (those values correspond to actual standards [4] in the countries of former Yugoslavia still in the process of adopting Eurocodes):

Table 1 Values of applied partial factors

Type of structure	Shearing strength parameter	FS [min]
Embankment on hard or fairly compressible ground	Φ', c' or Φ'_B, $\Delta\Phi'$, p_N	1.4
Embankment on saturated ground with low bearing capacity	Φ', c' or Φ'_B, $\Delta\Phi'$, p_N; c_u	1.4; 1.4 ÷ 2.0
Excavation in saturated clays	Φ', c' or Φ'_B, $\Delta\Phi'$, p_N; c_u	1.4; 1.4 ÷ 2.0
Excavation in coarse grained materials	Φ' or Φ'_B, $\Delta\Phi'$, p_N	1.2

However, in a case of unreliable geomechanical parameters minimal values specified in Table 1 shall be increased by 0.25, while in a case of average reliability those shall be increased by 0.1. In addition, for highly reliable parameters it is recommended to apply the parameters Φ'_B, $\Delta\Phi'$, p_N and non-linear criterion of failure of hyperbolic type, instead of Φ', c' or Φ'_r [3].
Specified FS are applied in conditions of permanent and static loadings, so in the analysis of transient conditions of loading it is common to accept FS=1.30, while the FS for pseudo-static conditions is 1.10. However, the Standards do not differentiate between embankments/pits for roads and railways [4].

2.2 Eurocode 7

Eurocode 0 [1] suggests application of partial factors (PF) in analyses and designs; PF in EC7 factorize actions, material properties and resistances, and are imposed by the reliability of data, type of load, analyses, construction, cost effectiveness, maintenance and possibilities and effects of failure. Thus, depending on their position in equation, three design approaches (DA) are in use. The actual practice has shown the efficiency of "outdated" approaches through stability and functionality of structures, so the similarities between an "old" and new method allow adoption of relevant DA, while the approximation of dimensions of designed structures (with guaranteed safety) shall suggest the value of PF. The application of PF in analysis requires achieving of FS of 1.0. Comparative analyses have shown that the DA3 – among all approaches offered in Eurocode 7 – is the most appropriate for future analyses of slope stability [6], and it is also adopted in many European countries [9]. Within DA3, PF are applied on forces or effects and shearing resistance of the soil, thus only one calculation performed with values of input parameters is required. There are two types of PF for actions, depending on the fact if they originate from the structure or if they are of geotechnical origin, but in a case of slope stability and overall stability analyses, the effects over the ground (from any permanent load) are interpreted as geotechnical, thus using action PF=1,0. Different action PF i.e. PF=1,30, is used only for transient and unfavorable loadings [2].

3 Correlations

Until now, slopes were designed and analyzed according to the proved methods based on global factor of safety. The Bishop's method is one of the most popular methods for calculation of their stability in relation to the limit equilibrium. Besides many other advantages, this method is also acceptable from the aspect of EC7 [10]. Within this method, an iterative calculation is performed according to the following equation:

$$Fs = \frac{\sum_{i=1}^{n}\left[c'\cdot b + (W - u\cdot b)\cdot \tan\phi'\right]\cdot m_\alpha}{\sum_{i=1}^{n} W\cdot \sin\alpha} \tag{1}$$

where:

$$m_\alpha = \frac{1/\cos\alpha}{1 + \tan\alpha\cdot\tan\phi'/Fs} \tag{2}$$

Other methods vary mostly in regard to the manner of treatment of inter-laminated forces which, however, do not affect the selection of an approach and value of partial factors. Next step is determination of PF intended to reduce shearing resistance parameters (SRP); Annex A in EC7-1 suggests the value of 1.25. The condition for their determination is to provide same degree of stability prescribed so far, i.e., to assure same slope inclination, because the practice has proved their safety. If c=0 kPa and u=0 kPa, then Bishop's expression may be reduced to:

$$Fs = \frac{\tan\phi'\cdot m_\alpha}{\sin\alpha} \tag{3}$$

$$Fs = \frac{\tan\phi'\cdot \dfrac{1/\cos\alpha}{1 + \tan\alpha\cdot\tan\phi'/Fs}}{\sin\alpha} \tag{4}$$

$$Fs = \frac{\tan\phi'}{\sin\alpha\cdot\cos\alpha + \sin^2\alpha\cdot\tan\phi'/Fs} \tag{5}$$

Eqn (5) implies that:

$$\tan\phi' = Fs\cdot\tan\alpha \tag{6}$$

If eqn (5) is applied in conditions of limit state (when FS=1.0), then $\tan\Phi'$ should be replaced with design value of the angle of friction derived from the condition:

$$\tan\phi_d = \frac{\tan\phi'}{\gamma_\phi} \tag{7}$$

so the expression for FS would be as follows:

$$Fs = \frac{\tan\phi_d}{\sin\alpha\cdot\cos\alpha + \sin^2\alpha\cdot\tan\phi_d/Fs} \tag{8}$$

knowing that FS=1.0, this eqn (8) would imply that:

$$\tan\phi_d = \sin\alpha \cdot \cos\alpha + \sin^2\alpha \cdot \tan\phi_d \tag{9}$$

which, after transposing tanφ' to the left side and rearranging trigonometry expressions would gain that:

$$\tan\phi_d = \tan\alpha \tag{10}$$

$$\frac{\tan\phi'}{\gamma_\phi} = \tan\alpha \tag{11}$$

$$\tan\phi' = \gamma_\phi \cdot \tan\alpha \tag{12}$$

The equalization of the last two expressions with tanΦ' on the left side (eqns (6) and (12)) would gain:

$$Fs \cdot \tan\alpha = \gamma_\phi \cdot \tan\alpha \tag{13}$$

and, finally:

$$\gamma_\phi = Fs \tag{14}$$

According to fore mentioned it can be stated that the PF that shall reduce the tangent of friction angle [γ_Φ] in limit state conditions – while maintaining the same degree of safety previously provided with the global FS – is equal to the actual FS; the latter depends on the material, type of structure, nature of loading and design situation in which stability of the slope is being observed: permanent, transient or accidental condition.
Similar method was also used to prove that the same stands for cohesion (whether effective or undrained), which is also being verified [8].
The described approach for determination of partial factors allows this analysis to be used both in application of a Mohr-Coulomb law and non-linear failure envelope of hyperbolic type [3]. Non-linear interpretation of shearing resistance – due to realistic description of all types of soil within overall range of stresses – is particularly helpful during the optimization of slopes. Above all, this stands for soils with coarse grained materials, which apparently show critical stability of shallow surfaces to shear (and therefore require most of the engineering attention), but also for regular dimensioning and prevention of eventual failures at slopes with fine grained materials. Both instances derive from imperfections of a Mohr-Coulomb linear envelope in zone with low normal stresses, which are commonly competent for determination of SRP required for analysis of slope stability: it overestimates the strength of fine grained materials and underestimates the strength of coarse grained materials.
Related to this nonlinear failure envelope (Firuge 1), it was also found that it can be implied with partial factors [6, 7].
The described approach and findings allow a slope with previous global factor of safety of 1.50 to gain factor of 1.0 in the limit state. In both cases the specified values of factors will relate to the same sliding surface. So, several procedures have proved that in calculation of slope stability the value of partial factors by which SRP are reduced is equal both for the tangent of angle of friction and cohesion, and is also equal to the global factor of safety. However, besides on the proper parameters, its intensity also depends on actual conditions in which the slope stability is

examined: permanent, transient or accidental; they also may be distinguished in relation to the type of structure (dam, road, mine, etc.). Eurocode 7 Annexes do not offer such categorization of values of PF, so they are proposed as constant and independent from particular case, which poses one of its rare shortcomings. However, some possibilities are partially mentioned in Eurocodes 0 and 1. Those Eurocodes allow variations in PF based on the extent of consequences and reliability, but also on design situation, i.e., on load case, which is particularly appropriate to our recent practice! Proposed values maintain the actual and confirmed degree of safety, i.e., the same slope inclination, which is particularly important in a case of possible rehabilitation and upgrade, thus avoiding any future threats to the slope usability and allowing comfortable accommodation of engineers to the new design approaches according to EC7.

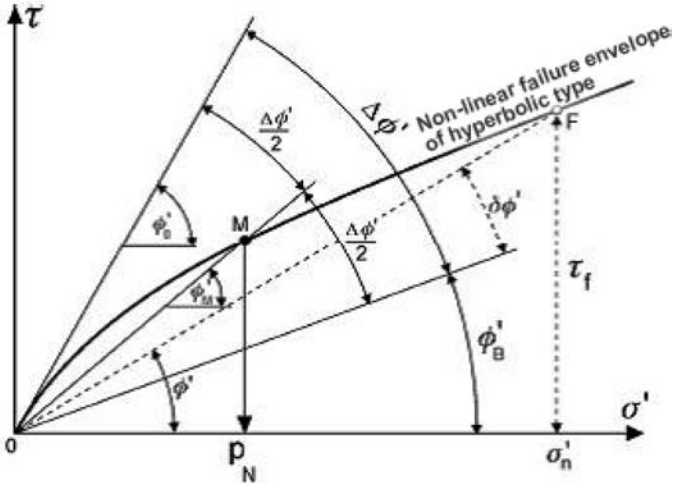

Figure 1 Non-linear failure envelope of hyperbolic type and its parameters.

4 Conclusions

In order to determine the relation between “old” and “new” design approach, some theoretical analyses were performed. The findings were confirmed with numerical calculations. This established direct relation between the actual factor of safety and future material partial factors, while respecting the Eurocodes and actual designing practice. Moreover, the results gained from investigations are appropriate for Mohr-Coulomb linear and non-linear failure envelope.
It was concluded that analyses of slope stability in our region (former Yugoslavia) require Design Approach 3, also adopted in many European countries. However, the value of PF for SRP is not constant as offered with Eurocode 7, but variable and dependable on the material, reliability of parameters, load cases etc. Thus, in order to keep designing safe slopes at roads and railways, following the analyses shown, it can be concluded that SRP in our region – when calculating the stability of excavation or embankment slopes with different types of materials – and provided that parameters have average reliability, during their application in DA3 should be reduced by:

- 1.50 for excavations in saturated clays and embankments (regardless to the base material) for permanent load conditions (1.40 for high reliability of SRP)
- 1,30 for excavations in coarse grained materials (1.20 for high reliability)
- 1.30 for analyses in transient load conditions
- 1.10 for pseudo-static analyses
- to maintain original values, in case of reverse analysis, because of reduction by 1.0.

Although it seems that these factors are higher than the primary offered in EC7-1, it has to be said that they are needed such in circumstances of initial application of EC7. Namely, in order to introduce EC7 to the new users, either as concept or from aspect of results, they have to have these values as only they keep the proved stability and slope. Their reduction should be expected, but only after several years of continual application of the proposed design approach and partial factors, followed by monitoring of such designed and built slopes and with respecting of the recommendations for quality and number of field and laboratory tests as stated in EC 7-2

As it is extensively described and commented in papers [6], [7] and [8], the specified approach and identical value of coefficients are rather favorable and recommended for analysis of slope stability in computer applications based on the finite element method, as well for modeling of materials using non-linear failure envelope of hyperbolic type.

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