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Eurocode 7 202x: Avoided offside in slope stability analyses

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Abstract. The national working group for Eurocode 7 (EC7), who prepared the National Annex (NA) to EC7 in R. N. Macedonia, has already started analyses for the implementation of the next EC7 202x. So far, analytical comparisons between the design procedure and dimensions gained with actual and prospective EC7 have been conducted for the most common geotechnical structures. Construction activities on several large infrastructure projects enable site check: the obtained findings related to slopes will be presented in the paper. They confirm the importance of increased attention and consideration, respecting the positive design tradition and applied conservatism while preparing the actual NA, which might divert from the majority of European NAs, in order to avoid some shortcomings of the existing EC7 which are improved in the EC7 202x.

Keywords: Eurocode 7 202x; Comparisons; Slope stability

1 INTRODUCTION

In order to prepare and successfully accept the next-generation Eurocodes, research was conducted using the original Eurocode 7 (EC7), the current National Annex (NA) to EC7 in Macedonia (MKS NA:2020), the former Macedonian standards (MKS) with general safety factor (FS) and the proposals for the future EC7 202x, through the prism of a current design and construction of slope. Bases were taken from a geotechnical design of a highway in R. N. Macedonia (RNM), along whose route a large number of geotechnical structures are being implemented. In general, the most common structures are slopes, whose analysis requires considerable amount of input data and reliable design bases. Their stability design was made according to EC7, but not fully in line with NA in RNM, because the designers come from EU country where EC7 has been into effect for a long time, while it still was not entered into force in RNM during the design stage of slopes in question. The legal vacuum partly contributed to appearance of instabilities at certain sections of the highway, and this paper provides critical review of the applied methods and partial factors (PF) in order to facilitate the transition to the second generation of EC7.

2 BASIC INFORMATION ABOUT THE ROUTE AND THE ANALYZED SLOPE

Large cuts stand out as a particular engineering challenge within the highway route under construction in RNM. According to the geology of the terrain, they should be formed in a flysch series. Boreholes, field tests and laboratory tests were carried out in order to conduct comprehensive geotechnical research. Based on the observed phenomena, similarities and tendencies, "consolidation" of findings was performed with adoption of representative values for similar materials along the route. The data presented in the geotechnical report suggests that the soil (from a geomechanics point of view) consists of large percentage of clayey sand, with rare presence of gravel or rounded rock particles. Figure 1 shows an example of material taken after drilling a borehole near the cross section which is examined in further analyses.

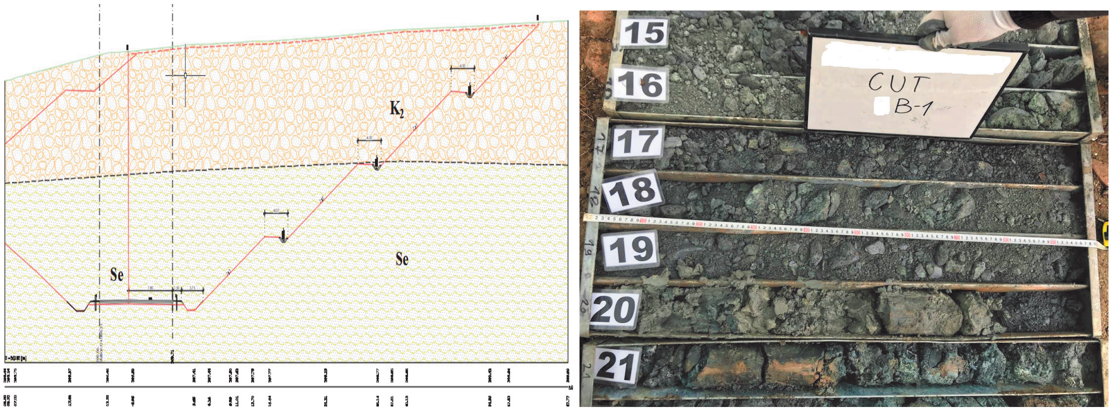

Figure 1 Cross section of characteristic slope (left) near the borehole (right)

The section and the borehole were chosen since rather satisfactory findings were obtained in the stability analyses: for these, the experiences with EC7 in the designers' country (the so-called EC7: Annex A and model factor) were applied, introducing the shearing resistance parameters (SRP) representative of similar materials along the route. The geometry and material properties are given in Table 1. However, cases of failure and collapse were detected in the construction stage (Fig. 2), indicating divergence of on-site parameters from those included in the analyses and questioning the applied PF.

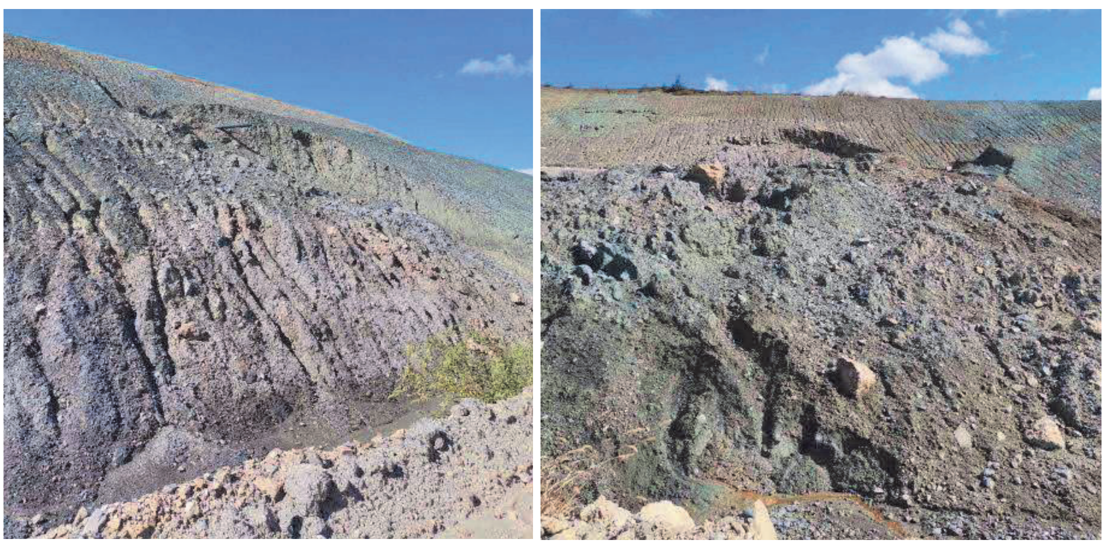

Figure 2 Surface and deep instability of analysed slope

Table 1 Geometry and material characteristics of the analysed slope

Slope design	Material type (0 – 26 m)	Strength parameters		Unit weight
		φ_k' (deg)	c_k' (kPa)	γ (kN/m^3)
Height: 30 m Inclination: 2:3 (34°) Intermediate bench: h=8 m, B=4 m	Silty sand (SM) to sandy silt (ML)	34°	8	19

In addition, the stability check was performed by applying NA, using Design Approach 3 and PF from the MKS NA:2020. One of the MKS NA:2020 characteristics is that the PFs for slope stability are variable (Papić et al., 2014), e.g., the material PFs should be equal to the general FS that existed in MKS. The reliability of the SRP is one of the conditions that influence the value of FS, and therefore PF.

Namely, the tradition of designing slopes according to MKS requires FS=1.40/1.50/1.65 in cases of high, average and low reliability of input data, respectively. Thus, if an average reliability is applied, and PF=1.5 is used, the achieved amount of safety would be 1.07, which seems satisfactory. The approach with variable PF should have been respected in this case, since the analyses were performed with parameters that were adopted as representative for the entire route, but not for those drilled from the borehole in question (near the slope), which reduces the reliability of the SRP, especially if boreholes and tests were not conducted frequently enough. Namely, these input parameters are not necessarily appropriate for the existing materials, as the SRP applied in the analyses may be higher than those observed after the testing of materials at the analysed cross section and borehole! At the same time, the conditions after one year of exploitation, like occurrence of erosion and landslide, suggest the need for additional analyses of recommendations contained in the standards.

3 RELIABILITY MANAGEMENT

3.1 Categorization

Considering the availability of information from the design, as well as the proposals in EC7 202x, it is necessary to categorize the structure by the reliability of data (Reliability management). The EC7 202x requires the Geotechnical Complexity Class (GCC) and Consequence Class (CC) to be defined before the verification of the structure (Bond et. al., 2019). Guidance on the definition of GCC is given in the informative Annex E of EC7-1 202x, which takes into account the uncertainty of soil conditions, the variation of geological conditions and the sensitivity of the geotechnical structure to ground and surface water conditions.

By processing the data obtained after field and laboratory tests, the soil material is defined as separate geotechnical unit. Table 2 shows some characteristics that do not correspond to the geotechnical bases on which the design for the considered slope was based. The classification of material is made by statistical processing of values, using the method of standard deviation for a certain parameter. Thus, the SRPs – which play a major role in the stability – were obtained by analytical methods based on SPT and other correlations.

Table 2 Geotechnical categorization with consideration of the design reliability (EC7 202x)

Design information		Reliability	
Basis	Considerations	Specific ground features	Categorization
- uniform composition material for the whole profile (depth = 26m) - strength parameters with analytical methods: AASHTO LRFD - $N_{1,60,ave}$=50	- borehole required depth: min 40 m ($d_{min}>1.4H_{slope}$) - statistic evaluation of parameters - SPT site testing for 0-6 m of borehole - no laboratory testing	- ground with thin weak layers or zones - unfavourable discontinuity patterns - fine soil sensitive to disturbance - exposure to erosion - variability of water level	- Geotechnical Complexity Class 3 - low data reliability (MKS)

The insufficient depth of BB-1, the small number of laboratory and field tests, and some specific ground features (thin and weak layer) that can be taken into account here according to the field conditions (prescribed in EC7-1 202x), lead to definition of the third class of GCC.

On the other hand, having in mind that a permanent structure is being designed and that possible failure during the period of exploitation can have major consequences on the environment, it will be categorized as the third level, i.e., CC3, according to the recommendations of EC7 202x (Estaire et al., 2019).

3.2 Importance of modelling

A further step in the process of geotechnical design is defining of design conditions (permanent, temporary, accident) and taking into account all available data on the site conditions. Such an approach in EC7 202x can be described by preparing a Geotechnical Design Model. This model, according to the concept, should show design geotechnical parameters and appropriate structures through sketches, drawings or 2D/3D models and general rules for verification from EC7-1 (Bond et al., 2019).

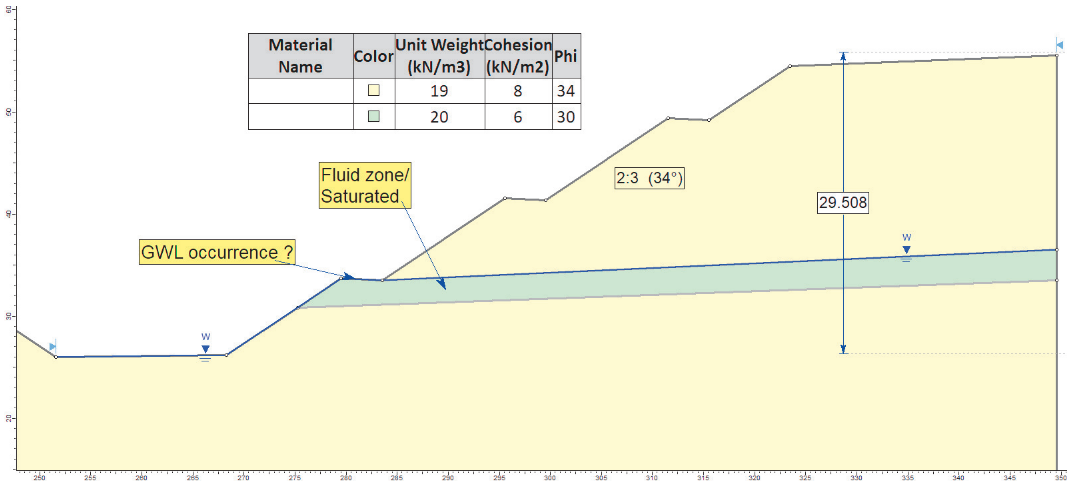

Figure 3 Geotechnical Design Model of the analysed slope (conceptual)

Hence, basing on the available data and geotechnical conditions, a model was created (Fig. 3) with some basic characteristics of the section and indication of relevant situations that should be taken into account: the occurrence of a fault zone or wet material from 20 to 23 m (Fig.1, near the appropriate borehole), and the possible occurrence of ground water, which in this case would be categorized as an accidental load on the slope. This is followed by ULS verification of the slope according to this geotechnical model and the specified design conditions that should be taken into account during the analysis of the structure.

4 GEOTECHNICAL ANALYSES

4.1 Selection of method and partial coefficients

Slope stability design was performed using the Bishop's method in Slide2 software, in order to obtain the FS of the slope, which, by definition, should meet the condition of stability according to EC7: FS>1.0. According to the clauses of EC7 202x, DC3 (M2) was applied, which, according to the action sets and the treatment of geotechnical loads on the slope, is fully identical to DA3 used in MKS NA:2020 and results in same safety degree (Sarev, 2022; Sarev and Papić, 2022). Moreover, in line with the analyses conducted for the adoption of MKS NA:2020, when MKS (general FS) and EC7 were compared, it was observed that PFs for reduction of the SRP should be equal to the factor of safety for the slope: $\gamma_\varphi=\gamma_c$=general_FS (Papić et al., 2012). This value is variable and depends on reliability of parameters, type of structure etc. (Papić et al., 2014)! However, this is part of the EC7 202x. Namely, the definition of the CC3 allows PFs to be increased by additional sub-factors of K_M (Bond et al., 2019), while according to EC7, for similar purposes, the model factor γ_M (an approach that was applied in the design during the stability verification for the analysed slope) was provided. Values of these factors are given within the M sets for persistent, transient and accidental design situations (Estaire, 2019). Thus, the stability analysis of the analysed slope is performed with the obtained material factors γ_M according to the three specified standards given in Table 3 – original EC7 (applied in the design), future EC7 202x and existing MKS NA:2020:

Table 3 Defined PF according to EC7 and MKS with consideration of consequences

Design situation	EC7 (Model factor)	EC7 202x (Consequences factor)	MKS (global FS) and MKS NA:2020 (Data reliability)
persistent and transient	(γ_m =1.1) γ_M=1.25*γ_m= 1.38	(K_M =1.1) γ_M=1.5K_M=1.65	γ_M=FS_{min}=1.65
accidental (water)	γ_M=1.0	(K_M =1.1) γ_M=1.1K_M=1.21	γ_M=FS_{min}=1.1

These sub-factors, and the selection of PF in the NA may lead to differences in the slope stability which, in this case, may have a crucial consequence. Nevertheless, it would be in line with the past positive practice and the recommendations in MKS NA:2020, and would contribute to the stability and reliability of the structure, although they may deviate to some extent from the application of EC7 in most countries.

4.2 Comparison of the slope stability results

The software analyses are based on the geometry given in Figure 3 and the indicated geotechnical parameters. For the verification in static conditions, only Ru=0.1 was used for the pore pressure in fine-grained materials. The second load case considered an increase of ground water, as a consequence of periodic intense rainfalls, up to the first bench on the slope. The values of achieved margins of stability are given in Fig. 4, showing equal results for MKS / MKS NA:2020 and EC7 202x, which are far below those obtained with EC7, while the on-site situation (failed slope) confirms the lower values:

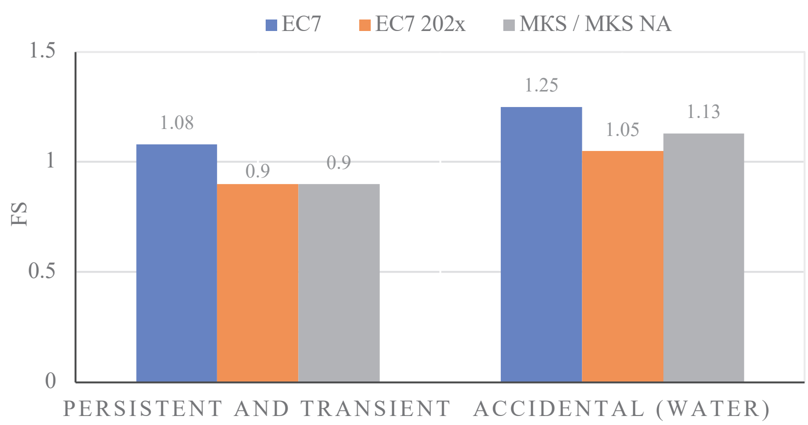

Figure 4 Diagram view of outputs from analyses

Variations were performed for persistent conditions, for pushing the FS to boundary values. Hence, φ_k' was reduced by 2°, resulting in FS=1.0/0.84/0.84 (case 1), while φ_k' increased by 3.5° gives 1.20/1.0/1.0 (case 2), respectively for EC7, EC7 202x and MKS NA:2020. So, for case 1, the calculations with EC7 would still confirm stability and actually result in slope failure on site, while case 2 requires SRP to be at least 3.5° higher, so that it would become stable. Similar is given in Papić et al., 2012, and Sarev, 2022.

5 CONCLUSIONS

This paper compares the results of slope stability analysis according to former MKS (using general FS), current MKS NA:2020 and EC7 used in an EU country, which was used for slope design in RNM with observed instabilities, in order to create conditions for application of EC7 202x. A cut zone on designed highway was selected, where a landslide caused by intense inflow of (ground) water was observed in one-year period, tending to progress in a wider zone, both horizontally and vertically.

The analyses were conducted with parameters adopted as representative of the materials found along the route, even though this does not imply that they are applicable for that material at the location in question, where a borehole was drilled. In such circumstances, it is preferable to use somewhat higher PFs, which is not explicitly given in EC7, but is provided within EC7 202x and has been proved as necessary and was respected when preparing the MKS NA:2020, through the adoption of variable material PFs that are a function of the degree of reliability of parameters, type of structure, load case, etc. This avoids some concerns that may arise from direct application of the original EC7 only. Hence, by applying the recommendations of EC7 202x, some of the mentioned issues can be overcome with an additional PF present within the EC7 202x, obtaining greater safety in case of accidental design conditions. This is in line with the MKS NA:2020 and the positive tradition of designing slopes according to MKS, enabling bridging the gaps and successful introduction of EC7 202x.

On the other hand, the geotechnical design is based on design parameters according to EC7. It mainly uses statistical data processing, which, in this particular case, probably lacks sufficient field and laboratory experiments. Nevertheless, if PF for low reliability of parameters is used (MKS / MKS NA:2020) or appropriate consequences class (EC7 202x), a lower FS than the minimum allowed for static conditions would be obtained, requiring stabilization in the design stage and thus avoiding the current site state: collapsed slope.

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