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EUROCODE 7: A New Way to Verify a Slope's Stability

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Abstract: The paper intends to detail the new approach for slope stability design. The Eurocode 7: Geotechnical Design represents a radical change in the geotechnical design. The new limit state design recommended by Eurocode 7 introduces the notion of partial safety factors which allow a more detailed consideration of the elements which determine the stability conditions for the slopes stability. They are grouped in three categories. The first category refers to actions applied on the structure, the second to the material properties and the third to the resistances. These partial safety factors are introduced in the calculus from the beginning, in contrast to the former general factor of safety which had to be verified at the end of the calculus.

Keywords: slope stability, partial safety factor, Bishop's method, Eurocode 7, geotechnical design

1. INTRODUCTION

Eurocode 7. Part 1 has been published as a prestandard (ENV) in October 1994, for experimental practical application in the countries member of the European Committee for Standardisation (CEN). Eurocode 7 is included in a set of structural Eurocodes, its objective being establishing a set of harmonized technical rules for structural and geotechnical design of buildings and civil engineering works in the states members of European Union.

This Eurocode differs from other structural Eurocodes because of the specificity of materials and problems with which geotechnical design is confronted. Differences in principle are occurring in determination of characteristic and design values of the soil properties. Eurocode 7 does not prescribe the derivation of the characteristic value of a given soil property function of the test results, but requires that the characteristic value to be estimated from a value affecting the occurrence of the limit state.

In Romania the Eurocode 7 became a national norm in June 2004 as SR EN 1997-1 as Eurocode 7: Proiectarea geotehnica.

The present paper intends to disseminate the Eurocode 7 prescriptions, particularly in the domain of the slope stability calculus. The paper presents the calculus manner for a slope stability check following the Eurocode 7 prescriptions.

2. SLOPE STABILITY CHECK ACCORDING TO EUROCODE 7

The problem to be solved consists in a slope stability check following the Eurocode 7 design prescriptions.

The first step to be solved consists in establishing the partial safety factors for each of the three Design Approaches recommended by Eurocode 7.

The slope to be verified is presented in Fig. 1.

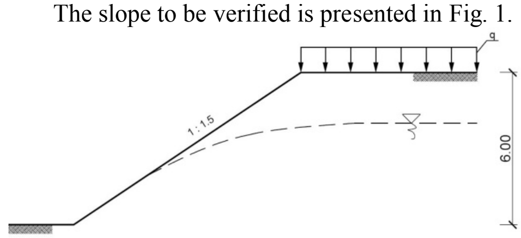

Fig. 1. Slope geometry and ground water location.

The soil characteristics and the values for the actions to be considered in the calculus are:

Soil characteristics:

- Characteristic bulk unit weight: $\gamma_k = 18.7 \frac{kN}{m^2}$

- Characteristic internal friction angle: $\phi_k^{'} = 22^\circ$

- Characteristic value for cohesion: $c_k^{'} = 15 \frac{kN}{m^2}$

Values for actions:

- Characteristic applied load: $q_k = 15 \frac{kN}{m^2}$

The values presented above are characteristic values. To obtain the design values, which are used in the calculus, one has to consider the partial safety factors recommended by Eurocode 7.

To verify the stability conditions of the slope is necessary to perform all verifications considering the Design Approaches DA1, DA2 and DA3.

For the calculus of the Design Approaches will be used partial safety factors. There are three categories of partial safety factors:

- Partial factors for actions: γ_G and γ_Q;
- Partial factors for soil parameters: $\gamma_{\phi^{'}}$, $\gamma_{c^{'}}$ and γ_γ;
- Partial factors for sliding resistance: γ_{Rh}.

The **Design Approach 1** means the use of two combinations of partial factors of safety:

- DA1 Combination 1: A1+M1+R1
- DA1 Combination 2: A2+M2+R1

For **Design Approach 2**, the partial factors of safety to be considered are:

- DA2: A1+M1+R2

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The **Design Approach 3** considers the following combination of the partial safety factors:

- DA3: (A1 or A2)+M2+R3

The values of the partial safety factors to be used for all Design Approaches for a GEO design made before are presented in Table 1.

Table 1. Partial safety factors values.

Parameter	DA1-C1	DA1-C2	DA2	DA3	
Partial safety factors				A1	A2
γ_G	1.35	1.00	1.35	1.35	1.00
γ_Q	1.50	1.30	1.50	1.50	1.30
$\gamma_{\emptyset'}$	1.00	1.25	1.00	1.25	1.25
$\gamma_{c'}$	1.00	1.25	1.00	1.25	1.25
γ_γ	1.00	1.00	1.00	1.00	1.00
γ_{Rh}	1.00	1.00	1.10	1.00	1.00

The Ultimate Limit State (ULS) analysis of the overall stability of the slope is performed using the Bishop's Conventional Method.

Figure 2 illustrates a potential circular slipping surface. Using AutoCAD facilities one can draw and determine the slipping surface, the area of the slices, the length of the slipping surface, the angles between the vertical and the radius drawn to the mid-point of each slipping surface of the slices. The centre of the slipping surface was determined graphically following the prescriptions which establish the area where is placed the centre for the most critical circle.

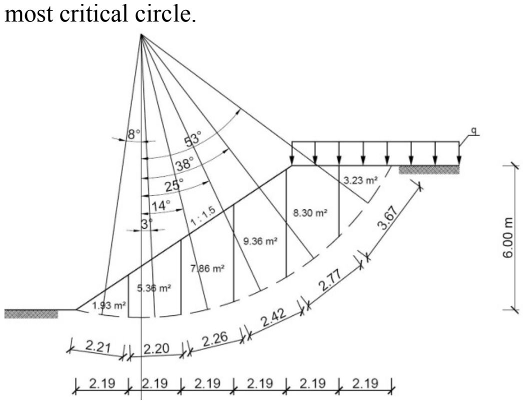

Fig. 2. Geometrical characteristics of the slices.

The groundwater level variation in the slope area was determined by the Casagrande's Method (see Fig. 3).

The graphical method for determining the phreatic surface in an earth dam was evolved by Casagrande (1937) and involves the drawing of an actual parabola and then the correction of the upstream end. Casagrande showed that this parabola should start at a point which depicts a cross-section of a typical earth dam, the focus F being the upstream edge of the filter. To determine the directrix was drawn with the compass the arc of the circle using as centre the point defined before. The vertical tangent to this arc is the directrix. The parabola passing through the point which depicts a cross-section, through the focus and through the directrix was constructed and afterwards this parabola was corrected.

This graphical solution is only applicable to dams resting on permeable materials. When dams are sitting on impermeable soil, the phreatic surface cuts the downstream slope at a distance up the slope from the toe.

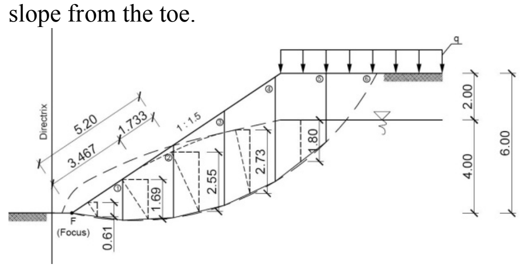

Fig. 3. Groundwater level variation.

Following the Casagrande's Method was determined the variation of the groundwater level and the values of the pore pressure ratio for each slice.

3. BISHOP'S CONVENTIONAL METHOD

Contemporary methods of investigating slope stability are based on assuming a slip surface and the centre about which it rotates, studying the equilibrium of the forces acting on this surface and repeating the process until the worst slip surface is found.

The worst slip surface is that surface which yields the lowest factor of safety, F, the factor of safety being equal with the ratio between the restraining moment and disturbing moment, each moment being considered about the centre of rotation. If stability assessment is to be performed in accordance to Eurocode 7, the strength parameters of the soil are first divided by partial factors and stability is then confirmed by checking the GEO limit state.

The effective stress methods of analysis now in general use were evolved by Bishop (1955). The Bishop's conventional method allows a rapid determination of the factor of safety for a certain slipping surface.

The formula for the calculus of the factor of safety of the slipping surface is:

$$F = \frac{1}{\sum W \cdot sin\alpha} \sum \left[c' l + W(cos\alpha - r_u \cdot sec\alpha) tan\emptyset' \right] \quad (1)$$

This formula gives a solution generally known as the conventional method which allows rapid determination of F when sufficient slip circles are available to permit the determination of the most critical. For analysing the stability of an existing tip it should prove perfectly adequate.

The value of the global factor of safety, F, determined at the end of the calculus, in the concept of safety conditions before Eurocodes appearance should be greater than 1.5 ... 2.0, function of the safety factor value recommended by the standards or by the experience of each designer.

By the new concept of Eurocodes, the safety problem for a structure is analysed through the influence that have different parameters which are used for the calculus. These parameters are divided into three categories:

- Actions on structures (A): self weight, live load, wind, snow and so on;
- Material properties (M): from which the structure is composed, that in the case of soils are the unit weight and the shear resistance parameters, $\emptyset$ and c;
- Resistance of the structural elements (R) that in case of soils are shallow foundations bearing capacity, piles bearing capacity, stability general conditions at the slopes stability calculus and so on.

According to Eurocode 7 safety concepts, the value of the over design factor Γ is enough to be greater than 1.00 due to the fact that the safety conditions are fulfilled by the partial factors of safety considered at the beginning of the calculus.

The calculus by the Bishop's procedure will be performed using the design values of the loads and of the material properties. Practically, the calculus was repeated four times (DA1-C1, DA1-C2, DA2 and DA3) for different sets of values for the partial safety factors.

The design values of the applied load on the structure are:

Load from surcharge acts only on slices no. 5 and 6:

$$Q_d = q_k \cdot b \cdot \gamma_Q \qquad (2)$$

where:

q_k - characteristic applied load;

b - width of a slice;

γ_Q - partial safety factor for actions.

Weight of one slice:

$$G_d = A \cdot \gamma_k \cdot \gamma_\gamma \qquad (3)$$

where:

A - area of a slice;

γ_k - characteristic bulk unit weight;

γ_γ - partial safety factor for weight density.

Total weight used in calculus will be equal with the sum of the load from surcharge and the weight of the slice as:

$$W_d = G_d + Q_d \qquad (4)$$

Resistance force to sliding due to cohesion will be equal with $c'_d \cdot l$ (5)

$$c'_d - \frac{c'_k}{\gamma_{c'}} \qquad (6)$$

where:

c'_d - design value for cohesion;

c'_k - characteristic value for cohesion;

$\gamma_{c'}$ - partial safety factor for effective cohesion.

Sliding resistance forces results from the formula:

$$R_d = c'_d \cdot l + W_d(\cos\alpha - r_u \cdot \sec\alpha) \cdot \tan\emptyset'_d \qquad (7)$$

$$\emptyset'_d = \frac{\emptyset'_k}{\gamma_{\emptyset'}} \qquad (8)$$

where:

$\emptyset'_d$ - design value for internal friction angle;

$\emptyset'_k$ - characteristic value for internal friction angle;

$\gamma_{\emptyset'}$ - partial safety factor for shearing resistance.

For the pore pressure ratio calculus were used the following relationships:

$$u = \gamma_w \cdot h_w \qquad (9)$$

$$r_u = \frac{u}{\gamma_k \cdot z} \qquad (10)$$

$$z = \frac{A}{b} \qquad (11)$$

where:

u - pore pressure at any point in soil mass;

γ_w - unit weight of the water;

h_w - height of groundwater;

r_u - pore pressure ratio;

γ_k - characteristic bulk unit weight;

z - height of the soil column on the vertical passing through the mid-point of the slice (see Fig. 3).

The calculations for the Bishop's conventional method for the Design Approach DA1-C1 are set out in the next table (Table 2):

Table 2. Design Approach DA1-C1.

slice	b (m)	A (m^2)	G_d (kN)	Q_d (kN)	W_d (kN)	α (°)	cos α	sec α	h_w (m)	r_u	cos α-$r_u$sec α	W_d(cos α -r_u*sec α)tanΦ_d'	l (m)	c_d*l	sin α	W_d *sinα
1	2.19	1.93	36.0		36.0	-8.0	0.9	1.01	0.61	0.36	0.6	9.0	2.2	33.1	-0.1	-5.02
2	2.19	5.36	100.2		100.2	3.0	1.0	1.00	1.69	0.36	0.6	25.7	2.2	33.0	0.0	5.24
3	2.19	7.86	146.9		146.9	14.0	0.9	1.03	2.55	0.37	0.5	34.7	2.2	33.9	0.2	35.54
4	2.19	9.36	175.0		175.0	25.0	0.9	1.10	2.73	0.34	0.5	37.9	2.4	36.3	0.4	73.94
5	2.19	8.30	155.2	49.2	204.4	38.0	0.7	1.27	1.80	0.25	0.4	38.9	2.7	41.5	0.6	125.84
6	2.19	3.23	60.4	49.2	109.6	53.0	0.6	1.66	0.00	0.00	0.6	26.6	3.6	55.0	0.8	87.56

Table 3 presents the calculus of the pore pressure ratio computed for each slice function of the height of the groundwater column, h_w for each slice and the height of the soil column corresponding to the mid-point of each slice.

Table 3. Pore pressure ratio calculus.

slice	h_w (m)	u (kPa)	z (m)	r_u
1	0.61	5.98	0.88	0.36
2	1.69	16.58	2.45	0.36
3	2.55	25.02	3.59	0.37
4	2.73	26.78	4.27	0.34
5	1.80	17.66	3.79	0.25
6	0.00	0.00	1.47	0.00

As intermediate results from Table 2 was obtained the sum of the resisting forces due to the internal friction of the soil and the sum of the resisting forces due to the cohesion, respectively the sum of the sliding forces.

All these forces are acting at the same distance from the centre of the circular slipping surface which equals with the radius of the slipping surface and are acting tangentially to the circle. Consequently, all these forces will act from the same distance relative to the centre of the slipping surface.

Due to the fact that all forces (restraining forces and disturbing forces) are acting at the same distance relative to the centre of the slipping surface it is not necessary to be known the length of the slipping surface radius.

The over design factor can be calculated directly as the ratio between the sum of the resisting forces and the sum of the disturbing forces, acting all tangentially to the slipping surface.

The relationship used for computing the over design factor is the following:

$$\Gamma = \frac{\sum R_d/\gamma_{Rh}}{\sum W_d \cdot \sin\alpha} \quad (9)$$

The value of the obtained over design factor for the case DA1-C1 was 1.26.

4. CONCLUSIONS

The calculus was performed following the Bishop's Method repeating the calculus for all Design Approaches according to EN 1997:2004 Eurocode 7: Geotechnical Design.

Using the specific partial safety factors the calculus was performed four times for different sets of values for the partial safety factors.

The values obtained for the over design factor for each Design Approach are presented in the Table 4:

Table 4. Values for over design factor.

Design Approach	DA1-C1	DA1-C2	DA2	DA3	
Over design factor				A1	A2
Γ	1.26	1.02	1.14	-	1.02

It results that the slope fulfils the stability conditions for the initial considered data, because the over design factors have for all Design Approaches a value greater than 1.00.

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