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Road embankment for bridge accessing rural area

D-M Pohrib[1*], D Platică[1], P Turcanu[2] and C Pleșcan[3]

[1,2] "Gheorghe Asachi" Technical University of Iasi, Faculty of Civil Engineering and Building Services, Iasi, Romania
[2] S.C. PROCONRIM S.R.L. Iasi
[3] "Transilvania" University of Brasov, Faculty of Civil Engineering, Brasov, Romania

[*] madalina.pohrib@yahoo.com

Abstract. The article aims to show the construction on soft soil of a road embankment for access to a bridge which passes over a stream. To strengthen, consolidating and draining the embankment near the stream a combined geosynthetic and gabions solutions it was use.

1. Introduction

The construction of a road embankment that gives access to a bridge, which passes over a stream, is to be constructed in order to make the traffic possible again on the only direct road that connects two nearby settlements.

A combined geosynthetic and gabions solutions were used on a soft soil to strengthen, consolidating and draining the embankment near the stream.

2. The causes of bridge access degradation

The studied embankment in which a collapse of the lane has occurred is located on a communal road near the "Ichim" bridge.

Analysing the figure 1, 2 and 4 presented below it can be easily observed that beside the perimeter of the embankment adjacent to the bridge, during periods with high stream flows, the water seeps into the embankment of the bridge road access, washing of fine particles. Thus contributing to the decrease of the shear strength parameters of the constituent soil layers and to the decrease of the stability factor of the bridge road access embankment.

The collapse occurred due the infiltration of water from the stream or rainwater into the embankment adjacent to the bridge during periods with high flows and high amount of precipitation. Is also considered that the improper management of rainwater and the lack of ditches favors the seepage of water into the lane and into the embankment.

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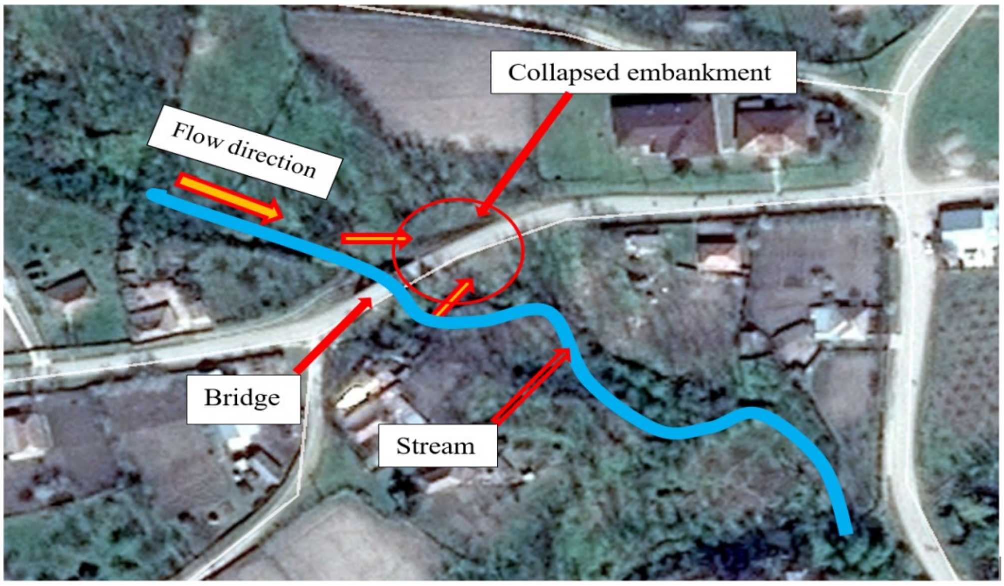
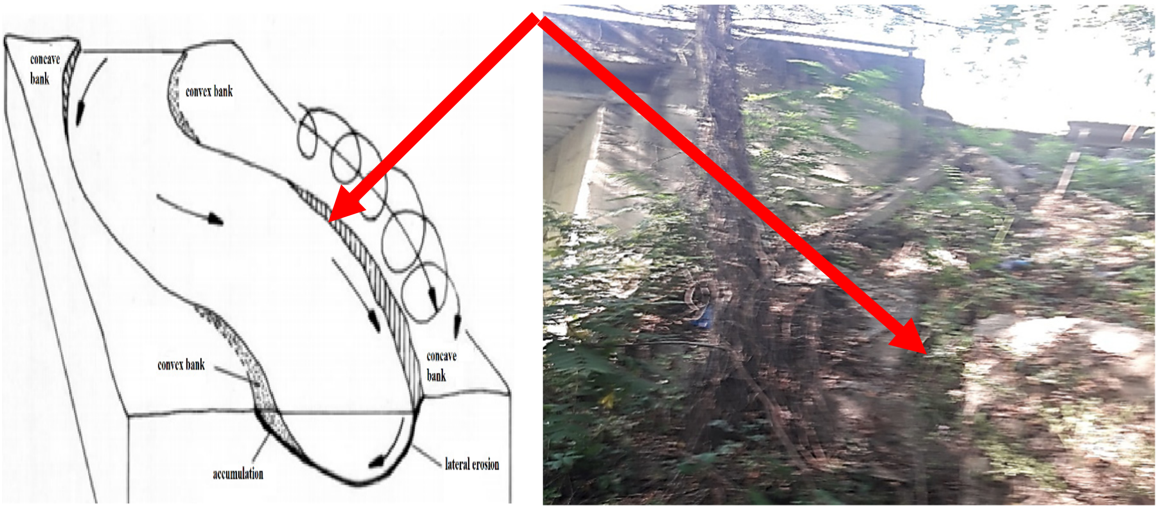


Figure 1. Analysed embankment site.

A cause for the collapsed embankment (see figure 1 above) is the wrong positioning of the bridge with the embankment located on a concave bank (see figure 2 below) with lateral erosion from the stream [2], opposite the stronger right bank that is forested.



a. Lateral erosion of meandered stream [2] **b.** In situ erosion

Figure 2. Exemplification of erosion.

Another inconvenience of the access to the bridge is the lack of verge and ditches, because of this the discharge of rainwater into the stream takes place at about 2.00 m higher level difference from the stream water level. This is leading to an increase in humidity of the foundation layer of the road and to a continuous erosion on the discharge area, according to figure 5.

The affected embankment bridge access has a length of about 10.00 m with a height of the break step according to in situ measurements in September 2018 of about 0.70 m.

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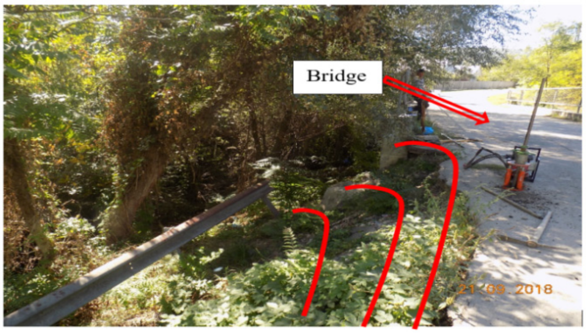

Figure 3. Rotational type slip (collapse).

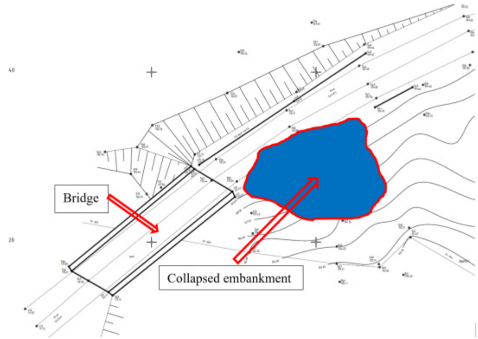

Figure 4. Collapsed embankment map.

a. Collapsed embankment view **b.** Embankment rift

Figure 5. In situ embankment views.

3. Geotechnical context

The soil studies carried out according to the positioning from figure 6 below have revealed that the mechanical characteristics of the soil on site are mediocre. The free ground water level is at a depth of -2.00 m in borehole f01, at a depth of -7.00 m in the dynamic penetration DPSH-B 1and at a depth of -3.00 m in the dynamic penetration DPSH-B 2.

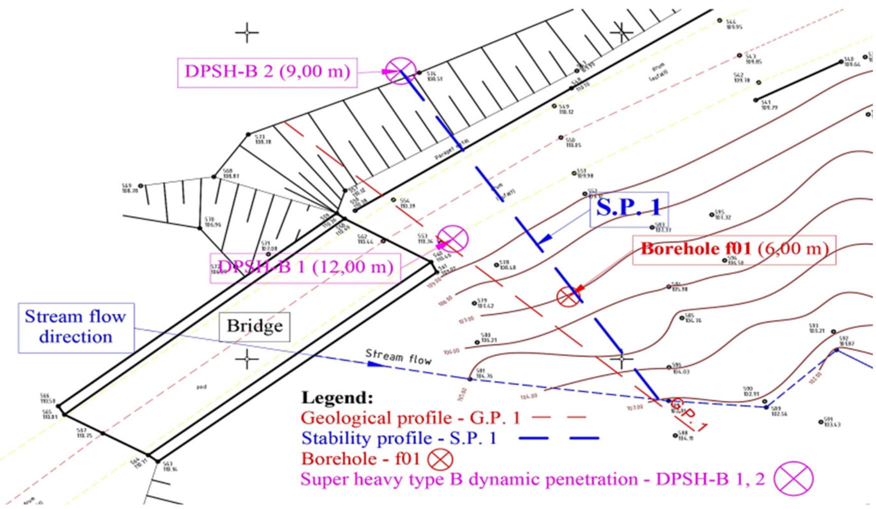

Figure 6. In situ soil investigation positioning.

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On average, from –0.20 m to -1.50 m, the soil contains silty clay, from -1.50 to -3.50 m, plastic soft sandy silt with base sand and beyond this depth the soil is composed of sandy clay.

3.1. Characteristic and design calculation values of geotechnical parameters

The determination of the characteristic and design values of the geotechnical parameters was performed according to SR EN 1997:1-2004 [3] and NP 122:2010 [4]. The design values are determined based on euro code SR-EN 1997:1-2004 depending on the Design Approaches used.
Following the calculations made, the Design Approach 1 - Group 2 presents the most unfavorable states of effort, so that in this article only the results of the analyzes performed for this approach are presented.

3.1.1. Characteristic values of geotechnical parameters

Considering the uneven stratification of the soil layers intercepted in the borehole, statistical processing of the geotechnical parameters values was perform as exemplified in figure 7 below, thus resulting the values presented table 1.

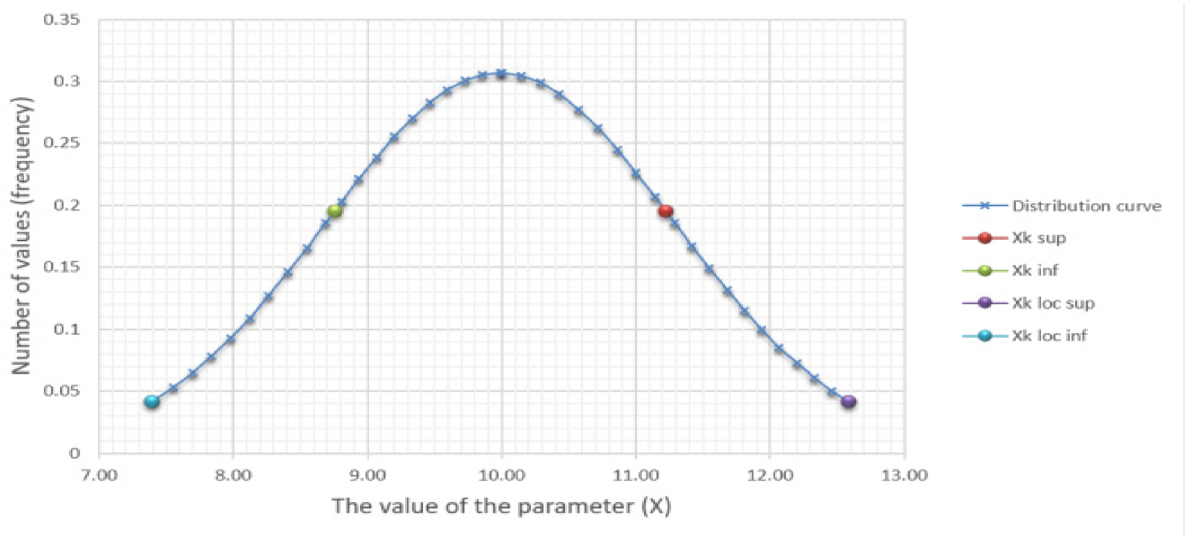

Figure 7. Example of statistical processing of the characteristic values of geotechnical parameters.

Table 1. Characteristic values for geotechnical parameters of the soil layers.

Layer	Upper elevation	Lower elevation	Thickness	Design Approach 1 – Group 2				
				E	φ'_k	c'_k	γ_{nat}	υ
-	m	m	m	kN/m^2	°	kPa	kN/m^3	-
1. Silty clay	0.00	1.50	1.50	1.0E+4	10.00	20.00	19.40	0.35
2. Sandy silt+silt	1.50	3.50	2.00	9.0E+3	32.00	5.00	19.50	0.30
3. Sandy clay	3.50	8.70	5.20	2.2E+4	20.00	25.00	20.85	0.35
4. Hard clay	8.70	13.00	4.30	2.9E+4	12.00	80.00	21.18	0.42

3.1.2. Design values of geotechnical parameters. The values used for the partial factors on Design Approach 1 – Group 2 for permanent and variable unfavourable actions (A2) are$\gamma_{G,unfav}$ = 1.00, $\gamma_{Q,unfav}$ = 1.30, and for soil parameters (M2),γ_{φ} = 1.25 for internal friction angle, γ_c = 1.25 for cohesion and γ_{γ} = 1.00 for volumetric weight.

Table 2. Design values for geotechnical parameters of the soil layers.

Layer	Upper elevation	Lower elevation	Thickness	Design Approach 1 – Group 2				
				E	φ'_d	c'_d	γ_{nat}	υ
-	m	m	m	kN/m^2	°	kPa	kN/m^3	-
1. Silty clay	0.00	1.50	1.50	1.0E+4	8.03	16.00	19.40	0.35
2. Sandy silt+silt	1.50	3.50	2.00	9.0E+3	26.56	4.00	19.50	0.30
3. Sandy clay	3.50	8.70	5.20	2.2E+4	16.23	20.00	20.85	0.35
4. Hard clay	8.70	13.00	4.30	2.9E+4	9.65	64.00	21.18	0.42

3.2. Methods used in programs for stability analysis

As a synthetic indicator of the equilibrium state of a slope, for a given situation, the stability factor is used, Fs, which in the most general way is defined by comparing the stress states along the potential slip surface, respectively:

$$F_s = \frac{\tau_f}{\tau} \tag{1}$$

where τ_f representing the value of the shear strength of the mobilized ground, and τ the value of the existing tangential stress in the mass for the calculation hypotheses considered; In order to ensure stability, Fs must have super unit values.

In order to assess the stability based on the stability factor Fs, the calculation is based on a method of analysis established in geotechnical practice and based on the concept of limit equilibrium of the Spencer type. The formulation of this method considers the mass of the earth, above the potential slip surface, discredited into bodies, elemental volumes - strips, separated by vertical planes as in figure 8.

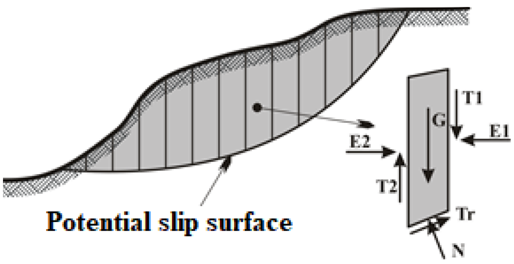

Figure 8. Spencer type limit equilibrium.

In addition, the method admits that the sliding surface is of circular-cylindrical shape with the horizontal axis or of some shape. Figure 8 illustrates a potential landslide divided into strips and, in a simplified way, the forces acting on a strip. The method developed by Spencer considers the complete interaction between the strips (through vertical and lateral components, E modulus and friction, T) and satisfies both the global balance of moments and forces.

The stability conditions are represented by two stability factors, evaluated based on the global balance of moments Fs, M and of forces, according to the horizontal direction Fs, F and which imply the satisfaction of the Mohr-Coulomb yield criterion and the balance of forces according to the vertical direction for each one [5, 6].

As a common feature of the formulations of the methods that take into account the complete interaction between the bands and for which both equilibrium conditions are satisfied (Spencer, Morgenstern-Price, General Limit Balance Method), it is assumed that between the normal (lateral) interaction forces) and shear between the bands there is a relation of the form:

$$T=\lambda\times f(x)\times E \tag{2}$$

where f (x) is a function and λ is a parameter of function adjustment (λ = 0 means that there is no vertical component of the interaction between the bands).

The particularization λ = 0, the expression of the stability conditions through Fs, M and the neglect of the shear interaction forces between the strips ensure the conditions of the simplified Bishop Method; expressing the stability conditions through Fs, F ensures the conditions of the simplified Janbu method. In the Spencer Method f (x) = 1 (the ratio of the interaction forces between the strips becomes constant and the same for each strip) and λ is determined by an iterative calculation until Fs, M and Fs, F are approximately numerically equal (figure 9), the Spencer method being thus the most complete method based on the limit equilibrium.

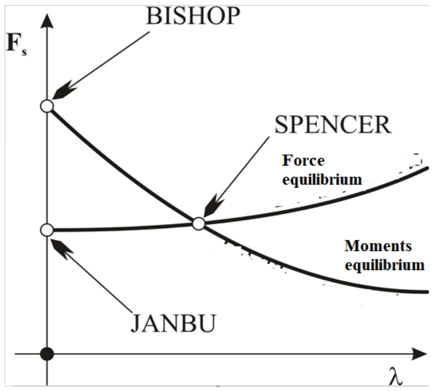

Figure 9. Comparison between used stability methods.

4. Performed calculations

Based on the topographic survey carried out on site, in the analyzed area and the geotechnical design values from anterior chapter, a stability profile "S.P.1" was performed with Geoslope 2D and Plaxis 2D v8.2. This helps to determine the local stability of the embankment and the state of effort on the bridge embankment access in the existing situation and in two proposed situations: first situation with geosyntethics with gabions and the second with interspaced piles.

In the stability, calculations considering the road loads, the forces induced by braking-starting vehicles, analyzing the following situations:

- existing situation - natural state and natural state with earthquake
- existing situation - flooded state and flooded state with earthquake
- proposed situation - flooded state with earthquake

The calculation programs use the calculation approaches according to SR-EN 1997:1-2004 [3], thus a stability factor higher than 1.00 indicates stability.

When carrying out a calculation in the flooded state, the design values of the shear resistance parameters of soils are reduced as presented in table 2 by about 25-60% leading to important horizontal and vertical deformations in the soil.

4.1. Existing situation

Stability analyzes performed for S.P. 1 indicates phenomena of loss of stability in the current situation in both static and dynamic regimes.

In case of the increase of the ground water level (flooded state) as a result of abundant precipitation and the perimetral flooding of the embankment caused by an increase of water level in the stream, the values of the sub unitary stability factors decrease. In this case is resulting in instability both in the seismic situation and in the situation, which considers the earthquake, according to figure 10 and table 3 below.

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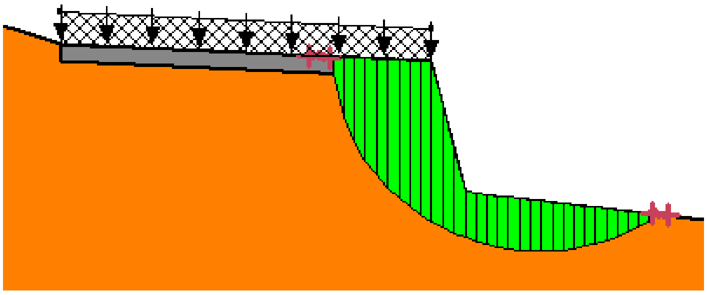
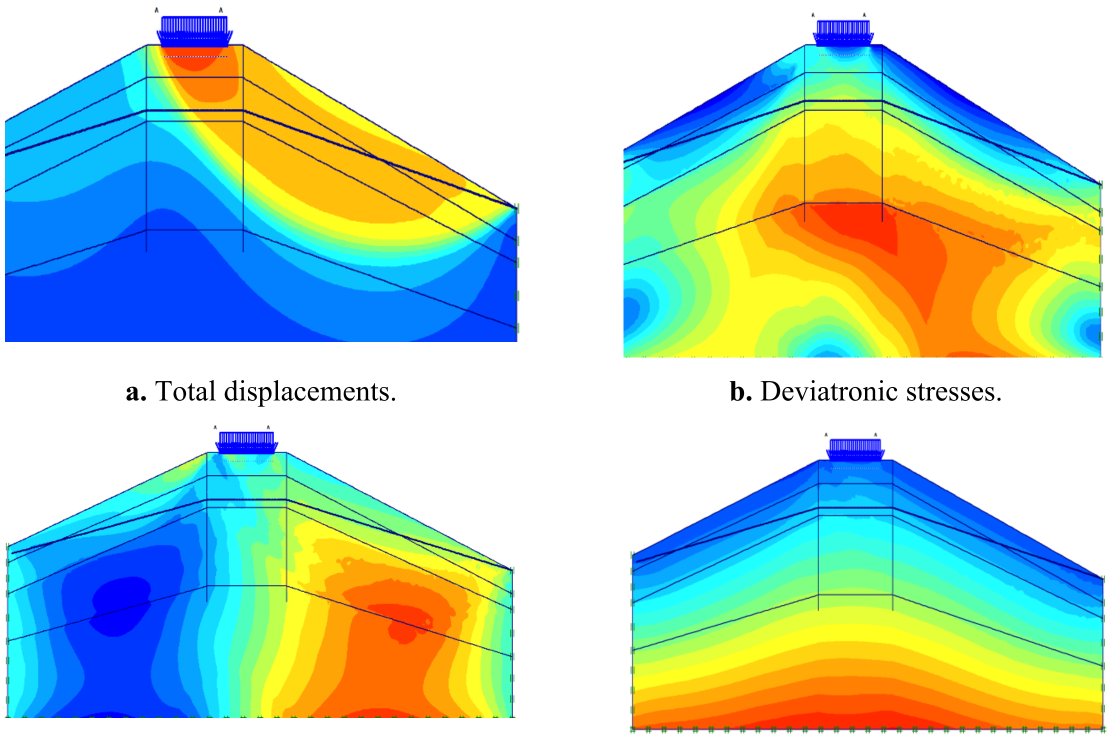


Figure 10. Allure of the slip surface in existing situation (with Geoslope 2D).

Table 3. Centralizing stability analysis factors (Fs) and total displacements in existing situation.

Stability profile S.P.1		Natural state without earthquake	Natural state with earthquake	Flooded state without earthquake	Flooded state with earthquake
Bridge access road embankment	F.S.	0.95	0.76	0.78	0.52
	Total displacements (mm)	55	115	168	274

The representation of existing displacements and state of efforts in the embankment is shown in figures11 below.



a. Total displacements.

b. Deviatronic stresses.

c. Shear stresses.

c. Vertical total stresses.

Figure 11. Displacements and efforts in the embankment (withPlaxis 2D).

4.2. Proposed situation

The article shows the construction on soft soil for a road embankment that gives access to a bridge that passes over a stream. To strengthen, consolidating and draining the embankment near the stream it was used combined geosynthetic and gabions solution [1].

In the case of carrying out mixed support works from reinforced soil at the level of the road sub base and protection from gabions on the left-right slope of the road area, the values of the stability factors are higher than 1.00, both situations without earthquake and with earthquake, according to figure 12.a and table 4 below.

In the case of making the bridge road access support from interspaced piles, the values of the stability factors are higher than 1.00, both situations without earthquake and with an earthquake. There will be problems of stability of the slope situated downstream of the piles that will be eroded further by the stream, according to figure 12.b and table 4 below.

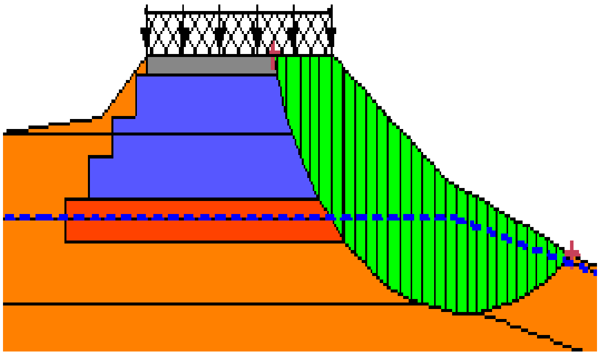


Figure 12.a Allure of the slip surface in proposed situation with geosynthetics and gabions. (with Geoslope 2D).

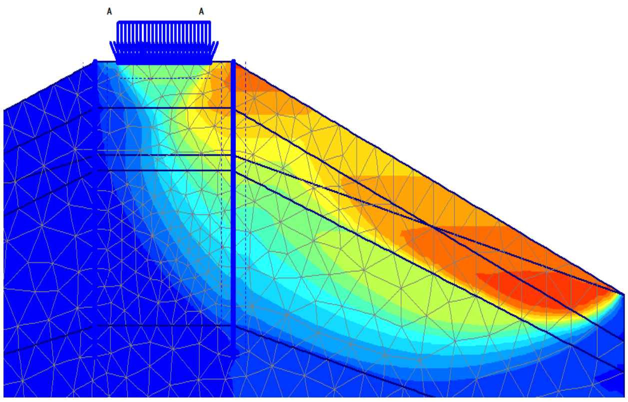


Figure 12.b Allure of the slip surface in proposed situation with piles. (with Plaxis 2D).

Table 4. Centralizing stability analysis factors (Fs) and total displacements in proposed situation.

Bridge accessroadembankment	Stability profile	Flooded state with earthquake	Total displacements (mm)
Solutionwithgeosyntheticsand gabions	S.P. 1	1.41	11
Solutionwithinterspaced piles	S.P. 1	1.46	8

The pile solution is very expensive, time consuming, and does not solve the erosion problem downstream of the road, resulting from a technical and economic point of view, that being more plausible with geosynthetics and gabions.

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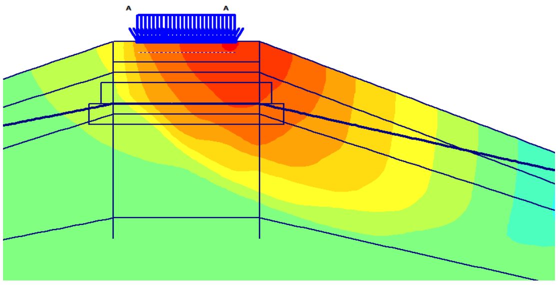
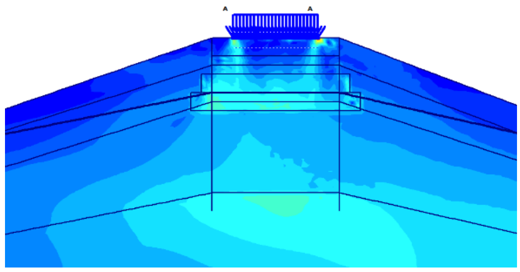
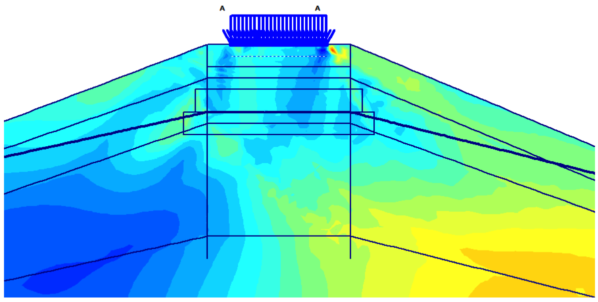
The representation of displacements and state of efforts in the gosynthetics with gabions reinforced embankment is shown in figures 13 below.



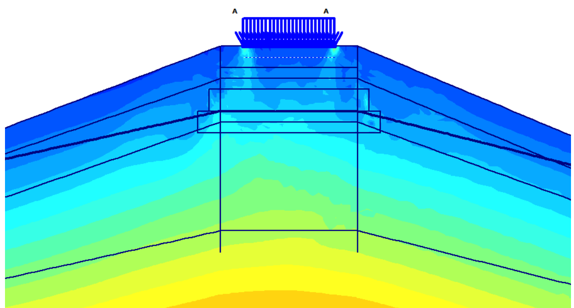
a. Total displacements.



b. Deviatronic stresses.



c. Shear stresses.



c. Vertical total stresses.

Figure 13. Displacements and efforts in the embankment (with Plaxis 2D).

5. Applied solutions

The article shows the construction on soft soil of an road embankment that gives access to a bridge which passes a stream.

The embankment near the bridge access was excavated on a length of about 10 m from the bridge and was restored in a mixed terramesh system with georgics filled with ballast in elemental layers of maximum 30 cm and a height of 1.00 m and protection on both slopes with gabions. Before making the first layer of ballast with geogrid, a blockage was made of compacted stone until refusal as exemplified in figure 14 and figure 15 with execution phases below.

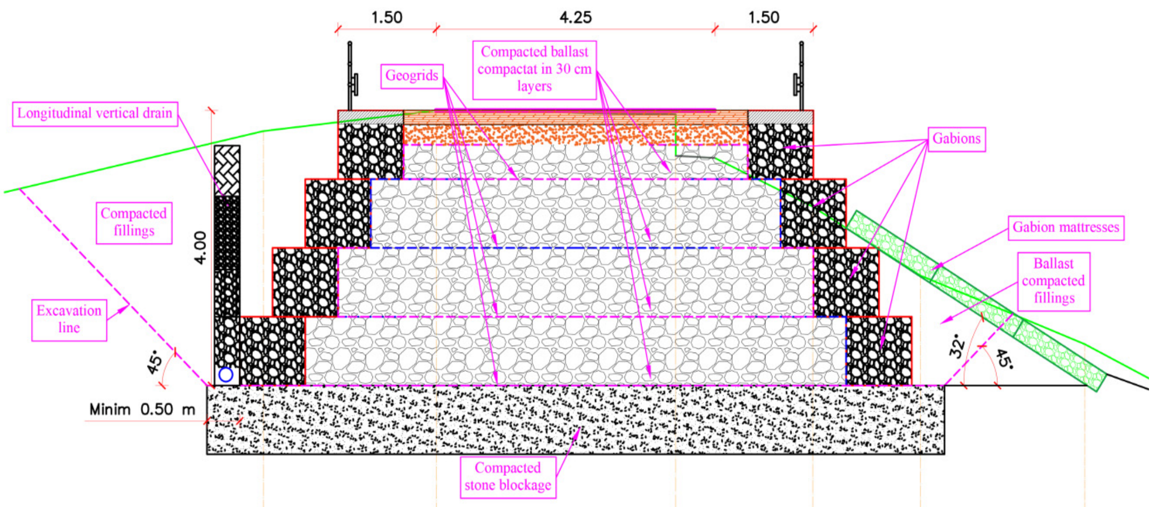


Figure 14. Characteristic cross section for the embankment with the applied solution.

a. Excavation.

b. Blockage with compacted stone.

c. Geosyntheticsand gabions executions.

d. After execution.

Figure 15. Execution period.

On the slope of the south side (to the stream), compacted fillings were made and after that gabions mattresses were placed for protection.

In order to collect the waters on the north side of the road, a longitudinal vertical drain was made up to a depth of -4.00 m measured from the carriageway level with controlled gabion mattress evacuation in the stream near the bridge abutment.

6. Conclusions

The article shows the construction on soft soil of a road embankment that gives access to a bridge, which passes over a stream. To strengthen, consolidating and draining the embankment near the stream it was used a combined geosynthetic and gabions solution.

This solution resulted from a technical and economic point of view, being more plausible than a more expensive solution with drilled reinforced concrete piles along the affected road embankment.

Reinforced earth is somewhat analogous to reinforced concrete. But the direct comparison between the reinforcement functions in the two cases is not valid. The mode of action of the reinforcement in the ground is not one of taking over the tensile stresses developed as in reinforced concrete, but of anisotropic reduction of the normal tension.

A drainage system with protected evacuation areas are very important for the lifetime of an embankment situated near a stream with fluctuating water levels.

When carrying out a calculation in the flooded state, the design values of the shear resistance parameters of soils presented in table 2 above are reduced by about 25-60% leading to important horizontal and vertical deformations in the soil.

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