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Catastrophic landslide stabilization on a restricted area through a combined solution in Bran, Brasov County

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Abstract. The paper presents a combined method for the rehabilitation of a road on a restricted area by reinforced soil above a double sheet of piles. The principle is illustrated by a case study of a landslide in Bran, Brasov county. Due to the restriction imposed by the limit of properties we have to find out the way to stabilize a small part of the landslide and in the mean time to let the efforts induced by the rest of the sliding mass to act. To determine the status of efforts the problem on a restrained area without stabilizing the rest of the landslide which is much bigger we have considered that there are lateral surcharges due to the movement of the sliding mass.

1. Introduction

This article was brought about by a landslide that has affected properties, utilities and communications in the village of Bran, Brasov county. The main problem is that because of the huge dimensions of the phenomenon that passes through many more private properties it was not possible to stop the causes, rather to limit some effects that concern the whole community.

Landslides has affected the street Bradul Inalt from Sohodol district on the length of 50 meters, with moving a compartment (the northern one) by about 6 meters horizontally and 3-4 meters vertically (figure 1).

1.1. Technical premises

From a technical point of view the problem becomes more complicated than other similar situations where the solution is probably routine, because of the restrictions imposed by the legal limitations. As a result, the landslide cannot be stabilized by eliminating the causes.

They are for the most part outside the public domain where the street is and for which the government funds were allocated.

Thereby only the effects were covered, but keeping in mind that the phenomenon is dynamic and ongoing, efforts required by the next ground movements were taken in consideration.

The area affected by movements is very large, so the field investigations did not cover the entire surface. The landslide is regressive.

The major triggering cause is the erosive action of the downstream creek, located about 500 m away. The destabilization of the foot of the slope has brought ground movements, the surface has become irregular, and cracks appeared, favoring water stagnation and water infiltration in terrain.

The highly varied lithology in which the cohesive material alternates with the non-cohesive one (with high permeability) has permitted groundwater circulation, creating areas of minimal resistance.





(a)



(b)



(c)

Figure 1. (a) Local effect of the landslide; (b) A building destroyed by the landslide; (c) The same building before the landslide.

1.2. Existing data

On the left side of the street (north) there was a sewerage system beneath the concrete ribbon and on the left side of the street there was at that time a gas pipe of 120 mm diameter.

The slip surface with a possible circular shape in the plane has a maximum arrow of about 5 meters from the right edge of the road, endangering the safe operation of the upstream tennis court (about 2 meters distance) and the construction in the adjacent area.

The slip has affected the communal road on a length of about 50 meters owned by the Bran City Hall, as well as two buildings, privately owned, downstream. In fact, the sliding is much broader, having a length of over 500 meters, over a width of 50-100 meters in the north-north-eastern direction of the road to the affected area (figure 2).

The instability phenomena were reported at the level of the road and neighboring constructions from 2013-2014 and accentuated in the summer of 2016 when the street became impracticable.

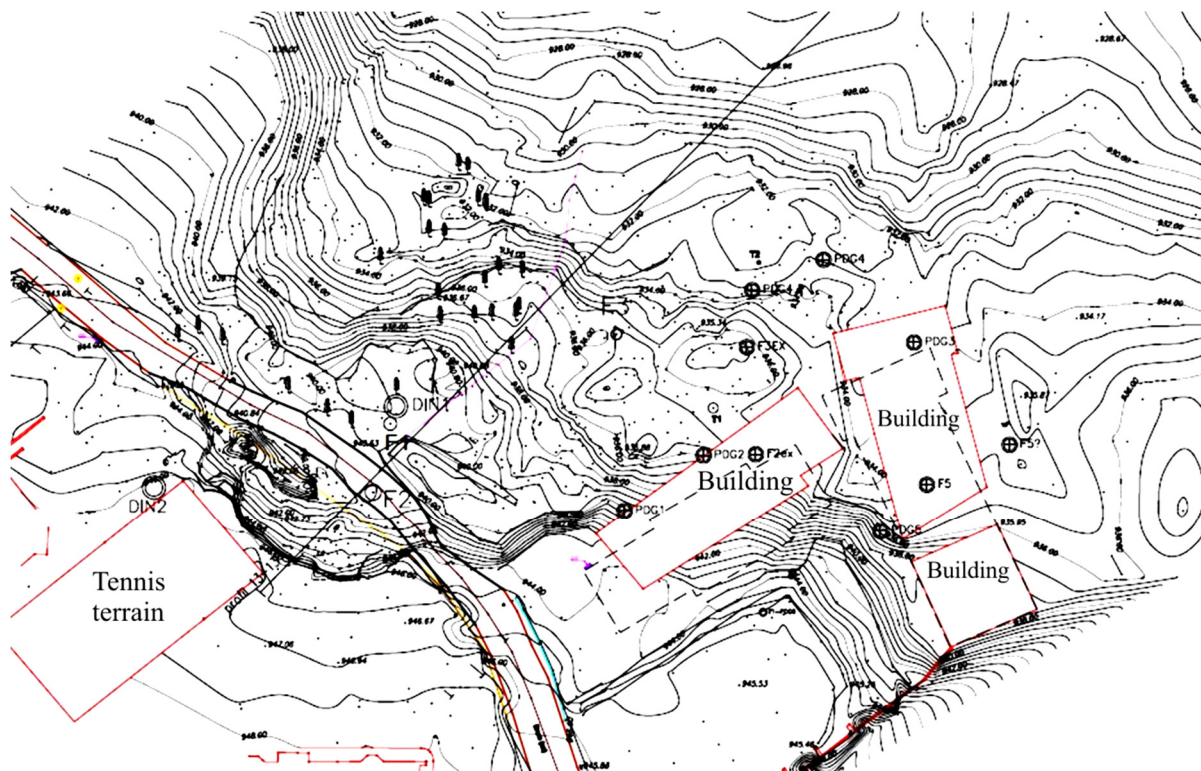


Figure 2. Detail of the landslide plan (contours are at every 0.5 m).

1.3. Geological-geomorphological contexts

From a geographic point of view, Bran is located in the depression headway Bran-Rucar, which is highest in the Giuvala Pass from Fundata commune (1235 m), a depression corridor guarded on the south-eastern side of the Bucegi-Leaota Mountains (2504 m) and the Pietra Craiului Mountains to the west.

The studied area belongs geologically to the Oriental Carpathians, and geographically in the Rucar-Bran corridor, belonging to the Meridional Carpathians. This depression corridor corresponds to a vast tectonic depression with the north-south direction situated between the Bucegi mountains in the east and the Fagaras massif in the west.

The Bran Branch, to which the studied area belongs, is an intermountain depression in which “Sohodol Piedmont” is one of the high piedmonts. The site itself is located above the Turcu valley, where deposits from the alteration of the base rock, low-cemented sandstones, is developing. The “Bradul Inalt” hill area is part of an intermountain basin of the Oriental Carpathians, constituted as a patch of Miocene sedimentary formations built from sandy clays over which a dacitic tuff follows, and then a gray quartz sandstone.

Surface deposits are generally made of cohesive materials and various sands with gravel and boulders.

2. Geotechnical data

Soil investigations was made by drilling with continuous coring and collecting undisturbed samples and also by dynamic penetrations.

According to the groundwater level also, the slip surfaces are situated at 6 m, and 9 m depth from the ground level at that time (figure 3 a).

The results of the investigations revealed a complex lithology, in which cohesive soil alternates with non-cohesive material (figure 3 b).

Here are the results of the most significant boreholes:

Borehole - F1:

- 0.00 – 0.60 m fill (gravel, silt, topsoil);
- 0.60 m – 2.50 m sandy clay with gravel, yellow-grey with low plasticity and consistency, wet;
- 2.50 m – 5.50 m sandy clay, yellowish, plastic consistent;
- 5.50 m – 8.20 m clayey sand yellowish with lens of reddish sand and rare gravel, wet;
- 8.20 m – 8.60 m micaceous sand, yellowish-brown, saturated;
- 8.60 m – 9.00 m clayey silt with gravel yellowish-brown, plastic stiff with low moisture;
- 9.00 m – 10.30 m clayey sand, grey with gravel, compact;
- 10.30 m – 10.60 m silty sand, brown, with gravel;
- 10.60 m – 11.10 m gravel with sand light brown.

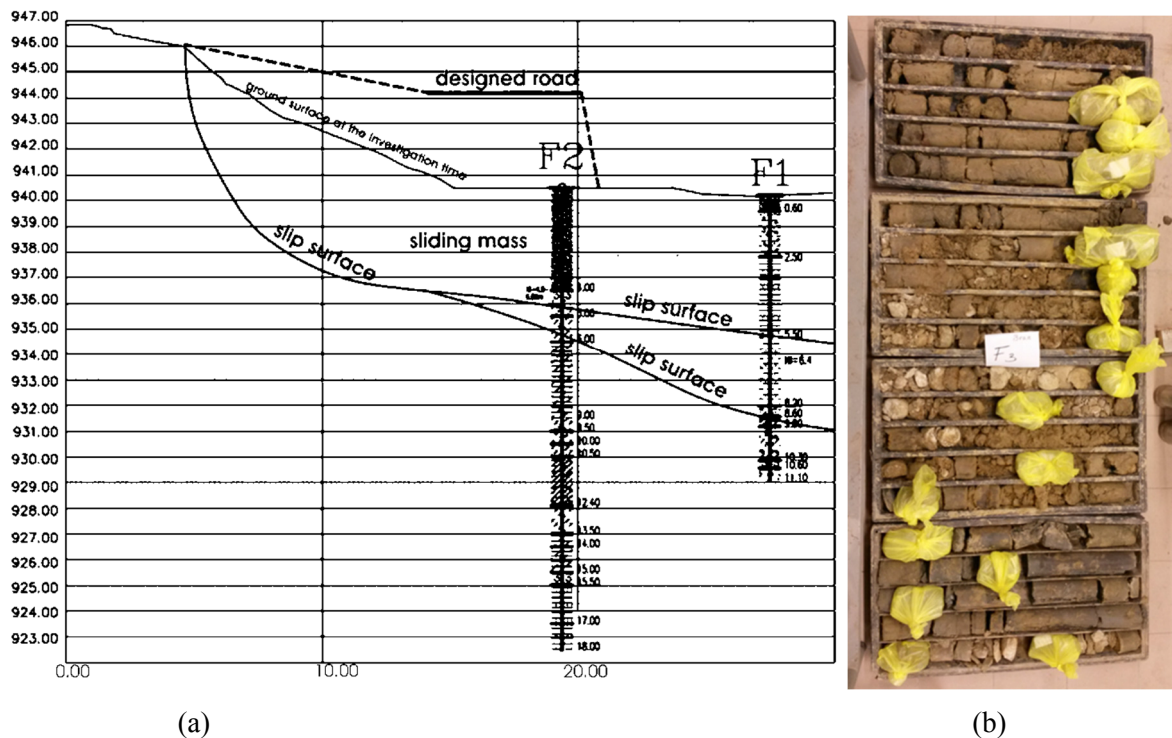


Figure 3. (a) Simplified landslide profile; (b) Samples from borehole F3.

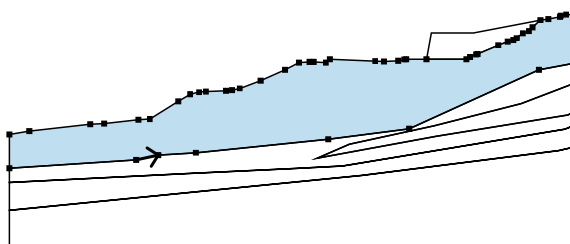


Figure 4. Meshing profile with highlighted sliding mass (with GEO5).

Slope stability (figure 4) was determined with Geo 5 software by analytical methods. Presuming only that the road will be restored, the safety factor was unacceptable (less than one).

On the next step it was calculated adding a double sheet of piles; the piles dimensions were adjusted until it has been obtained a safety factor over 1.5.

The length of the piles was calculated on the ground pressure plus traffic surcharge, without counting the passive resistance of the soil below the road.

This lack of resistance was counted because the sliding phenomenon is much larger and it is possible to go on in the future. The system with a double sheet of piles was conceived according to [1], and over it a blanket made by reinforced soil.

3. Conclusions

General stability analysis (figure 5) assuming that the slip surface has a multi-planar shape. The analysis (made with Geo 5 and Geo-Slope software) on the existing situation calculated a safety factor equal to $F_s^{\text{static}} = 1.02$.

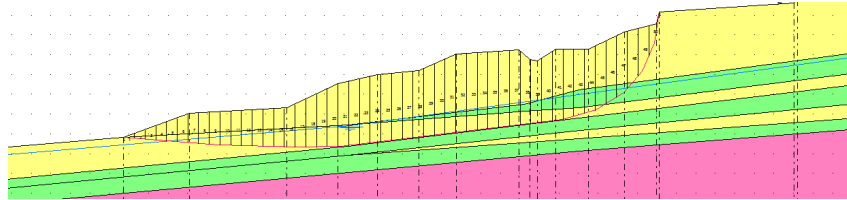


Figure 5. Analysis on the existing situation.

So the condition of verification, even in analytical way, under static conditions is not satisfactory and it is required to ensure the overall stability of the slope. After re-profiling the slope to correct the existing road, the safety factor decreases. It is necessary to carry out retaining works down the road at the limit of the existing platform in order not to require additional expropriations. Thus, a retaining work was provided from pilots drilled down the road on two rows of pilots to reach the safety factor $F_s = \min. 1.3$ (figure 6). The re-profiling of the downhill slope will be made with a slope of 1:6 and upstream of the road will be re-profiled with a slope of 1:3. In this case the safety factor will increase up to $F_s^{\text{static}} = 1.39$.

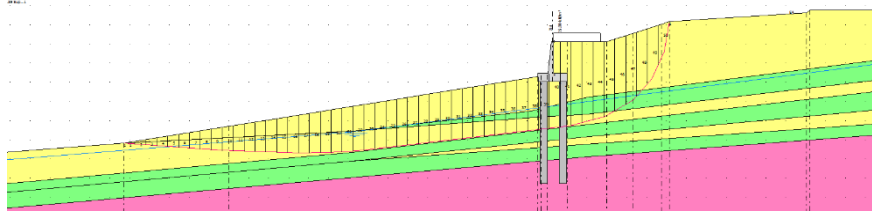


Figure 6. Analysis on the existing situation with a retaining structure.

Analyzing the general stability of the versant in seismic conditions according to SR EN 1998-125/2004 for approach 1, group 2, were applied the following partial coefficients: $\gamma_\phi = 1.25$ (partial coefficient for the internal friction angle of the material) and $\gamma_c = 1.25$ (partial coefficient of the cohesion of the material); as a result the safety factor was $f_{s_{\text{seism}}} = 0.72$, much less than the acceptable $F_s^{\text{adm}} > 1.0$. General stability analysis by cylindrical - circular slip surfaces (figure 7 and figure 8) has led us to lower values of the safety factor $F_s^{\text{seism}} = 0.66 < F_s^{\text{adm}} = 1.0$.

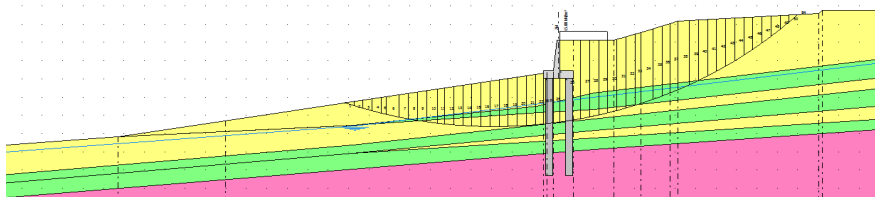


Figure 7. General stability analysis by cylindrical - circular slip surfaces.

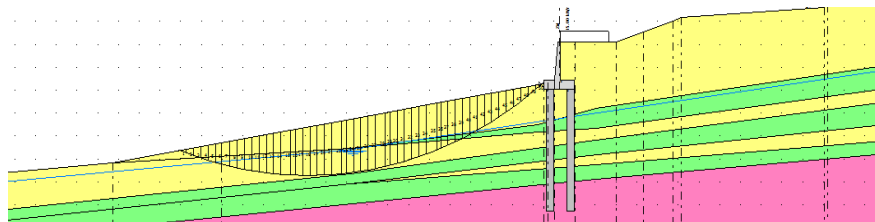


Figure 8. Analysis of downstream stability of support after re-profiling assuming a cylindrical - circular slip surface.

The slope is not stable downstream of the retaining structure. To ensure the stability of the slope upstream of the supporting work it must be able to take the thrust of $E = 1150 \text{ KN}$. The main solution was to increase the pile's dimensions.

In these reasons, to accommodate additional loads that were induced to execution by downstream compaction, there were provided two rows of piles embedded in the base rock layer with an average length of 18.00 meters in the chess board with 1.50 m diameter, at a distance of at least 3.50 cm apart and 2.0 m between strings (figure 9).

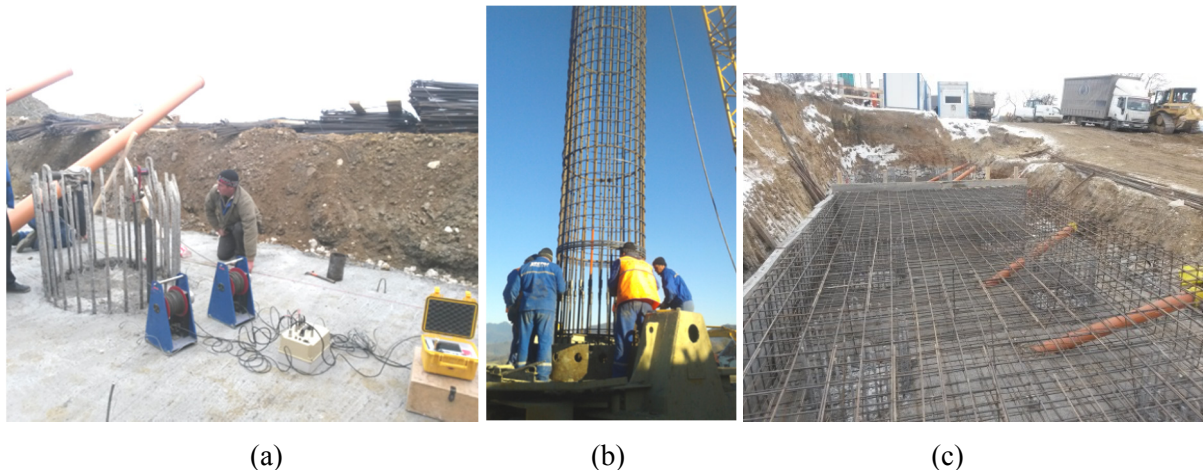


Figure 9. Aspects during and after the executions: (a) checking of pile's continuity with down-hole method; (b) introducing steel reinforcement cage of the piles (c) beam's reinforcement with anchors casing; (d) panoramic view of finished structure; (e) rehabilitated road segment.

The so described position of the piles is also in agreement with the [2] report's conclusions. The reinforced soil was calculated according to [3]. The geogrid is 4 meters large, enough to act like a support structure (figure 10).

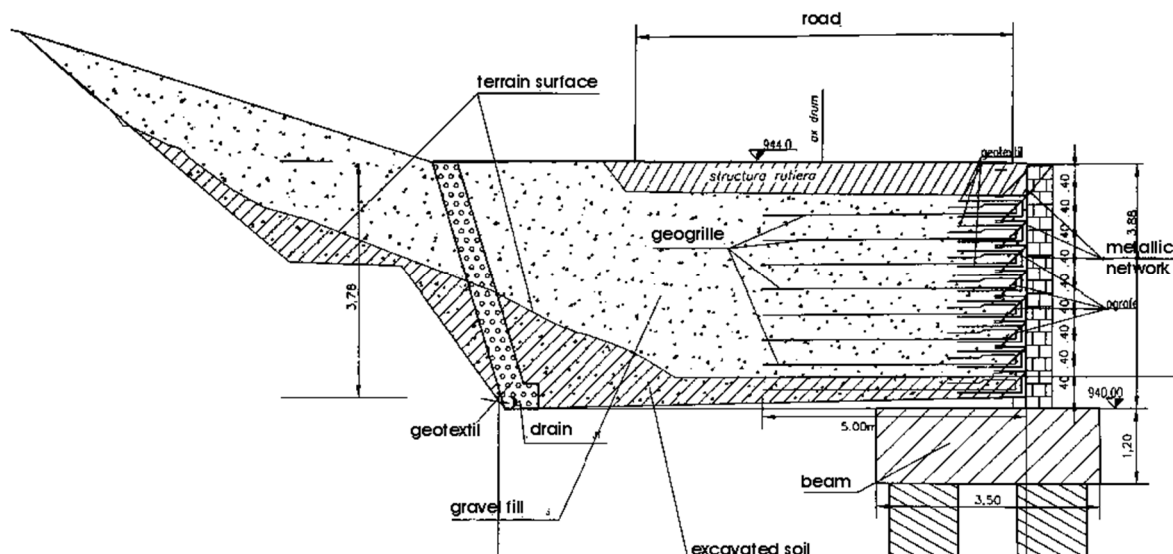


Figure 10. Typical profile through stabilization's structure.

The continuity of the piles was checked by with down-hole method, according to [4].

The forces that act on the slope have been limited to a narrow area for now. In any case, the sheet of piles has a positive effect in many ways, in addition to the stability of the road. Thus, according to [5] the vibrations transmitted by the traffic will be attenuated and it will act as a stiff wave barrier. The efficacy is determined by the depth and the stiffness contrast with soil.

Assuming the results described in this study, traffic-induced vibrations will be significantly attenuated over a distance of at least 50 meters; adding to it the effort's shadow behind the piles as is mentioned in [6] and the restoring of the slope geometry over that distance by uniforming the surface, results in an increase in stability in the significant area. However, these parameters have not been included in the calculation of the safety factor, they are implicitly found in the supra-unitary fraction.

Because of the unpredictability of the events, a monitoring program was set up to raise alerts of potential displacements that go over the reasonable limits. To mitigate unfavorable developments, additional solutions have been provided that can be added to the existing ones (anchors, horizontal drains). A monitoring system was also provided according to a schedule for the next two years. Topographic benchmarks were mounted on the beam of the piles and measurements were carried out which up to this date did not indicate any movement; however, we consider it too early to be able to draw conclusions on the behavior of the structure.

For this reason, casing anchors included in the pile's beam were included. Depending on the results during monitoring time, anchors will be installed.

However, the sliding phenomenon remains active downstream, which requires that steps be taken in the future to stabilize the entire slope by completing a second stabilization step. This will be achieved by restoring the slope geometry, squeezing the sliding mass and possibly introducing other support systems at a later stage of the present. Without these measures, in time, the measures envisaged in this study could also be affected.

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