Influence of the Palaeo-Landslides on the Project of Rehabilitation of a National Road in the Southern Carpathian Area

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Abstract. The mountain Paduchiosu is a part of the Southern Carpathians, in the South-Eastern Bucegi National Park. Significant palaeo-landslides occur on the Eastern slope of the mountain Paduchiosu, affecting the DN 71 alignment, between Valea Dorului and Valea Carpiniș, on a length of approx. 10 km [1]. The palaeo-landslides occur along the tectonic contacts of various cretaceous formations. The landslides occur both at the level of Quaternary deposits, forming the alteration layer of the old geological formations (alluvial, deluvial and colluvial soil deposits), and at the level of Pre-Quaternary geological formations, whose structure is clayey-marl, or within the harder rocky formations, with seams of clayey – marl nature also. Two large palaeo-landslides can be distinguished: landslide I, affecting the national road alignment between pk 96 and 101+500, with sliding orientation towards South and South-West and landslide II, affecting the analysed alignment between pk 102+500 and 106 (with sliding orientation towards East and North-East). The landslides are significant and very old. The main cause of occurrence of these landslides is the tectonic nature of the area. The two main landslides occur on large surfaces. Generally, the sliding plan is under the „fissure clay” level, so it tends to be 12 to15 m deep. Numerous reactivations occur within their congestion, on narrow or large surfaces. Many of the reactivations occur due to the malfunctions of the systems of rainfall draining and taking over from the national road that runs South to North on the Southern slope of the mountain Paduchiosu. There are no underground waters, but considering the change of the natural water drainage due to the existing road works, there are areas where the drainage is impeded or slowed, leading to the water infiltration and rocks moistening under the deluvial formation. The local reactivations may also be influenced by the unarranged torrential valleys. The project of rehabilitation of DN 71 is strongly influenced by existence of these significant landslides. Acknowledgement of the risk of landslide and allocation of funds for maintenance and remedial of the arisen damages following reactivations, as well as monitorization of the road areas affected by the landslides both during the works and after their completion, during operation, is the rightest solution, and actually, the least expensive one.

1. Introduction
The DN71 Băldana – Târgovişte – Sinaia alignment, on the analysed sector, runs at the Northern part of the counties of Prahova and Dâmbovița. Starting from the DN1, in the locality of Sinaia, it runs parallel to Izvoru Brook (or Dorului Valley), crossing Vanturisului Valley, running at the Eastern side
of the Mountain Paduchiosu. The landslides prone areas affecting the DN71 between Dorului and Cărpiniş Valleys are laying along the tectonic contact, between the Sinaia Layers (inner level, prevalently made up by clayey and marly-clayey shales, marls and marl-limestone) and Comarnic Layers, representing a calcareous-marly flysch, to which fine limestones and limestone-marls are added. This also happens between the Sinaia and Piscu cu Brazi Layers [1]. The landslides occur both at the current Quaternary deposits level, forming the path of alteration (eluvium, deluvial and colluvium deposits) of the old geological formations, and at the pre-Quaternary geological formation level, whose structure is marly-clayey, or within the harder formations consisting of marly-clayey intercalations, as well.

2. Description of the palaeo-landslides

We will herewith call the two landslide types as follows: landslide I: that affects the analysed sector between km 96 and km 101+500, with its sliding direction towards S and SW; and landslide II: that affects the analysed sector between km 102+500 and km 106, with its sliding direction towards E and NE.

The landslides are high and significantly old, they are historical. The main cause of these landslides is the tectonic nature of the area. In general, the area of flysch, to whom the analysed sector belongs, is a convulsed area from the tectonic point of view [2]. More factors contributed here chronologically (geological ages):

a) Post-depositional folding. The cretaceous deposits are folded, the national road alignment following more or less the direction of an anticlinal, between km 96+500 – km 103+000. The crest of the anticlinal is NE-SW oriented. Under the folding phenomenon, superposition and failures arise, with directions parallel to the anticlinal crest direction.

b) Pre-Quaternary movements followed by appearance of a system of fissures, perpendicular on the anticlinal direction, and on the fissures and superposition parallel to it. A system of 3 fissures parallel to each other can be found, on NW – SE [3] direction.

c) Formation of the Quaternary deposits, by alteration of the basic rock with allochthone deposits (deluvial, proluvial, colluvial, alluvial), as well as alteration of the status of the basic rock up to its change into a formation, described as “clay of fissure”, made up itself based on the basic rock.

The two main landslides, whose trigger effect resulted in tectonic causes, cover large surfaces. In general, the sliding plan is under the level of the “clay of fissure”, so it may reach depths of 12-15 m. A lot of reactivations take place in their mass, on reduced or large surfaces. Many of these reactivations are produced by malfunctions in the rainwater/snowfall drainage and takeover system. There are no underground waters, but considering the change of the natural drainage, by the existing road works, there are areas where the drainage is impeded or slowed, this leading to the water infiltration and rocks moistening under the deluvial formation. The local reactivations may also be influenced by the unarranged torrents.

2.1. Geotechnical investigations

The performed geotechnical investigations have shown the following stratigraphic sequences:

2.1.1. The area between pk 85+000 – 97+000.

Formation 1: allochthone material (deluvial, proluvial, colluvial, alluvial), known on the geological profiles and drilling logs, as deluvial material (fragments of sedimentary rocks, especially sandstones with diaclaze of calcite and marly limestone, and under this, conglomerate and limestones, with brownie-clayey binders, sometimes greyish. The quantity of binder may differ, so that sometimes the coarse material is subordinated. The fragments of rock have in general, big sizes, of centimetre. They come from the ground surface up to depths of 5.20-10.00 m.
Formation 2: Bedrock, Layers of Sinaia: prevalently made up by greyish sandstones, with millimetric diaclaze of calcite, sometimes massive, some other times in centimetre or decimetre shoals, alternating with thin packages of friable marly/clayey slates, sensitive to moisture, easily subjected to landslides.

2.1.2. The area between pk 97+000-101+500.
Formation 1: allohtone material (de
duvial, proluvial, colluvial, alluvial), known on the geological profiles and drilling logs, as deluvial material. They come up from the ground surface up to depths of 3.00-7.50 m, Figure 1'.

![Figure 1. Geological profile C-C', km 99+620](image)

Formation 2: sandy-dusty clays, lightly marly, with centimetre fragments of sandstone and marly limestone, sometimes chaotically placed, with rubbing mirrors, indicating a tectonic nature (clay of fissure), very sensitive to water, that may develop large surfaces of sliding. It comes up right under the deluvial deposits. It is made up based on the bedrocks, brought to the current shape due to the tectonic and sliding movements, between 2.40-8.00 thick. It does not come up constantly, but only between pk 98 and 101.

Formation 3: bedrock, Layers of Comarnic: prevalently made up by argillite, with obvious stratification and variations from greyish to blackish colour, in millimetric layers, rarely centimetric, friable, sensitive to moisture.

2.1.3. The area between pk 101+500-109+000.
Formation 1: allochthone material (deluvial, proluvial, colluvial, alluvial), known on the geological profiles and drilling logs, as deluvial material, Figure 2’. They come up from the ground surface up to depths of 4.50-7.50 m. In the area of the bridge over Izvorul Dorului these deposits may reach 10 m thickness.
Formation 2: comes up in drillings between km 104+500 – km 106+500, constituted from sandy-silty clays, lightly marly, with centimetre fragments of sandstone and marly limestone sometimes chaotically placed, with rubbing mirrors, indicating a tectonic nature (clay of fissure), very sensitive to water, that may develop large surfaces of sliding. It comes up right under the deluvial deposits up to depths of 8.50-10.00 m. It is made up based on the base rock, brought to the current shape due to the tectonic and sliding movements.

Formation 3: Bedrock, Layers of Sinaia: prevalently made up by greyish sandstone, with millimetric diaclaze of calcite, sometimes massive, some other times in centimetre or decimetre shoals, alternating with thin packages of friable marly/clayey slates, sensitive to moisture, easily subjected to landslides. They appear right under the deluvial deposits or under the formation 2 (clay of fissure), up to depths >100 m.

2.2. Calculation values
For the representative layers, the calculation values were determined: apparent density and compression strength for bedrock (table 1) and plasticity, consistency and shearing strength
parameters for covering rock (table 2). The parameters of shearing strength were determined by the direct shear trial under consolidated-drained conditions.

| Type of layer      | Apparent density $\rho$ (g/cm³) | Monoaxial compression strength $R_c$ (kPa) |
|--------------------|---------------------------------|------------------------------------------|
| Layers of Sinaia   | 2.41                            | 2762.05                                  |
| Layers of Comarnic | 2.26                            | 4882.41                                  |

Table 2. Calculation values for the clay of fissure.

| Type of layer         | Volume weight $\gamma$ (kN/m³) | Index of plasticity $I_p$ (%) | Index of consistency $I_c$ | Friction angle* (grade) | Cohesion * (KPa) |
|-----------------------|---------------------------------|-------------------------------|---------------------------|------------------------|------------------|
| Clay of fissure, area I | 20.99                          | 19.37                         | 0.37                      | 14.55                  | 2.81             |
| Clay of fissure, area II | 20.85                          | 17.97                         | 0.76                      |                        |                  |

* determined by the direct shear trial under consolidated-drained conditions

2.3. Slide hazard map

Slide hazard map was carried out for the analysed area, in accordance with the provisions of the Decision no. 447/2003 [6], resulting in the analysed territory split-up into two distinct areas of hazard.

The Eastern part of the analysed territory goes into areas of average potential of landsliding, with an average-high probability and an average hazard ratio, $K_m = 0.31-0.50$. This includes the right side of the Izvoru Valley (Dorului Valley) and Plaiul Frasinului.

The Western half and a Central-Southern part of the analysed area goes into areas of high potential of sliding, with a high probability. This includes the Paduchioșu Mountain, the area crossed by DN71 starting with Dorului Valley towards South, the parts affected by Palaeo-sliding with recent local reactivations.

3. Results and discussions

The existence of landslides directly influenced the project of rehabilitation of the analysed road sector. In order to give to the Beneficiary (the National Company of Motorways) the possibility to wittingly choose, calculation estimates for three hypotheses of project were carried out, as follows: 1. maintenance of the existing platform width and its stabilisation; 2. maintenance of the existing platform and increasing the lane’s width in the difficult areas for the road traffic users; 3. adding an extra lane on the ascension way and increasing the lane’s width in the difficult areas.

In order to ease the understanding of the proposed solutions, the unstable areas were split-up in “critical areas with old active landslides”, characterised by appearance of failures, unevenness and cracks in the existing road platform and “areas with less active, or inactive old landslides”, characterised by road sectors with no failures, unevenness and cracks, presently, but they lay on surfaces subjected to landslides, apparently stabilised.

Following the calculation estimates, significant differences of values have arisen between the three variants of design, thus giving the Beneficiary an efficient evaluation of the effective costs for the solution that he will choose.
Table 3. Calculation estimates for 3 variants of design.

| Consolidation of earthworks (retaining structures) | Variant 1 Maintenance of the existing platform | Variant 2 increasing lane’s width in the difficult area | Variant 3 an extra lane and increasing lane’s width in the difficult area |
|--------------------------------------------------|-----------------------------------------------|-------------------------------------------------------|-----------------------------------------------------------------|
| Length                                           | Financial evaluation                          | Length                                               | Financial evaluation                                               |
| Critical areas with old active landslides         | 3.800                                         | 3.800                                                | 4.900                                                           |
| Areas with less active, or inactive old landslides | 2.000                                         | 2.000                                                | 900                                                             |
| Total                                            | 5.800                                         | 5.800                                                | 5.800                                                           |
|                                                   | 27.950.000                                    | 41.150.000                                          | 51.150.000                                                      |

Figure 4. Slide hazard map

4. Conclusions

There are two high size Palaeo-landslides. The landslide I affects the area between km 96 and 101+500 and the landslide II affects the area between km 102+500 – km 106+500.

The landslides formed based on the tectonic pattern. The anticlinal area is crossed by a three-parallel fault system. The sliding plan may reach depths up to 13.50 - 15.00 m. Reactivations occur in the palaeo-landslides body.
The reactivations may occur in the Quaternary formations (deluvial) and pre-Quaternary formations, as well, in the clay of fissure, or at the contact between the clay of fissure and base rock.

Reactivations appear due to the rainfall/snowfall infiltration (the most frequent), works of interventions in mountains or due to seismic causes (deep or local earthquakes). In general, the landslides are slow. Accelerations may appear in the rich rainfall seasons.

There may be situations when strong tectonic movements may determine the sliding plan to reach depths up to 20 m, particularly in the area where the stratification complies with the mountain slope (km 102-104).

The slide hazard map emphasized existence of two distinct areas of hazard to slide: The Eastern area – with an average potential of landslide and an average-high probability, and the Western and Central-Southern area – with a high potential of landslide and a high probability.

In order to follow the behaviour in time, both up to commencement of the project and during construction, 6 inclinometer drillings of monitorisation (30.0 m deep) were designed and the measurements are under progress, so placed that they best reflect the ground movement in the analysed area.

Taking into account the oldness of the landslides and their horizontal and vertical (deep) extension, the general stability of the mountain sides cannot be provided. It is possible that parts of the pavement are ensured by great size supporting/retaining works, but there will always be the risk of landslides appearance between the consolidation works or at the edge of the performed works. Additional costs of maintenance or removal of the landslides effects should be taken into consideration. All the consolidation or road platform works should be monitored and maintained by periodical interventions.

References
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