PRESENT ENVIRONMENT AND SUSTAINABLE DEVELOPMENT, VOL. 7, no. 1, 2013

THE IMPACT OF LANDSLIDES ON THE DN15 NATIONAL ROAD IN THE AREA OF THE IZVORU MUNTELUI – BICAZ RESERVOIR

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Keywords: Izvoru Muntelui – Bicaz reservoir, DN 15, landslides, effects, remediation.

Abstract. In the 47 years of utilization, landslides have had destructive effects on the DN 15 national road and on some of the accompanying constructions (retaining walls, bridges etc.). Studies conducted by researchers from different fields (geomorphology, climatology, geology, hydrology and hydrogeology) have had as purpose the identification of the complex of natural and anthropic causes that have contributed to the triggering of these processes and the search for solutions for risk diminishing. Also, these studies have been the base for execution projects of consolidation works of the national road in the affected sectors.

Introduction

The construction of the mentioned sector of national road was needed because at the moment the bottom flood gate of the reservoir was closed, the old national road that connected Bicaz and Poiana Teiului ceased functioning. The functioning of this road sector was obligatory, because it connected the Moldavian region with the central-northern parts of Transylvania, Maramures and Bukovina and then with Hungary and Ukraine, and it also ensured the local circulation of the population from Bistriţa valley. The local as well as international traffic was intense, being conducted with all sorts of vehicles, including heavy-duty ones.

The work at the road platform has begun in 1958 and ended in 1964.

In the present paper are made some considerations on the geological, geomorphologic, climatic, hydrologic and vegetation conditions that favor the occurrence of landslides along DN15 in the area of the Izvoru Muntelui reservoir, on the areas of landsliding maximum intensity, as well as comparisons between the period with severe road problems (1964-1980) and the situation from the first semester of 2012 and prognoses on the following period.

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1. Position

The DN15 national road has the start point at the intersection with DN 1 near Turda. Beginning with km 244, from the Poiana Largului viaduct in north and up to the reservoir dam, the length of the road is of 36.6 km. The road route longitudinally crosses the central part of the south-western slopes of Stânişoara Mts. The north-eastern limit of the study area is the main summit of the mentioned mountains, while the south-western limit is given by the lake. The area is crossed by the 47^{o} north latitude parallel and by the 26^{o} eastern longitude meridian, which intersect almost near the center of the lake (Fig.1).

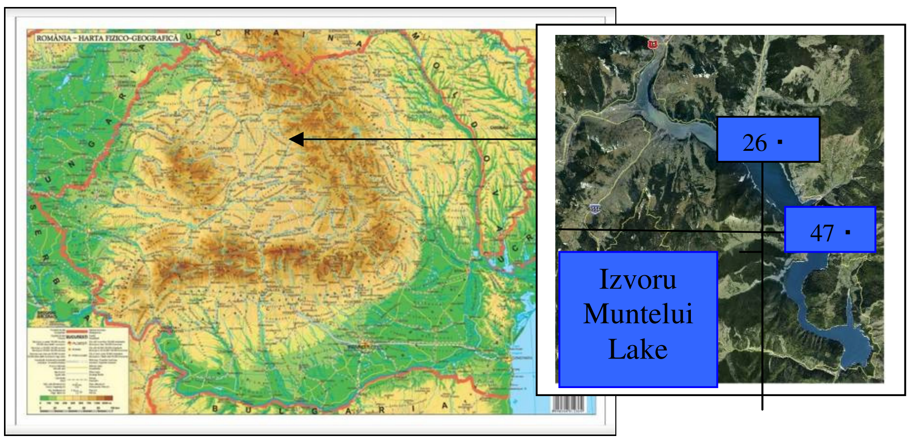

Fig. 1 Geographic position of the study area

2. Review of researches

At the moment the field researches needed for the projects regarding the Bicaz-Stejaru Hydropower Complex have begun, there were no previous studies on the landslides from the area, although their existence was known.

The first studies on the landslides were conducted together with the geological ones. A geological map of the entire area was drawn, and along the line that the road platform was emplaced were conducted geotechnical drills. The results of these studies have been partially published (Băncilă 1958, 1980).

The fact that the slope surfaces affected by landslides were easily identifiable, the scarps being visible from distance, allowed the estimative evaluation of the vulnerability degree and of the risk of landslide occurrence (Fig. 2 and 3). As a consequence, special attention was given to geotechnical studies. Thus were determined the rock characteristics, depth of debris body and the localization of surfaces affected by humidity excess. Based on these studies were conducted works for landslide mitigation: retaining walls, drains for eliminating water excess, Japanese wattleworks. The great majority of these works is functional at the present (Fig. 4).


Fig. 2. Landslide area on the left slope of Potoci gulf, 1966 (Photo I. Cărăuşu)


Fig. 3. Area with landslides at Huiduman, 1966 (Foto I. Cărăuşu)


Fig. 4. Consolidation with retaining walls and spring alimented with water from the drain upstream Motel Cristina


Fig. 5. Drains in an area with landslides and humidity excess

The occurrence of a large reservoir (the lake has at the maximum level 32 km length, 2 km maximum width, a mean depth of 37 meters, surface 3200 ha and a volume of 1230 mil m^3) was normally to produce not only a change in the landscape, but also changes in the local natural factors. The construction in the inter-war period of large reservoirs in different countries has offered the possibility to study the influences they have on the neighboring areas. Thus it was seen that the most affected were the climatic factors.

So, in the period when the constructions of the Bicaz-Stejaru Hydropower Complex were made, there was sufficient knowledge so as to allow the elaboration of relative prognoses regarding the possible influences that the reservoir might have had on the environment.

The possibility of constructing in the near future other large reservoirs (Vidraru on Argeş, Vidra on Lotru, Stânca-Costeşti on Prut) led to the idea of founding units that would study the influences that large reservoirs have on the environment in the specific conditions of Romania. Thus in 1957 the A.I. Cuza University of Iaşi founds the Biological, geological and geographical research station „Stejarul” from Pângăraţi. In 1968 the National Water Council founds the Lake Hydrologic Station from Piatra Neamţ. In both units was deployed a thorough and sustained research activity. This was unfortunately late, because the execution works were almost finalized. We can mention the studies and works published by Ciaglic V. (1960), Drăghindă D., Ciaglic V. (1973), Ichim I., Surdeanu V. (1972-1973), Mihăilescu I. F. (1975), Surdeanu V. et al. (1980), Surdeanu V., Todoran G. (1981), Ichim I., Rădoane Maria (1986,1987) and Rădoane Maria, Rădoane N. (2003). A part of these studies have been elaborated as PhD theses or syntheses (Mihăilescu I. F. 2001; Ichim I., 1979, 1983; Rădoane, 1983, 2004; Surdeanu V., 1987, 1998).

3. The route of DN 15 in the study area

The route of DN 15 in the area is a typical slope one, with many curves imposed by the terrain configuration and which reflect in its length. Because of this, on large distances, in longitudinal profile, the mean value of declivities is about 4 % while the maximum values reach 6 - 7 %.

The crossing of the slopes intensely fragmented by brooks and small torrential organisms and affected by intense landslides extended on large surfaces, with humidity excess, has raised many problems even during construction. To overcome the natural obstacles from the area was needed the emplacement of a large number of slope consolidation works, were emplaced earthworks and cut-and-fills which also needed retaining walls. On the terrains with excessive humidity was emplaced a network of drains (Fig. 5).

With all the efforts made for these consolidation works, in only one year from the construction finalization, in 1965, was witnessed the existence on the road of 70 sectors strongly affected by landslides (Fig 6).

Fig. 6. Consolidation with arches with pilasters on the affected DN 15 at Grozăveşti

Fig. 7. Anchoring pile arches at the Vale Bubei viaduct

The impact of the landslides has been severe, overcoming the estimations of the constructors. The most affected areas have been Buba and Huiduman. In the torrential basin of Buba was needed to be emplaced canal embankments, drains, bank-sloping arcades, arches with pilasters and retaining walls (Fig. 7).

In 1969, in the Huiduman basin was constructed a retaining wall with pilasters. Under the road ditch was emplaced a longitudinal collecting drain that intercepts the slope drains from the area.

4. Description of the areas affected by landslides

The DN 15 national road was constructed on a polygenetic slope modeled in strongly folded and intensely tectonized flysch rocks, in which the alternating strata (sandstones of different hardness, limestone, clays and marls) behave differently in relation to water action and freeze-thaw processes (Fig. 8).

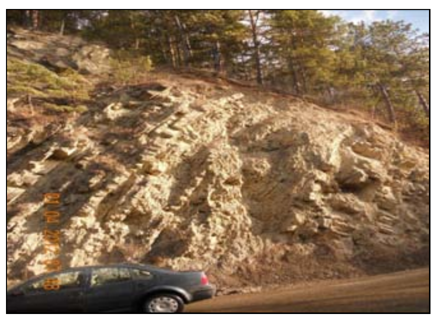

Fig. 8. Strongly folded and tectonized flysch strata near DN 15

The lithologic characteristics of these formations allowed in the morpho-climatic conditions of the Pleistocene-Holocene the formation of thick deluvial deposits (up to 20 m).

The slope is situated in the mixed forest climatic and denudational floor. It has a dominant southern exposition, situation that favors insolation. Because of this in the periods with low rainfall from the cold period of the year snow melts very fast. The consequence is an increase of the freeze-thaw and associated processes having as result the weathering of the superficial deposits, an intensification of sheet erosion and the transport of the resulting materials by torrential organisms.

The floodplains of the tributaries of Bistriţa: Largu, Hangu, Buhalniţa and Potoci have strongly deepened. The concave form of the longitudinal valley profiles of the respective rivers shows that their evolution has reached equilibrium. The slopes between these rivers have been subjected to geomorphic modeling much more lately, and this modeling process is in full development due to the activity of some torrential organisms that have deepened their valleys up to the bedrock, fragmenting the slopes is low secondary summits. This process develops in the deluvial deposits resulted from weathering, which lack cohesion among the constituent particles and thus oppose a minimum resistance. This situation favors the intensification of sheet erosion on slopes, caused by sheet flow and the transport of solid particles to the foothills and floodplains. At the same time the small brooks are deepening their valleys, thus undermining the equilibrium state of the deluvial deposits from the slopes and finally triggering landslides.

5. The behavior in time of the DN 15 road platform and the accompanying consolidation works

From the bringing into service in 1964 and up to the present, the road platform and the accompanying consolidation works have periodically suffered important degradations caused by landslides. The first such occurrences manifested during the construction works, after this moment repeating with a certain periodicity during 1965-1966, 1972-1973, 1977-1980 because of heavy rainfall. After the landslides occurrences from 1965-1966, Ichim and Surdeanu have drawn the map of landslides from the Borca – Bicaz sector, which they published in 1973.

Pressed by the extension, intensity and frequency with which landslides manifested as well as by the high value of the damages inferred to the road platform of DN 15 and the accompanying consolidation works, the Iaşi Roads and Bridges Direction decided to conduct complex studies regarding the dynamic evolution of landslides affecting DN 15 Poiana Teiului - Bicaz, in the areas of Buba and Huiduman. To conduct this study an interdisciplinary research collective was formed. The research plan included the analysis of several parameters: the evolution of the main meteorological elements, superficial and subterranean discharge flow, dynamics (movement speed) of the deluvial mass in different points and at different depths. Field activities began in 1976, after the research points have been previously instated with all the equipment, and the results have been published in 1980 by Surdeanu et al. and in 1981 by Surdeanu and Tudoran.

During 1972-1973, as a consequence of abundant rainfall, some old, apparently stable landslides have been reactivated and new landslides occurred. The destruction caused by the landslides occurring after the 1972-1973 rainfalls have involved applying urgent measures so as to ensure good circulation conditions on DN15.

The most affected areas have been:

1. *Buba torrential catchment,* km 247+925 – 247+990. The energy discharges exerted by the landsliding deluvial mass on the road platform from the area provoked very large destructions. To allow circulation again was constructed a Benotto piles viaduct over the landslide body (Fig. 9). There were also undertaken

works for the consolidation of the landslide area uphill the viaduct and organizing water drainage. During the execution of the viaduct landslides have intensified and have broke the freshly installed concrete pillars from pile P2 at about 3 meters from the terrain level. Thus was needed to replace the broken parts, to reconstruct the pillars up to the initial level and consolidating them with strongly enforced sill plates. At the same time, upstream the viaduct was executed a consolidation with strengthening coffers united by reinforced concrete arches on pillars emplaced with the help of drop hammers. Later the P2 pile has been anchored for consolidation with the help of metallic grubs protected by concrete.

In 1980, approximately 3 years from the end of the constructions, was witnessed a reactivation of the landslide, which caused the destruction of the canal embankment at the exit from the viaduct.

Fig. 9. Valea Bubei viaduct

2. *Huiduman catchment,* km 258+585 - 258+675. In the same period (1972-1973) the road platform was degraded partially or totally on a length of 90 m. Due to the large depth at which the bedrock is found (8-12 m) was decided that for the crossing of this area a viaduct on Benotto pillars was needed. The viaduct has 6 openings of 15 m (Fig. 10).

Fig. 10. Viaduct and drains at Grozăveşti (Darie)

The infrastructures anchored in the bedrock (sandstones alternating with marls) are made of piles each on three Benotto pillars. The viaduct was not designed to support the pressure of the whole slope. As in the previous case the viaduct behaved well from the moment it was finished in 1974 up to 1977, when fissures in the pillars and in the strengthening beams occurred. Because the state of the viaduct was not proper for circulation, another one was built upstream it, in parallel taking place the repairing works on the degraded portion. Thus were executed the covering of the broken pillars in steel concrete that reach a depth of 10-12 m from the lower level of the beams. During these works were intercepted springs with a discharge rate of 2-4 l/min which haven't been previously detected in the geotechnical studies. It was considered that the occurrence of the springs has been caused by infiltrations due to a repositioning of the strata after the 1977 earthquake. As a consequence was conducted a work of strengthening the viaduct in the downstream part, with draining caissons buried at 8-9 m from the terrain level, linked between them through a network of drains. The execution of the works has been cumbered by the fact that in the deluvial mass were found large rock blocks which have hardened the positioning of the caissons.

Fig. 11. Drain network on DN 15

3. *Huiduman catchment,* km 259+200-259+324. Here occurred reactivations of old landslides, mentioned in the geotechnical studies even from the design phase in 1958. During 1965 was constructed a legged abutment wall which was again affected by landslides in 1969. The landslides from the area have a distinct delapsive character, being triggered from downstream the road, from the margin of the lake and ending upstream de road. It is considered that the large variations of the lake level decisively contribute to a permanent state of terrain instability, due to the short distance to the lake shore. Thus have been strongly affected a series of buildings upstream the road which have later been demolished. The road has been consolidated with pillars in the area of the abutment wall, which was continued

later with arches on pillars. At the same time was constructed a longitudinal drain under the road ditch which collects the smaller drains from the area (Fig. 11).

The pillars have been dimensioned so as to transmit to the terrain compression efforts of up to 5 kg/cm².

In the following years landslides have reactivated both upstream and downstream the road, affecting the pillar arches from the area of km 259+200 - 259+324, the bridge from km 259+345 (which moved downstream), the pillar arches from km 259+405 - 259+450 and the school. To solve the situation, in 1974 were conducted the doubling of the longitudinal drain, the construction uphill the road of ditches to help eliminate water excess, were reconstructed the wings and the sill plate of the affected bridge with a system of transversal drains, two arches and three pillars in the area of km 259+405.

In 1977, after a period of relative stability, landslides have reactivated and produced a vertical accident of about 70 cm between the right and left sides of the road. This caused the degradation of the pillars and arches that have slid downhill. The bridge from km 259+345 and the brushed corrections downhill the bridge have also been moved. The arches and pillars from km 259+405 - 259+450 have again fissured and moved. As a consequence was proposed that in a first stage to be executed the consolidation of the pillars through drilled anchors up the bedrock and of the arches with strengthening and post-comprimation grubs.

In the second stage was proposed the increase in the number of grubs for the arches and suspending them with the help of steel concrete beams that would stand on pillars, the respective works reducing the compression effort up to 4 kg/cm². Also, after the landslides from 1980 was proposed the consolidation of the entire landslide affected slope.

Up to the present the proposed works have been conducted only locally in the areas where the road platform has been severely affected.

4. *Valea Mormântului catchment, km 272+534*. The landslides that have affected the road platform occurred during 1968-1970, favored by the declivity of the marls and sandstones strata from the base of the deluvium, of over 60 degrees downhill. To this is added the fact that Valea Mormântului brook goes parallel to the road after it crosses the viaduct, situation which leads to heavy rains exerting strong erosion on the slope base. To solve the problem was constructed an abutment wall anchored in the bedrock, re-constructed the portion of destroyed arches and the elastic bond of the abutment wall with the viaduct through a wall of gabions.

In 1980, after 4 years from the stabilization, a reactivation of the landslide occurred causing a vertical displacement of about 20 cm of one of the wall sectors, while the other 11 suffered fissures. The first urgency measure was to manage the floodplain of Valea Mormântului brooks so as to prevent erosion at the slope base.

5. *Motel Cristina area, km 280+200 - 280+400*

The landslide occurred in 1973, producing a displacement of the abutment walls from the road cut-and-fill. At the same time occurred a displacement of the filling material on which Motel Cristina was built. The measures taken initially have been draining the slope through a network of drilled drains and strengthening the walls through inclined drilled anchors up to the bedrock (16 m). These works didn't brought results, so in consequence in 1977 were built abutment walls on Benotto pillars, anchored and placed linearly. Landslides re-occurred in the spring of 1979, when the lake level decreased much, the walls being displaced by about 10 cm. Also during this period occurred the strong fissuring of Motel Cristina. The increase in the lake level stopped the progression of the landslides for a short time period.

In the spring of 1980 the water level in the lake severely decreased, reaching the minimum for its existence period (about 25 meters under the maximum level). This caused a massive landslide. The scarp departed from the slope above the water level, crossed the road at km 280+200 and continued up to about 400 m above the road level, then going down towards the road area at km 280+450 and ending under the water level.

The landslide broke the pillar wall from km 280+200 and displaced with about 10-15 cm the wall from km 280+400. To save the construction were used anchors, during 1974 -1978 being executed a large number of such works with very large expenses. In relation to the volume of works can be separated two categories: of large volume and intensity and of small volume.

Due to the large sums spent on these works, the National Company of Highways and National Roads reached the conclusion that to diminish the effects was necessary a more profound analysis of the landslide processes that have generated them, taking into account the following aspects:

- The analysis of the entire slope with all the potential landslides from the affected basins;
- Ensuring the flow of rainfall and underground waters;
- The analysis of the influence the lake level variations have on the slope base;
- Foresting the slopes so as to consolidate the terrain and retaining a larger water quantity;
- Taking urgency measures to protect the works immediately as certain instability signs occur.

During 16.02 - 18.03.2012 were conducted a series of field observations in the area and have been observed a reactivation uphill Grozăveşti viaduct, which led to a displacement of buildings from the near vicinity and a subsidence of the DN 15 road platform of over 70 cm in comparison to the initial level (Fig. 12 and 13).

In the same period it was noticed that on the road from the dam to Poiana Largu all the brooks were depleted although at the end of the second decade of February 2012 were registered heavy snows (Fig. 14). Immediately downstream Vârlan brook were conducted some flood control works for a small torrent that had affected the road platform (Fig. 15).

Fig. 12. Subsidence of DN 15 road platform at Grozăveşti

Fig. 13. Building displacement, Grozăveşti

Fig. 14. Poiana Largului hydrometric station on Bolătău brook

Fig. 15. Flood control works downstream Vârlan brook

At the end of the second decade of February began a period with heavy duration snows which continued up to March. From the second decade of April rainfall came back with even heavier intensity, continuing with small pauses up to June.

Conclusions

Having in view all the mentioned aspects, it is expected that in a short time interval to occur some new landslides and the reactivation of older ones in the maximum risk areas. We consider that due to the integral consummation of the water from the deluviums as well as the partial one of the low depth ones the probability of landslide triggering is imminent. This is mainly due to the fact that the largest part of the rainfall fallen from 20.02.2012 up to the end of June have been retained underground to replenish the quantities exhausted previously.

Also we appreciate that the previous studies didn't paid enough attention to some very important climatic elements. Thus it wasn't taken into consideration the water volume lost from the lake through evaporation and that partially comes back on the slope surface through condensation (1963 – 16,004.5 x 10³ m^3, 1964 – 18,829 x 10³ m^3, 1965 – 18,124.1 x 10³ m^3, 1966 – 20,857 x 10³ m^3, 1967 – 23,820 x 10³ m^3, 1968 – 21,940 x 10³ m^3, 1969 – 15,470 x 10³ m^3). Dionisie Drăghindă and Valerian Ciaglic (1973) have analyzed the evolution of evapotranspiration from the lake surface for the 1963 -1969 period (Fig. 16).

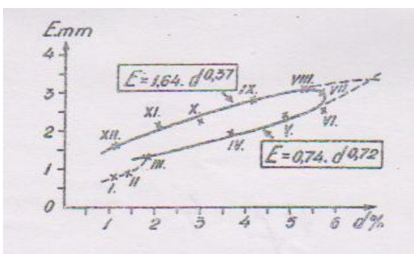

Fig. 16. Correlation between evaporation and water deficit at Ceahlău-sat meteorological station (mean monthly values) E.mm – evaporation; d % - water deficit (Drăghindă, Ciaglic, 1973)

Fig. 17. The evaporation phenomenon in the area of the Ruginești – Potoci reservoir (V. Ciaglic, 1987)

The largest water volume evaporated is registered in the second period of the year, phenomenon accompanied by a high frequency and duration of fog (Fig. 17).

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