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# Geophysical landslide investigation and prediction in the hydrotechnical works

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***Abstract:*** *The results of the geophysical surveys of some of Albania's largest landslides are analysed. The slides have developed along the shores of the hydropower plant lakes in Fierza, Vau Dejes, and Banja. These three slides are analysed in various geological and morphological conditions. The applied geophysical surveying methods in these areas are also described.*

***Key Words:*** *Landslide prediction, Hydrotechnical works.*

## INTRODUCTION

Hydrotechnical works in Albania are generally constructed in rugged terrain and over geological formations in which the land sliding phenomenon is often present. The land sliding phenomenon develops in the basement rocks and the overlaid loose sediments. This phenomenon has been accelerated by the construction of hydrotechnical works. A study conducted in the Fierza hydropower plant, constructed over the Drini River in Northern Albania, is a clear example of this occurrence. The hydropower plant was constructed in 1974 and has an installed capacity of 500 MW. The lake, created after the construction of the plant, has a water volume of 2.7 billion $m^3$. The hydropower plant consists of several complex hydrotechnical works. The main work is the dam constructed of stones and a clay core. The dam is 165 meters high and 500 meters long. The large Porava landslide is located on the shore of the lake, 2.5 kilometers from the dam. In view of the geological data collected during the design period, this landslide has a slipping mass of about 34 million cubic meters.

The more than 20-year exploitation period of such a huge hydrotechnical work has influenced the physical-mechanical properties in various parts of this landslide. This situation made it necessary to start the in-situ tests. Several geophysical methods have been applied, to study the slipping body, its slipping dynamics and the prediction of the slipping area's expansion.

In this framework, the Porava landslide became the target of the first of geophysical engineering mar-kers in 1996. A geophysical survey line was located in the centre of the slipping body. Electrical soundings and high frequency refraction seismic surveys were conducted in the study area (Frasheri et al., 1997).

This paper presents the results of the geophysical surveys performed in the Porava and other landslide areas. In addition to the geophysical methods, previously mentioned natural seismic tracking, micromagnetic and microgravity surveying, and borehole logging were performed in some of the landslide areas.

## SURVEYING METHODS

The intricate geophysical survey lines lie on the slipping body (Frasheri et al., 1997). The surveying stations were placed in particular locations to control the actual and perspective situation. Electrical soundings were conducted by the Schlumberger array of spacing up to 500 m. Seismic recordings were performed at the same stations as the electrical soundings, by using a high frequency refraction seismic survey. The longitudinal and transversal waves were recorded through the time intercept method. The seismoacustic activity was also recorded for a continuos time of 5 seconds. These seismic recordings were registered by the 12-channel seismic station S-2 ECHO, in response to mechanical excitement caused by seismic waves, with a 50 meters maximum distance of the twelve geophones.

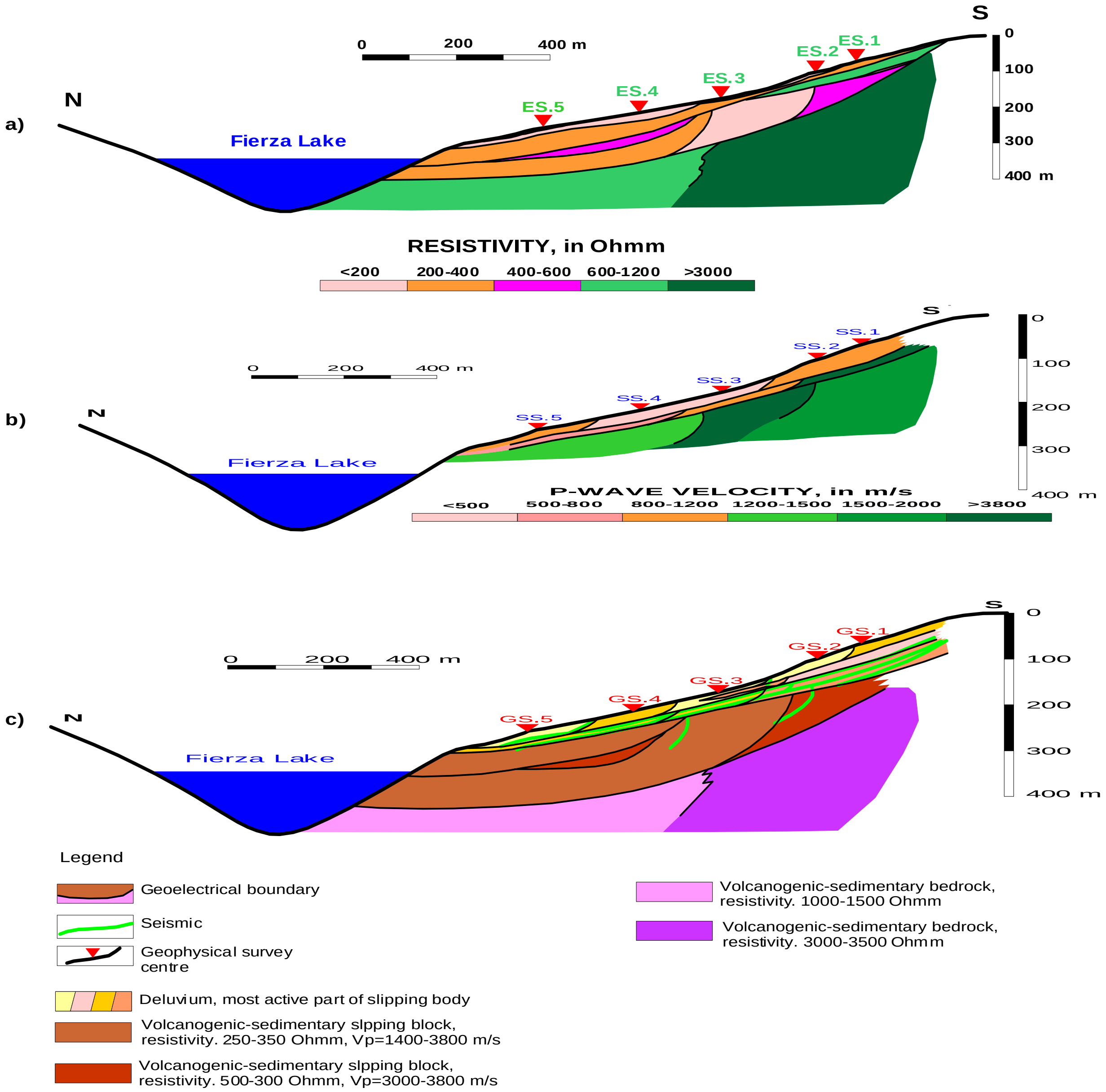

**FIG. 1**. Geoelectrical (a), seismic (b) and geological-geophysical engineering (c) sections Porava landslide, Fierza hydropower plant.

The depth of investigation was about 25 m. Special care has also been taken to monitor the seismological activity.

The collected data was interpreted and processed by application of the respective software. By examining data processing results for all survey stations, the complex geophysical and geophysical-engineering sections were respectively constructed for each survey parameter. The results of previous geological studies, conducted in this region about 25-30 years ago, were taken into consideration during this study.

## DISCUSSION AND ANALYSIS

### Porava Landslide

Special attention has been given to the slope stability on the shores of Fierza Lake, especially to the Porava landslide. The Fierza hydropower plant is a large hydrotechnic work containing many constructions and a complex composition of previous constructions.

The studies not only consist of a general geological understanding of the shore's stability and a particular understanding of the landslides, but they also include the solidity, and complex calculations through hydraulic modelling. For this reason, the fall of the Porava landslide’s body was simulated at different speeds (from 5-10 m/sec). The existing geological information served as the study parameters. The study results that the dam should be raised 12 meters higher than the one initially projected, so that it would be more secure.

Based on the data generated from geophysical surveys, the geological knowledge about this zone and the visual study of the actual situation of the Porava landslide, the respective analysis of these geophysical works was achieved.

Figure 1-a present the detailed geoelectrical-engineering sections. These sections were formed based on the data compiled from the vertical electrical soundings. The presence of the very heterogeneous electrical media in strike direction and in depth can be recognised. Two types of geoelectrical boundaries are present in the profile. These are the primary boundaries, related with the separation of the main zones of the slipping body (with that of the deepest plain 140-160 m deep and with that of the most superficial plane 20 m deep). These slipping plains have varying geoelectrical characteristics because of their geological properties. The second category belongs to the secondary geoelectrical boundaries, which clearly identifies the physical differences between these slipping planes and the basement.

First the geoelectrical markers define the full configuration of the sliding structure in the rocks of the volcano-sedimentary section. As a result of the slide, these rocks have low to medium electrical resistivity values (200-100 ohm-m). The basement rocks beneath the massive slipping body have relatively high electrical resistivity values (in the furthest sector of the profile, the lake side, 3000-3800 ohm-m and 1200-1400 ohm-m in the sector located near the Fierza hydropower plant artificial lake.

The most upper part of this slipping body, represented by the deluvial - eluvial deposits, is very active today and has relatively low electrical resistivity values (120-500 ohm-m). This activity is observed by a continual damage that affects the houses, and other objects in the Porava area.

The apparent geoelectrical heterogeneity in the strike direction expresses the blocking content that is typical for this landslide. It also gives a picture of the development of this landslide over time.

Figure 1-b presents the seismic section in the same profile with the geoelectrical one. The upper part of the slipping body (the 25 meters deep zone) can be easily distinguished in the figure by two seismic parameters (the speed of the longitudinal and transversal waves). The deluvial deposits are represented with the values, Vp = 400-1200 m/s and Vs = 150-450 m/s values, while the eluvial deposits and the volcano-sedimentary rocks of the most upper part, located over the slipped plane have Vp = 800-3880 m/s and Vs = 350-800 m/s. The volcano-sedimentary section located below the first slipping plain have the following values, Vp = 1400-3800 m/s and Vs = 600-1500 m/s.

The evaluation of the physical-mechanical characteristics of the slipping body, was evaluated in both strike and depth directions. The seismic and the geoelectrical sections, indicate the blocking nature of the upper part of the slipping body and also the lower part of the body over the basement volcanic rocks.

Observation of the natural seismoacoustic activity was performed at all of the surveying stations. This shows that the sliding activity varies in different parts of the slipping body. The most dynamic zones of this massive slide are located in areas where the micro-movements reach maximum intensity. The Porava village is located over one of these zones. Because of this activity, many houses have been damaged and slopes have moved about 2-4 m within a 2-3 years period of time (1994-1996). The details of the geophysical-engineering sections indicate that the electrical sounding results are comparable to that of seismic surveying (Fig. 1-c).

Moreover, the nature the sliding plains, mechanism and content of the two parts of the slipping body can be determined from this section (Fig. 1-c). The most upper part is formed by deluvial - eluvial deposits that reach up to 20 m deep, and overlies the most dynamic plain of this zone. A mass of volcano-sedimentary rocks overlies the deepest plane of the Porava slide (100-160 m). This plain separates the block type slipping body from the stable volcano-sedimentary basement.

In view of the geophysical-engineering and geotechnical study the following results can be concluded. A sudden fall cannot be expected at incidental speeds. Even in cases of powerful earthquakes, the complete mass of the slipping body could not fall, because of it's unique block like masses. It can fall partly or in fragments. Natural or induced earthquakes of normal intensity, which occur often in this region, have not caused massive detachments of the slipping body until now.

## Ragami Landslide

This landslide is located on the shores of the Lake Vau Dejes. It is developed in the ophiolitic formation, represented by serpentinized rocks. The slipping body consists of a large mass of serpentine that was defeated and covered by a thin layer of deluvions. This landslide has developed mainly in the last five years. The front part of the slipping body spread along the shores of the lake. In the shape of a scarp that starts about 2-3 m high, and is made of defeated, shelled and mylonitized serpentine.

Superficial levels of three detachments can be seen in this landslide:

-The first, 35-45 meters from the shore, has a horizontal displacement of about 2 meters.

-The second, about 70-90 meters from the shore, has a vertical detachment with amplitude of about 2 meters.

-The third, about 115-130 meters from the shore, is the newest level and has the lowest amplitude.

The geophysical-engineering section of the slipping bodies shown in Fig. 2. Two main plains separate the body. These plains break down into smaller plains. The depth of the first plain is 5-7 meters, while the second one reaches up to 22 meters. The lowest part of the second plain is in contact with the lake below

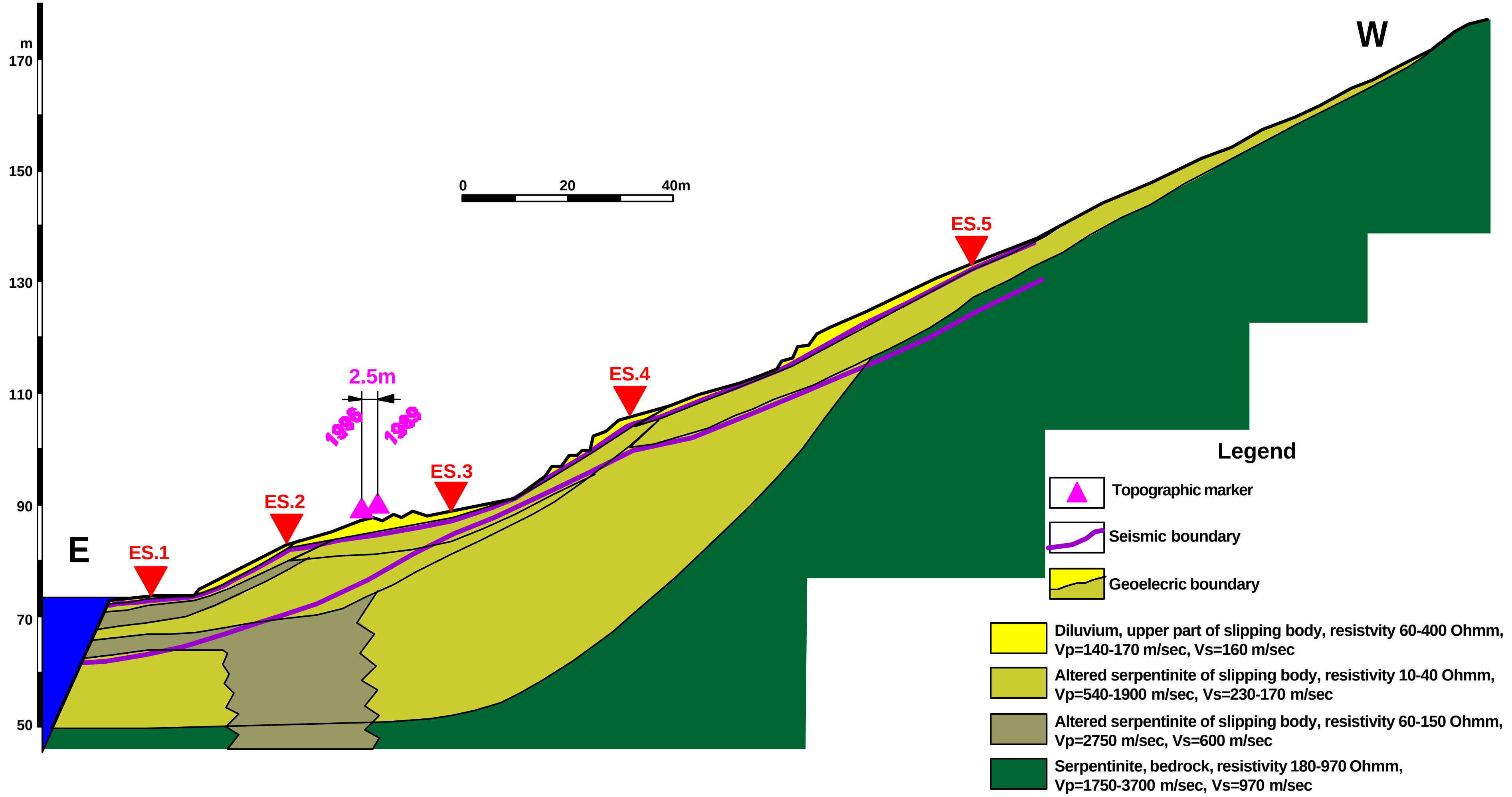

Fig. 2. Ragami landslide, Vau i Dejes Lake

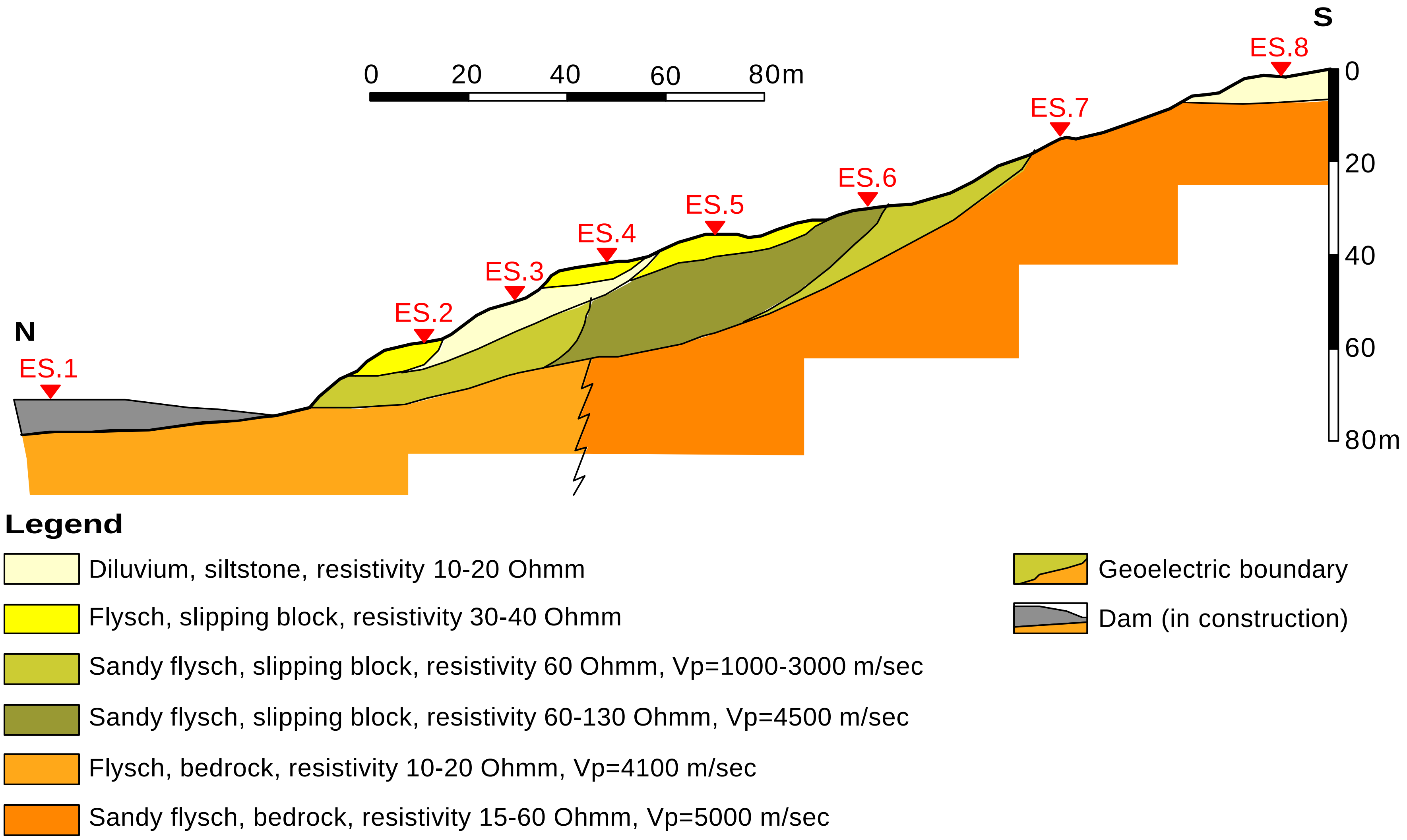

Fig. 3 Banja landslide, Banja hydrotechnic works

the water level. In this manner, the slipping body shows a block type nature. The physical - mechanical properties of the slipping body's rock mass are lower than those of the basement rocks that are not influenced by the slide. The micro movements in the slipping body are very intensive and have a wide frequency band, while there is no such activity outside of the body.

This dynamic is also pointed out by the natural seismoacustic activity. High frequency seismoacoustic activities dominate inside the slipping body and the amplitude of the micro-movements is higher several times in comparison to its vicinity.

### Banja Landslide

This slide occurred as a result of construction activities for a derivation tunnel at the Banja hydropower plant. Thick sandstone layers, dipping in accordance with the relief, constitute the main part of the Paleogene flysch section. The constructed part of the derivation tunnel then collapsed because of the landslide activities.

Fig. 3 shows the geophysical-engineering section along the Banja slipping body. The maximum depth of the strike of the sliding mass is 22 meters (in the center of the profile). The geoelectrical characteristics of the slipping body can be clearly distinguished from those of the flysch formation located outside the slide. The same is also true for the velocity of the seismic wave. The slipping body is very heterogeneous and is made of various blocks.

The intensive movement of the slipping body's mass is characterised by this slide. For about one month, the geodesic markers determined that a sliding mass of 17 000 cubic meters was displaced about 5-7 meters. This dynamic is also pointed out by the natural seismoacustic activity. High frequency seismoacoustic activities dominate inside the slipping body and the amplitude of the micro-movements is several times higher.

## CONCLUSIONS

1. The following results can be concluded in view of the above analyses: The intricate geophysical profiles have revealed the boundaries of studied landslides and identified the sliding plains. Although the geological conditions are different for each case, the landslide plains show similar structures in which the maximum depth is located over the centre of the profiles.
2. Often the slipping body is made of several blocks like slipping plains. These slipping plains are located at depths of 15-20 meters, especially those that are currently active. The slipping body overlies this plain and it is mainly made of deluvial-eluvial sediments or rocky masses with very weak mechanical characteristics. Their dynamics cause progressive damages to the houses of Porava village.
3. Of the studied landslides, the Porava landslide is the largest. The lower plane of this landslide is approximately located at a depth of 100-160 m. It separates the volcano-sedimentary rocks with very low petrophysical characteristics from the stable volcano-sedimentary section. By using the results of preliminary geophysical data, the total volume of the complete sliding body is estimated to be over 40 million cubic meters.
4. Porava's slipping body is heterogeneous and is composed of several blocks.
5. The blocking nature of the sliding bodies suggest that the bodies generated by the landslides can not fall down instantaneously. Only in particular cases, such as in Banja, instantaneous falling occurs.
6. The structure of the slipping body and the dynamic of its displacement determine the slide's development. Besides many other factors, the height of the dam is directly defined from this development. By accepting the slipping body as a unique mass, it is necessary that the dam would be built higher. This raising causes a rise in the cost also.

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