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SLOPE STABILITY IN ACTIVE SEISMIC ZONES IN ALBANIA

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ABSTRACT

Albania is a hilly and mountainous country and it is situated in active seismic region. By our studies exists a considerable risk for instability of slopes under static and dynamic loads. From many cases of studies related to landslide activities in Albania results that they occurred in soils deposits of mountain-hill slopes, as well as, on weathered molasses and flysch rocks mountain-hill slopes, which are affected by tectonics and neo-tectonics phenomena. In this paper we would like to present the integrated geological, geophysical and geotechnical studies, the methodology for in-situ testing to make the evidence of different factors which influence in slope instability and respective engineering measures to reach their stability. From analysis of these phenomena we have specified some correlations between soils conditions, soil's characteristics and safety factors.

Keywords: Albania, AGS, slope, landslide, stabilization, investigation, monitoring

INTRODUCTION

Albania represents a hilly-mountainous country and Albanides are represented the geological structures with possibilities of instable slopes and landslide development (Fig. 1). The slope stability problems are well known in Albania. They are responsible of considerable economic losses in last decade as increased scarcity of land. The Albania is a major seismic area where slope instability and mass movement are common. A lot of mass movement occurred throughout in Albania. They are related to:

Lithology characteristics of rocks and soils
Geomorphologic conditions of Albanian area
Physical and mechanical properties of rocks and soils
Hydro-geological and hydrological conditions
Seismo-tectonics and seismicity characteristic

In Albania, 3/4 of area covered by mountains-hills with slopes angle range from 10-20^o up to 35-45^o and some places it's more. According to geology most of the Albanian territory is built by metamorphosed rocks-schists, argillaceous shale, serpentines and weathered ophiolitic rocks, as well as, molasses and flysch rocks, claystones and siltstones intercalated with conglomerates and sandstones layers, whereas related to geotechnics properties, these rocks included in medium and soft strength rocks group. Also, along active faults and neo-tectonic line are mostly concentrated the earthquake epicenter, favor mass movement occurrence. In Albania, the three main longitudinal seismically active zones and three main transversal ones and many neotectonic lines are identified.

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Based on the geological formations and landslide body mass can be present following landslides classification in Albania:

- Instable slopes and intensive landslides developed in weathered bedrocks and overburden bed at the lakeshores of hydropower plants.
- Instable slopes and intensive landslides occurred in Oligocene flysch formations.
- Instable slopes and landslides occurred in Neogene's molasses formations.
- Landslides occurred in soils deposits of mountain-hill slopes.
- Rock falls occurred in steepest of mountain-hill slopes in the weathered and fractured of hard rocks.

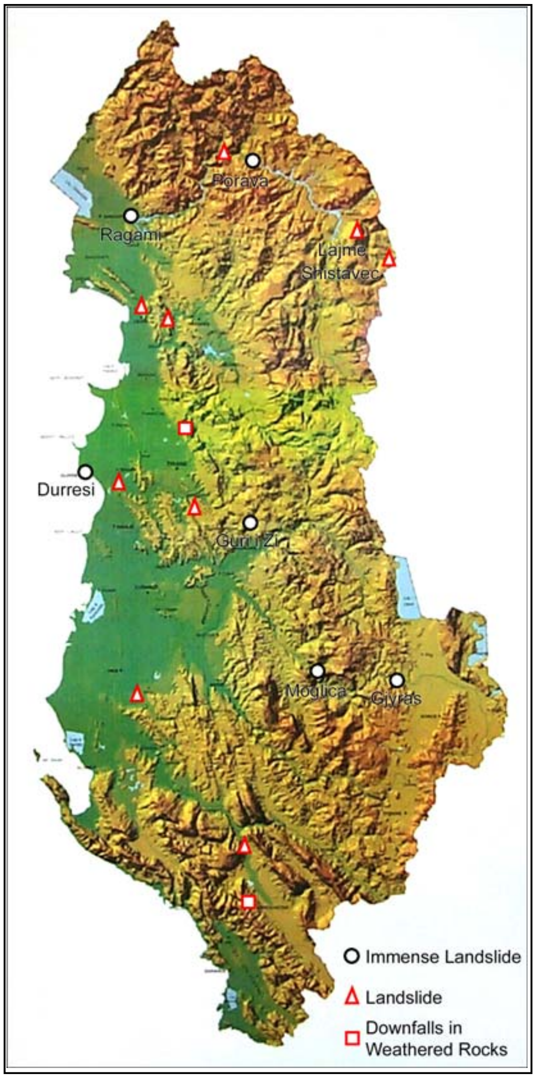

Figure 1. Main location of unstable slopes in Albania

Developing of new landslides or re-activation of the old ones is mainly due to construction works. Special constructions, such as hydro-technical works, civil, industrial, urban and rural constructions, as well as constructions in the infrastructure, particularly during last years have destroyed equilibrium in ecological systems through deforestation etc., contributing and creating landslides events. Landslides are located in the soils deposits (deluvial), and in the altered-bedrocks. The slipping bodies of some landslides have very big volume, exceeding 50 million cubic meters. The biggest ones is observed near of Fierza hydro-technical works.

INTEGRATED GEOLOGICAL-GEOPHYSICAL IN-SITU INVESTIGATION FOR LANDSLIDE PROGNOSIS, STUDY AND MONITORING

In-situ investigations and monitoring for investigation for landslide prognosis, study and monitoring were carried out by integrated engineering geology-geophysics methods:

- Geological Mapping
- Geomorphological Mapping
- Hydrogeological Mapping
- Engineering Geological Mapping
- Geophysical Mapping, in-situ investigation and monitoring
  - · Gravity micro survey
  - · Magnetic micro survey
  - · High Frequencies Seismic Tomography and profiling
  - · Geoelectric Tomography, electric soundings and profiling, etc.
  - · Electrical, radiometric, sonic etc. well logging
- Laboratory analysis and determinations
- Geodesic observations.
- The basic method is the seismic tomography and high frequency refraction seismic profiling. The tomography can be combined with refraction seismic profiling of high frequencies at the different sectors of the landslide area.

- The natural seismic-acoustic activity inside and outside of slipping body is necessary to observe. According to the surveys' data the velocity of-waves (Vp) and S-waves (Vs) can be calculated, as well as, the layer thickness. Also, by the seismic data, the physical-mechanical properties must be calculated for the soils and rocks as Poisson coefficient, elasticity dynamic modulus of Bulk modulus, rigidity modulus and module of compression volume strength.

- Electrical soundings can be performed by the Schlumberger array.

In-situ geophysical investigation and monitoring are programmed to perform in three phases:

- · Surface integrated geological-geophysical survey and installation of geodesic markers.
- · Drilling of shallow boreholes, cross-hole seismic survey and well logging.
- · Periodical geophysical surveys and geodesic observations in boreholes and on the ground surface.

Consequently, geophysical-engineering studies have a complex character:

a) To prognoses slope instability and landslide development possibility in the future,
b) To study the landslide body structure and soil of the landslide area,
c) Evaluation of in-situ physical-mechanical properties of soils and rocks and
d) In-situ monitoring of landslide phenomena.

DISCUSSION AND ANALYSES

Landslides at the lakeshores of the hydropower plants

Hydro-technical works in Albania are generally constructed in conditions of rugged terrain and in geological formations in which the land sliding phenomena is often present (Fig. 2). The land sliding phenomena develops in the basement rocks and the overlaid loose sediments. This phenomenon has been more evidently activated after the construction of hydro-technical works. The exploitation period of more than 25 years of such a huge hydro-technical work has influenced to the physical-mechanical properties at various parts of this landslide.

The Porava Landslide

A study conducted in the Fierza hydropower plant, constructed over the Drini River in northern part of Albania, is a clear example of it. This hydropower plant was building 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 hydro-technical works.

Figure 2. Ragami and Porava landslides location, scale 1:300 000 (Drini River Basin)

The main one is the dam with stones and a clay core, which has 165 m high and 500 m long. There are observed active landslides in the lakeshores of hydroelectric power plants, which represent a great geological risk at Porava village, about 2.5km from the dam (Figs. 2, 3).

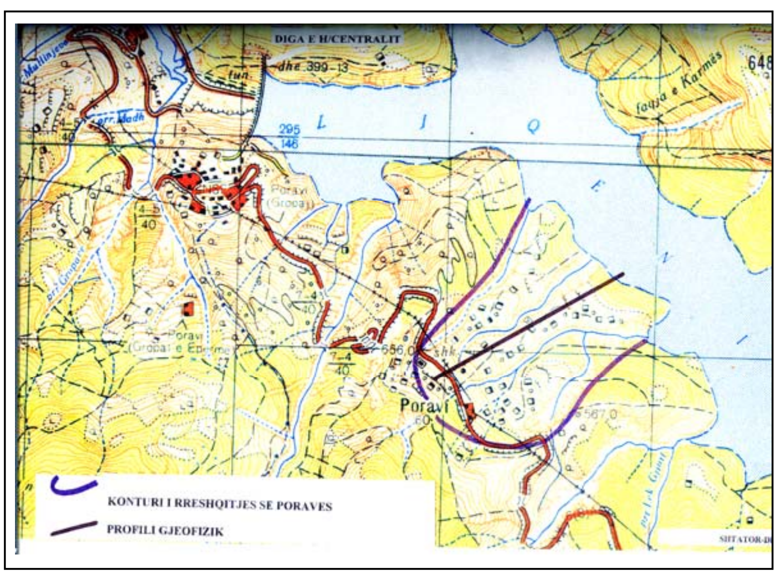

Figure 3. Porava landslide area (Scale 1:25000)

Many buildings have been destroyed. This phenomenon has been more evidently activated when hydro-technical works started to be used. During the exploitation period of more than 25 years, the huge hydro-technical works influenced the physical-mechanical properties in the shore area and caused a series of landslides.

The geology of Poravi area consists of soils, silty-clay mixed pebbles, and rocks blocks etc. which are situated on shale's rocks. These formations tectonically overlies over melanzhe rocks, which are composed by schists and argillaceous shale's formations. The Poravi landslide occurred on left side of the Drini River valley slope (actually artificial lake) that has an inclination angle 16^o up to 25^o. The slides body consists of silty-clay mixed pebbles in upper part and basalts rocks blocks in lower part. The dimension of it is 1000-1500m long, 500-700m up to 1000m wide and 50-70m up to 120-125m thick with total volume 34 000 $000m^3$. The slides plane is situated on red argillaceous shale. As result of landslide occurrence several engineering object (village's buildings and road) are demolished and damaged. Special attention has been paid, since the projection period of this study, to the big slides in the shores of the Fierza Lake, especially to the Porava one (Fig. 4). The studies have not only included the geological understanding of the shore's solidity but also the understanding of the landslides. They also include solidity-integrated calculations through the hydraulics patterns. For that, the body fall of the Porava landslide at different speeds (from 5-10 m/sec) was simulated. As calculating parameters were used the ones resulted from geological studies of that time. All those studies brought to the conclusion that the dike should be raised 12 more meters over the one initially determined in the project, so that it would be more secure.

Today, 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, it was realized the respective analysis of these integrated geophysical works.

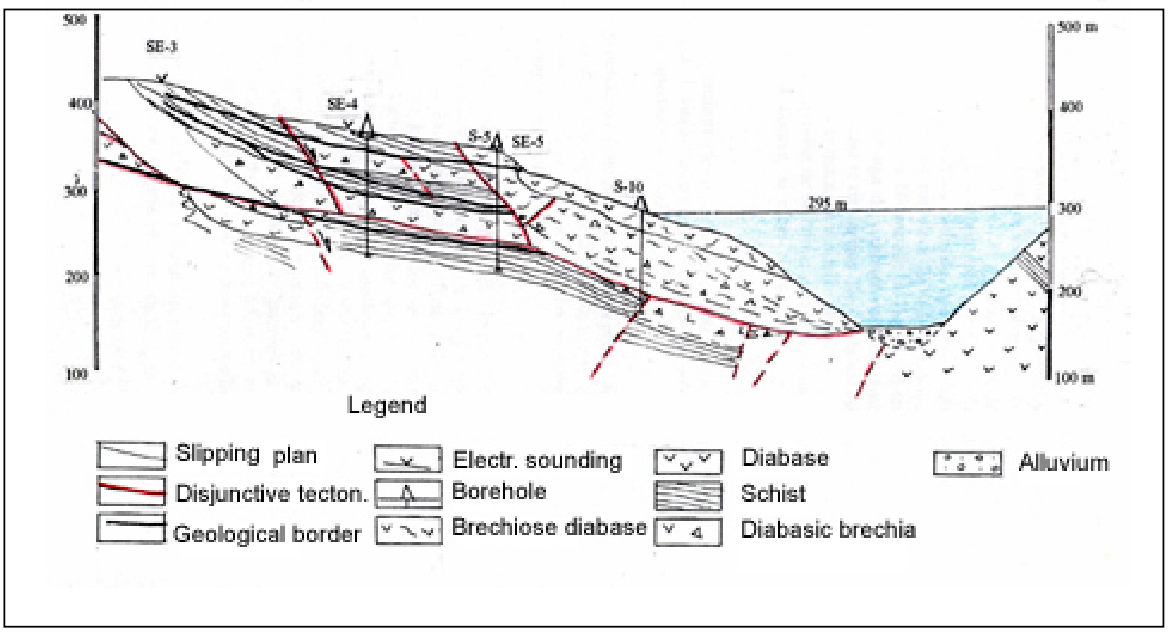

Figure 4. Geological (L. Dhame, 1974) and geo-electrical data comparison, Porava landslide (Frashëri A., etc. 1998)

In Fig. 5 is presented the detailed geo-electrical - engineering section. This section was compiled based on the date of the vertical electrical soundings. In that can be noticed the presence of the very heterogeneous electrical medium in strike and depth. There are two categories of geo-electrical borders in the profile. These are the primary borders, connected with the separation of the main zones of the slipping body (with that of the deepest plains 140-160 m deep and with that of the most superficial plane 20 m deep).

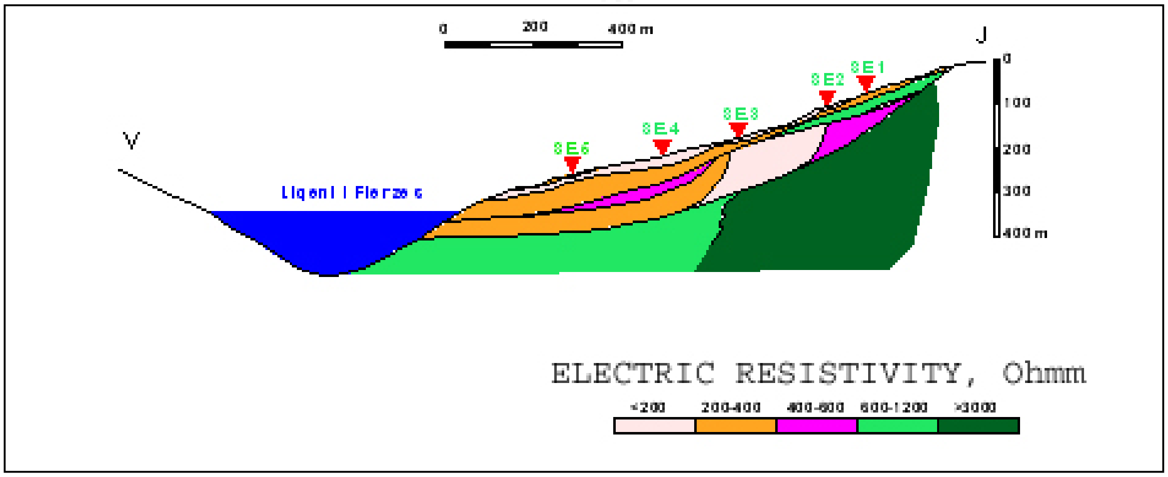

Figure 5. Porava landslide, geo-electrical engineering profile

These slipping plains have very different geoelectrical characteristics, because they have different geological properties. The second category belongs to the secondary geoelectrical borders, which clearly express the changes and the heterogeneity that exists in these two slipping planes and in the environment under them. In fig. 6 is presented the seismic-engineering section in the same profile with the geo-electrical one. In this figure can be distinguished very well the upper parts of the slipping body (the zone 25 m deep). In this section are very well distinguished the two seismic parameters (in the speed of the longitudinal and cross waves). The deluvial deposits have been fixed with Vp = 400 - 1200 m/s and Vs = 150 - 450 m/s values, while the eluvial deposits and the volcanic rocks of the most upper part, located over the slipped plane have Vp = 800 - 3880 m/s and Vs = 350 - 800 m/s values. The volcanic deposits located below the first slipping plain have been fixed with Vp = 1400 - 3800 m/s and Vs = 600 - 1500 m/s.

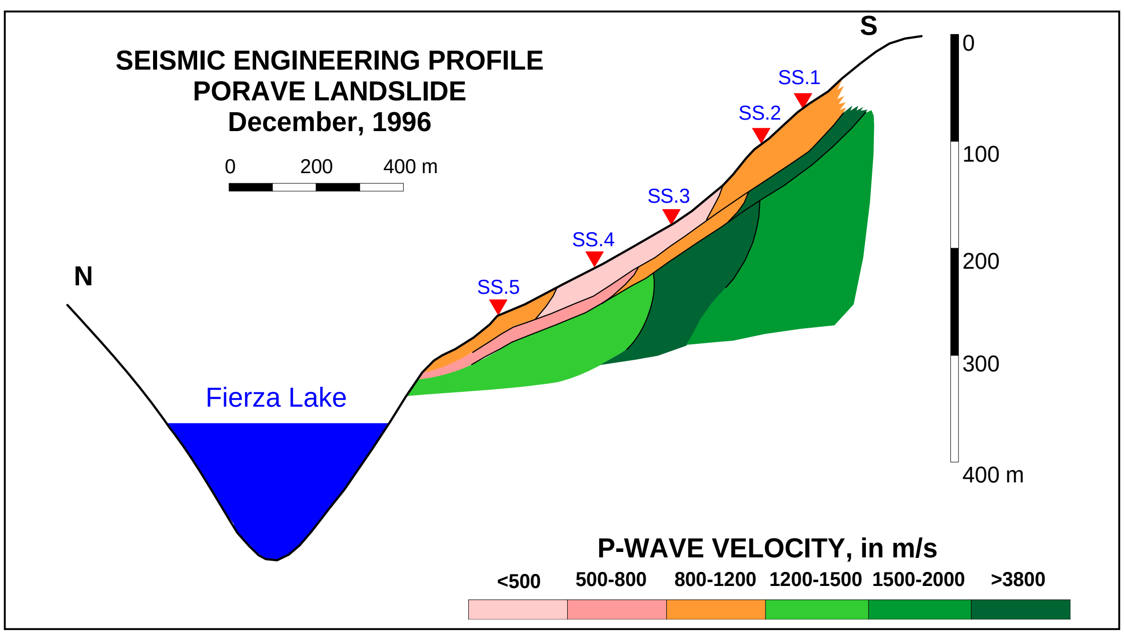

Figure 6.a. Seismic profile of Porava Landslide

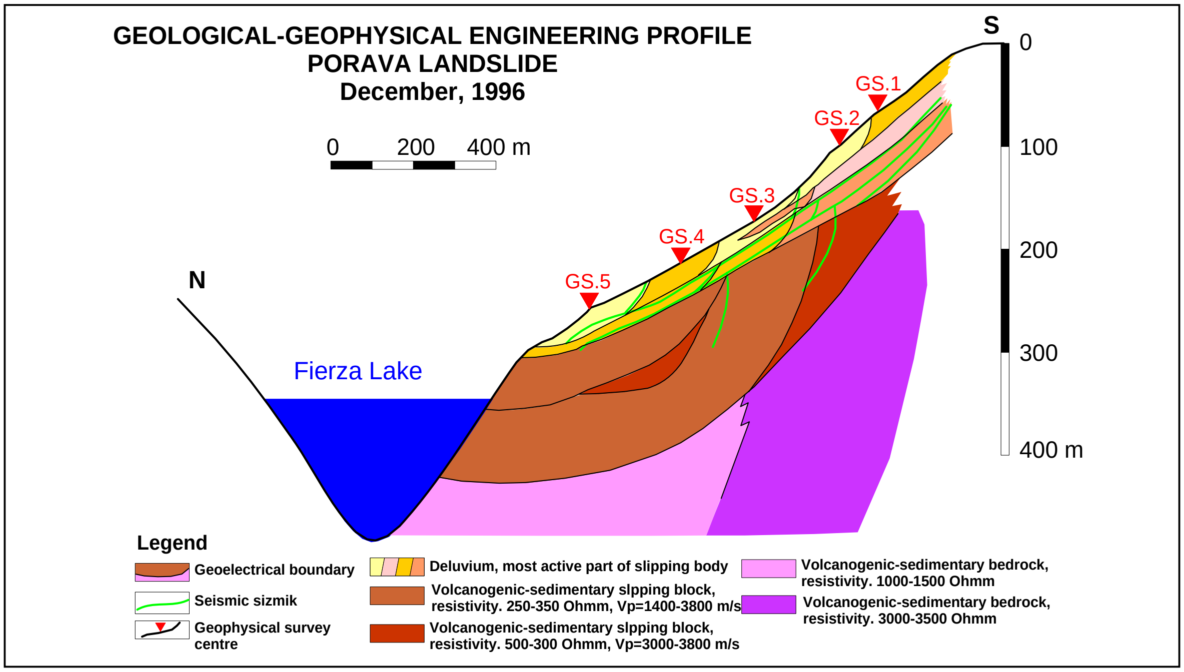

Figure 6.b. Porava Landslide, Geological-geophysical engineering profile

Based on the seismic parameters, the evaluation of the physical - mechanical characteristics of the rocks of this sliding body was carried out in strike and depth. In this seismic section and in the geo-electrical one, can be seen the block kind nature of the upper part of the slipping body and also of the lower part of this body in the basement volcanic rocks. By studying the natural seismic-acoustic activity, different recordings can be noticed in all the surveying zones. This shows that the sliding activity is different for different parts of the slipping body. The most dynamic zones of this sliding massif are located in places where the micro - movements have maximum intensity values. The Porava village is located in one of these zones. Because of this activity, many houses, and the soil is damaged and slopes have moved about 2 - 4 m within a 2 - 3 years period of time (1994 - 1996).In the detailed and integrated geophysical - engineering section, can be noticed a concordance between the electrical sounding results and the seismic surveying ones, used for studying this slide.
Also, in this section can be determined sliding plains, their nature, situation and the content of the two parts of the slipping body. The most upper part is made of deluvial-eluvial deposits and reaches up to 20 m deep, above the first most dynamic plain of this zone. Under this lays the volcanic rock massif, located over the deeper plane of the Porava landslide (100- 160 m). This plain is determined and separates the block like sliding body from the volcanic rocks, which have not been touched by this sliding activity.

The Ragami Lanslide

The typical landslide was developed at lakeshore of the Vau Dejes Lake of Hydropower Plant in Northwestern Albania (Fig. 2, 7). It is developed in the ophiolitic formation represented by serpentinized rocks. The slipping body represents a big mass of serpentines, which is eolated, destroyed and covered by a thin layer of deluvium. According to the geological survey in 1992, the landslide did not exist. Landslide has been significantly developed during the last ten years. The yearly movements of water level at Vau Dejes Lake caused a big landslide at eolated, weathered and destroyed serpentine rocks. Slipping body increased in the extent and in the volume substantially during this period. The front part of the slipping body is located along the shores of the lake. This part has the shape of a scarp about 2 -3 m high, and represents a destroyed, schistose serpentines, partly in a form of mylonite.

In fig. 8, 9 are given the integrated geophysical - engineering sections of the slipping body. Two main sliding plains separate this body. These plains are broken up. The first plain is at depths of 5 - 7 m, while the second one reaches up to 22 m. The lowest part of the second plain touches the lake, under the water level. In this way, the sliding body has a block like nature. The physical - mechanical properties of the rock massif of the slipping body are lower than those of the basement rocks, not touched by the sliding phenomena. The micro movements in the slipping body are very intensive and have a wide frequency band, while outside the body there is no such activity (Fig. 12).

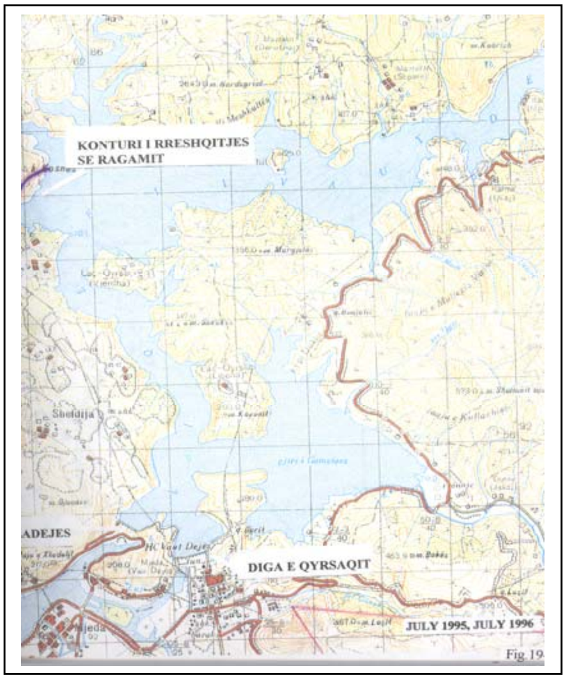

Figure 7. Vau Dejes hydropower plant and Ragami landslide location

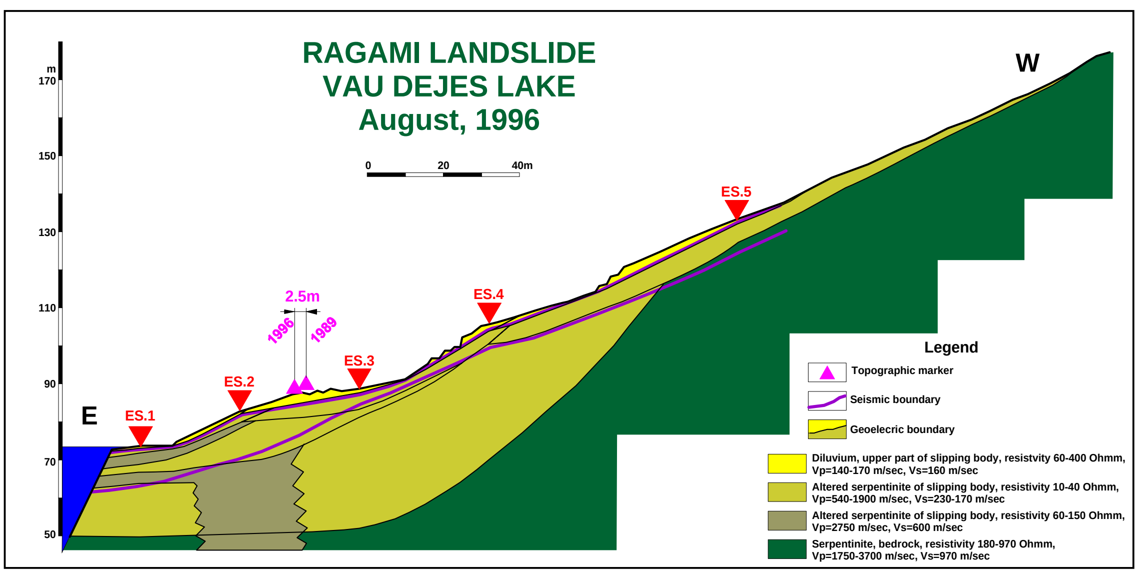

Figure 8. Engineering integrated geophysical transversal section, Ragami landslide

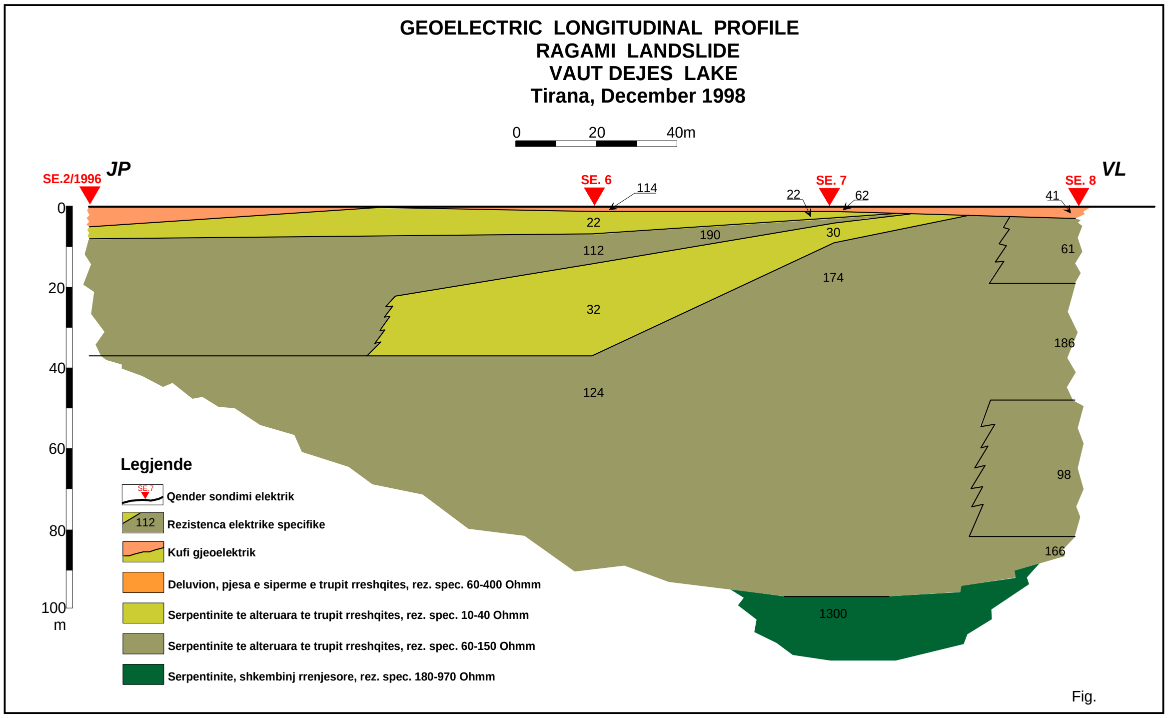

Figure 9. Engineering integrated geophysical longitudinal section, Ragami landslide

Three failures in different superficial levels can be observed in this landslide:

- The first one 35 - 45 m from the shore, with a horizontal dislocation of about 2 m.
- The second one about 70 - 90 m from the shore, with a vertical jump of about 2 m.
- The third one about 115 - 130 m from the shore. This is the newest level and has the lowest amplitude.

The physical-mechanical properties of the slipping body are lower than those of the basement rocks, not touched by the sliding phenomena. Physical-mechanical properties of rocks in the area of Ragami Landslide according to the seismic data are presented in **Table 1** and **Table 2**.

Table 1, Physical properties in Ragami landslide's area

Layer Number	Thick-ness, in meters	Resistivity in Ohm	Density, in g/cm^3	Wave Velocity, in m/sec		Lithology
				Vp	Vs	
Slipping body						
1	0.7	76.4	1.34	210	160	Deluvium
2	4.0	29.5	1.61	540	230	Breaking serpentinite
3	6.5	46.5	2.45	3700	680	Water-bearing serpenti-nite,
4	17.4			1500		Breaking serpenti-nite
Bed rocks						
		485	2.56	3500	1920	serpentines

Table 2, Mechanical properties in Ragami landslide's area

Layer Nor	Poisson's Ratio	Dynamic Modulus of Elasticity, E_d^s in $*10^5$ kg/cm^2	Rigidity Modulus G, in $*10^5$ kg/cm^2	Volume Compre-ssion, σ, in $*10^5$ kg/cm^2	Rock state
Sliding body					
1	0.35	0.00370	0.00140	0.00420	soft rocks
2	0.39	0.02413	0.00868	0.03630	Destroyed, shattered rocks
3	0.48	0.56586	0.19167	3.26503	Cleavages and fissured rocks
4		0.26325	0.09608		Destroyed, shattered rocks
Bed rocks					
	0.29	2.46271	0.96199	1.91408	Compact rocks

As documented in Tables 1 and 2, four layers with different physical-mechanical properties create the slipping body. First layer represents the deluvial cover. Layers 2 and 4 are represented by destroyed-shattered serpentines. The third layer in between is characterized by low electrical resistivity and low shear waves velocity. It corresponds to the water saturated cleavages and fissures in the serpentines. The dynamics of slope movement is also reflected in the natural seismic-acoustic activity. The micro-movements in the slipping body are very intensive and have a wide frequency band.

Influence of Soil conditions to Factor of Safety

Re – activation of the old landslide has been from effect of the water oscillation in Vau Deje and Fierza lakes and the seismic activity in these zones. By these phenomena we have:

a) The softening of soil in the contact planes between sliding body and rock basement. There resistance has decreased 40 – 50 %
b) The appearance of the water flow in the slope and reduction of the safety factor from 1.5 to 1.0
c) The presence of water in the failure surface, reduce the effective stress and the shear stress is in the minimum value (estimated by combination's methods, seismic data and laboratory testes).

$$c_{\min} \cong 0.5c$$
$$\varphi_{\min} \cong 5^o - 7^o$$

The soils in the sliding body were categorized in second category by seismic properties. The epicenter of the earthquake is 30-50 km and the frequency of the earthquake was M = 5.5 – 6.5 is 25 – 30 years. In these conditions in the sliding masses to act a horizontal inertial force K * W (with K = 0.12 – 0.2, W - weight)which has favored activation of landslide.

CONCLUSIONS

a) Based on the results of this integrated geophysical-engineering and geotechnical study result for Porava landslides:

1- There could not happened an immediate fall at any speed of the Porava slipping body.

2- Even in cases of powerful earthquakes, the slipping body mass can not fall as a whole, because it is made of broken up block masses. It can fall parts by parts or in fragments. Natural or inductive earthquakes of normal intensity, which happen often in this region, till now have not caused massive detachments of the slipping body.

b) After analysis of geophysical investigations in Ragami landslide, have been concluded:

1- Thick and high volume slipping bodies represent the Ragami active landslide in the shore area of the Vau Dejes Lake

2- The extent of the landslide and the position of sliding plains were precisely fixed using the integrated geophysical survey.

3-The block-like character of the sliding bodies brings to the conclusion that the block of these bodies can not fall down immediately in any kind of velocity.

4- In these zones it is necessary to construct buildings which resist large deformations, or the construction must be prohibited.

5- In the zones which the failure surface is 5 – 10 m depth, it can be used engineering measures as piles, anchored sheet piles, retaining walls, drainages etc, for the stabilization of the situation.

6- Combination of all methods (geological, geophysical, geotechnical) for monitoring, investigation and study of slope stability have big advantages for the future development of this zones and for the minimization of the risk and material damages.

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