SLOPE STABILITY EVALUATION AND MONITORNG USING PETROPHYSICAL DATA

1. Presentation of the problem:

Albania represents a mountainous country and Albanides are represented geological structures with possibilities of instable slopes and landslide development (Fig. 1).

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

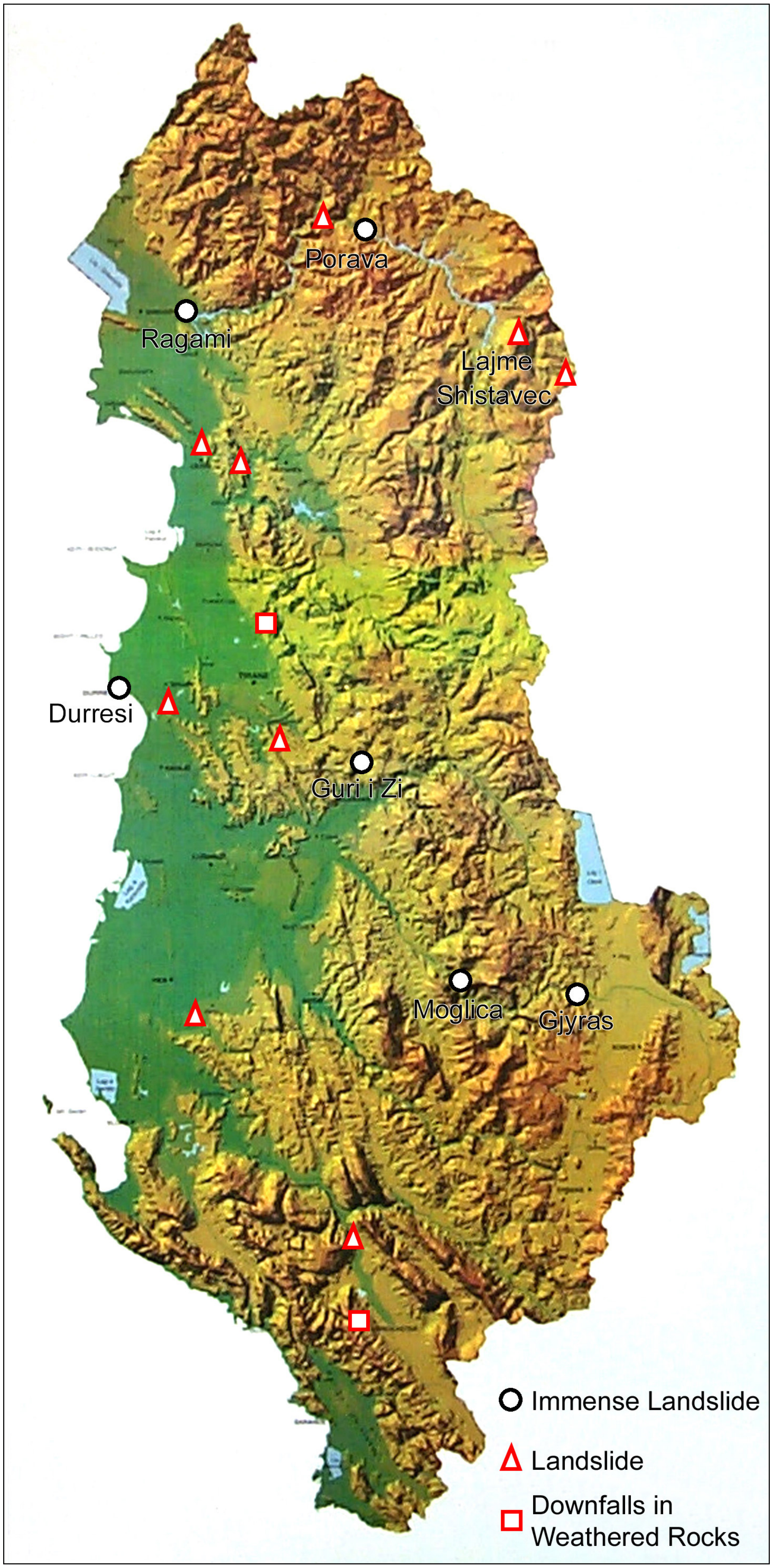
- Instable slopes and intensive landslides developed in weathered bedrocks and in overburden bed at the lakeshores of hydropower plants.
- Instable slopes and intensive landslides developed in Oligocene flysch formation.
- Instable slopes and landslides developed in Neogene's molasses formations.
- Landslides developed in loose Quaternary deposits.
- Downfalls in the weathered rocks

Developing of new landslides or re-activation of the old ones is mainly due to construction works. Special constructions, such as hydrotechnical works, civil, industrial, urban and rural constructions and constructions in the infrastructure, particularly during last years, as well as destroyed equilibrium in ecological systems through deforestation etc., all these events have contributed to landslide development. Landslides are located in the deluvial deposits, and in the altered-bedrocks. The slipping bodies of some landslides have very big volume, more 50 than million cubic meters. The biggest ones are observed near of hydrotechnical works.

1.1. 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.


Porava
Ragami
Lajme
Shistavec
Durresi
Guri i Zi
Moglica
Gjyras
Immense Landslide
Landslide
Downfalls in Weathered Rocks

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

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

Consequently, geophysical-engineering studies have a complexe 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
c) In-situ monitoring of landslide phenomena.

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 different sectors of the landslide area. Geophone setting in the survey line had distances from 1-50 meters, according to the object size and the required seismic depth investigation. The longitudinal and shear waves were recorded through the time intercept method. The hole-hole seismic tomography of longitudinal and shear waves can be included in the surveys program. The natural seismic-acoustic activity inside and outside of slipping body is necessary to observe. According to the surveys' data the velocity of P-waves (Vp) and S- waves (Vs) can be calculated, as well as the layer thickness. According to all the seismic data, the physical-mechanical properties must be calculated for the soil 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, with spacing up to AB/2 = 500 m, which allowed to reach a survey depth of 120-150 m. Resistivity profiling can be carrying out by multiple Schlumberger arrays with two-five investigation depths, relating to the required depth of investigation for each object. It is necessary evaluating of the anisotropy of geoelectrical section. Geoelectrical tomography to investigate the landslide area must be included in the investigation program. Resistivity Realsection of the geoelectric tomography can be performed by multiple spacing gradient arrays, with maximal spacing in dependence of the investigation depth.

Together with the geophysical methods mentioned above, the micro-magnetic and micro-gravity surveys are part of the integrated investigation of landslide areas. Micro magnetic mapping present important information for landslide activity prognostic.

The gamma-gamma density logging, neutron-gamma logging, electrical logging, acoustic logging and inclinometers can be applied for boreholes documentation.

Samples of soil and rocks from the studied area must analyzed in the laboratory for determination of their physical-mechanical properties and for further petrological studies of thin sections.

In Albania, the study of the shape and structure of the slipping body, estimation of physical-mechanical properties of the slipping body and of the bedrocks, and evaluation of the level of the landslide natural seismic-acoustic activity were carried out using the results based on the interpretation of geophysical surveys. Physical-mechanical properties of the rocks in the landslide area have documented their important role in relation to the slipping body mapping, study of slope stability and dynamics of the landslide's development.

1.2. Discussion and Analyses

There are analyzed some representative results from the investigation of slipping in Albania, which have been developed in different geological conditions. There are discussed the possibility of using geophysical studies to learn about the slipping phenomena and situation in the condition of the geomorphologic architecture of a mountainous country as Albania. The results of the geophysical data for in-situ evaluation of the physical-mechanical properties of the rocks in the unstable slopes is included in this analyze.

1.2.1. Landslide at the lakeshores of the hydropower plants.

Hydrotechnical works in Albania are generally constructed in conditions of rugged terrain and in geological formations in which the land sliding phenomena is often present. 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 hydrotechnical works.

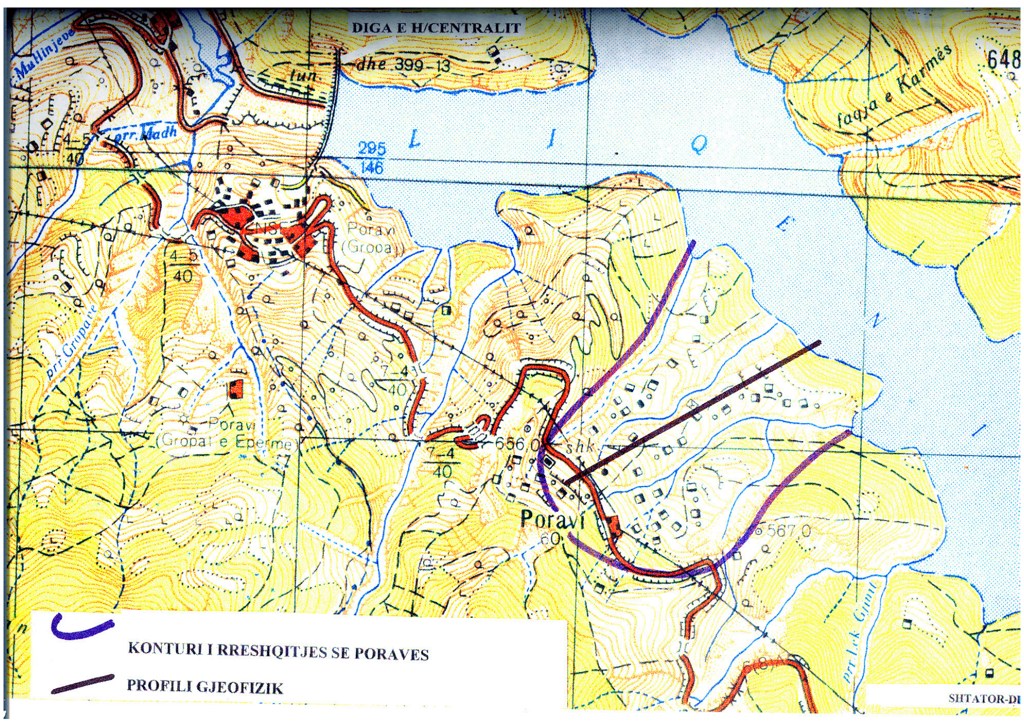
The exploitation period of more than 25 years of such a huge hydrotechnical work has influenced to the physical-mechanical properties at various parts of this landslide.

1.2.1.1. The Porava Landslide

A study conducted in the Fierza hydropower plant, constructed over the Drini River in Northern Albania, is a clear example of it. This hydropower plant was build 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 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 (Fig. 2, photo 1). Buildings have been destroyed in some villages and some people died in ruins. This phenomenon has been more evidently activated when hydrotechnical works started to be used. During the exploitation period of more than 25 years, the huge hydrotechnical works influenced the physical-mechanical properties in the shore area and caused a series of landslides. According to geological data, gathered during the design period, Porava landslide has a slipping mass of about 34 million m^3.

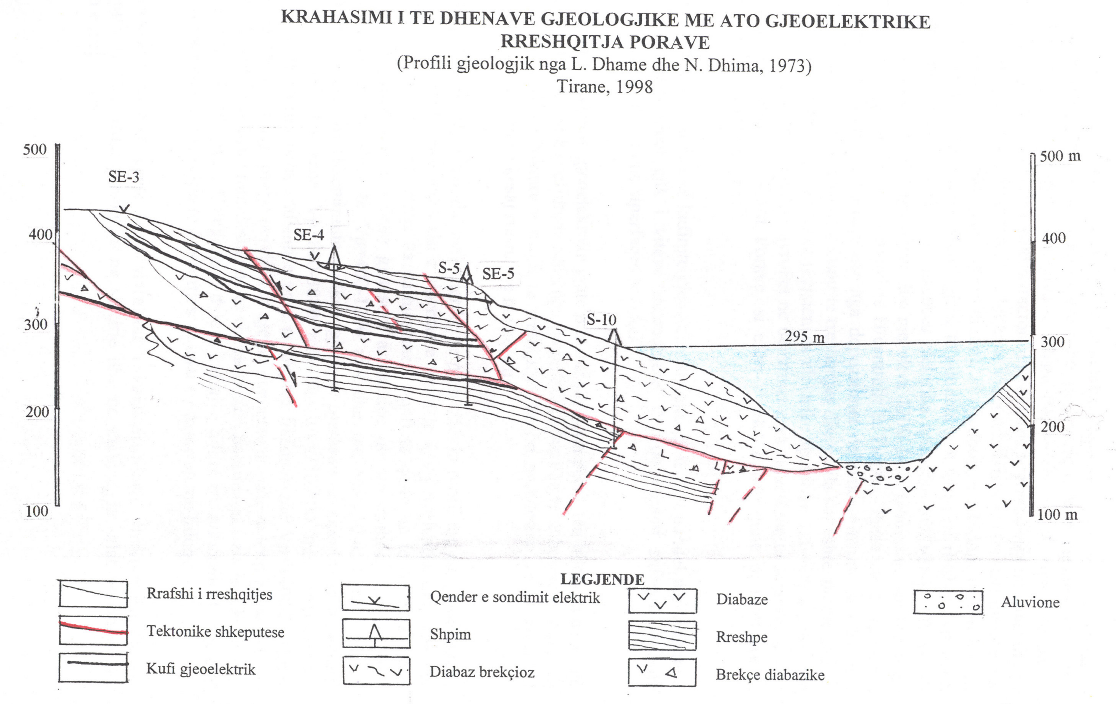
Special attention has been paid, since the projection period of this study, to the big slides in the shores of the Fierza Lake, especially to the Porava one (Fig. 3). The studies have not only included the geological understanding of the shore's solidity but also the understanding of the landslides. 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

Drini River Basin
Ragami and Porava Landslides location (Scale 1:300 000)

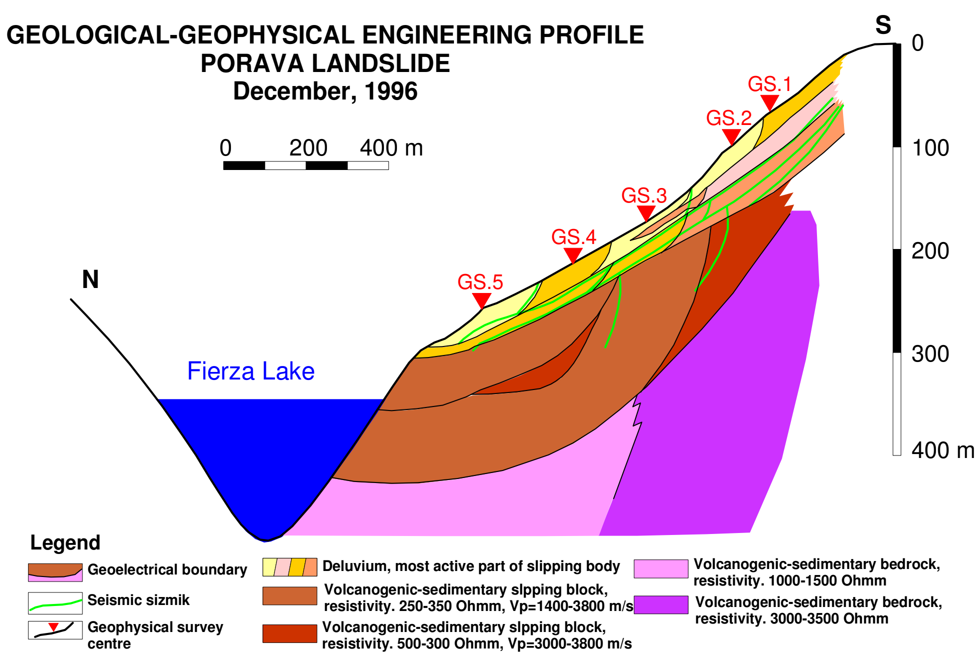


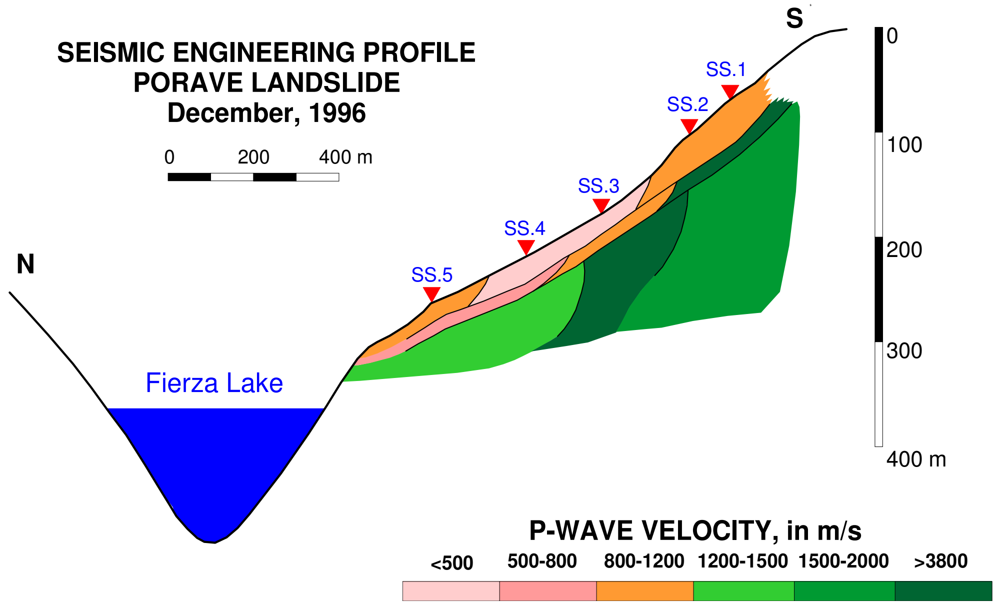
Porava Landslide area (Scale 1:25000)

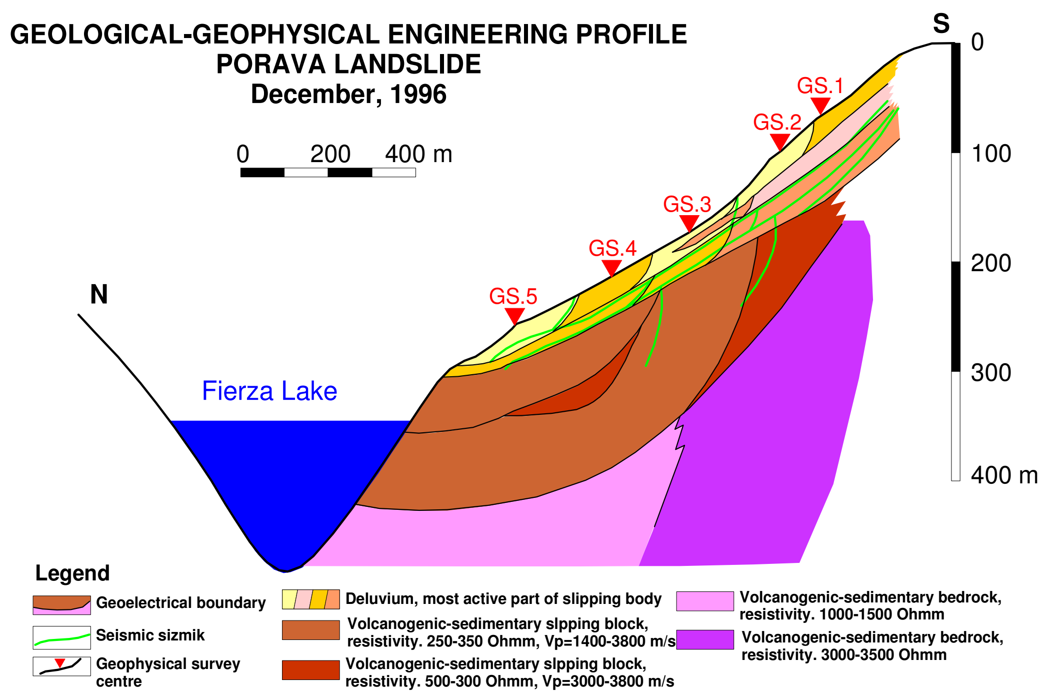
Cracks of the village houses walls



Geological (1074) and geoelectrical (1996) data comparison.




SEISMIC ENGINEERING PROFILE
PORAVE LANDSLIDE
December, 1996
0 200 400 m
N
S
SS.1
SS.2
SS.3
SS.4
SS.5
Fierza Lake
0
100
200
300
400 m
P-WAVE VELOCITY, in m/s
<500
500-800
800-1200
1200-1500
1500-2000
>3800


GEOLOGICAL-GEOPHYSICAL ENGINEERING PROFILE
PORAVA LANDSLIDE
December, 1996
0 200 400 m
N
S
GS.1
GS.2
GS.3
GS.4
GS.5
Fierza Lake
0
100
200
300
400 m
Legend
Geoelectrical boundary
Seismic sizmik
Geophysical survey centre
Deluvium, most active part of slipping body
Volcanogenic-sedimentary slpping block, resistivity. 250-350 Ohmm, Vp=1400-3800 m/s
Volcanogenic-sedimentary slpping block, resistivity. 500-300 Ohmm, Vp=3000-3800 m/s
Volcanogenic-sedimentary bedrock, resistivity. 1000-1500 Ohmm
Volcanogenic-sedimentary bedrock, resistivity. 3000-3500 Ohmm

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.

In Fig. 4 is presented the detailed geoelectrical - 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 geoelectrical 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). 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.

First of all, in these geoelectrical markers is expressed the full configuration of the sliding structure in the rocks of the volcanogenic sedimentary section. As a result of the slipping phenomena, these rocks have low, up to medium specific electric resistivity values (200 - 100 Ohmm). While the rocks located under the whole massive slipping body have higher specific electric resistivity values (in the furthest sector of the profile in the lake side 3000 - 3800 Ohmm and 1200 - 1400 Ohm in the sector located near the artificial lake of the Fierza hydropower plant).

The most upper part of this slide's body, represented by the deluvial-eluvial deposits, is very active today and has very law specific electric resistivity values (120 - 500 Ohmm). Houses and other objects of the Porava district are constantly damaged by this activity.

The apparent geoelectrical heterogeneity in the strike of the profile, expresses the block kind composition that has in general this slide and it also gives an envision of the development of this slide in time.

In fig. 5 is presented the seismic-engineering section in the same profile with the geoelectrical one. In this figure can be distinguished very well the upper part 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.

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 geoelectrical 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)(Photo 2, 3).

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. (Fig. 6).

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.

Based on the results of this integrated geophysical-engineering and geotechnical study result:

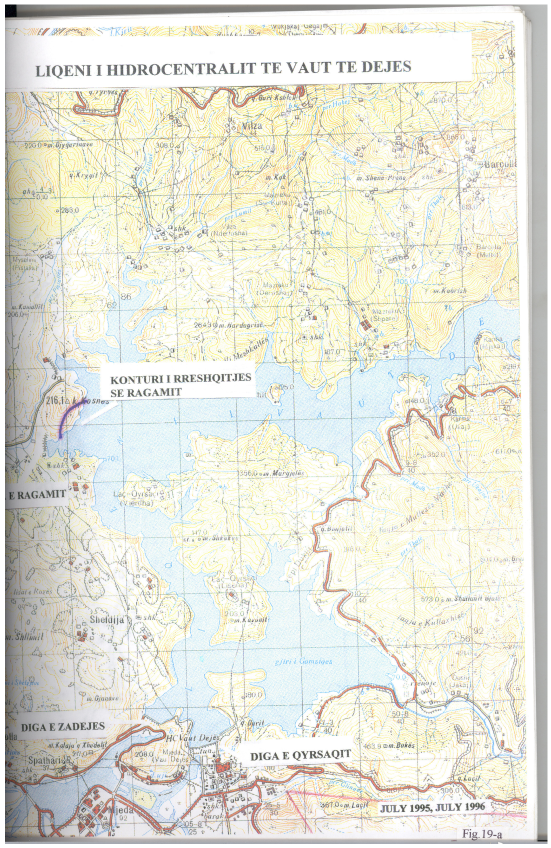
1. There could not happened an immediate fall at any speed of the Porava slipping body.

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.

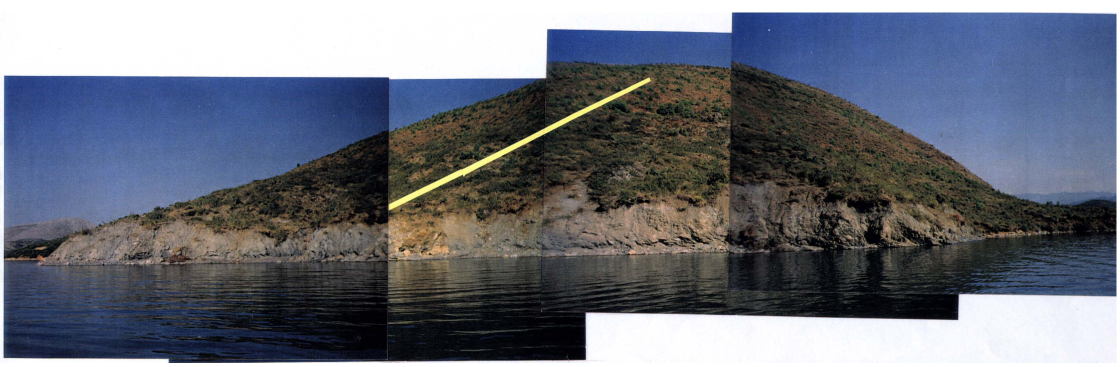
1.2.1.2. The Ragami Lanslide

The typical landslide was developed at lakeshore of the Vau Dejes Lake of Hydropower Plant in Northwestern Albania (Fig. 7). It is developed in the ophiolitic formation represented by serpentinized rocks. The slipping body represents a big mass of serpentinite, 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 (Fig. 8). 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 serpentinite, partly in a form of mylonite (Photo 4, 5).

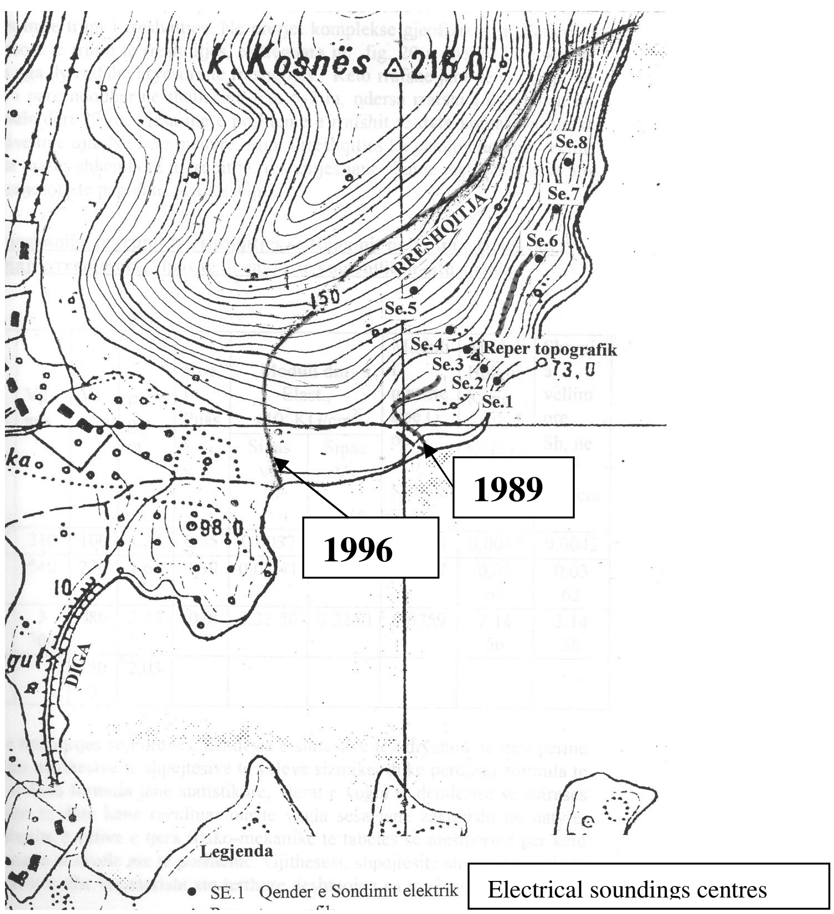
In fig. 9, 10 are given the integrated geophysical - engineering sections of the slipping body. Two main sliding plains separate this body. These plains are broken up. The first plain is at depths of 5 - 7 m, while the second one reaches up to 22 m. The lowest part of the second plain touches the lake, 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. 11).



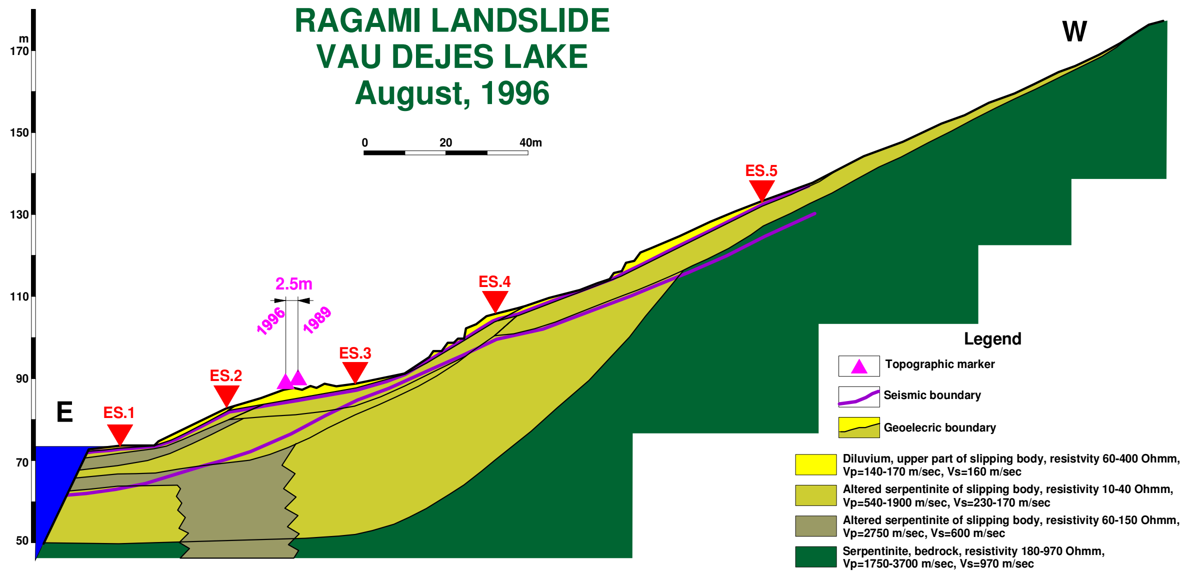
Vau Dejes area and Ragami Landslide



Ragami landslide body, mylonite serpentinites



Topographical sketch of Ragami Landslide area
1989; 1996- Landslide body contours, respectively .



Transversal profile

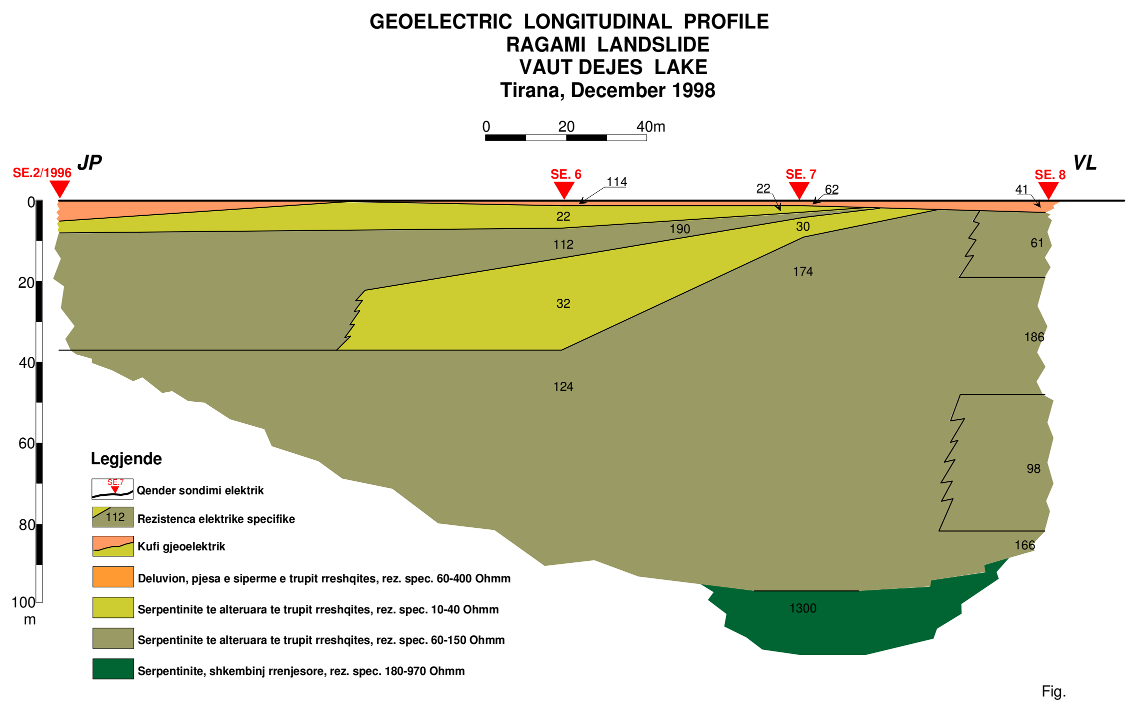


Fig. 7. Engineering integrated geophysical section of the Ragami landslide.

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 are presented in Tables 1 and 2.

Tab. 1

PHYSICAL PROPERTIES IN LANDSLIDE'S AREA

Layer Number	Thick-ness, in meters	Resistivity in Ohmm	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	Serpenti-nite

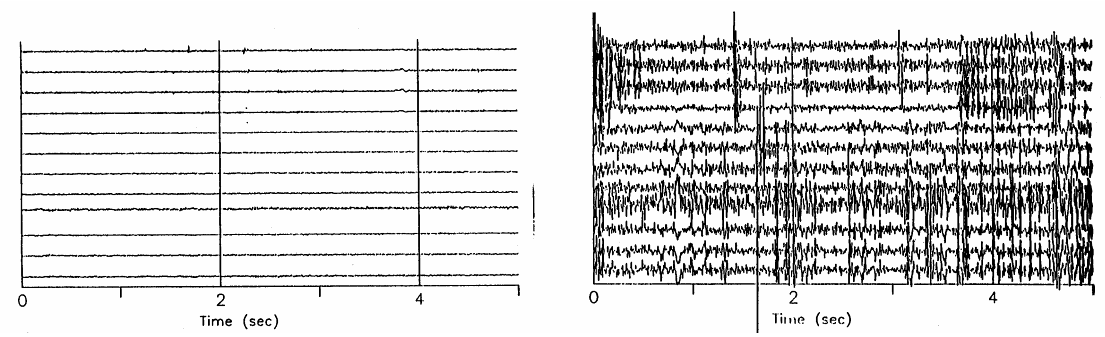
Tab. 2

. MECHANICAL PROPERTIES IN LANDSLIDE'S AREA

Layer Num-ber	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**
SLIPPING 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 serpentinite. 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 serpentinite.

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. No movement activity is observed outside the slipping body (Fig. 11).



Outside of slipping body Inside of slipping body

Fig. 8. Natural seismic-acoustic activity in the Ragami landslide area

After the analyze 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.

1.2.3. Landslide in the Oligocene flysch formation.

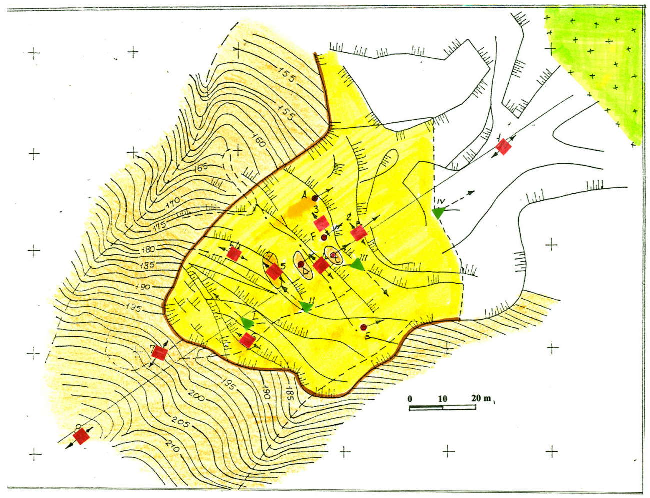
There are instable mountain and hill slopes, slipping of rocks masses, sometime of great sizes and catastrophic results. In some cases even villages or parts of villages were destructed, as Guri Zi in Elbasani region, Moglica in Devolli River region, Gjyras in Maliqi region etc., and without mentioning the blockage of auto-roads and railways.

1.2.3.1. The Banja Landslide

This slide was created when the derivation tunnel of the Banja hydropower plant was dug. It was developed during drilling in the flysch formations of Paleogene (Fig. 12, photo 6). The high content of thick sandstone layers, dipping according to the relief, is very characteristic for the flych section. This landslide completely ruined the derivation tunnel built till that time.

In fig. 13 is given the integrated geophysical - engineering section along the Banja slipping body. The maximum depth of the strike of the sliding mass is 22 m (in the center of the profile). The geoelectrical characteristics of the slipping body are very distinguishable from those of the flysch formation located outside the slide. The same thing is for the spreading velocity of seismic waves. The slipping body is very heterogeneous and is made of different blocks.

SKEME TOPOGRAFIKE E RRESHQITJES SE BANJES
Shkalla 1: 1 000



LEGJENDE
Konturi i trupit te rreshqitjes
Shkembinjte rrenjesore, flish
Reper gjeodezik
Qender e sondimit elektrik
Qender e vrojtimit sizmik
Dige

Sketch of Banja landside area

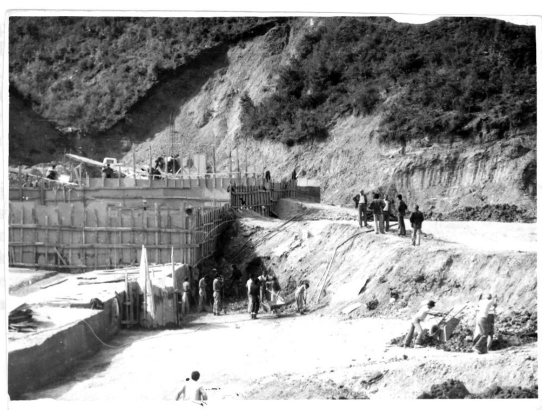
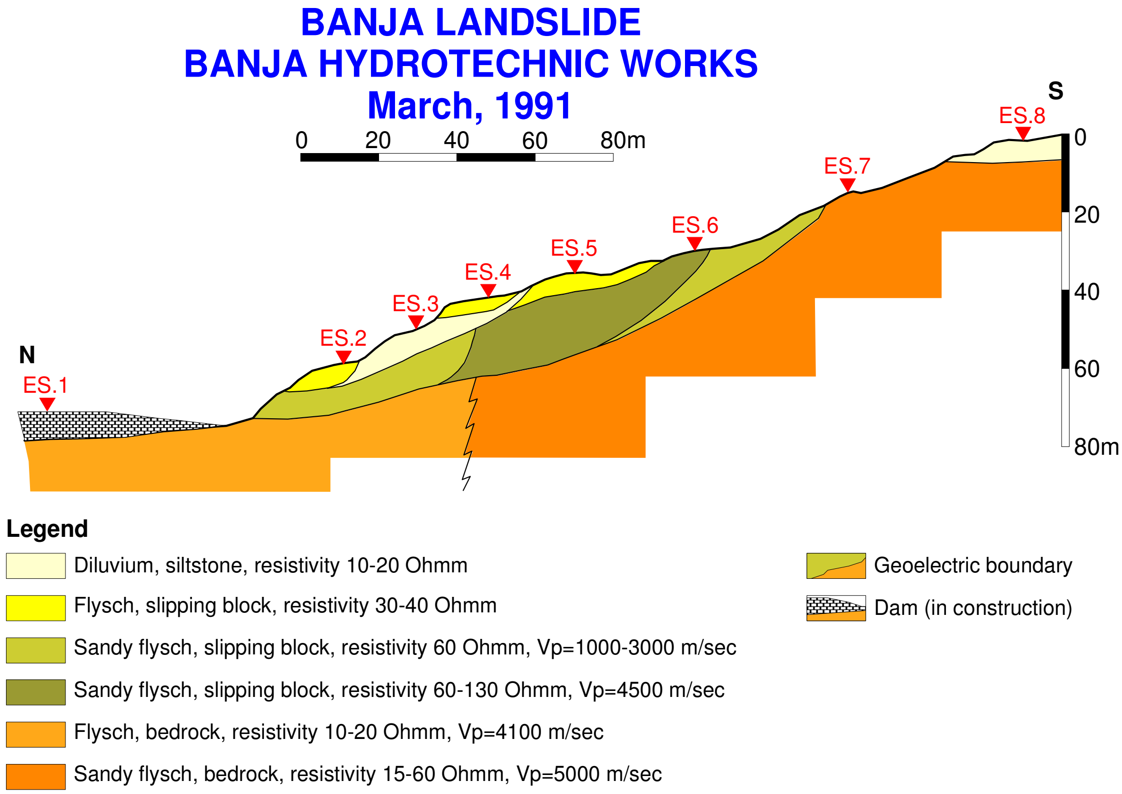


Foto 15. Pamje nga rreshqitja ne vepren hidroteknike te Banjes (Korrik 1987).

Banja Landslide area


BANJA LANDSLIDE
BANJA HYDROTECHNIC WORKS
March, 1991
0 20 40 60 80m
N
S
ES.1
ES.2
ES.3
ES.4
ES.5
ES.6
ES.7
ES.8
0
20
40
60
80m
Legend
Diluvium, siltstone, resistivity 10-20 Ohmm
Flysch, slipping block, resistivity 30-40 Ohmm
Sandy flysch, slipping block, resistivity 60 Ohmm, Vp=1000-3000 m/sec
Sandy flysch, slipping block, resistivity 60-130 Ohmm, Vp=4500 m/sec
Flysch, bedrock, resistivity 10-20 Ohmm, Vp=4100 m/sec
Sandy flysch, bedrock, resistivity 15-60 Ohmm, Vp=5000 m/sec
Geoelectric boundary
Dam (in construction)

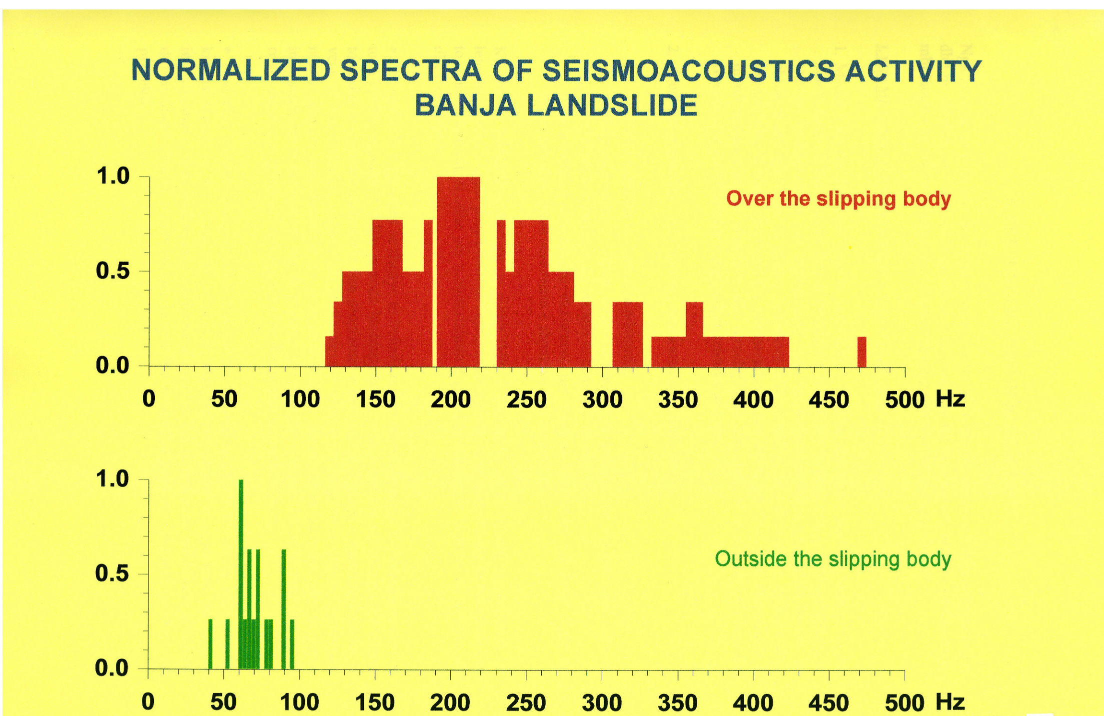
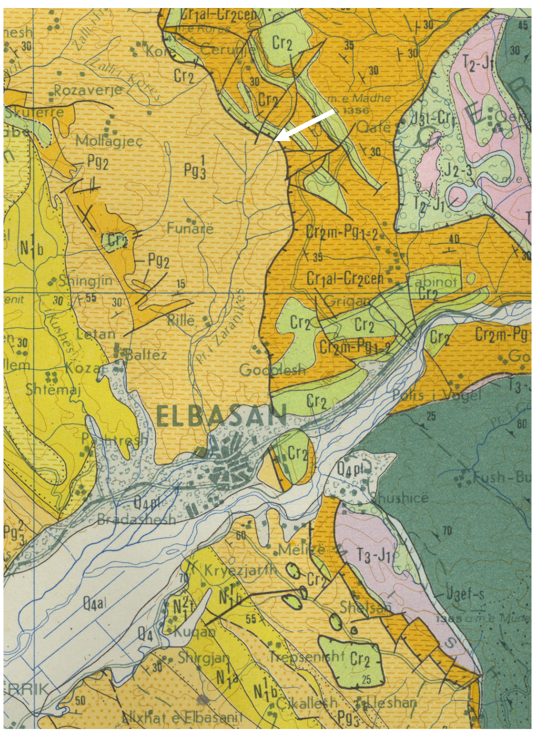

NORMALIZED SPECTRA OF SEISMOACOUSTICS ACTIVITY
BANJA LANDSLIDE
1.0
0.5
0.0
0 50 100 150 200 250 300 350 400 450 500 Hz
Over the slipping body
1.0
0.5
0.0
0 50 100 150 200 250 300 350 400 450 500 Hz
Outside the slipping body

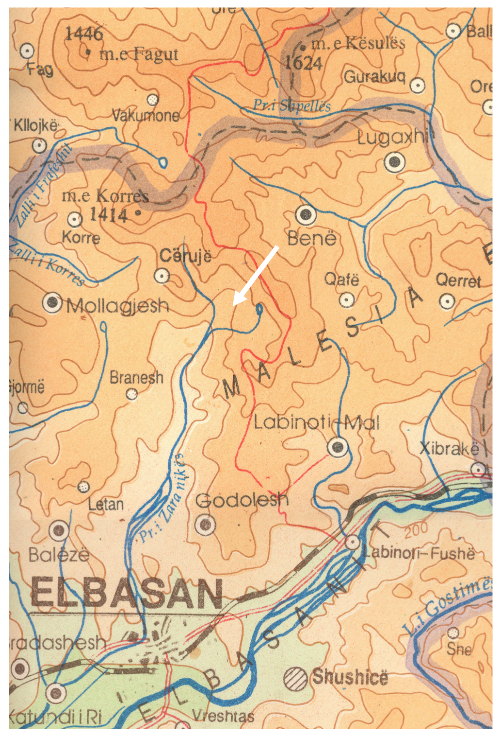
Fig. 15

This slide was characterized by a very intensive dynamic of the movement of the sliding body mass. For about one month, a sliding mass of 17 000 m^3 was displaced about 5 - 7 m, according to geodesic markers. This dynamic is also expressed in the natural sismoacustic activity. Inside the sliding body predominate higher frequencies than outside it (Fig. 14). The micro - movements have an amplitude many times higher.

1.2.3.2. Guri Zi village landslide

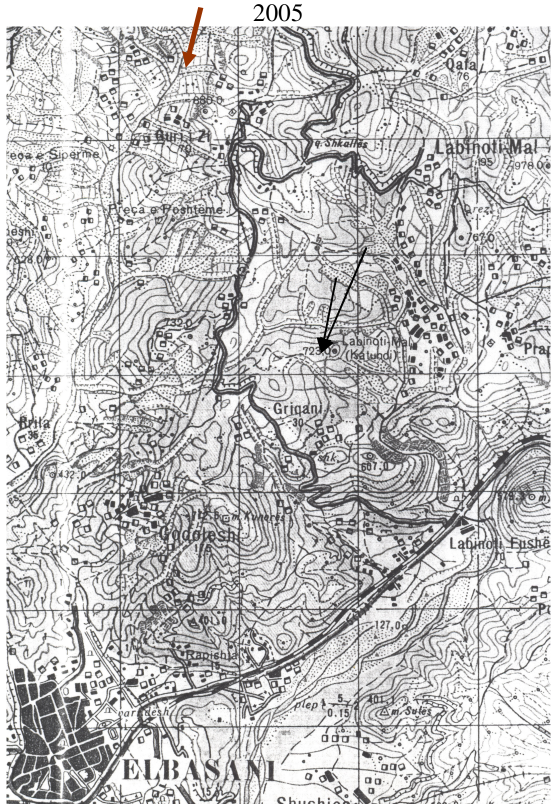
Guri Zi village is located about 12 km north-east of Elbasani city, at the upper stream of Zaranika River. Oligocene flysch formation is extended in this mountain area (Fig. 12, 16). At the Guri Zi village and its environment area is located intersection of the regional transversal fault Vlore-Elbasan-Diber and western thrust tectonic of the Krujas tectonik zone. This area represents a part of very seismically active Elbasani zone, with the earthquakes intensity 9 balls MSK-64. Geological setting, very intensive seismological activity in the past, hydrological regime of the mountain's streams, have created the unstable slops and landslide development, with gigantic sliding body (photo 7, 8).





GEOLOGCAL MAP OF ELBASANI AREA

TOPOGRAPHICAL MAP OF ELBASANI AREA
(Scanned after 1:300 000 scale)



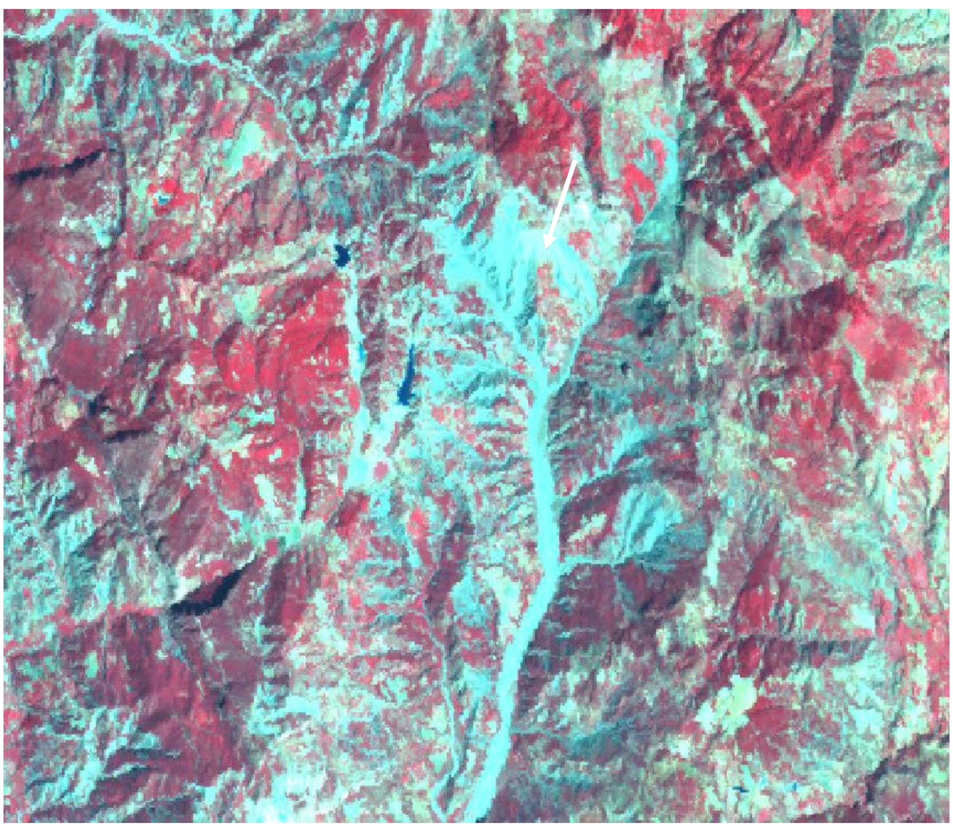
Topographical Map of Elbasani area (scanned after 1:100 000 scale)

Guri Zi Landslide area

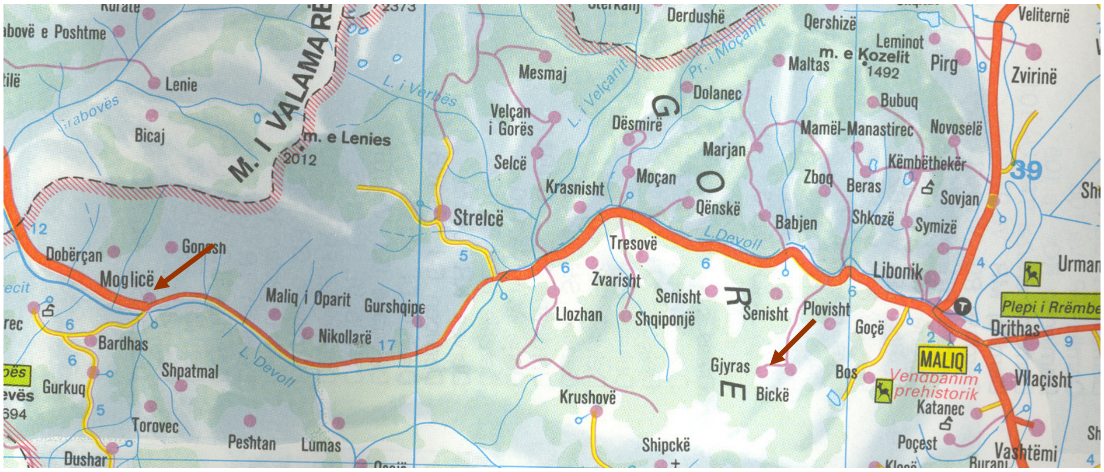
TM Image 1986 c AWAP

Processing by Ismail Hoxha, 2004

Guri Zi Landslide area



1.2.3.3. Moglica and Gjyrasi village landslides



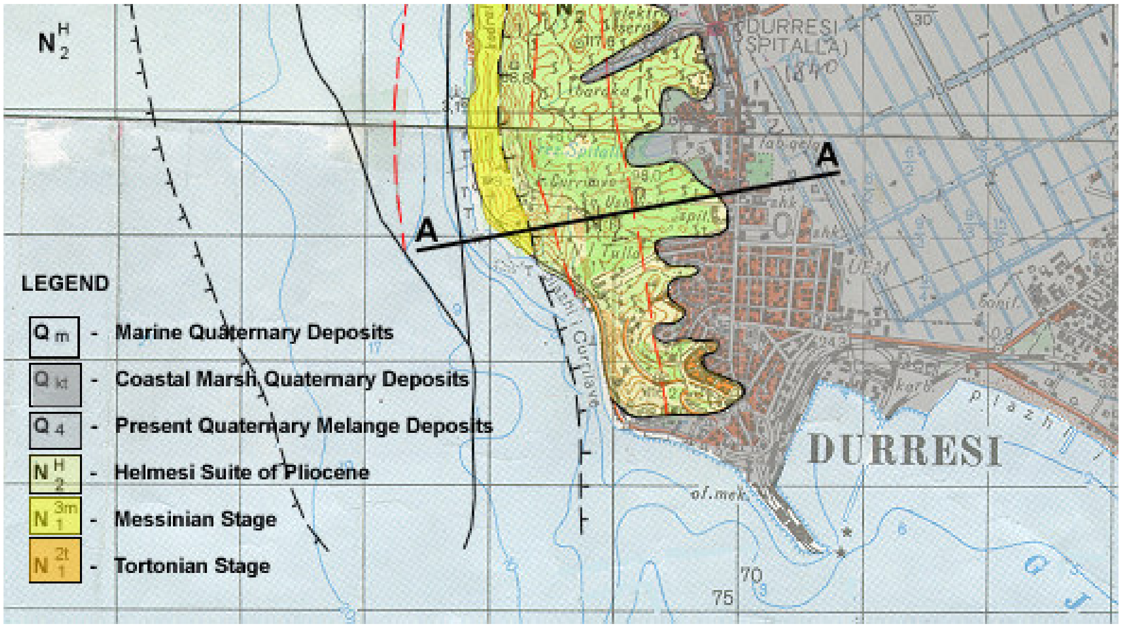
1.2.4. Landslide in the Neogene's molasses formations.

Landslides in the Neogene's molasses are located in several Albanian zones, with different sliding body mass.

1.2.4.1. Durresi landslide

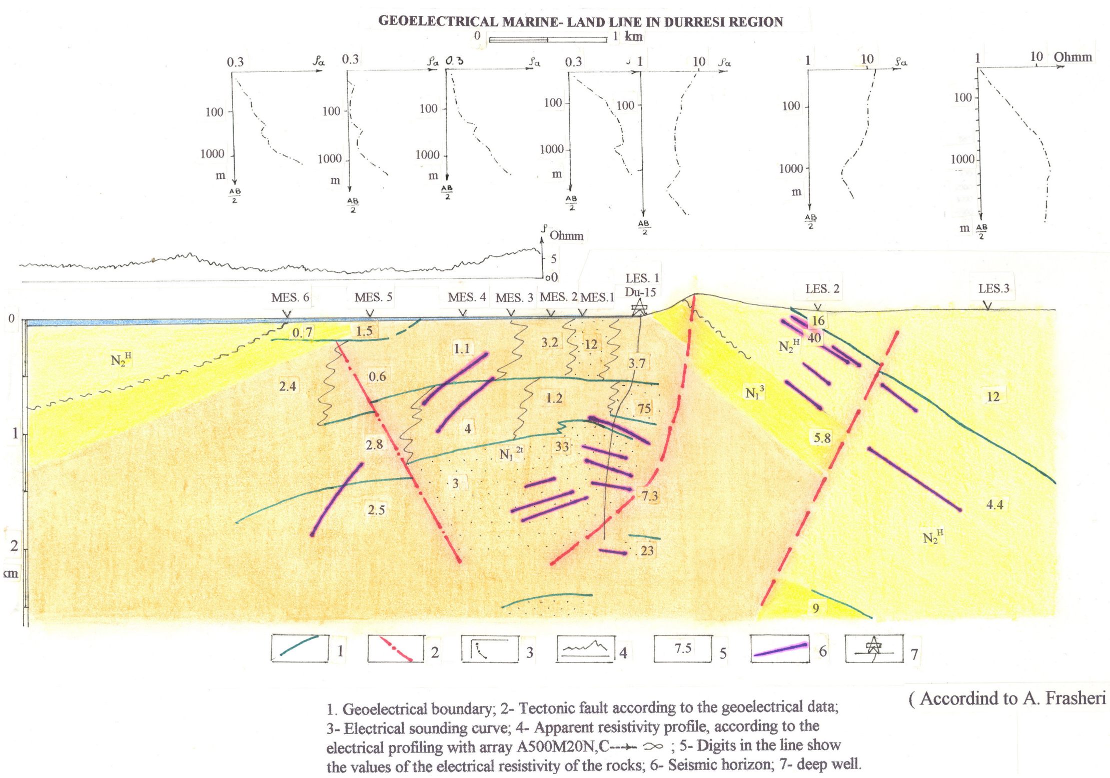
Durrësi city area is characterized by a presence of neogene molasses formation: (Frashëri A. 1987, Hyseni A., et al, 1976, 1986, Leci V. et al. 1986): sandstone-clay Tortonian deposits, clay, sandstone interbeds and lens, and gypsum debris and blocks Messinian deposits, and silty clay of. Pliocene Helmesi Suite (N_2^H). Durrës structure is asymmetric top part of the big anticline. Western anticline limb has a dipping about 20-30°. Eastern flank is tectonically abrupt and has a dipping 45-55°. Top Durresi anticline is located about 1600 m at the west of the coastal line. Part of Durresi city is located over the Neogene's molasses hills (Photo 9). The Pliocene clay slope at southern part of the Durresi hills is unstable. There the big landslide activity is observed (photo 10). Over this slope have been constructed many buildings. Actually, in several buildings have observed wide wall craks.

Durresi City and landslide location



Geological Map of Durresi area

Profile A-A



(Accordind to A. Frasheri)

(a) **(b)**

Wievs of Durresi Hill, Northern Slope (a), Southern Slope (b)

Landslide

Durresi Landslide

Subsidence of the villa wall, caused by landslide

Cracks in the villa walls and transversaly of the road

1.2.4.2. Krraba landslide

1.2.4.3. Landslide in irrigation reservoir at Vuno village.

Landslide in the irrigation reservoir in the Vuno village has been activated during the drawing, caused by mechanical suffusion from augmentation of the hydraulic gradient at the reservoir slopes.

Geological setting of the reservoir area is presented by overburden bed, composed by mylonite breccia in the allochtone tectonized belt of the Upper Jurassic carbonate layers and calcareous slate, which have been dislocated by gravity tectonics, over the terrigenous formation. Overburden deposits are classificated as coarse and granule sand with cohesion θ=0.1 kg/cm2 and fraction composition:

Fraction >2mm	30-28%
2-0.05 mm	24-39%
0.05-0.002 mm	15-21
<0.002 mm	0-12%

Unrounded clastic chert and limestone mater composes granule sand fractions.

Electrical soundings, located at two profiles over the landslide body, have carried out by Schlumberger array, with a current electrode maximal spacing AB/2=150m (fig. 1). At fig. 2 Is presented the geoelectrical profile. First geoelectrical layer represents sliding body, with a thickness 10m. Overburden deposits compose landslide body with a resistivity 50 Ohmm. Second layer is composed by plastic and soft clay deposits with lower resistivity (1.2-50)Ohmm, cohesion $\theta=0.12$ kg/cm^2, internal scouring angle 11^o, and thickness 4m. This layer represents slickenside. Lower geoelectrical layer has higher a resistivity (200-

750)Ohmm, which is represented by elluvial sand and argilloite, carbonate mylonite and tectonics breccia, and several limestone blocks with higher resistivity (2600-4500)Ohmm.

Borehole has very good verified electrical soundings interpretation. Electrical well logging, by a B0.1A0.95M has very detailed selected all layers. After laboratory analysis of the samples has been observed that landslide body deposits and bedrocks have different physical-mechanical properties: respectively volume weight 1.71 g/cm^3 and (1.83-1.95)g/cm^3, porosity 57.3% and (34.7-46.4)%, natural rock moisture 33.4% and (28.3-29.8)%.

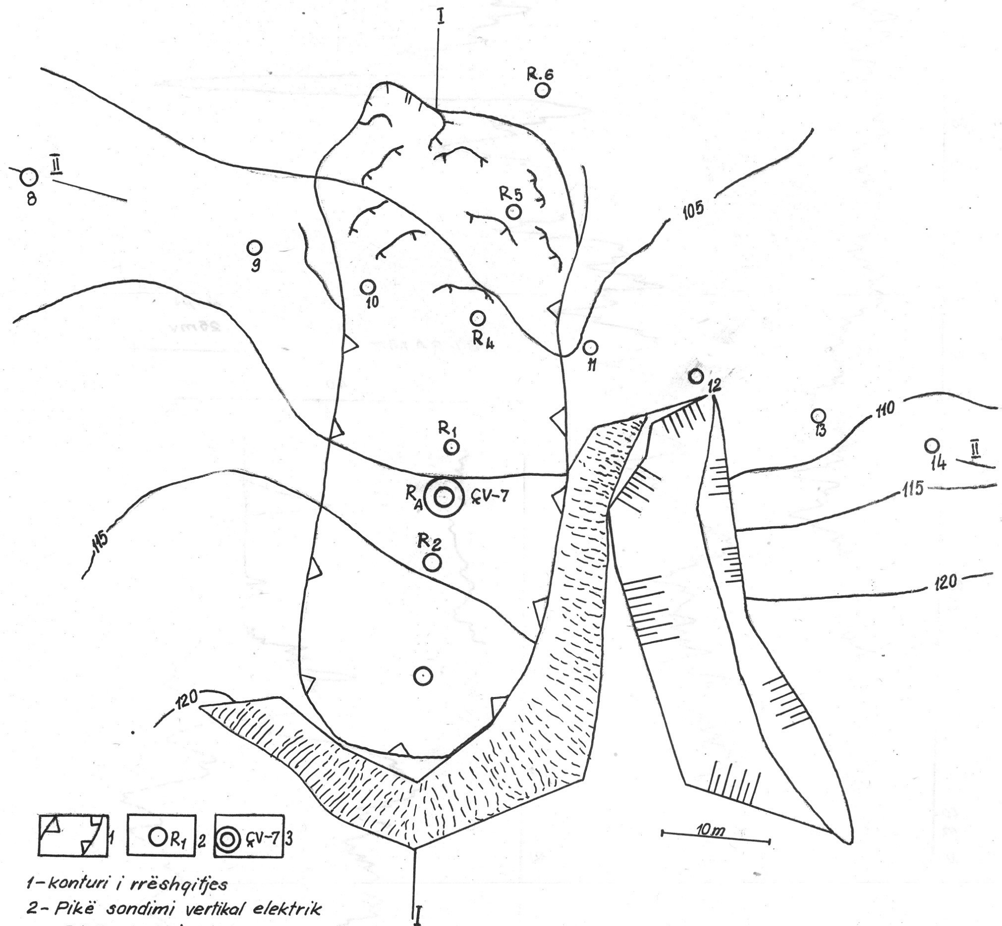


Fig. 1. Vuno landslide topographic sketch

1- Landslide contour
2- Eletcrical sounding centre
3- Borehole

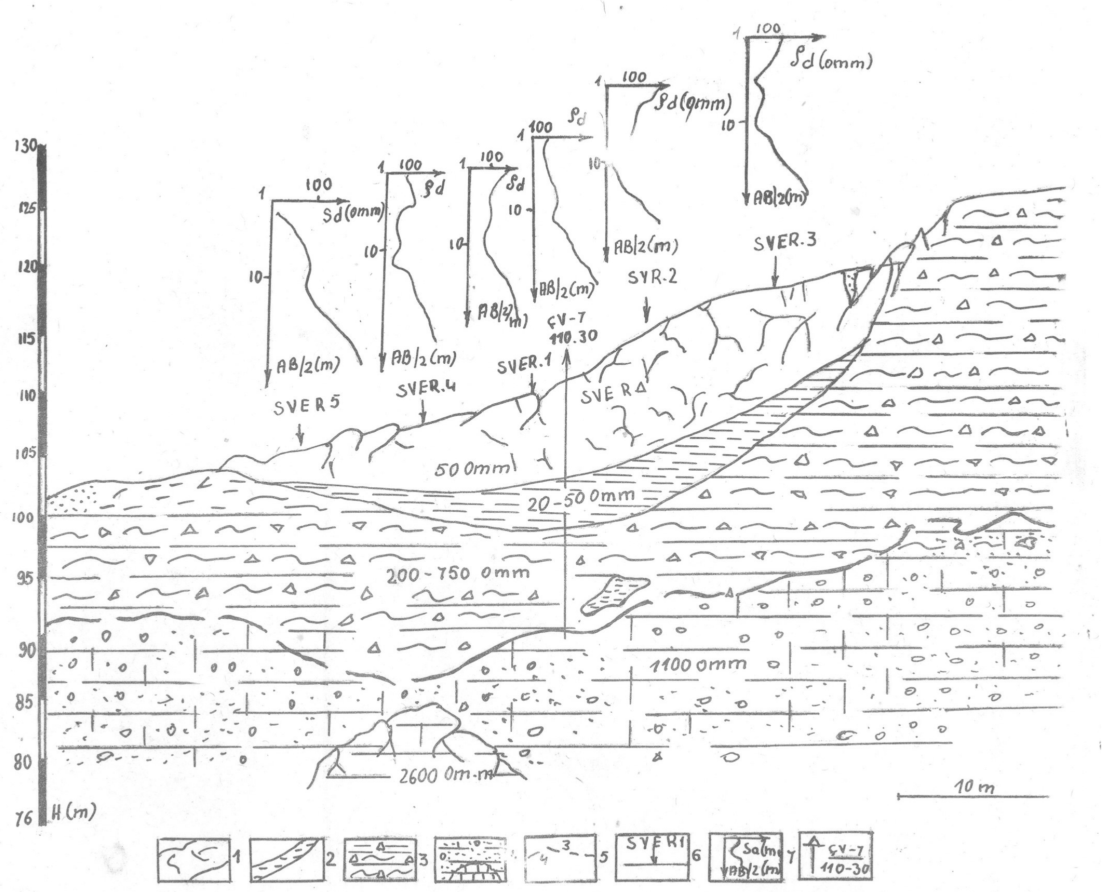


Fig. 2. Geoelectrical section, Vuno landslide

1- Sliding body; 2- Slickenside bed; 3- Overburden bed; 4- Mylonite and tectonized breccia of thin layered limestone; 5- Lithological boundary; 6- Electrical sounding centre; 7- Apparent resistivity curve of electrical soundings; 8-Borehole.

1.2.5. Downfalls in the weathered rocks

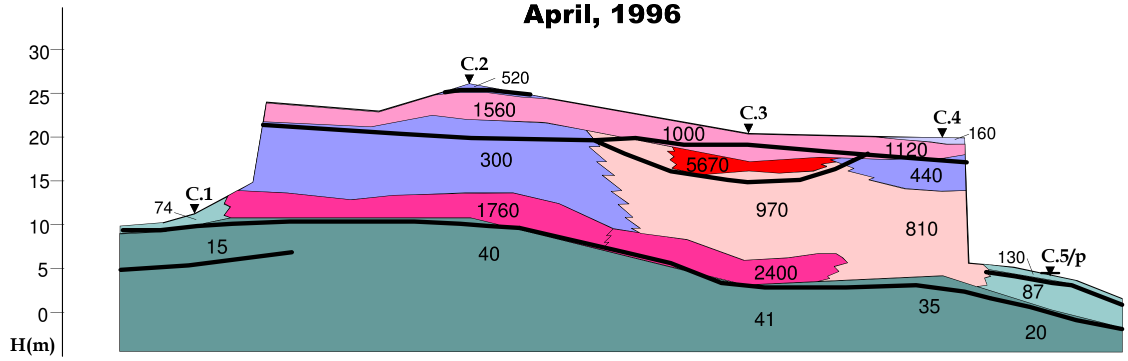
1.2.5.1. Kruja Castle

The Castle of Kruja is the symbol of the culture and Albanian history. This castle is related with the most glorious epoch of the Albanian National Hero Skanderbeg (Photo.11).

Kruja Castel

Downfalls in the Kruja hill

GEOPHYSICAL ENGINEERING SECTION
KRUJA CASTLE AREA
April, 1996



Legend

C.1 Geophysical-engineering survey centre

Seismic boundary

Seismic micronoise

970 Resistivity, in Ohmm

Fig. 2

Many excavations have been conducted up to present, aiming at bringing out the interior part of the Castle and the clock tower. The surrounding walls have been completed with a museum structure as the Museum of the National Hero, where every visitor gets acquainted with one of the most remarkable moments of the Albanian history. In 1995, the Castle, which was considered relatively safe, was “shaken up” under the Gjergj Kastrioti Skenderbeg Museum. The downfall occurred after a period of heavy rainfall, characterized by heavy showers and a rapid decrease of temperature. The overnight downfall of the large detached masses of about hundreds of cubic meters was unexpected. Now the ground has started to deteriorate and at the sides of the castle, in some places is developing a process of collapse. This is a well known phenomena for this Castle. The deterioration has also continued during 1996-1997 though the detached rocks have been smaller in size.

Geophysical surveys have been carried out for ground investigation. The results of the surveys are presented on the geoelectrical-geotechnical section (Fig.18). It can be seen on the section that the rock massive, where the Castle was constructed, is composed of breccia-conglomerate formation. The breccia-conglomerate formation onlaped on the Oligocenic flysch section. The upper part of the flysch section around the Castle is covered by deluvium, 1÷4 m thick. Under the deluvium lays the weathered layer. The breccia-conglomerate massive, where the castle was constructed, consists in 3-4 main layers, which, in extension have different thickness and are heterogeneous. The layer that attracts the attention more is the third geoelectrical layer, which is located at a depth of 3-24 m. Its resistivity varies between 300-900 Ohmm, which is significantly less than those lying over and under that. This layer, generally is characterized also by smaller velocities of longitudinal and transversal seismic waves, which vary between V_{pl} = 500-1800 m/sec and Vs_1 = 400-830 m/sec, meanwhile the layers lying under it have a velocity of the range 2300-

3100 m/sec and 870-1050 m/sec respectively. The dynamic module of elasticity of the first seismic layer varies between the limits 390-1400 kg/cm^2, which apparently has a very low value. The statistical analysis of the samples of the volumetric mass resulted in a large distribution of this property. The minimum values vary from 2,12 g/cm^3 to a maximum of 2,45 g/cm^3. These indexes underline the fact that in the surveyed centers we are in the presence of a breccia-conglomerate layer heavily destroyed, containing a large quantity of saturated clay, though in a very weak state.

The observation of the natural seismic micro noises has shown that the breccia conglomerate rock massive has a noise level 2-8 folds higher than in the flysch profile touching along side this massive (Fig. 19). This shows that the systematic destruction of the massive is in a continuous process. Inside the rock massive, the seismic micro noises increase towards its outskirts.

4. Conclusions

Based on the above analyses can be reached the following conclusions:

1. In the profiles, where integrated geophysical surveys have been conducted, were fixed the bodies of the studied landslides. In these profiles were also clearly fixed the sliding plains. In general, even though the geological conditions in which these slides have been developed are different, the plains have regular configuration, with maximum deepness in the center of the profile.

2. The slipping body, very often, is made of several slipping plains of block like character. Especially active today, are the slipping plains located 15 - 20 m deep. The slipping body over this plain is mainly made of deluvial - eluvial sediments, or rocky masses with very weak physical - mechanical characteristics. Their dynamic is causing more damages every day to the houses of the Porava village.

3. The Porava landslide is the biggest slide studied till now. The lower plane of this landslide is located about 100 - 160 m deep. It separates the volcanogenic-sedimentary rocks with very low petrophysical characteristics from the volcanogenic-sedimentary deposits untouched by the sliding phenomena. The total volume of the whole sliding body, from some approximate calculation based on these preliminary geophysical data, is estimated to be over 40 million m^3.

4. The Porava slipping body is heterogeneous and composed of blocks.

5. The block like nature of the sliding bodies brings to the conclusion that in general these bodies can not fall immediately as a whole, in any kind of velocity. Only in particular cases, like in Banja, the fall occurs immediately.

6. The structure of the slipping body and its dynamic stands in the foundation of the patterning on the landslide development. Besides the others, the height of the dam is directly defined from this pattern. Accepting the slipping body as a unique mass, has sent to the over heightening of the dam and greater expenses.

7. Thick and high volume slipping bodies represent the Ragami active landslide in the shore area of the Vau Dejes Lake.
8. The extent of the landslide and the position of sliding plains were precisely fixed using the integrated geophysical survey.
9. 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. Geophysical-engineering studies have a triple character: a) to study the soil of the landslide area, b) evaluation of in-situ physical-mechanical properties of soils and rocks and c) in-situ monitoring of landslide phenomena.

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