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SLOPE STABILITY AND LANDSLIDE INVESTIGATION AND MONITORING USING GEOPHYSICAL DATA

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1. Introduction

Albania represents a mountainus country and Albanides are represented geological structures with possibilities of instable slopes and landslide development.

Based on the geological formations and landslide body mass, can be present following landslide classification in Albania (Fig. 1.1):

- 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. Slope mass movements (landslides, debris flow, rock falls, rock slides, etc.) have become a big issue in recent years, especially after several casualties. Special constructions, such as hydrotechnical works, civil, industrial, urban and rural constructions and constructions in the infrastructure, particularly during last year's, 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,

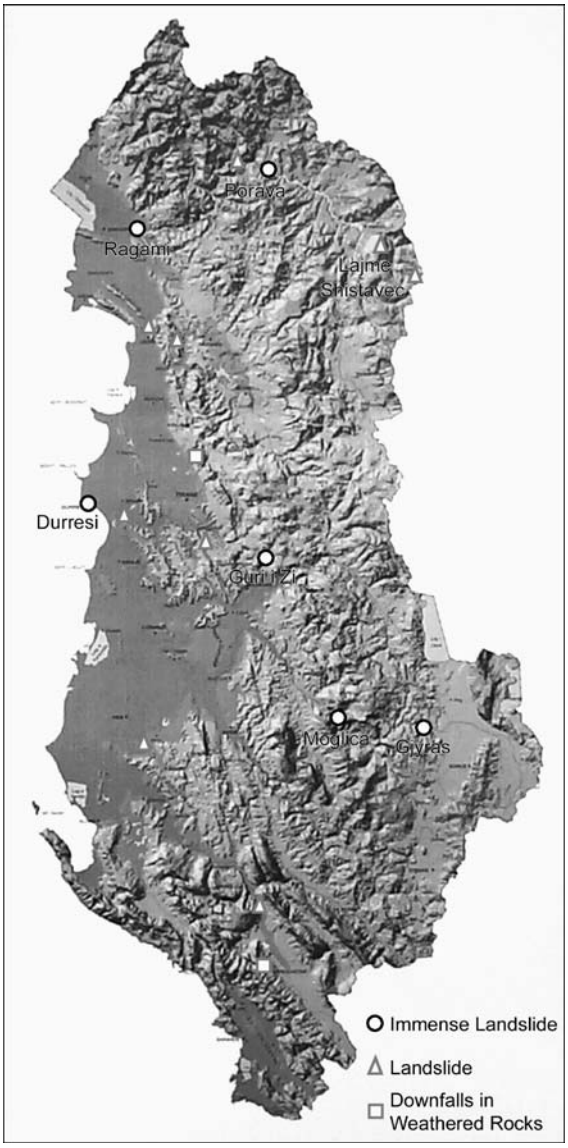


Fig.1.1. Landslides and rock downfalls in Albania.

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. Actually the landslides are present even in some dams of the reservoirs used for irrigation. This phenomenon is risking even some historical objects of national importance such as the Medieval Castles of Kruja, Gjirokastra, Rozafa in Shkodra, and that of Lezha. The activation of the landslide is stimulated from the big activity of the earthquakes in Albania.

Slope stability and landslides has been an object of the geological-engineering studies in Albania. During the last twenty years, the landslides have been investigated using integrated geological, geophysical engineering and geodetic methods.

Control and monitoring study of stability of slopes and landslides that are presented in this lecture has been prepared on the basis of the third chapter of the book "Engineering and Environmental Geophysics", a publication of the Academy of Sciences and the Faculty of Geology and Mining, Tirana, 2005, of the author Alfred Frashëri, (ISBN 99943-763-5-7), on the monograph: 'Slope Stability Evaluation and Investigation and Monitoring landslide using geophysical data " of the authors Bushati, S, Frashëri, A., A., Nishani, P., Silo , V., Pambuku, A., Dema Sh., Komac M., Bavec M., Jemec M., Kumelj Sh., a publication of the Academy of Sciences, Tirana, 2008, (ISBN: 978-99956-10-14-7), as well as Open Lecture "*Investigation and monitoring of the slope stability and huge landslides in Albania using geophysical method*, *of Prof. Dr.* Frashëri A., Faculty of Geology and Minig, and Faculty of Construction Engineering, Polytechnic University of TiranaUniversiteti Politeknik i Tiranës, 2010..

This lecture has also reflected the new achievements of research and monitoring of slopes and landslides over the past five years, as the problem of occurrence of intense slides across the territory of Albania in the winter of 2010.
The author will consider that his duty is done if this lecture will give its contribution towards the multidisciplinary integrated study of slope stability and landslides invetigation, as well as monitoring the dynamic development of the landslis by application of modern methods and technologies by the specialized Institutions, to avoid human losses and minimize material losses. But above all it is necessary to state legislators and central and local administration should prepare the relevant legislation and require the strict enforcement of laws to remedy the human impact of causing deterioration in the stability of slopes and development of landslides. It is the pressing problem of the day to take the appropriate measures to monitor known landslides to minimize damage and avoid catastrophes.

The lecture will serve the students of engineering faculties, who in their profession related to the landslide's phenomenon.

- Integrated and multidisciplinary study methodic for slope stability evaluation, and landslide investigation - monitoring
- Slope stability evaluation and landslide investigation and monitoring using geophysical data in Albania
- Bibliography

2. INTEGRATED AND MULTIDISCIPLINARY STUDY METHODIC FOR SLOPE STABILITY EVALUATION, LANDSLIDE'S INVESTIGATION, AND MONITORING

2.1. Integrated geological-geophysical-geodetical in-situ investigation for landslide prognosis, study and monitoring in Albania.

Slope stability evaluation and the investigation and monitoring of landslides represent a multidisciplinary investigation, which should be performed by in situ integrated multidisciplinary geophysical-geological-geodesic-geotechnical-remote sensing and borehole logging technologies :

- Geological Mapping
- Geomorphological Mapping
- Hydrogeological Mapping
- Engineering Geological Mapping
- Remote sensing surveys
- 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.
- Mthematical-physical-geological modeling of the landslide;
- Statistical analysis of the acquired information and to determine the deformation processes through systematic measurements in order to forecast hazardous geodynamic processes.

These methods enable collecting accurate data and sufficient information for implementing constructive projects in order to avoid the risk of the nature related to the land sliding phenomenon (Aliaj Sh. et al. 2010, Anon: 1995, Bogoslovsky V.A. et al. 1977,Camberfort H., 1972, Dziewanski J. et al., 1981, Bushati S. et al. 2008, Frashëri A., 2005, 2010, Konomi N. etj. 1988, Prem V. Sharma, 1997, Telford W.M. et al. 1990,).

Integrated geological-geophysical-engineering studies have a complex character:

a) To study the landslide body structure and soil of the landslide area,
b) Spatial analyse of landslide driven factors, landslide susceptibility model development.
c) Evaluation of in-situ physical-mechanical properties of soils and rocks,
d) In-situ monitoring of landslide phenomena dynamics
e) Determination of the near Earth surface and deep geological-geophysical factors that controlled creation, activation and dynamics of ecosystem's destruction.
f) Evaluation of the anthropogen impact for activation of the slope systems destruction and their dynamics.
g) Slope stability, landlides and downfalls classification in region and country, according to the area geological setting and geological hazard.
h) Presentation of the technical-engineering measures recommendations for avoid or reduction of the negative environmental effects from the land-sliding phenomenon.
i) Prognosing of the slope instability and landslide development in the future,
j) Organization a geophysical, geological, geodetic, Geographic Information Systems (GIS) and other information's database, for landslide sites on the country territory.

Consequently, geophysical-engineering studies with their complex character are able:

1) To study the landslide body structure and soil of the landslide's area,

2) To in-situ evaluate physical-mechanical properties, and mineralogical stydy of soils and rocks, and
3) In-situ monitoring of the landslide phenomena development dynamics.
4) To prognoses slope instability and landslide development possibility in the future,

In-situ intergrated investigations and monitoring is necessary programmed to perform in three phases:

1. Surface integrated geological-geophysical maping, geodesic and remote sensing surveys, and installation of geophysics and geodesic markers.
2. Drilling of shallow boreholes, cross-hole seismic survey, well logging and sampling.
3. Monitoring through periodical geophysical surveys and geodesic observations in boreholes, and remote sensing surveys on the ground surface, and soil and rocks mass movement dynamics.

2.2. Geophysical investigations

In the geophysical methods complex can be included application (Bushati S. et al. 2008, Frashëri A. 2005, 2010, Frashëri A, et al. 1999, 2000):

- Seismic tomography and 2D and 3D shallow refracted and reflected multiple covering survey;
- Recording of the seismic-acoustic activity;
- Setting the accelerometer network in one of the biggest landslides;
- Geoelectrical tomography, vertical electrical sounding and profiling;
- Well-logging in boreholes;
- Magnetic micro survey;
- Gravity micro survey;

Seismic syrveys: 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 landslide's area sectors. The longitudinal and shear waves were recorded through the time intercept method. The hole-hole time-lapse 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 the layer thickness, as well as the physical-mechanical properties must be esstimated for soils and rocks: Poisson ratio, elasticity dynamic modulus, Bulk modulus, rigidity modulus and compression volumetric strength modulus (Bruno F. et al. 1998, Frashëri A. 2005, 2010, Pyrak Nolte et al. 1998, Rykounov L.N. et al. 1983, Williams R.A. et al. 1996).

Puasson Ratio:

$$\nu = \frac{V_p^2 - 2V_s^2}{2\left(V_p^2 - V_s^p\right)}$$

Dynamic Elasticity Modulus:

$$E_1 = \rho \cdot V_p^2 \frac{(1+\nu)\cdot(1-2\nu)}{1-\nu} \cdot \frac{1}{10} \qquad \text{in } \left(\frac{N}{cm^2}\right)$$

$$E_2 = \frac{1}{9.81} \cdot E_1 \qquad \text{in } \left(\frac{KG}{cm^2}\right)$$

where: ρ - Density, in (g/cm^3)

V_p, V_s – The longitudinal and shear waves velocity, respectively, in (m/sek)

Static Elasticity Modulus: in cases for $E \geq 2.5 \cdot 10^5 \ \frac{KG}{cm^2}$:

$$E_s = \frac{E_2 - 0.97 \cdot 10^5}{0.83}$$

Bulk Modulus:

$$K = \frac{E_2}{3(1-2\nu)} \cdot 10^5 \qquad \text{në} \left(\frac{KG}{cm^2}\right)$$

Rigidity Modulus,.

$$G = \frac{E_2}{2(1+\nu)} \cdot 10^5 \qquad \text{në} \left(\frac{KG}{cm^2}\right)$$

Volumetric compression strength modulus:

$$\sigma = \rho \cdot \left(V_p^2 - \frac{4}{3}V_s^2\right) \cdot \frac{10^{-6}}{9.81} \cdot 10^5 \qquad \text{në} \left(\frac{KG}{cm^2}\right)$$

Geoelectrical surveys: 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 time lapse tomography to investigate the landslide area and monitoring of the landslide developing dynamics should 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 (Dahlin T. et al.. 1997, Li Y. et al. 1992, Loke M.H. et al. 1996, Frashëri A. 2005, 2010, Ogilvy R.D., et al. 2009, Wilkinson J.Ch., et al. 2011,).

According to statistical dependencies can be evaluate the physical-mechanical properties of the soils and rocks, according to their electrical resistivity values.

Elasticity Static Modulus: ex. for diabase:

$$E = \left(38{,}6 \cdot \rho + 4{,}7 \cdot 10^4\right) \cdot 10^5 \quad \frac{N}{m^2}$$

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.

h) Well logging:. The gamma-gamma density logging, neutron-gamma logging, electrical logging, acoustic logging and inclinometers can be applied for boreholes documentation. Different well logging methods are able to present high accuracy information about rock lithology, thickness of the layers and physical-mechanical propoerties of the rocks:

Rock's porosity: after electrical resistivity of the rocks, ex. for the sandstones:

$$P = 0.85 * K_p^{-1.7}$$

where: P – porozitety parameter:

$$P = \frac{\rho_{shu}}{\rho_u}$$

Where: ρ_{shu}, ρ_u - eletric specific resistivity of the rock that is 100% satured with water, and water resistivity, respectively.

Rock's permeability:

$$K_{pr} = \frac{1}{P} \cdot \frac{K_p^2}{(1-K_p)^2} \cdot \frac{10^3}{K_{uo}^2}$$

where: P- porosity parameteri,

K_{uo}- remanant water saturation coefficient.

Porosity coefficient: according to the sonic logging data, ex. for the sandstones:

$$K_p=0.175*\Delta t - 31.6$$

Where: Δt- difference of arrival times of the sonic vavew from source to two receivers in the well logging sonde.

or according to the neutron-gamma well logging data:

$$\log K_p = \log K_{p1} - \frac{I_{n\gamma}^1 - I_{n\gamma}}{I_{n\lambda}^2 - I_{n\gamma}} \cdot \left(\log K_{p1} - \log K_{p2}\right)$$

where: K_{p1}, K_{p2} – coefficients of two marker layers,

$I_{n\gamma}^1, I_{n\gamma}^2$ - neutron-gamma intensivities in two marker layers.

According to these data carried out time-lapse monitoring of physical properties of the slipping body, to evaluate movement slipping mass dynamics.

2.3. Remote sensing technique

Besides the traditional geodetic methods, it is important to apply a new remote sensing technique that uses radar satellite images. Potentially hazardous areas can be detected on the basis of the common interpretation of radar satellite images of high resolutions in complex with the existing geological, geophysical, and geodetical data. The available methods and equipments for estimating vertical ground movement are becoming more and more precise, being able to supply accurate measurements of displacements over the studied region (Boundarchuk V.A. etj. 2010, Bushati S. et al. 2008, Frashëri A. 2010, Geological Survey of Slovenia, 2009, Kin Wah Leung 2003, Kurabashi T., et al 1998, Mialkin B.V. et al. 2004, Zlatopolski A.A. 1992, 1997).

Satellite Radar Interferometry (InSAR) is a technique in which the phase component of the returning radar signals of two or more synthetic aperture radar (SAR) scenes of the same location are processed to allow the detection of ground movements (Fig. 2.1). The need for more accurate results has led to the inevitable technical advances seen over the last few years, including Persistent Scatterer Interferometry (PSI).

PSI is a non-invasive surveying technique used to calculate fine motions of individual ground and structure points over wide-areas covering urban and semi-urban environments. The technique uses an extensive archive of satellite radar data (dating back to 1992) to identify networks of persistently scattering (i.e. radar reflecting) features such as buildings and bridges, or natural features such as rocky outcrops, against which precise millimeteric motion measurements are calculated retrospectively over the time spanned by the data archive. The unique benefit of PSI is its ability to provide both annual motion rates and multi-year motion histories for individual scattered points.

PSI software analyze the phase responses of the point targets and are able to separate the ground displacement. The levels of measurement precision achieved on the annual displacement rates are of the order +/- 0.1mm/year. With all that satellite observations are not very high periodicity (from 2.5 days to 35 days for existing satellites that have equipment SAR), in some cases satellite methods are able to detect catastrophic phenomenon of active landslides.

Currently used innovative techniques for the analysis of satellite images of the deep structures (Boyarchuk KA, NI Maloushina, Miloserdova LV). The method is based on Geodynamic analysis of geological systems information, and spatial imaging formulation based on the size of the study objects. Results represent the structural model of the territory, which can detailed through the existing geological and geophysical data. In these cases, these data are not mechanically linked with spatial imagery, but they build on and enrich the model, providing new details about the interconnection of internal components. The great advantage of this method is the ability to adapt to tectonic and surface conditions at different, until the landslide's criteria and indicators vary depending on the geological and practical conditions.

Can also be performed computer analysis of space images using standard methods, including software package LESS (Lineament Extraction and Stripe Statistical Analysis-Statistical Analysis of Extraction and deleting features) to compilate the structural and tectonic line and blocks scheme of the area (Fig. 2.2). Performed liazing of the spatial image with the existing topographic, geological and geophysical maps for the realization of complex interpretation.

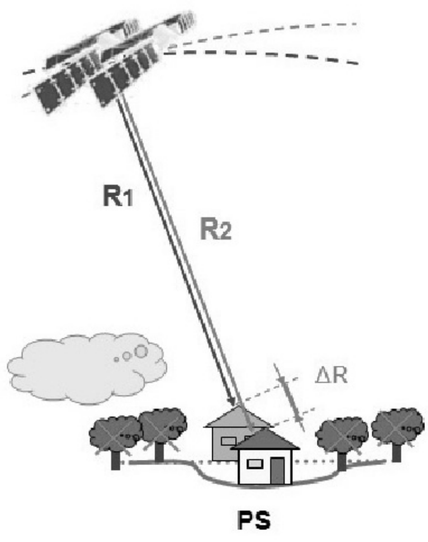


Fig. 2.1. Persistent Scatterer Interferometry technique (PSI) (Geological Survey of Slovenia, 2008-2009)

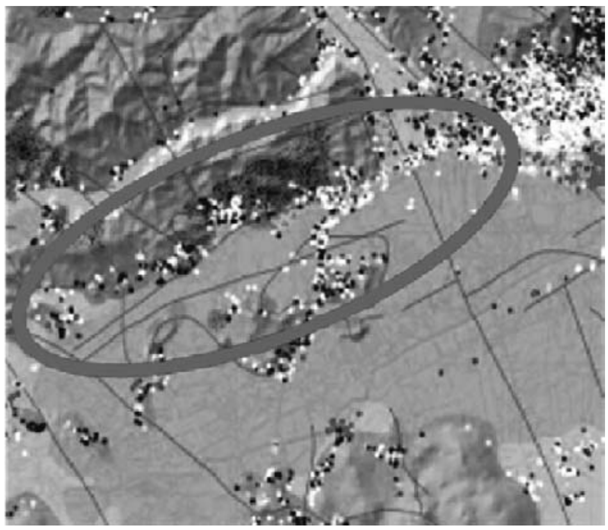


Fig. 2.2. Field validation of displacements Detected with PSINSAR (Geological Survey of Slovenia, 2008-2009)

Based on the results this investigation's phase differ potentially vulnerable slopes and classify their level of the hazard. According to space observation informations, actually can realized the classification of slopes with different potentially hazard levels, which can be accomplished based on:
- Analysis of the deep "photo-portraits of the landscape" areas expected to slide,
- The deep analysis of 3D digitals maps of different indicators
- Developed criteria for the classification of slopes,

Besides the above, studied the internal structure of potentially dangerous slide through:
- a) Detailed examination of the internal structure of potentially dangerous landslides, discovery of the tectonics lines, and glide plane,

- b) Directly survey of the small dislocations (dislocation trend) within the probable slipping bodies.

2.4. Geotechnical methods

Geotechnical landslide's investigations present a wide complex of methods and studies (Bushati S. et al. 2008, Camberfort H. 1972, Dzienvansky J. etj. 1981, Frashëri A. 2005, Galgaro A. et al. 2004, Konomi N. et al. 1982, 1986, Konomi N. 1988, Kurahashi T. et al. 1998,):

- Engineering Geological mapping accompanied with hydrogeological-hydrological observations.
- Samples laboratory determinations of the physic-mechanical properties of soils and rocks of the slipping body and the bedrocks, as well as for further mineralogical and and petrological studies.

- Mathematical modeling, landslide occurrence analysis and production of landslide susceptibility map.

2.4.1. Geological mapping: to map the lithological types of rocks and their structure. He carried out through field surveys, combined with drilling, aerophotogrametric analysis, as well as laboratory determinations. Mapping is performed at different scales up to 1: 2 000, depending on the mapping task. Survey network determined the scale of the mapping. Ex. for the map at the scale 1:10.000 the survey grid should be 20 x 100 m, 10 x 50m for the scale 1: 5.000, etc. Should paid special attention for surveys of the disjunctive tectonics, karst phenomena development, as well as physical-chemical rock's alteration.

2.4.2. Geomorphological mapping: for separate types of the landscape and neotectonics development. In geomorphological maps classified sites according to their suitability for construction and waste collection. Classification can carried out in several classes according to stepness of the landscape surface: $<3^o$; 3^o-4^o; 4^0-5^o; 8^o-12^o; and $>12^o$.

2.4.3. Hydrogeological mapping: by means of which there are data on the water bearing bassins of different types, for aquifer layers and their structure, the water content in the aquifer, the groundwater level and their chemical composition. There are studied ways of supplying water reservoir, the direction of movement of groundwater and assess their dynamics, determining the speed of water flow in the layer.

2.4.4. Engineering geological mapping: which provides data on the geological setting of the area, mainly on the relatively small depth lithology, usually 2 m, 5 m, 10 m, or deeper, as needed, mapping lanslide areas and downfalls, and generally assess the slope's stability, are identified risk areas of soil liquefaction during earthquakes, and determined physico-mechanical properties of soils and rocks. In particular attention is devoted to determining granulometry and compression stregth of soils and rocks, classifying them into several classes.

2.4.5. Laboratory determinations: In not destroy the samples samples determined physico-mechanical properties of rocks and soils, mineralogical - chemical composition and their pertographic peculiarities:

- Granulometric composition
- Plasticity
- Natural moisture
- Volumetric mass and sceleton volumetric mass
- Specific weight
- Porosity coefficient
- Consistency indicator
- Angle of internal friction
- Cohesion
- Compressional Module, Permitted Charge
- Mineralogical determinations, Petrographic study

2.4.6. Borehole drilling: Drilling of boreholes made to obtain rock samples from the bedrocks, for the geophysical well logging, and hydrogeological surveys, as statics and dynamics water's levels, dynamics of the freatic and underground waters, their monitoring.

2.5. Geodetic surveying;

- Topographic detailed mapping and geomorphological surveys,
- Setting of the geodesic markers, GIS levels and coordinates monitoring (Coe J.A. et al. 2000).
- Analysis of the surface deformation based on PSInSAR method in the landslide area.
- Borehole deflection records monitoring.

2.6. Monitoring records

Monitoring of the slope stability and the landslide dynamics should be carry out by a time-lapse complex methods: remote sensing observations and repeatable geophysical integrated surveys on landslide.

Analyze of the time-lapse of the physical-mechanical properties of slipping body and top of the bedrocks, the landslide monitoring represents. The monitoring center will have shallow boreholes down to the bedrocks. The hole-hole time – lapse seismic and geoelectric tomographies, and gamma-gamma density logging can be included in the surveys program. Consequently, slipping body between these boreholes will be object of periodically in-situ determinations of physical-mechanical properties, and mineralogical changes of the glide plane rocks through their influence in the underground waters. The natural seismic-acoustic activity inside and outside of slipping body has been observed for a continuous time of 5 seconds.

2.7. Constructive and environmental evaluations

Based on results of integrated geological- geophysical-remote sensing and geotechnical investigations and evaluations, landslide monitoring, specific impact's effects of Climate Change on nature observations, studies on the flora in the sliding areas, anthropogeneous impact on geoenvironment, and risk assessment, can be prepared and presented the constructive recommendations for avoiding the natural risk, which can be possible. During the phase of planning infrastructural objects, landslide zones could be placed outside the areas planned for construction of infrastructural structures. Method of landslide rehabilitation it is necessary to develop.

3. SLOPE STABILITY EVALUATION AND LANDSLIDE INVESTIGATION AND MONITORING USING GEOPHYSICAL DATA IN ALBANIA

3. 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.

3.1. 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 in lakeshores. This phenomenon has been more evidently activated after the construction of hydrotechnical works (Frashëri A. etj 1997, 1998, 2000, Konomi N. et al. 1986). 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.

3.1.1. 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. 3.1). 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 (Dhame L. 1974, Frashëri A. et al. 1997, Muço B. 1987, Radovicka P. etj. 1976).

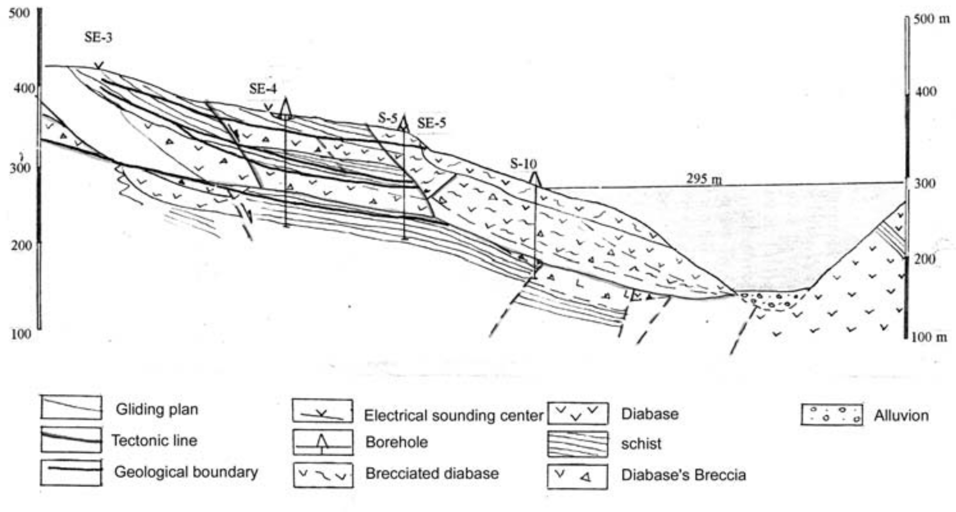
The studies have not only included the geological understanding of the shore's solidity but also the understanding of the landslides. They also include solidity-integrated calculations through the hydraulics patterns. For that, the body fall of the Porava landslide at different speeds (from 5-10 m/sec) was simulated. As calculating parameters were used the ones resulted from geological studies of that time.

Fig. 3.1. Porava Landslide area map, satellite view, and landslide impact on willage houses.

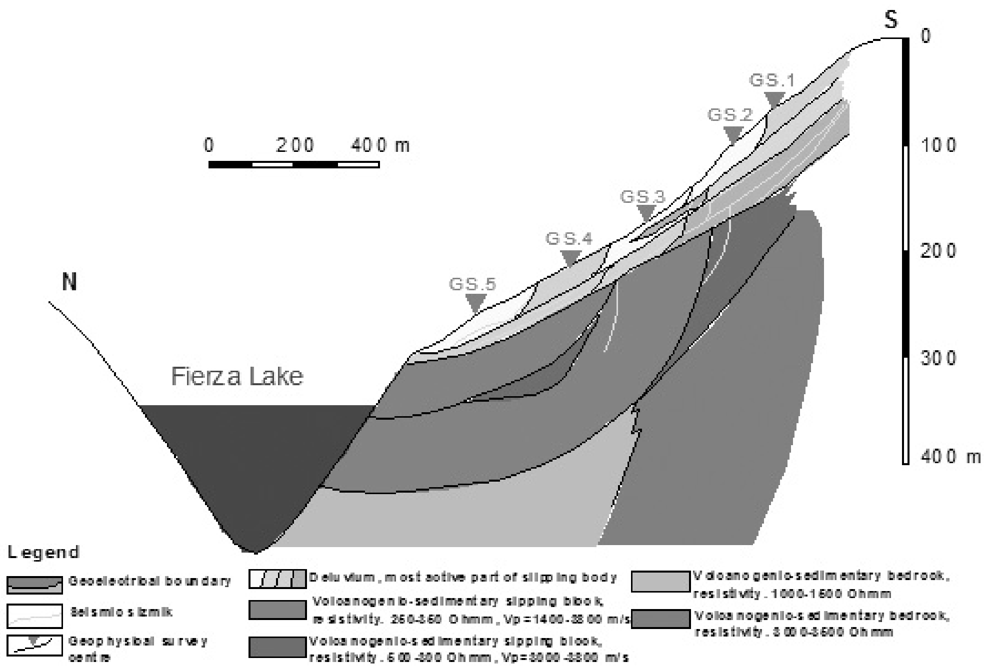
In Fig. 3.2 is presented the detailed geoelectrical - engineering section. This section was compiled based on the date of the vertical electrical soundings. In that can be noticed the presence of the very heterogeneous electrical medium in strike and depth. There are two categories of geoelectrical borders 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).



a)



b)

Fig. 3.2. Geological (1974)(Dhame L. 1974 (a) and geophysical data (b) (1996) data comparison.

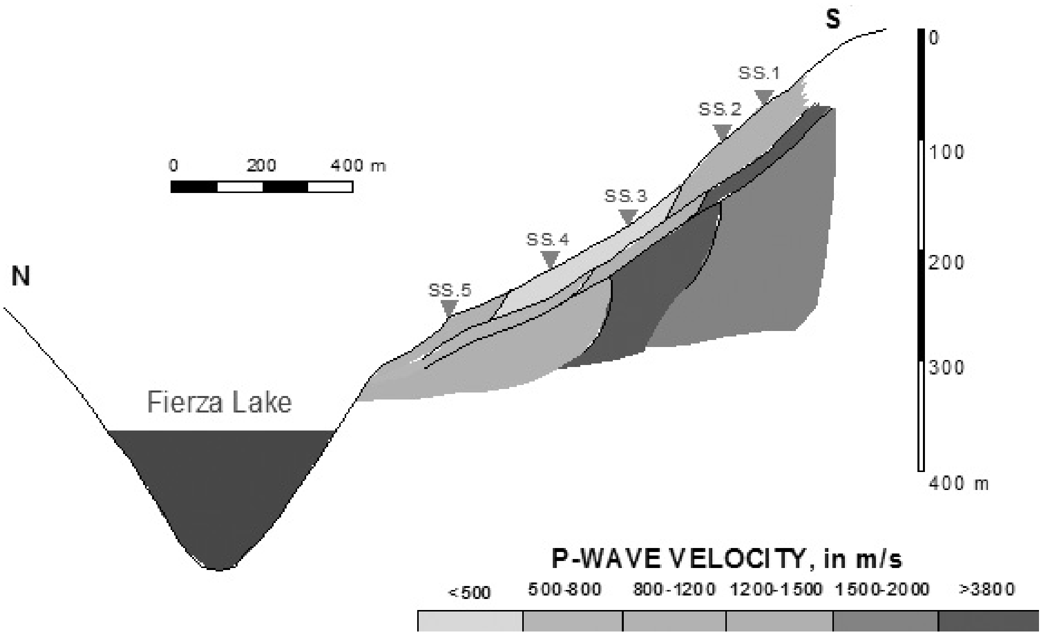


Fig. 3.3. Seismic engineering profile, Porava Landslide (1996).

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. 3.3 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)(Photos, fig. 3.1).

In the detailed and integrated geophysical - engineering sections, can be noticed a concordance between the electrical sounding results and the seismic surveying ones, used for studying this slide. Also, in these sections 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.)

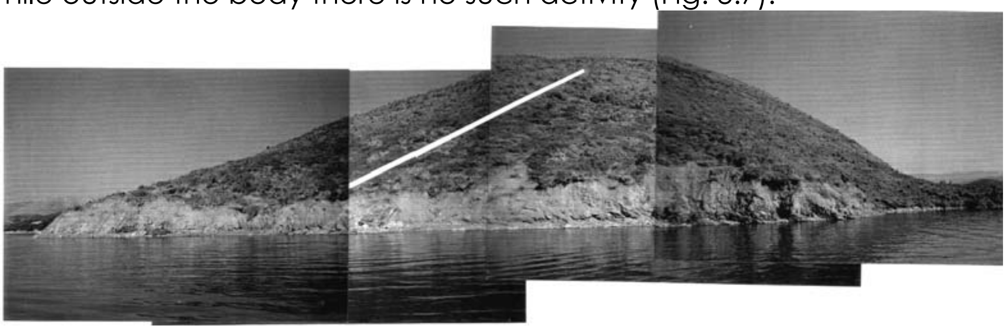
Based on the results of this integrated geophysical-engineering and geotechnical study result:

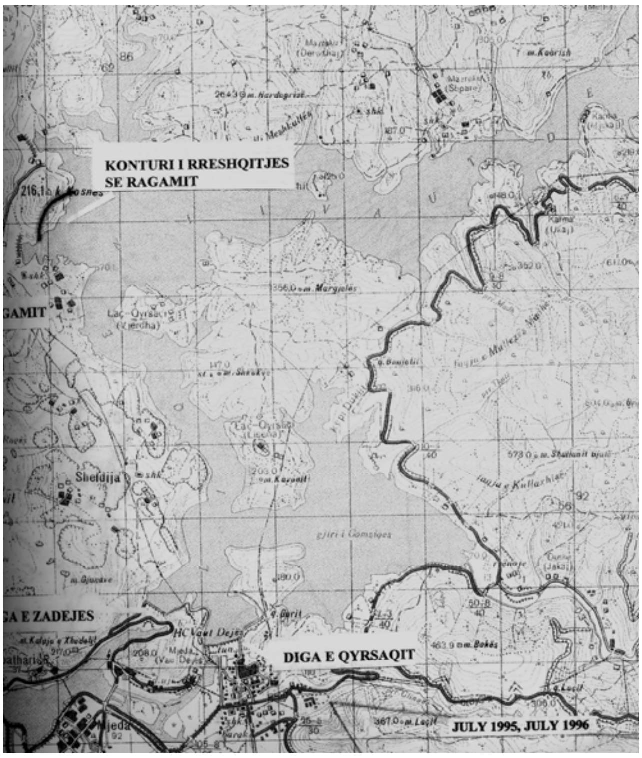
1. There could not happened an immediate fall at any speed of the Porava slipping body.
2. Even in cases of powerful earthquakes, the slipping body mass can not fall as a whole, because it is made of broken up block masses. It can fall parts by parts or in fragments. Natural or inductive earthquakes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

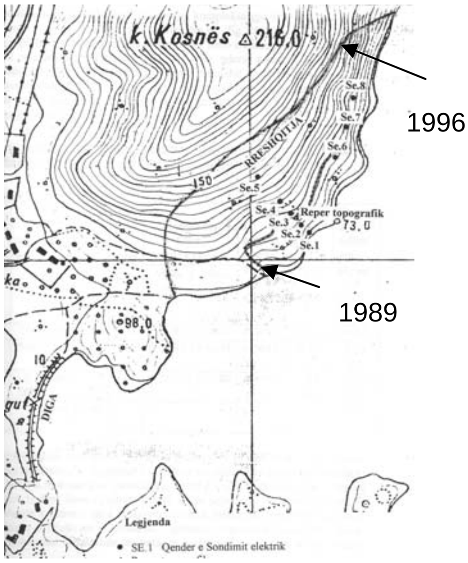
3.1.2. The Ragami Lanslide

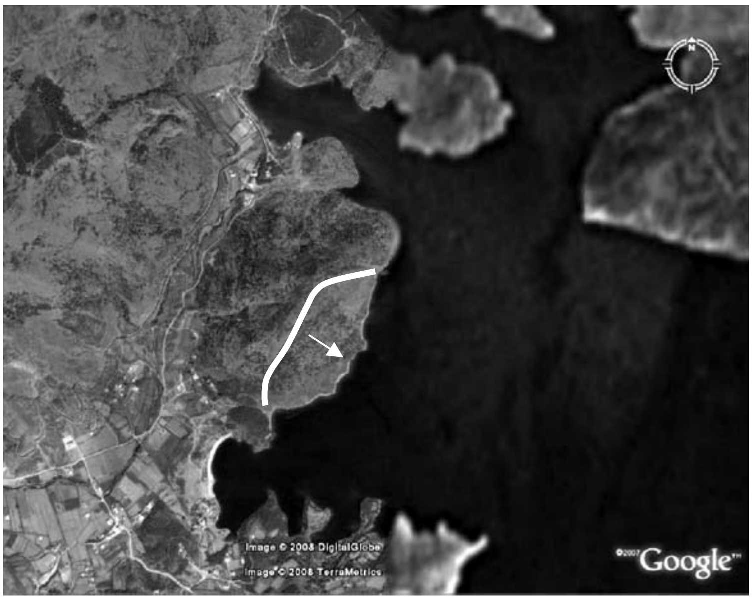
The typical landslide was developed at lakeshore of the Vau Dejes Lake of Hydropower Plant in Northwestern Albania (Fig. 3.5). It is developed in the ophiolitic formation represented by serpentinized rocks. The slipping body represents a big mass of serpentinite, which is eolated, destroyed and covered 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. 2.7). 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 in fig. 3.5) (Frasheri A. et al. 1996, 1989).

In fig. 3.6 –a, b are presented 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. 3.7).









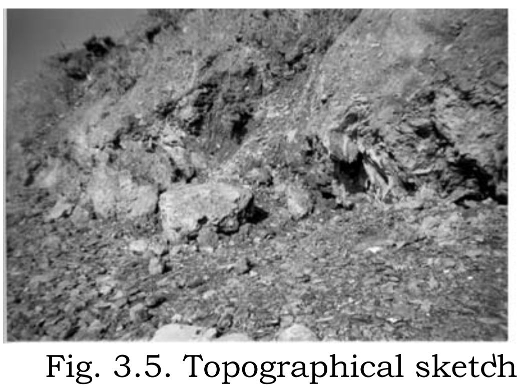
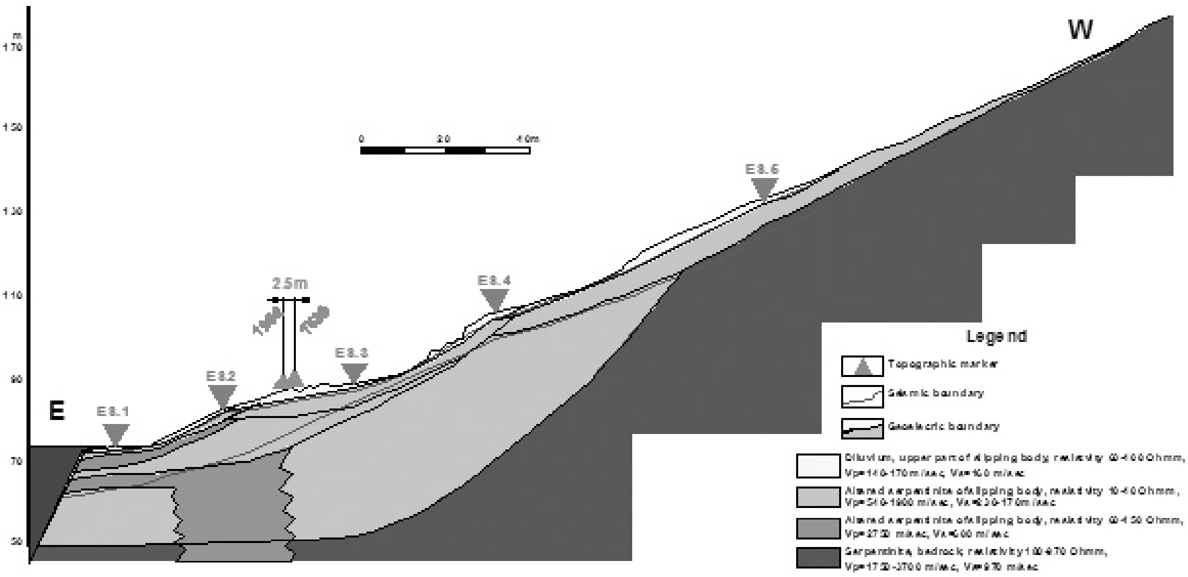
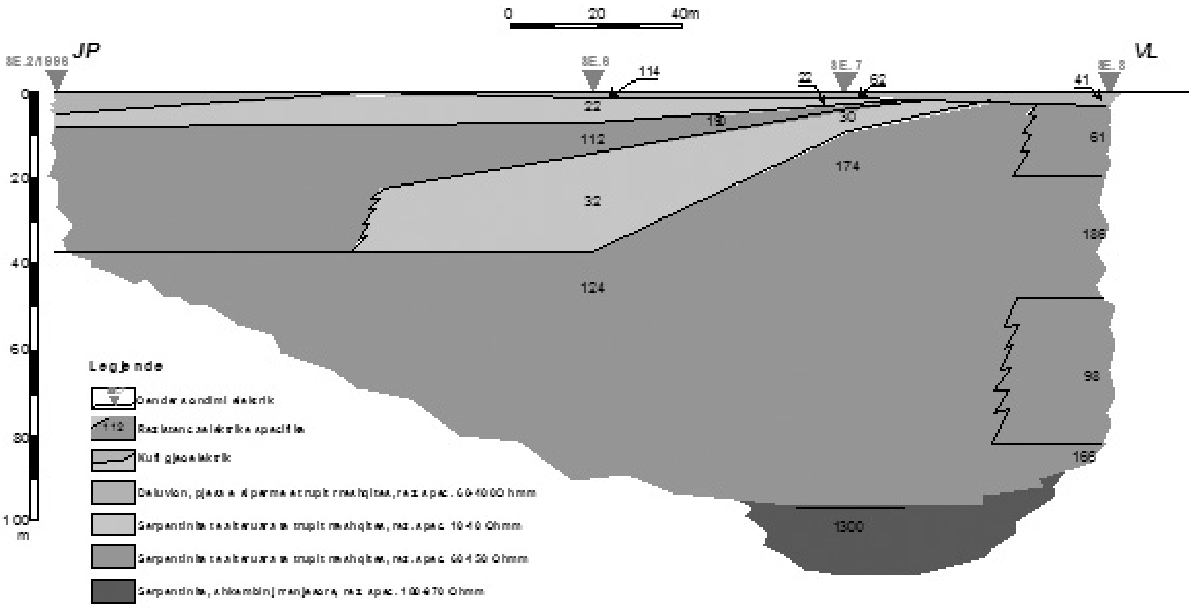


Photo of the Ragami landslide area, andf front of the body, represented by mylonite serpentinites (b)

Fig. 3.5. Topographical sketch of Ragami Landslide area (1989; 1996) Landslide body contours, respectively, and satellite view.



Transversal profile



Longitudinal profile

Fig. 3.6. 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 2.1 and 2.2.

PHYSICAL PROPERTIES IN LANDSLIDE'S AREA

Tab. 2.1

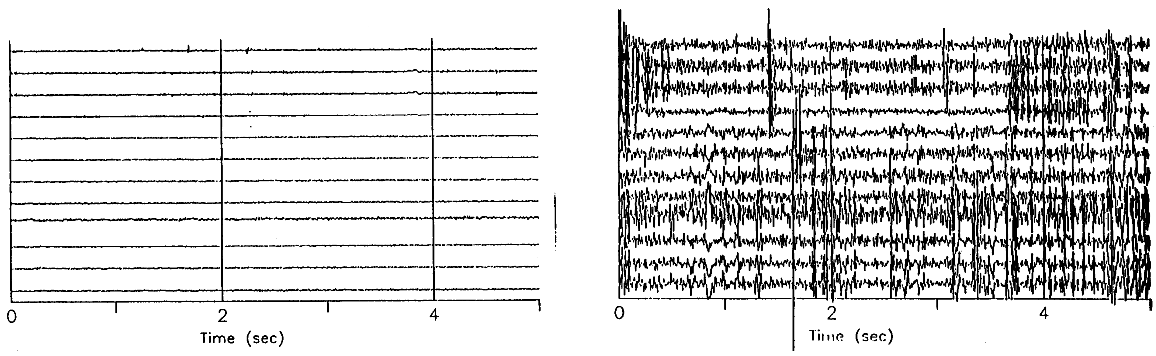
Layer Number	Thick-ness, in meters	Resistivity in Ohmm	Density, in g/cm^3	Wave Velocity, in m/sec		Lithology
				Vp	Vs	
SLIPPING BODY						
1	0.7	76.4	1.34	210	160	Deluvium
2	4.0	29.5	1.61	540	230	Breaking serpentinite
3	6.5	46.5	2.45	3700	680	Water-bearing serpenti-nite,
4	17.4			1500		Breaking serpenti-nite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

MECHANICAL PROPERTIES IN LANDSLIDE'S AREA

Tab. 2.2

1. Layer Number	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 2.1 and 2.2, 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.



Outside of slipping body Inside of slipping body
Fig. 3.7. 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.

3.2. Landslide in the Oligocene flysch formation.

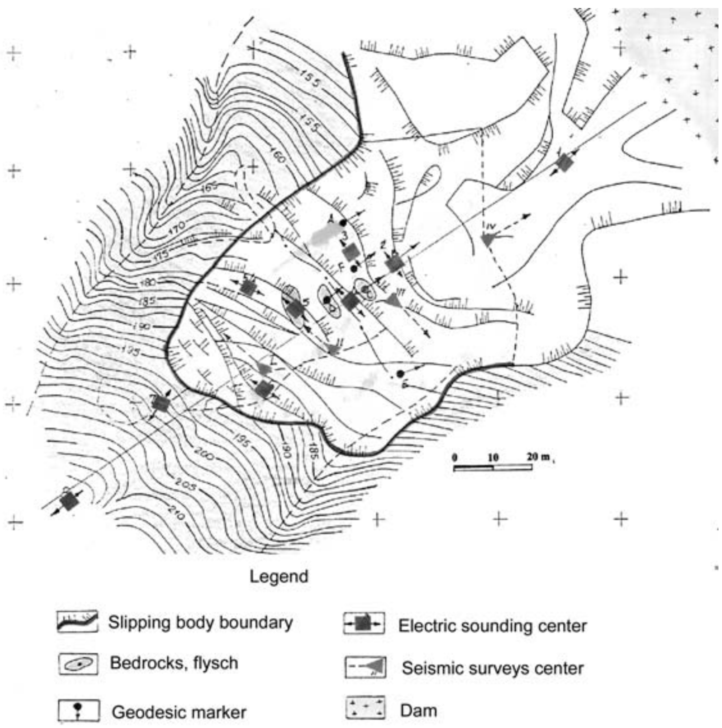
There are instable mountain and hill slopes, slipping of rocks masses, sometime of great sizes and catastrophic results. In some cases even villages or parts of villages were destructed, as Guri Zi in Elbasani region, Moglica in Devolli River region, Gjyras in Maliqi region etc., and without mentioning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

3.2.1. 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. 3.8). 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. 3.9 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.

Fig. 3.8. Banja Landslide area,July 1978



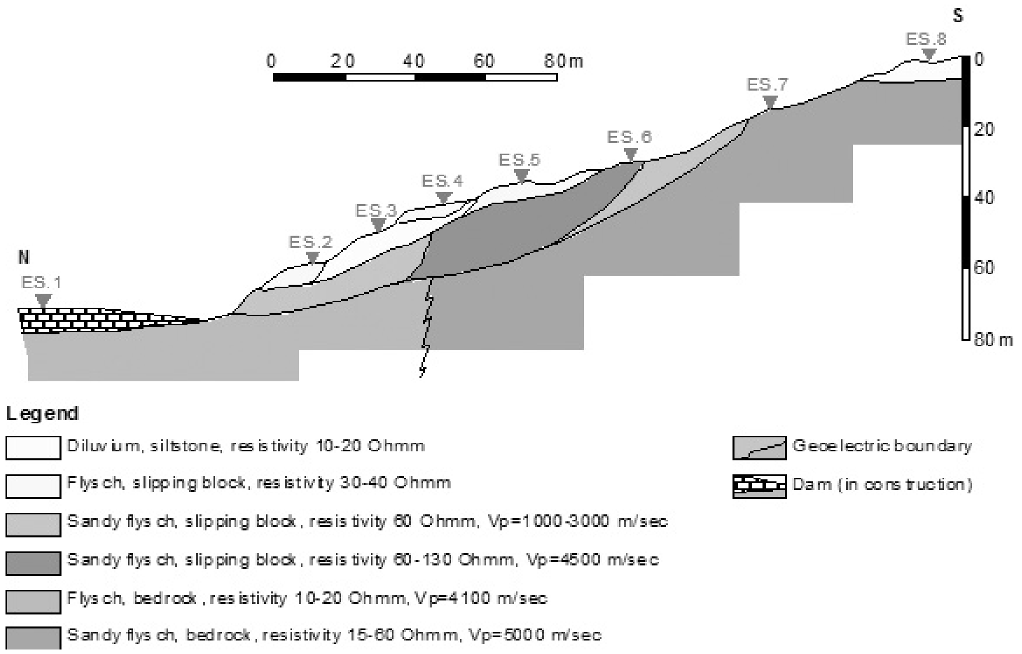


Fig. 3.9. Geophysical section, Banja landslide

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. 3.10). The micro - movements have an amplitude many times higher.

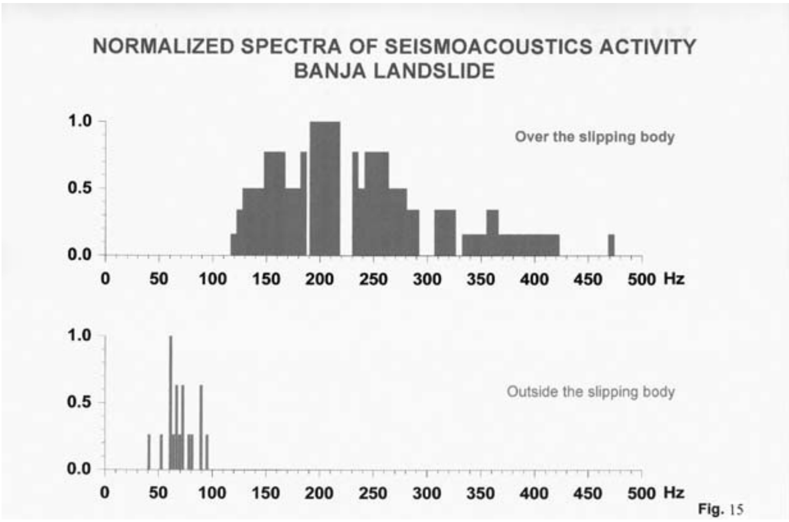


Fig. 2.10. Normalized spectra of seismoacoustic activity, Banja Landslide

3.3. Landslide in the Neogene’s molasses formations.

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

Durresi landslide

Durrësi city area is characterized by a presence of neogene molasses formation (Fig. 3.11) (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 4.6). The Pliocene clay slope at southern part of the Durresi hills is unstable. There the big landslide activity is observed. Over this slope have been constructed many buildings. Actually, in several buildings have observed wide wall craks (Fig. 3.12)

Fig. 3.11. Subsidence of the villa walls, caused by landslide

Photo 3.12. Cracks in the villa walls and transversaly of the road

3.4. Downfalls in the weathered rocks

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 (Fig. 3.13) (Frashëri A. et al. 1997).

Fig. 3.13. Downfalls in the Kruja Hill.

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.3.14).

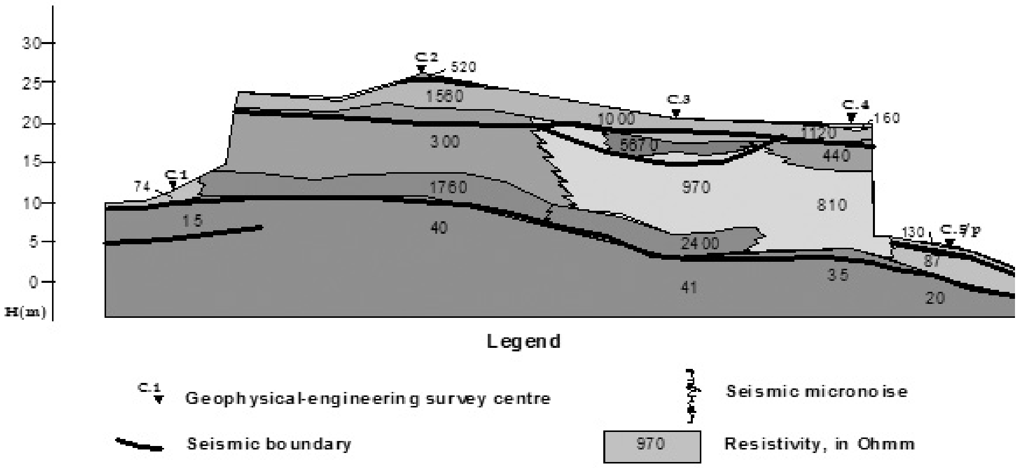


Fig. 3.14. Physical Engineering Section, Kruja Kastel Area.

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. 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.

2.3. Conclusions

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

1. 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.

2. 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 gliding 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.

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