Stability Monitoring System Implementation for "Rural Mare Retezat" Dam

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Abstract

To avoid the hazards which can affect the construction stability, it is imposed to control the risk factors which can occur because of the geo-mechanical parameters modification in mass's rock and body dam's rock. The geo-mechanical parameter of rock samples was tested in laboratory and their variation will be analyzed and the crack of rock masses established. The paper takes into consideration the implementation of computer monitoring system and the optimization of network markers which are used in topographical measurements for tracing deformation purpose.

Keywords: Dam stability, monitoring system, remote control, rock mass properties

1. General Consideration

Gura Apelor dam is situated at the confluence of Lapusnicu Mare, Lapusnicu Mic and Ses rivers, where forming Raul Mare, at 47 km from Hateg City. The slope makes parts from mountain mass Retezat, Godeanu and Tarcu. Gura Apelor dam is situated at 600 m of confluence Lapusnicu with Ses River.

The upstream hydro-energetic development of Raul Mare River includes a dumped rock-fill dam which accumulates a water volume of 225 million m3, a pressure tunnel for the transport of water to the Retezat underground hydro-electric power plant with an installed power of 335 MW and a return power plant, the Clopotiva Power Plant. The production capacity of this power plant is of 629.5 GWh/year. The works began in 1975. The dam has a height of 168 m, and it is built of local materials: rock, filter and clay, Figure 1.

Figure 1. View on the Gura Apelor Retezat Dam

Evacuation of big waters is making through two gallery of emptying of the lake, and through discharging of big water, which is situated on the right versant. All the evacuations have a debit of 1700 m3/sec. Principal bringing workings provide transport of the water from the Gura Apelor to underground power station Retezat, consist from a tunnel with lengthwise of 18,432 m, excavated at a diameter between 5.5 and 6 m, with a final section of 4.9 m (interior concrete diameter).

The principal characteristics of Gura Apelor dam is: maxim high 168m above foundation, breadth at base 574m, total volume with filling 10,285,000 m3, rock fill 6,422,000 m3; clay in core 1,127,000 m3; filter and sorted gravel 183,000 m3; gravel 983,000 m3; filled in stability prism 883,000 m3.

The emplacement on the superior flow of the Raul Mare at just 660 m downstream of the Ses River confluence with Lapusnic River, which together forming Raul Mare, the rock-fill dam with a central nucleus of clay Gura Apelor create an accumulation with a total volume of 210 million m3 with 200 million m3 useful volume, representing the biggest accumulation from hydro energetic settlement of Raul Mare.

2. Geological and Geomechanical Characterization

General characteristics of Retezat Mountain are the presence of two big blocks of granite and granodiorite, one stronger developed on the principal north crest and other restrict on the principal south crest. Geological studies in the dam area, on the geologic elements base, structural-tectonics and mineralogical-petrography, have shown the difference between tree blocks (Bancila 1989).

It is known that Gura Apelor dam must be almost impermeable if is possible. The dam is known as non-homogeneous because there were used different materials (sand, gravel, clay) with different values of permeability coefficient, especially to reduce the infiltration debit, problem which represents a constraint for every hydro technique construction.

The Retezat Mountain has a lot of rivers, with a rich and permanent debit. The modification in time of precipitation and hydro energetic regime of versants, have a direct impact to shape the relief, and the tendency of rising the temperature determinate some modification of the vegetal cover.

From the hydro energetic point of view, on the natural open base, and in depth (drillings, gallery, caves), to realize a hydro geologic model of the dam, was determinate the characteristics: the level of underground water, permeability, water absorption, mineralizes of water and the consumption of solid materials necessary waterproof of rocks. From the geologic point of view, using geologic maps have tried to find a particular underground, but the underground need to be homogeneous, it don't need to present fracture or liquid accumulation which can produce the submerge.

Gura Apelor dam is situated in crystalline rocks and limestone belongs of Getic Clots, structures from granite, granodiorite, crystalline schist in the right versant and chlorite, gneiss in the left versant (Paunescu 2008). Rocks from the area are affected by two major faults and frequent discontinues. The characteristics of the realized section were taken from geologic documentation from Raul Mare. The lateral prism is composed from the same material with the upstream and downstream of the dam, with the characteristics shown in Table 1: Clay I (I), Clay II (II), Filter (III), Rock fill (IV) and Foundation (V).

Table1. Geotechnical characteristic of dam materials

Type of rock	I	II	III	IV	V
Unit Weight γ (MN/m^3)	0.019	0.02	0.02	0.025	0.0220
Friction angle φ (degree)	15	25	40	40	20
Cohesion c (MPa)	1	0.5	0	0	0

The dam is built from local materials, with clay nucleus. The rock from the emplacement foundation of the dam is built from hard granite schist, compacts and impermeable in the central zone and left versant. The dam prisms are made on the rock base with the exception in the river bed where is done on the existent gravel. The tight nucleus and the filters zone was foundation after removing the layer of rock of 3.5 m. In the nucleus zone was executed injection of consolidation on the rock, at 6-12 m depth. The left versant is especially made, on the superior part, of less resistant rock: peach stone, breccia, tectonical and altered. These rocks proved to be less permeable and injection works already done in the used technology give us more and more good results. The left versant zone - in the medium and superior zone, has been divided in two tectonic -structural blocks. As we observe in the studies we have made, that the formations of the two blocks are affected by cracks, which in time, at geological scale, have generated the alterations of the rocks changing them, in rocks which have lost the rocky characteristic.

The tight veil is built from two principal rows of horizontal drilling injected with 50-80 m depth and other two rows of drilling with 10 m depth in upstream and 16 m downstream.

Hoek – Brown failure criterion (Hoek 2002) is used to determine geo-mechanical parameters of rock mass. The criterion started from the properties of intact rock and then introduced factors to reduce these properties on the basis of the characteristics of joints in a rock mass. A rock mass damage criterion is introduced to account for the strength reduction due to stress relaxation and blast damage in slope stability and foundation problems.

Analysis of rock strength has been done by RocLab software developed to accompany this paper (Hoek 2002). This program provides a simple and intuitive implementation of the Hoek-Brown failure criterion, allowing users to easily obtain reliable estimates of rock mass properties, and to visualize the effects of changing rock mass parameters, on the failure envelopes. The results obtained from RocLab software are shown in Table 2. Joint properties and other structures have been estimated taking into account by direct shear test obtained in the Geomecanics Lab of Petrosani University (Arad&Todorescu 2006).

Table 2. Rock mass properties results from RocLab software

	Claystone	Granodiorite
Hoek Brown Classification		
σ_{ci} [MPa]	35	175
GSI	38	43
m_i	4	29
d	0.7	0.7
Hoek Brown Criterion		
m_b	0.132616	1.26545
s	0.000125211	0.000258434
a	0.51302	0.509269
Failure Envelope Range	Application_Slopes	
σ_{3max} [MPa]	2.26079	3.55459
Unit Weight [MN/m3]	0.02	0.025
Slope Height [m]	168	168
Mohr-Coulomb Fit		
c[MPa]	0.284633	1.3642
Φ [degree]	20.5604	48.9267
Rock Mass Parameters		
σ_t[MPa]	-0.0330458	-0.0357391
σ_c[MPa]	0.348402	2.6059
σ_{cm}[MPa]	1.58324	25.3128
Em[MPa]	455.124	714.151

The results obtained by lab tests data analysis and by simulation with RocLab software allow us to predict the behavior of the dam body and hydro energetic construction state and to realize matrix with industrial risk.

3. Slope stability analyses

3.1 State of Art

To monitoring of the dam behavior was take in consideration 33 markers embedded on the dam, disposed on four alignments in downstream and three alignment in upstream, Figure 2. We realized the optimization of network markers which are used in topographical measurements for tracing deformation purpose (Dima 2004).

Equipment for the behavior control of construction it achieved and variety in the same time with the execution of investment. These are: geologic and piezometer-type drillings; measuring and control devices (MCD); pendulum; topogeodesy equipment for determination of movement in horizontal plane, vertical and in space; seismic station, transducers and automatic tracking systems for controls of signals (stress, strain, temperatures and electrostatic field).

This works was done on tree specific area of the left slope, named: (i) Zone I-Schist, (ii) Zone II – Breccia and (iii) Zone III-Granite.

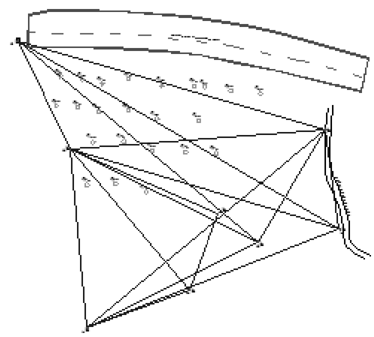

Figure 2. Monitoring markers outline

The measurements data, the experimental results from laboratory and all the data for monitoring activity are realized by specialized team or experts in domain. Drilling and injection works at Gura Apelor Dam was started in the year 2004 with execution of experimental drilling realized with classic endowment and have continued with a new lot of drilling executed with modern technology, Figure 3.

Supervision of the rocks deformation in foundation is done with the help some telemetry devices. The rotation or inclination of surface from dam body is measured with inclinometer. The extensometer is used for specific deformation. At all the instruments for resistive measure, the measurement is done from afar with the help of the telemetry (Arad&Arad 2006).

To have safety data for the dam measurement are necessary to obtain the external and internal stress, horizontal and vertical displacement over the fissure, interstitial pressure and so on. The inner temperatures are measured with the help of resistive or electric –acoustic remote control devices, the measurement device are situated in the section or point, the measurement is done at distance (downstream parameter, visitation gallery) through some electric cables. Specific deformation is measured with electric, acoustic or resistive extensometer.

Slope stability is put in danger by destroying the local equilibrium between forces which stress the slope and interior strength forces of rocks, under the direct action of diverse internal or external factors, naturals or artificially. Loosing of slope stability is producing through deformation and sliding of slope, on a surface, because of loosing equilibrium limit of rocks, expression through minimum stability coefficient.

Figure 3. Aspects from the waterproof process

3.2. Analysis of the slope stability

Slope stability is endangering through disturbing the local or ensemble equilibrium between the forces which solicit the slope and internal resistive forces, under the direct action of diverse internal or external factors, naturals or artificially. Loosing slope stability is producing through deformation and sliding of those, after a surface, because exceeding equilibrium limit state of rocks shown through minimum stability coefficient.

To eliminate slides of the field and trickling of water from left slope was performed a lot of drilling. From this drillings was established loosing of water from versant, and after was realized a veil of tight thru injection of water-cement- bentonit in massif.

TALREN software is ideal for checking the stability of geotechnical structures, with or without reinforcements: natural slopes cut or fill slopes, earth dams or dikes. In the present version of TALREN, the safety factor Γ is calculated by TALREN which should be ≥ 1 for equilibrium. TALREN used method of the limit equilibrium calculation along potential failure surfaces using the Fellenius method. The value of Γs, Γc and Γφ is imposed for each soil of the geometric model like in Figure 4, based on geotechnical characteristic of dam materials, shown in Table 1.

For the dam model with a full lake, with prism, friction internal angle for foundation φ = 30, was obtained the minimum safety coefficient Γ = 1.55 for the sliding surface from the Figure 4.

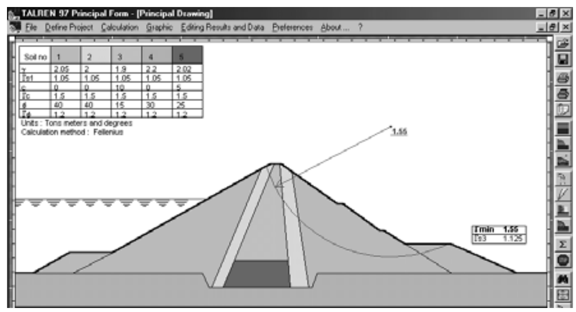

Figure 4. Safety coefficient determination

There is often in rock engineering to establish the geology and structure of the rock mass remotely. In this situation the choices are traditional photogrametry techniques enhanced by the advances of digital photography and an adaptation of the advances of digital airborne laser technology. Analysis of the rock slope requires a geometric description of the surface and knowledge of fracture patterns and their properties.

The geographic information system (GIS) is increasingly viewed as a key tool for managing spatial distribution of data (Grecea 1999). Advanced in digital technology provide tools that allow the generation of digital terrain models at the centimeters scale. The photogrammetry survey used two camera stations located on the upstream and downstream edge of the dam forming the dam crest.

Natural and human-induced slope movement and slope failures are complex geotechnical engineering problems involving both surface and subsurface conditions and their interactions to triggering factors. Current geotechnical modeling tools are focused on the numerical analyses and generally not designed to facilitate the requirements of site investigation and characterisation. The geophysical and geotechnical model of the dam and of the slope will be made with the data measured from monitoring the dam and the determined parameters, this model being integrated in the monitoring system.

4. The Monitoring System of Dam Stability

The architecture of the integrated system is presented in Figure 5 (Calarasu 2008). The system is composed of three stages which have to be followed for the implementation of specific tasks, like in Table 3.

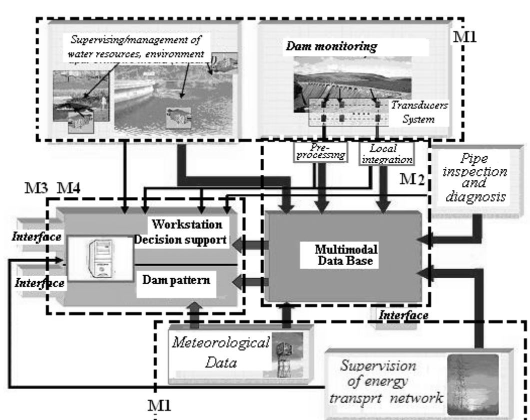

Figure 5. Architecture of the integrated system

Table 3. The stages on the implementation of integrated system

Stage 1: Data collection, Management & Synthesis		
Input data	Synthesis tools: GIS	Output
➢ Base Digital Elevation Model Data ➢ Geology/Geophysics ➢ Displacements ➢ Groundwater ➢ Field Observations	Field → Central Spatial Data Base Office → Central Spatial Data Base	Data integration Data presentation Data vizualization Data comunication Ground modeling
↓		
Stage 2: Development of Engineering/ Geotechnical model		
Input data	Tools: CAD software	Output
➢ Ground model Stage 1 ➢ Material properties ➢ Pore pressure		Geotechnical model
↓		
Stage 3: Engineering/ Stability analyses		
Input data	Tools: Numerical analysis	Output
➢ Geotechnical model ➢ Material properties ➢ Pore pressure		Engineering decisions

The integrate system contains many moduli, grouped in four functional categories (Figure 5), which can be explained as in Figure 6:

- Monitoring dam parameter, data acquisition and transmission (M1);
- Conceptual organization and pre-processing the data (M2);
- Post- processing data (M3);
- Data interpretation, assisting decisions (M4).

The monitoring, getting and transmission of data is made by means of automation equipments and the related software (firmware).

The group of conceptual organisation of data and preprocessing contains modules/software components which undertake the logging from transducers and operate and put them in the data base.

The modules from the preprocessing zone deal with data extraction according to the configurations of the hydrotechnic facilities and the machine work requirments.

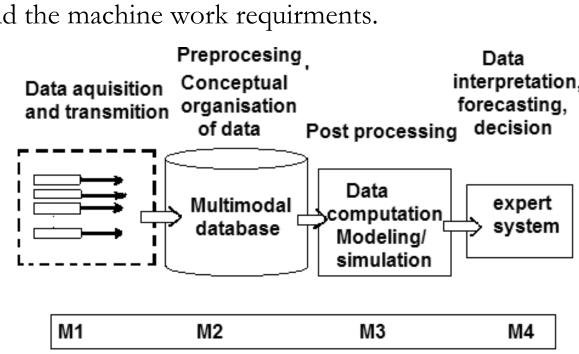

Figure 6. Block diagram of system

The functional blocks from the execution zone /decision assisting implement the computerised visual inspection, modelling/simulation/prediction functions, expert systems.

From identification the risk factors was established the category of elements necessary in dam monitoring for construction safety and to avoid the risk apparition:

- Morphological and hydro geological changes on the lake versants zone of dam emplacement.
- Changes in strength and tight structure of dam body.
- Hydro mechanic equipment function (empty bottom).

The systems functions of measuring and control propose have in consideration (measuring and control device): the water level in the lake; size and duration of rainfall; groundwater level downstream dam; interstice pressure; total pressure; linear specific stains; deformation rocks left side; fillings settlement; face and crowning deformation; closing - the opening of joints in left side mining working; geophysical characteristics of the foundation rocks; seismic control; warping and erosion; direct observations.

The parameters measured, which represents the input of the system, are: relative displacements measurement of the dam, the variations in the level of the water surface, ex-filtration, temperature and distance measurement, stress and strain in body and side of dam.

The system proposed allow the management of the specifically the data base about visual inspection of hydro electric settlement, with a specialized component for behavior analysis of the wall dam based on, computer vision' technical.

It is necessary to find a probabilistically model with data base measurements joint with the laboratory tests, on statistics criteria which should estimate the prediction of conduct in order to determine the normal or abnormal state of behaviour in the analyzed construction.

5. Conclusions

Based on investigations and a monitoring program, Hidroconstructia Company (RMR Hydro) decided that it is neccesary to be controlled the structuraly stability of Gura Apelor dam and to improve it. It was given special attention because of the serious consequences which could have resulted from the danger of slope slides or the dam body failure.

The displacement in different points of construction, measured with the measuring devices, show the answer of the building at external or internal stress.

The photogrammetry survey used two camera stations located on the upstream and downstream edge of the dam forming the dam crest.

Current geotechnical modelling tools are focused on the numerical analyses and generally not designed to facilitate the requirements of site investigation and characterisation.

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