QUANTIFICATION OF THE STRUCTURAL EVOLUTION OF LARGE DAMS BASED ON NUMERICAL AND INSTRUMENTAL INVESTIGATIONS

Project CEEX No. 37/2005

1. THE GENERAL PURPOSE OF THE PROJECT

In 2005, the Romanian Ministry of Education and Research initiated a new program entitled "Program of Excellence in Research" (CEEX), one of its main purposes being to promote the scientific research to a higher degree of performance. The Romanian National Center for Earthquake Engineering and Vibrations (RNCEEV), within the Technical University of Civil Engineering Bucharest (TUCEB), won by competition the program entitled "Quantification of the Structural Evolution of Large Dams Based on Numerical and Instrumental Investigations", having as partners the Romanian Academy of Technical Sciences, the Romanian Authority "Apele Române" and the Technical University "Gh. Asachi" Iaşi.

A large dam represents a notably important type of seismic risk evaluation problem. Not only is the dam in itself a relatively expensive project, but it is intimately involved in the whole economy, through power generation, flood control, irrigation etc. In addition, structural failure of a dam may lead to a major disaster because large populations may be exposed to sudden flooding. The actual situation in Romania is such, that it is necessary to deal mostly especially with existing dams and their safety in the future. The first reason is due to the fact they were built in compliance with regulations that are generally no longer in force during present days, a second one being the major changes of the climate, which led to an increasing volume of water in the reservoirs. The age of dams is, without doubt, a third logical reason.

The general purpose of the project was to develop and improve analytical and experimental procedures for risk reduction associated to large concrete dams, when subjected to severe dynamic motions. This would allow formulating a new methodology for predicting the structural evolution of large concrete dams and for the development of a program for enhancing the monitoring systems for three selected test-dams in Romania, having in view to extend it to all the important dams in Romania. There was also taken into account the seismic instrumentation of one of the three test-dams. The dams considered were: the "Poiana Uzului" dam, the "Gura Râului" dam and the "Paltinu" dam, the last one being the one selected for seismic instrumentation.

According to the thematic field of the project, the research program was devoted to reducing vulnerability and mitigating consequences of possible natural disasters associated to the performance of large concrete dams.

2. MAIN ACTIVITIES OF THE PROJECT

During the development of the project, the following directions were kept in mind:

1) field measurements to obtain dynamic characteristics for the three large test dams;
2) computation of the vibration mode shapes, natural frequencies, and their correlation with the measured results;
3) implementation of a surveillance concept for each dam, together with the seismic instrumentation of one of the three large dams;
4) theoretical analytical studies;
5) a better control of the structural safety of dams and risk reduction represented by these engineering structures.

3. DAMS SELECTED FOR THE RESEARCH PROJECT

In recent decades, worldwide, great progress has been made in understanding how earthquakes act upon dams, in monitoring ground motion and dynamic behavior during seismic events and in analyzing the design of new and existing dams for earthquake resistance.

„*A safe dam is one that provides people and property with a required level of protection against dam failure and which meets safety criteria commonly used by engineering profession*". The basic principle in safety control recognizes that all people are entitled to the same level of protection against a potential hazard and to the same level of emergency preparedness, independently of the size of the dam, or reservoir.

At present, in Romania there are 18 arch dams in operation. Their maximum height ranges for most of them from 24 to 64 m, three of them exceeding 100 m. From this type of dams, the "Paltinu" dam was selected, having in mind the following reasons: its age (period of construction between 1960 and 1971), its seismic location (incidence of the most seismic zone in Romania, located in the Vrancea region, together with the seismic zone Câmpulung-Făgăraş), its maximum height above foundation – 108 m and an abnormal behavior of the dam in 1974 (displacements larger than predicted, movements at the foundation level, joint openings, crack at the rock surface and significant increase of seepage, from 10 l/s to 150 l/s).

The second dam selected was the "Poiana Uzului" buttress dam. Four solid head buttress dams with maximum heights ranging from 41 to 82 m, built during the seventh and the eight decades of the twentieth century, are under operation in Romania. The main reason for selecting this buttress dam is its height of 82 m, the highest buttress dam in Romania. The second reason was its abnormal behavior in time, especially during the period of April 16 – May 15, 1984. The increase of the collected flows was significantly higher; previously inactive drillings came into operation, water jets occurred directly from the rock in the drainage galleries along the contraction joints. Simultaneously with this seepage flow increase there were also recorded abnormal displacements, higher than the previous ones and especially the sudden change of the displacement pattern. Upward movements of the blocks near the right abutment were also recorded.

The third dam selected was the Gura Râului buttress dam, considering the favorable geological conditions of founding. For this dam, both movements and seepages were lower than for other existing buttress dams under operation.

4. RESULTS OBTAINED

An analysis of the seismic effects on dam response is a complex task. It requires the availability of not only realistic mathematical models, but also of mathematical theory and algorithms to translate the information contained in the experimental data into practical information.

A series of ambient vibration tests was initiated in 2005. The eigenfrequencies, eigenshapes and damping ratios that have been identified were used for the development of mathematical models for assessing the structural evolution of the selected test-dams, together with the application of powerful calibration techniques for the mathematical models used for the assessment of their structural evolution, based on the information provided by the instrumental measurements. During the research program several sets of measurements were performed for both cold and warm seasons, taking into account the water level for each dam reservoir.

By extracting the modal parameters as well as vibration intensities from the measuring results, and comparing those with the computer models of structural analysis, statements on the actual load – bearing behaviour, the maintenance condition and forecasts for the future development of the structure were possible. For this purpose, several steps have been carried out:

- establishment of an FE model of structural analysis based on the existing plans for each test dam structure selected;
- determination of the eigenfrequencies and mode shapes for each dam structure by applying a dynamic analysis; the eigenfrequencies are an essential parameter for the description of the vibration behaviour of a dam in the linear elastic field; a mode shape belongs to every eigenfrequency;
- determination of the testing points for ambient vibration measurements based on the results of analytical tests;

- measurements concerning the vibration performance by means of highly sensitive velocity sensors installed at established characteristics points under ambient excitation for each dam;
- representation of the measuring results, assessment of the quality of the individual measurements and the FFT for the determination of the Fourier amplitude spectra for every check point;
- comparison of the eigenfrequencies identified from the spectra with the values calculated by the FE model of structural analysis, accurate calibration of the models after each set of measurements and interpretation of the differences;
- calculation of the structural damping parameters from ambient vibration measurements by means of the random decrement technique; assessment of the results based on tests already carried out and also on damping parameters known from literature; the damping properties are a significant value for system identification, in particular an indicator of the current degree of exploitation of the load-bearing of a dam; therefore, during a dynamic test of a dam, the determination of the damping properties is necessary, in order to obtain a complete picture on the load-bearing behaviour.

Another result of the project was the realization of a program for supervising and analyzing integrate medium of hydrotechnical construction behavior named “UCCWAT”. The product targets are:

- “UCCWAT” realizing and integrating in one IT product almost all the necessary tools currently used in the supervising and analyzing activity of UCC;
- manual or automatic data acquisition in the territory and their primary processing (conversion, filtering, validation, recording and security);
- data transfer through communication networks (INTRANET, private networks, etc.) all over the country from the acquisition points to the analyze and decision authorized labs;
- mathematical modelling with multiple instruments in order to point out the evolution tendencies of the monitorized parameters;
- dynamic limits evolution of the modelling parameters with their continuous actualization possibility, in order to obtain operative information;
- assistance of authorized documentation developers in the field of hydrotechnical construction behavior analysis concerning the predefinition and typifying documents;
- achievement of operative component with a warning ability for the competent authorities (in conformity with the present laws and codes);
- experimenting mathematical models and the typified documentation through multiple implementation, validation and authorization processes.

UCCWAT is meant to be used within the National Authority “Apele Române” which has in its patrimony dams and other hydrotechnical structures, and which has already been implemented at the working locations of the three test-dams, together with their data command centers.

Finally, as it had been decided, on the seismic instrumentation of the “Paltinu” dam, the following phases were performed:

- preliminary phase (location of the instruments and their characteristics);
- intermediate phase (evaluation of the possible instruments on the basis of technical, financial and operational considerations);
- final phase (acquisition of the instruments).

The National Authority “Apele Române” will be in charge for the necessary preparatory works in view of the equipment installation (accelerograph supports, power, interconnection of cables, security etc.).

5. THEORETICAL ANALYTICAL STUDIES

A first, main, direction of these developments was concerned with the analysis of oscillations of dams. After some references to the formulation of the system of mathematical relations and problem, more detailed references were made to some aspects that raise at present several

difficulties while to be considered in engineering activities. The topics referred to were the dam-rock dynamic interaction, the non-synchronous nature of seismic action along the dam - rock interface and the theoretical need to consider non-classical eigenvalue problems while analyzing natural modes in order to derive solutions of the oscillation problem. Stochastic models were referred to in connection with non-synchronous actions. The eigenvalue problem was dealt with in the space of Laplace - Carson images of the functions of time occurring in the analysis of oscillations. A simple illustrative example put to evidence the features of the solutions (eigenvalues and eigenvevctors depending on the oscillation frequencies, transfer functions derived on this basis)

Another direction was concerned with the analysis of seismic hazard affecting dam sites. New expressions were derived for the recurrence functions of magnitudes, for the three most important seismogenic zones of Romania. On the basis of corresponding probabilistic convolutions, recurrence functions of intensities were derived in a parametric way for some dam sites of Romania.

A review of some main problems of monitoring of dams, mainly in relation to the seismic risk, was developed. A summary of activities and experience of Romania was presented. Some illustrative analyses of dam performance, developed by Californian institutes in cooperation with other institutes, were presented as suitable examples to be considered.

A summary direction in this field was related to a discussion of some needs of future developments. They concerned analytical problems and, also, needs of improving the equipment and, consequently the techniques, of experimental activities, including the development of appropriate accelerographic networks at dam sites.

6. DISSEMINATION OF THE RESULTS

The research results were disseminated for all major Romanian dam owners. Demonstrations regarding the development of the hybrid models and the definition of the global elastic modulus (GEM) were organized. The Technical University of Civil Engineering of Bucharest has organized courses for professional improvement addressed to engineers working in design and in the hydrotechnical construction behavior departments. During the research program 32 papers were published at national and international symposia and conferences.

In 2007, the dissemination of the results was realized during an international symposium organized by R.N.C.E.E.V.–T.U.C.E.B., where a special session was devoted to large dams in Romania.

The entire research program resulted in a better control of the structural safety of dams and risk reduction represented by these engineering structures and not in the final to the progress of general level of engineering knowledge.