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GEODYNAMICAL HAZARDS ASSOCIATED WITH LARGE DAMS

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Manfred Bonatz
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EUROPEAN CENTRE FOR GEODYNAMICS AND SEISMOLOGY (ECGS)

ASSOCIATED EUROPEAN CENTRE ON GEODYNAMICAL HAZARDS OF HIGH DAMS (ECGHHD) INTERNATIONAL COMMISSION ON LARGE DAMS (ICOLD)

Luxembourg, November 10-12 1997

"GEODYNAMICAL HAZARDS ASSOCIATED WITH LARGE DAMS"

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GEODYNAMICAL HAZARDS ASSOCIATED WITH LARGE DAMS

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Organized by the European Centre for Geodynamics and Seismology (EUR-OPA Major Hazards), the Associated European Centre on Geodynamical Hazards of High Dams (ECGHHD), the International Commission on Large Dams (ICOLD)

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Preface

One of the features which constitutes a basic condition for a creature to be understood as a human being is the capability to build tools. In the course of the human evolution the realisable dimensions of such tools extended in both directions, towards the extremes of minimisation and maximization as well.

In this context large industrial edifices can be designated as a very special sort of tools, since they are immobile and fixed to the surface of our planet Earth. In addition, part of these constructions contain a serious potential of threat, not only in the case of technical trouble but also as a consequence of the potential appearance of relevant and unpredicted geophysical phenomena, such as tectonic or tectonically induced events, or meteorological or meteorologically induced effects. Recent public confrontations however concern mainly the threat by nuclear power plants in the normal state an environment-protecting and resources-saving *tool* for the production of energy, but in the case of technical or human failures or in the case of natural disasters a potential source of danger indeed. Of course, by effective technical safety measures, on the basis of reliable geophysical risk assessments, the industrial nuclear hazard can be controlled. But this can only little help to lift the public discussion to a rational level, since rationally based conclusions and decisions claim scientific and engineering expertise and insight. It is even impossible to convey the term *probability* to the public as well as the insight to understand any risk in the context of the whole *risk budget* to which human being is exposed.

This remark should just sketch the field of ignorance and social tensions in which engineers and scientists who are concerned with the safety problems of large *tools* may have to move. Fortunately, *ideological* objections against the construction, operation and the safety control of large dams for the storage of water masses are generally much less than those against nuclear power plants, maybe for the reason that a mechanical threat is easier to understand and to assess than the threat by invisible radiation.

Nevertheless, the risk potential of large water reservoirs may differ in the different cases, depending on the local tectonic and tectonically induced conditions for instance, but it can of course **not be** regarded as negligible. Prof. Chelidze (Georgia) contributed recently a remarkable figure to the problem: if the dam of the huge Ingouri barrage in the Caucasus would burst under worst case conditions the human victims would reach a number of 500 000, at least. In other sites the situation may be similar. Of course, the application of scientific and engineering expertise to the constructions has provided a high standard of security, but this must not be misunderstood that the state of the art should no more be improved; since we are not only concerned with the construction itself but also, and maybe to a larger extend, with properties of the "platform" on which the construction has been built. Therefore, it is still one of the major responsibilities of a combined effort of science and engineering (in many countries it is reasonably not distinguished between science an engineering engineering is regarded as a science as well) to rise the standard of safety of large barrages, defining the construction and its physical environment as *one* system with two interacting main components.

These Proceedings of the Workshop on "Geodynamical Hazards Associated with Large Dams" convey a certain synopsis of the spectrum of problems and a certain summary of at-tempts of solutions having (under different technological constraints) been performed in the past and being presently under consideration. The workshop was to my relief *commonly* organised by three international scientific organisations: *the European Centre for Geodynamics and Seismology, the Associated European Centre on Geodynamical Hazards of High Dams* and *the International Commission on Large Dams*.

Manfred Bonatz

WORKSHOP: LARGE DAMS

Presidential Address

in Luxemburg Nov. 10th 1997

The historical traces detected at the surface of continents, testify sometimes the existence of an ancient construction, even more than 2000 years old, showing up a destiny to govern the behaviour of water mass to the benefit of men and their environment.

During more than 20 centuries these primitive knowledge has been evaluating to applications like:

1 . irrigation for agriculture

2.canalisation

3. alimentation in drink water

4.regularisation of rivers, lakes and ports to the benefit of navigation

5. long ranged dikes against floodings and to win land surface (Netherlands)

6. smaller and larger dams, especially in our century to provide mechanical and electric energy.

Artificial created water surface actually on Earth, shows up to more than 450.000 km2. About 60 larger dams exceed a surface of 1 000 km2 each more or less 12% of the world-wide watered surface on continents is controlled by artificial lakes.

Two outstanding problems raised by these hydrological technics are those of climatic influences on environment, the second one concerns the risks engaged by the geophysical impact of the water mass on the regional stability of geology, especially in the neighbourhood of inhabited valleys.

If a government points out the necessity of constructing a dam for one or several reasons, the scientific specialists and engineers are immediately advised to study the local hydrology, topography, geology, the environmental as well as the economical impact, the safety control system for the region, finally to study the rescue action in case of natural and technological disaster.

During the last century the system of dam-construction has changed considerably; the large heavy walls have been replaced if possible by thin arched constructions due to the system of pouring amorphous concrete into preconceived iron framework. Evidently mathematical knowledge became more and more complicated by this new, elegant method of performing dams, but the architectural and estetic shape of those technical buildings has reached a high level.

Encyclopaedias mention numerous large dams over the continents of the XXth century, some covering 2000, 5000 even 8000 km2. The surface of the Gr. Duchy of Luxemburg has only 2500 km2. Nevertheless our country succeeded to built 2 dams and one superior lake: in Esch s/Sure and - as a German Luxembourg co-operation - in Rosport/Vianden. Both installations serve the population partly as drink water reservoir, partly as hydro-electric energy source. In our country we are extremely satisfied to note a strong attraction on tourists.

During more than 3 decades, these artificial water columns are submitted to a severe periodical survey system fixed to a local geodetic network, which itself is G.P.S. controlled. The accuracy of distance measuring is given with O.3mm for mecometer instrument by the University of Karlsruhe. Regional geophysical observations are done by 3 component seismic recorders one place in the cellar of the castle of Vianden, the other Kalborn, 1 5 km north of Vianden.

Since several years this observation program on the surface of the superior lake of the electric central near Vianden has turned to a continuous research activity of Professor Manfred Bonatz, to whom we have the honour and the pleasure to listen in a few minutes.

Denis Diderot, father of the French encyclopaedia - 1780-said:

"I distinguish two actions to cultivate sciences: the first one is to increase the mass of knowledge by discoveries (inventions) - that is the way to deserve the title of inventor, - the following one is to co-ordinate the discoveries in order to enlighten more individuals, and to invite each one to participate, corresponding to his reach, to illuminate his century".

In the name of Luxemburg Government and the European Council, in the name of the belgo_luxembourg organisers of our European Center for Geodynamics and Seismology, I thank all the participants for enriching our workshop by their assistance. I wish to each one to feel welcome and comfortable as well as to complete a good task.

J. FLICK, President

Safety Monitoring of Large Dams Objectives and Problems -

M. Bonatz

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On behalf of the Scientific Committee of the Workshop on Geodynamical Hazards Associated with Large Dams I would like to welcome all participants of this scientific meeting. It is a great pleasure for me being able to state that we are about equally coming from both parts of the continent and its surrounding neighbourhood, those parts which had been separated for many -too many - decades for political and ideological reasons. It makes hope, at the end of a millennium and at the beginning of a new one in front of us, that intemational science will now expand without artificial constraints and will less be concerned with destructive applications of human intellectual and technical capabilities, but will concentrate on the real welfare of mankind.

Let me now reflect a little upon what the concern of this workshop is and which objectives could be envisaged.

IMPACT OF TECTONIC MOTIONS ON LARGE DAMS

Aleksandar Bozovic
Yugoslavia

Chairman, ICOLD Committee on Seismic Aspects of Dam Design

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1) Introduction

The tectonic phenomena active at present are a concern for dam designers since long time. The main interest in this respect was directed to seismic shaking and related consequences for the safety of dams. Very significant advances were made in this field , both in monitoring earthquakes and quantifying the input parameters and in analysing the dynamic response of structures. But the possibility of surface fault breaking and of areal creep form of crustal mobility were usually disregarded notwithstanding the fact that the surface fault breaking under the dam was always understood to be the most dangerous tectonic manifestation that can influence a dam. Crustal movements, affecting larger areas, are also of interest for the safety of dams. Due to scarcity of such cases, disregarding their effects in dam designs was ge4nerally statistically acceptable since to date no dam was fatally injured by tectonic movements of such nature. But the few near misses, the growing number of dams, the tendency to make use of less favourable dam sites and the growing awareness that the crustal mobility hazard is about the most severe influence that could affect the structural integrity of dams, gave rise to the conclusion that such possibilities are not to be treated as negligible but should be considered and analysed each time when indicated by prevailing tectonic conditions. Surface fault breaks and crustal mobility of larger areas are the two forms of crustal movements that can affect dam structures.

The tectonic movements active at present time, result generally in the formation of fault breaks and in areal creep movements. Both forms constitute the crustal mobility phenomena which can directly affect the dam sites and structures. From the viewpoint of dam engineering the objective is to collect and evaluate the related information on crustal mobility and to consider them in the design of dams and in evaluations of their safety in a reasonably conservative manner.

Seismic safety analysis of concrete dams. Methodology and examples of studies performed at EDF

Eric Bourdarot

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Abstract: Electricité de France (EDF) is in charge of operating more than 100 high dams in France. Although France is not a highly seismic country, most of these dams are located in mountainous zones: the Alps, the Pyrenees, or the Massif Central regions where earthquakes of intensity VII14X MSK have already been observed in the past. For these reasons, EDF's National Hydro Engineering Centre, in charge of the studies on hydraulic works, has developed methods for the analysis of the seismic behaviour of high dams. In this paper are described the French seismic context

and the global methodology for the reassessment of existing dams developed with the French authorities in charge of the safety regulations. Examples of seismic analyses performed on the dams at greatest risk (arch or gravity dams) are presented. The different levels of analyses which can be carried out are discussed and the need for improvements and research in this field pointed out.

COMPREHENSIVE EVALUATION OF ZEYA DAM SEISMIC RESISTANCE Savitch A.I., Bronshtein V.I., Groshev M.E., Strom A.L., Doudchenko L.N.

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The Zeya multipurpose hydroelectric scheme is intended for flood control in the valleys of the Zeya River and middle reaches of the Amour River, as well as for electric power sup-ply to the southern regions of the Far East.

The HES consists of concrete dam, power house located at the tow of the dam, 220 and 500 kV switchyards. The power house contains 6 generating units with aggregate capacity of 1290 MW and generation of 4.91 TWh/year. The dam is of gravity-buttress type with a crest length of 714 m and maximum structural height of 115.5 m.

The Zeya hydroelectric scheme, put into service over 20 years ago, is located in a seismically hazardous area featuring complex geology and rather poorly studied seismotectonic framework. When working on the design, the background regional seismicity was taken equal to intensity 6, while the project main structures were designed for an earthquake of intensity 7.

INDUCING EARTHQUAKES AND ENVIRONMENT: CASE OF RESERVOIR INDUCED SEISMICITY AT ASWAN / EGYPT

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Abstract: Some of man's engineering activities influence the way crustal stress are released in earthquake (Induced Earthquakes). The problem of earthquake induced by water reservoirs has attracted considerable attention of seismologists since the devastating earthquake of 1 979 in the region of the Koyna big water reservoir in India (M= 6.3).

An earthquake with M=5.6 on Nov. 14, 1981, in the vicinity of Lake Nasser at Aswan, occurred a few days after the peak reservoir level.

Aswan Seismological Network (ASN) was erected in the Northern part of Lake Nasser. A long sequences of earthquakes were monitored. For hazard mitigation and earthquake prognostic, the relation between filling of artificial Lake Nasser at Aswan and the seismic activities was studied. Different aspects associated with 1(15 at Aswan was discussed. It was found that the seismic activity at Aswan is a unique case.

INDUCED SEISMIC EVENTS NEAR BIG DAMS AND A SALT MINE IN BULGARIA

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1. INDUCED SEISMIC EVENTS NEAR BIG DAMS

There are several indications for the increased seismicity near two big dams in Bulgaria (Grigorova et al., 1976, Elenkov, 1981) - fig. 1 . In both cases the number of events, respectively, the emitted seismic energy is proportional of the dam fulfilling during the time of the water level seasonal changes in spring and fall. The first described case is connected with the biggest dam in Bulgaria - "Iskar", located near Sofia city (1970- 1971). The dam is situated (about 20-30 km apart) near a seismic active zone where the expected maximum magnitudes reach ***6.5-7.0.*** The distance between the dam wall and the surface ruptures observed during the strong earthquake (estimated M=6.5, Sept. 1 858) is also about 20-30 km. The observed earthquakes provoked by the dam fulfilling do not exceed the magnitudes of about 3 during the observation period. The continuous seismic observations since the first fulfilling (more than 40 years), no extreme events have been observed. Due to these facts the local seismic hazard induced by the dam didn't consider as potentially dangerous by the specialists.

The second case belongs to the "Kurdzaly" dam, which has a wall exceeding 80 meters and has been located in the Eastern Rhodopes (Elenkov, 1981). It shows similar behavior as a previous described case for the period 1975-1979. It is situated in old metamorphic belt river' 5 bed and the main peculiarity, keeping the dam semifull many years are the serpentine lenses and the local tectonic block structures. This was the explanation of the possibility to create a potential danger for the city of Kurdzaly, located in a few kilometers down the dam wall, due to the expected slide effects by these serpentine lenses and fault's instability. In this case a local seismic station has been built near the dam wall for the registration of the local seismic events, provided with a sensitive three component seismograph as well as a triaxial accelerograph. After more than 25 years of observations, without any accidents the dam was fulfilled and now operates with its full volume. This fact shows that such events are not enough to provoke earthquakes.

SEISMIC MONITORING ON DAMS SOME EXPERIENCE AND RELATED PROBLEMS

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1. **INTRODUCTION**

A high dam is a particularly important element in seismic risk evaluation of the wider dam site area, i.e., in the definition of the seismic risk of the area an which a dam is planned to be constructed. A large number of high dams in the world and in our country are located within high seismicity zones or in zones close to areas which were affected by string earthquakes in the past.

The earthquake phenomenon involves almost always numerous problems which cannot be solved exactly due to the lack of instruments for recording earthquake intensities and response of structures. Without such a record, damage and behaviour of structures during strong earthquakes cannot be compared to the seismic design criteria nor proper decisions concerning rational repair and reconstruction could be made.

Data on the ground motion during earthquakes to which structures are exposed and behaviour of structures are fundamental for seismic hazard evaluation, definition of design parameters and criteria and for all other dynamic investigations in earthquake engineering. Without such data all investigations and analysis that follow would be based on assumptions. The irregularity in earthquake occurrence makes difficult the possibility to obtain immediately the most useful data.

One of the possible ways to solve these problems is to establish a network of a greater number of instruments for recording ground motion and response of structures during strong earthquakes. The main objective in seismic monitoring of structures (high-rise buildings, dams, power plants, bridges etc.) is to facilitate response studies that lead to improved understanding of the dynamic behavior and potential for damage to structures under seismic loading.

TESTING THE TRIGGERING OF STRONG EARTHQUAKES IN DAM AREAS- AN APPLICATION IN POLYPHYTO DAM, GREECE

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ABSTRACT

A stochastic approach is proposed for testing the random or non-random occurrence of strong earthquakes in dam regions. An appropriate probabilistic model for the earthquake time distribution in the dam region is adopted and, then, the probability is calculated for the occurrence by chance of particular earthquake(s) within particular time interval(s) counted from the impoundement or significant water level variations in the dam. The application in the Polyphyto dam (NW Greece) the impoundement of which took place in 1974, showed that the occurrence of the strong earthquakes of *25* Oct 1984 (Ms=5.5) and 13 May 1995 (Ms=6.6) is non-random at the 0.93 probability level.

A STUDY OF THE RELATION BETWEEN THE MAY 13, 1995 KOZANI-GREVENA (NW GREECE) EARTHQUAKE AND THE POLYPHYTO ARTIFICIAL LAKE

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Abstract :
On May 13, ***1995*** a strong earthquake of Ms= 6.6 occurred at Kozani-Grevena (NW Greece) region. In the same region, several years before the earthquake occurrence, three dams have been constructed for hydroelectric purposes. The first one of them, the Polyphyto dam, is close (40 km) to the epicenter of the earthquake. In order to detect any relation between the earthquake and the changes of the water level in the nearby reservoir, the focal mechanism and the source parameters of the main event are examined as well as the foreshock and aftershock spatial and temporal distribution is checked. Based on all these independent information and data, the behaviour of the foreshock and aftershock activity does not support any correlation with the reservoir loading. Since 1 974, the changes of the water level are less than 15m. Such a change cannot trigger a large earthquake, according to the experience of other cases of induced seismicity. Therefore, the earthquake of May 13, ***1995*** is rather an ordinary event in the frame of the regional seismicity than an event triggered by the load of the artificial lake.

VALIDATION OF SEISMIC STABILITY OF THE TEHRI DAM ON THE BHAGIRATHI RIVER, U.P., INDIA

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Abstract

A the Owner's request the SHC Institute "Hydroproject" (HPI), Moscow has performed experimental and theoretical studies of local materials planned to be used for construction of the Tehri rockfill dam, 260 m high, with clay core. These studies allowed for the main physical-mechanical properties of soil and rocks to be specified:

Determination of design parameters of soil and rocks based on the experimental studies and their check-up by comparison of computational-theoretical forecasts and experimental data on specimens behaviour under different static and dynamic loading pattern;

. Seismotectonic analysis of the site which was the basis for recommending two synthetic accelerograms (MBT- 11 and SHR-41) to simulate seismic load on the Tehri Dam with peak ground accelerations of O.4g and *O.5g* respectively.

Based on the performed studies an alternative of the dam design has been selected which ensured its seismic stability with an earthquake simulated by MBT- 11 and SHR-41 accelerograms.

In 1995 the Owner requested to carry out additional studies for the dam to withstand an earthquake simulated by a chain of accelerograms of the Gazli earthquake from 30s to 40s duration (2 and 3 Gazli events following each other). In these studies the computations for the second event were based on the dam stress-strain state established after the first event which was adopted as the initial state. The stress-strain state obtained in the second case was adopted as the initial state in computations for the third event.

The review of the obtained data showed that displacements in all points of the dam body tended to stabilize after the earthquake and there were no zones in the dam body featuring progressive growth of deformations. The dam withstands the specified loads and serves the purpose. However, the level of residual displacements caused by one and the same load is different. So, in the first event the maximum horizontal displacement does not exceed O.80m, in the second event an additional displacement makes up 1 .80m.

The performed computational seismic stability studies of the Tehri rockfill dam convincingly showed that the dam would withstand three shakings following each other simulated by accelerograms of the earthquake at Gazli without any considerable damages.

THE MAXIMUM EFFECTIVE ACCELERATION AND THE EUROCODE PRACTICE

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Abstract

A feasible implementation of the EUROCODE-8 into the standard building practice does not need only strict definitions of input parameters used in the code but it needs

to find also ways how to apply them in various tasks. One of the parameters, which has not been yet exactly defined, is the maximum effective acceleration (EUROCODE-8 ENV- 1 988- 1 - 1). Designers are often confused by the combination of the maximum and the effective values together, because in a recent practice under the maximum value the peak or peak-to-peak values are usually understood, whereas under the effective value, introduced up-to-now by a few authors, only parts of this maximum value are considered. These parts relate directly to destruction effects of structures which are caused just by "effective" strong seismic vibrations.

Our paper describes one possible approach how the above mentioned philosophical and/or linguistic discrepancy can be solved. The approach is based on an application of the amplitude frequency distributions of the particle accelerations, velocities and displacements (Schenk 1*985* a,b) to effective particle ground motions determination, which allow the maximum effective values of these motions to be exactly defined. In this approach levels of the seismic vibrations effectiveness are defined with respect to the percentage occurrence of all sampled amplitudes of ground motion records. It gives a possibility to put together sorted ground motion amplitudes according to their values and tn define the particle accelerations, velocities and displacements which are responsible for the structure destructions. Their maximum levels are account as the maximum effective values. A few examples display methodological applications.

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INSTRUMENTING LARGE DAMS FOR EARTHQUAKE RESPONSE

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Summary

A dam network was created in 1 992 and 1993 in Switzerland. It encompasses 29 accelerographs placed in 4 dams. The aim is to observe the free-field motions at the dam sites, the motions at the abutments and the dams' dynamic responses and characteristics. The installation took place according to clearly defined observation goals that led to specific array configurations and instrument specifications. Events have been recorded and a preliminary interpretation made.

FRACTAL MECHANICS AND PHYSICAL PROPERTIES OF FOUNDATION ROCKS

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Abstract

In this paper the problems of mechanical stability (fracture) and elasticity of heterogeneous (damaged) materials, including fractured rocks, are surveyed. It is shown that in many cases the classic methods, namely linear fracture mechanics and self-consistent theories of elasticity, are not sufficient to understand mechanical behavior of composites and that fractal mechanics approach is necessary to explain experimental data.

STATE OF CRACKS AND STABILITY OF CONCRETE DAM EXPOSED TO STRONG EXCITATION

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INTRODUCTION

The subject of this study is application of modem principles in mathematical modeling of concrete gravity dams for analysis of their static and seismic stability under strong earthquakes. The applied principle in mathematical modeling and seismic analysis is prediction of the occurrence of cracks into the concrete mass and their propagation through the dam body. The stability criterion for the structure is established based on the level of propagation of tensile stresses into the dam body. The applied numerical methods for solving of the seismic stability of the dam are explained separately. In the process of proving of seismic stability of gravity dams, the following stability states have to be checked:

Stability against sliding of the dam at plan;

. Stability of the dam against overturning in respect to the critical point of rotation of the dam;

Stress-strain state of the dam body.

TWO DIMENSIONAL NONLINEAR DYNAMIC ANALYSIS OF ROCK FILL DAM

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Due to the extremely nonlinear character of soil media , they are treated nonlinearly, using the Mohr-Coulomb's criterion regarding the ultimate bearing capacity which is characteristic for the friction material media. The investigations are performed by consideration of effective stresses wherefore the distribution of pore pressure through the coherent media is analyzed previously. The differential equation of motion is ' solved by using the incremental step-by-step linear acceleration method which incorporates the Wilson-® method for direct integration Within each time increment, conducted is the iterative procedure referred to as "Load Transfer Method" which enables balancing of the residual forces and satisfying of the dynamic equilibrium conditions within the considered time increment. A comparison between the obtained nonlinear dynamic response and the linear response of the system is made. The stability of the structure is checked by its both linear and nonlinear treatment.

The Mohr's hypothesis for failure and the Coulomb's equation for ultimate bearing capacity incorporated into the Mohr's diagram are known as the Mohr-Coulomb's criterion for ultimate bearing capacity representing an extension of the Tresca's criterion and its adaptation to frictional materials. According to this author, the critical shear stress is a ftlnction of the normal stress acting along the normal of the potential octahedral plane, the cohesion and the angle of internal friction. The normal stress in the octahedral plane is the mean stress, which means that the Mohr-Coulomb's criterion for yielding takes into account the spherical component of the stress tensor which is another difference from the Tresca's criterion and the criterion of maximal distorsional energy of von Mises, where yielding is determined only from the deviation component. It is proved that the behavior of soil and its resistance are controlled by the spherical tensor wherefore it must not be neglected. Also, the spherical tensor affects the ductility of the material, i.e., under higher spherical stress, the soil has the capability of developing larger deformations prior to failure.

ENGINEERING STABILIZATION OF LANDSLIDE SLOPE AT ZAGORSK PUMPED-STORAGE PLANT AND MONITORING OF ITS STATE AND BEHAVIOUR

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The experience gained in designing and construction of pumped-storage plants on plain rivers in Russia and C.I.S. (the Zagorsk, Central, Kanev, Dniester and Lemngrad PSPs) showed the following regularity: selection of the areas featuring intensively rugged topog_raphy for their location with maximum difference in elevations inevitably involves complicated engineering-geological conditions. This is an anomalous topography for plains, usually accompanied by geological anomalies. High slopes composed of loose rock are usually subject to various gravitational processes and landslide formation. Location of power houses with turbines set at a great depth at the foot of bank slopes whose natural state is often close to limiting state actuates gravitational processes.

Landslide control activities were a matter of great difficulty at the construction of the Zagorsk PSP. Great efforts were required to overcome these difficulties.

FULL SCALE DYNAMIC TESTS ON KEBAN DAM

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INTRODUCTION

This paper involves the results of full-scale dynamic tests performed on Keban Dam, a modern rock-fill dam in Turkey. This dam was chosen for the experimental studies because **it not only typifies** many rock-fill dams in seismic areas, but it also has been identified for strong motion instrumentation. The purpose of the full-scale experimental work was to gather experimental data concerning its dynamic characteristics which could then be used to test and develop various analytical and numerical methods for computing the natural frequencies and mode shapes of dams, particularly for predicting their earthquake responses. Full-scale dynamic testing of earth and rock-fill dams is a well known procedure with applications in USA, Japan, former Soviet Republic, former Yugoslavia, Turkey and other countries (Abdel-Ghaffar et al., 1978, 1980; Atrakova et al., 1980; Erdik et al., 1980; Gazetas and Abdel-Ghaffar, 1981; Keightley, 1964, 1966; Okamoto, 1973; Paskalov et al.,(1980); Perovski et al. (1974) and Yanagisawa (1980).

INDO-GERMAN RESEARCH COLLABORATION ON IN-SITU PORE PRESSURE STUDIES IN THE KOYNA REGION, INDIA (ext.Abstract)

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1 Introduction

The Koyna-Dam-Reservoir (Shivaji Sagar Lake) in Maharashtra, India, is stimulating the highest rate and level of seismicity worldwide since its first impoundment in 1 962. The strongest event, a M6.3 earthquake, occurred in 1967, claiming about 200 lives. More than 150 earthquakes of magnitude >= 4.0 have been recorded over the years till now, mostly restricted to an area 40 x 25 km2 south of the Koyna-Dam. This marks the area as probably the best in the world to study the phenomenon of reservoir induced/triggered seismicity (RIS). The height of the Koyna-Dam is 103 m, reservoir volume is 2780 x 106 m3; seasonal fluctuations of the lake level are typically 30 to 35 m and dominated by monsoon rainfalls (Gupta, 1992; Gupta et al., 1997).

CHANGES IN PROPERTIES AND STATE OF THE SAYANO-SHUSHENSKAYA DAM FOUNDATION UNDER OPERATION

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The Sayano-Shushenskaya hydroelectric scheme is the largest hydrodevelopment in Russia. It is located in Eastern Siberia in the upper reaches of the Yenisei River and it had been built in complex geological conditions. At the dam site, the Yenisei valley has a canyon shape with steep walls rising 800-900 m above the water level. At the flood plain level, the valley is 360 m wide. The valley bottom and its flanks are composed of hard crystalline ortho- and paraschist cut by branching diabase dikes. At a depth of 200- 1 000 m from the dam base it consists of granite. The rock mass is of a blocky structure split by 6 principal sets of steeply and gently pitching joints accompanied with thick (up to 5 m) zones of heavy jointing. These zones are traced to a depth of 30-40 m from the dam base. Heavy zones of weathering are developed especially in the left bank abutment.

The hydroelectric scheme consists of concrete dam, power house at the toe of the dam, spillway with stilling basin. The reservoir impounded by the dam has a storage capacity of 31 .3 cu.km and 320 km length at the full supply level of *540* m. The live storage (the maximum drawdown 40 m) is 15.3 cu.km.

The concrete dam is an arch-gravity structure 242 m high with the crest length of 1068 m. The dam is 105.7 m wide at its base and *25* m wide at the crest. The concrete volume of the dam body is 8.65x106 cu.m.

According to the present-day notion, each engineering structure during and after construction affects the geological environment which serves as its foundation or host media. This impact may consist in transmission of compressive and shearing stresses onto the foundation, changes in the thermal regime, water saturation or drying up of the rocks. In their turn the structure can be subjected to impact of geological and hydrogeological processes taking place in the geological environment especially in its near-surface zone (seismicity, karst formation, slides, leaching, piping etc.).

MONITORING OF REGIONAL AND LOCAL GEODYNAMIC PROCESSES IN AREAS OF HIGH DAMS IN C.I.S.

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On the territory of Russia and C.I.S. more than 3500 large dams intended for power generation and water management as well as several hundreds of industrial wastewater storages are in operation at the present time.

The largest and potentially most hazardous are the hydraulic structures incorporated in hydropower plants, such as the

Ingouri HPP in the Republic of Georgia with an arch dam, 271.7 m high, the Chirkei HPP in Daghestan (Russia) with an arch dam, 232 m high, the Sayano-Shushenskaya HPP in Siberia (Russia) with an arch-gravity dam, 242 m high and many other hydropower developments.

Majority of those projects indicated in the Table have already been in operation for several tens of years. The results of performed examination demonstrated that a number of these dams are in unsatisfactory condition.

The analysis of the behaviour of operating high dams gives all reasons to suppose that their unsatisfactory present-day state is mainly the result of:

- incompliance of the design and actual natural environment conditions of operation of the structures, and

- inadequate consideration during design, construction and operation of the projects of site-specific regional and local geodynamic processes caused by both natural and technogene factors.

High seismicity of the region is the most important factor determining geodynamic conditions of the areas of the majority of high dams in the Russia and C.I.S. Several dams the Zeya, Toktogul, Rogun, Kambarata - are located near earthquake generating faults which can be the sources of earthquake of M**max >7** 0 Sometimes active faults are located in the immediate vicinity to dam foundations. Such faults are detected at the Rogun and Kambarata dam sites.

GEODYNAMIC INFLUENCE OF THE SAFETY OF THE HIGH-HEAD DAMS

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The operation of high dams (Table 1) has already indicated a whole series of new phenomena: for example, changes in the stress state of the near-surface portion of the earth's crust during interaction with the structure, the opening of contact cracks and loosening of rock beds, anomalies in piezometric readings, induced seismicity, unstable rock masses in the area, rock deformations downstream, river bed degradation and eventually even coastal erosion.

Retrospective analysis of records of field observations conducted at all the high dams in the CIS has revealed the presence of significant geodynamic influences (1) in effect an active response of the geological environment to the technogenic "interference on the earth's crust. These effects can manifest themselves in various different ways, including: induced (or increased) seismicity; creep, landslides; the collapse of large rock masses, and changes in the hydrogeodynamic regimes and stress fields in dam foundations (Fig. l).

METHOD OF THE SEISMIC OBSERVATION ON SPANDARIAN DAM (ARMENIA) IN CONNECTION WITH HIGH SEISMICITY OF THE REGION

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Armenia is the country with high tectonic and seismic activity. It is situated in the continental collision zone between Arabian and Euroasian lithosphere plates. Strong and destructive earthquakes occurred here from time immemorial. In recent 70 years many dams of big and middle height were built on mountain rivers. Providing of seismic safety' of large dams in Armenia is a essential scientific and technical problem.

MONITORING OF DAMS OF ARMENIA AND ASSESSMENT OF OPERATION RISK

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Construction of dams in Armenia was conditioned closely with development of agriculture and energetics. Provision of service safety by organization of monitoring of dams is an essential technical problem.

Physical Geography

Armenia is a country with about 400km length and 200 km width.

Population of Armenia exceeds somewhat 3 million and 1/3 (a third) part of it lives in Ararat plain accounting for about 1/10 part of the land surface. 90% of the territory is situated at a height of more than 1000m. A natural source of energetics and water supply is Sevan lake situated at a height of about 2000m (area 1 400 km2, volume 58.5x1 09m3) and a small number of rivers having great variations of discharge.

On the whole, Armenia has favorable topographic conditions for dam sites, especially within the boundaries of the Central volcanic upland which is at a high level in relation to Ararat plain and is the main agricultural consumer of water. On the other hand, seismicity is of high level in Armenia and large scale earthquakes occur with high recurrence over the whole territory. The difficulties of topographic, geological and seismic conditions of the country make high demands of projection, building and operation of dams.

MULTIPARAMETER MONITORING IN PREDICTION OF GEODYNAMIC CONDITIONS INSTABILITY

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Regarding the geological media in the terms of the mechanics of solids one may consider the conceptual model by which the tectonic deformations (understood in the broadest sense) create in the vicinity of the Earth's heterogeneity strains, equalization of which or discharge may proceed slowly or rapidly, causing plastic flows or brittle (quasi-brittle) destruction. The last one is of the main interest for us.

Mechanical processes that are responsible for energy accumulation, of a scale that causes earthquakes, can hardly proceed without been reflected in time histories of natural fields described by the functions, arguments of which contain the parameters responsible for the stress and strain distribution in the volumes considered. Such a function - the carrier of some phenomenon anticipating the 1055 of media stability (landslide, shock bump, earthquake) or the precursor is supposed to be any realization of the physical, chemical or any other natural process been recorded in which, according to investigator's heuristics, the precursor signal may occur. The precursor will be understand as such a change of stationarity in behavior in time of function-carrier , that with sufficient probability may be related to the future (seismic) event.

The earthquake prediction problem may be approached using two situational models. The precursor signal appearance in the first one is controlled by the conditions in comparatively small volume of the source zone. The time variations of these conditions may by studied passively by recording the seismic emission, or actively, "illuminating" the source zone by elastic or electromagnetic waves. In this case the location of the emission and recording points is not critical.

The second model regards substantially grater volume of geological media as the space of precursor signal generation, and the last ones are considered as the anomalies of natural fields time histories. As it was mentioned before, it is supposed that the arguments of the function - precursor carrier contain the parameters the change of which is controlled by the earthquake preparation process. Contrary to the first model, the search for the function-carrier and information channel (point of observation) becomes the main problem.

The geological evaluation of faults (obvious defects of geological media) efficiency as the channels of precursory information transmission is not obvious, because the geological evidence, containing relative age and activity data, may provide only indirect estimations. Besides, the fault activity level is very essential factor in safety assessments of high risk industrial objects situated in close vicinity.

REGIONAL GEODYNAMIC NETWORK "SUDETEN" (the Eastern Sudeten Area, the Czech Republic and Poland). Its Relation to River Dams

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Summary: In 1997 the regional geodynamic network SUDETEN was established in the Eastern Sudeten, covering broad neighbouring regions of the Czech Republic and Poland. On the territory of the Czech Republic the network contains altogether 1 0 GPS measuring points. The GPS points, in a form of concrete blocks, were built on places of hard rock outcrops and/or very stable structures. In the area still four other GPS networks operate. One is the regional network MORAVA, which partly overlaps the network SUDETEN in its southern part, and other three local networks S'NIEZNIK, STOLOWE Mts. and PACZKO'W investigate movement potentials of selected Sudeten fault zones and their effects to water reservoirs Otmuch6w and Nysa. It means that the regional network SUDETEN does not monitor only the recent geodynamic processes occurring in a large area in the Central Europe but also creates an umbrella to all existing GPS networks.

The first GPS campaign was realised in August 1 997. The accuracy of determination of coordinates was below 1 mm.

GEODYNAMICAL PROCESSES ON THE BANKS OF THE WATER RESERVOIR NECHRANICE

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Abstract:

The dam and water reservoir Nechranice as the largest earth dam is also one of the biggest water reservoirs concerning surface area and volume of dammed water in the Czech Republic. The dam was built in very unfavourable geological conditions, but without any technical defects. The inundation area of the dam, through which an important tectonic fracture

runs, consists mainly of tertiary rocks and to a lesser degree, of crystalline rocks. However, certain secondary effects appeared in a scale not predicted by the results of the geological survey.

The analysis of development of exogenous processes on the Nechranice water reservoir banks shows that even after twenty-eight year-long period of operation of the dam no consolidation of the process of bank line deformations has been established. On the contrary, in areas formed by Quaternary sediments of the Ohre river terrace where only sorting of gravel on the beach took place, today very intensive abrasion and landslide processes can be found, we meet cliffs as high as 6 m.

BEHAVIOR OF INGURI DAM DURING THE FIRST 10 YEARS OPERATION AFTER THE FIRST FULL FILLING OF THE RESERVOIR

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Introduction

With its installed capacity of 1 300 MW, Enguri is the largest hydro-electric scheme in Georgia. The Enguri hydro-electric station including the 271 ,5 m high arch dam (the world's highest arch dam), a deep tunnel-type water intake, a Pressure tunnel, 15 km long and 9,5 m, in diameter the underground power station with five 260 MW generating units.

Enguri dam itself was completed 1 984, Construction of the dam began 1 965 . The first concrete was placed in 1 97 1 . The reservoir was progressively impounded since the years seventies and was completely filled for the first time in 1987.

MONITORING OF GEODYNAMICAL PROCESSES AT LARGE DAMS BY TILTMETERS AND STRAINMETERS; EXAMPLE OF INGURI HPS (GEORGIA)

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Construction and operation of modem large hydro-engineering objects with large water reservoirs exerts an essential influence on the environment, causing considerable changes in the physical fields in the zone where an interaction of these structures with their basement and environment occurs. Hence the development of geophysical criteria of geoe_cological monitoring becomes a task of the primary importance, since such a monitoring enables one to observe and predict dynamical processes connected with construction and operation of large water development projects. That was the main reason for us to con-duct tiltmetric and stainmetric studies combined with other geophysical methods in the Inguri HPS area. This work is of extreme importance, since the Inguri HPS was constructed in one of the seismoactive and densely populated regions of Georgia.

However geomorphological data alone could not provide a unique quantitative solution of the problem about an extent of recent movements of individual blocks. Therefore the Institute of Geophysics of Georgian Academy of Sciences carries out stationary geo_physical studies in the Inguri HPS area with the following objectives:

I to determine background values of recent vertical tectonic movements of the Earth's crust in the arch dam construction area;

II to establish the intensity and direction of tectonic movements of structural blocks geo_logically identified under the dam construction;

III to study the behaviour of expected crustal deformations caused by technogenic processes (excavation of the dam foundation pit, placement of concrete into the dam body, filling and operation of the reservoir);

IV to establish optimal norms for water level regulation in the reservoir that would en-sure a safe operation of the Inguri HPS.

GEODYNAMIC PROCESSES AT THE INGOURI DAM AREA

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Introduction

The Ingouri HPP on the Ingouri river in Western Georgia has been constructed and operates in difficult geological conditions. Regional tectonic dislocations such as the Ingirishsky fault and Tkvarchel flexure are occurring in the dam area, the dam centreline crosses the right-bank fault and nearly 20 large tectonic fractures of higher orders. Seismicity of the area is 8 points of intensity.

The arch dam, 271 .5 m high with the total volume of concrete, nearly 4x10 6 cu.m and the reservoir of 1.1 x l09 cu.m capacity have a considerable effect on the pattern and intensity of geodynamic processes at the dam area.

Complicated natural conditions of the area and the size of the structure have governed the necessity of monitoring of natural and technogenic geodynamic processes.

Geodynamic monitoring here was started during construction (in the mid of the seventies) and continued till 1991 -92. The last examination of the dam foundation and body has been fulfilled in 1996.

SEISMICITY AND SEISMIC HAZARD ASSESSMENT OF THE INGURI ARC DAM TEST AREA

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Review of seismological study of the Ingouri dam area

Seismological studies of Ingouri dam area have a certain tradition. In 1 962-63 seismol_ogical field experiments were carried out on the territory of projected high dam, but only after creation of local seismic network in 1 972-76 the detailed seismological study of the area became possible. In 80-ies the threshold magnitude of recorded events has been sig_nificantly decreased and accuracy of determination of earthquake parameters has been increased due to the farther development of the local network.

Several scientific investigations had been carried out on the basis of local and regional seismic data. The results of these investigations are given in scientific reports (Murusidze 1980, Murusidze at el.1983; Savich at el. 1981; Litanishvili at el. 1989; Gotsadze at el. 1 990; Varazanashvili at el. 1 992). It should be noted, that relatively short period of seismological study (about *25* years) is partially compensated by high level of geological and geophysical study, as well as by the data about historical seismicity and paleoseis_modislocations. These data allows us to carry out comparative 3D study of geological and seismological structures with real geometrical dimensions (faults, sources) on the basis of seismotectonic similarity principal. The direct result of the studies is delineation of seis_mic source zones (SSZ) and their parameterisation

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ON THE STUDY OF THE INGURI ARCH DAM SETTLINGS BY GEODETIC METHODS

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Since 1972 and up to now, i.e., over *25* years the Chair of Engineering Geodesy and Mine Surveyance of the Georgian Technical University in cooperation with the Topogeodetic Department of the 11Tbilhydroproject" and some other organizations has been carrying out the observations of the Inguri hydro electric power station dam, as well as of the banks of the river Inguri.

In 1 972 we carried out 3 cycles of measurements in the high-level reticule of the dam which after removal of the river deposit of about 40 m thick, showed the nsing of the rocky foundation of the dam up to 2 mm. During the next years up to 1 978, when the first section of the station was put in operation, the Chair was implementing 2-3 cycles of levelling per year observing the growth of settling marks on the dam base with the limits of approximately 1 OO m from the site of the dam. Settlings were within the limits of expected magnitudes [1] and did not excite any special anxiety. As the dam was being erected the marks were set on the base and on the downstream face of the dam. This made possible to determine the settlings of the dam itself.

Before the first section of the station was put in operation, the Chair spent a lot of time on studying the high-precision levelling technique and the environmental conditions in the canyon of the river Inguri. The researches were carried out using statistical methods. They proved that the differences of adjacent stations and sections in the reticule were independent and that the results of levelling during different seasonal conditions were of equal precision and normally distributed. Further, it became evident that on wind-protected route sections with excessive inclines an intensive accumulation of systematic errors was taking place. Besides, it became clear that measurement conditions near the dam differed from those in other parts of the reticule. These studies also revealed that during construction the dam settled non-uniformly and tilted in the direction of the upper water by approximately 23'.