Forecasting of extreme hydrodynamic action in hydrosystems and environmental protection

The head of scientists teams

Professor Gela Kipiani

Secretary-General of the Georgian National Committee
of Theoretical and Applied Mechanics
Full Professor of the Department of Engineering Mechanics
of Georgian Technical University
M.Kostava 77
TBILISI 0175
GEORGIA
gelakip@mail.ru
gelakip@gmail.com
Tel : +995 32 2371984 (office)
+995 32 2342571 (home)
+995(8)599 106263 (mob)

Project Summary:

Large seismic-induced landslide could lead to the generation of waves in natural and artificial reservoirs leading to the overtopping of dams with impacts along up and downstream resulting in tremendous facilities and property damage, and life loss.

The main objective of this proposed project is to develop and apply hydro and geodynamic methods for the prediction and assessment of the effects which these extreme waves on a dam, the bank slopes of reservoir and the adjacent environment. In the project, a number of hitherto unconsidered problems are identified. They are concerned with (1) extreme waves overtopping the dam crest and probability of such events, (2) 3-D wave processes in reservoirs caused by a large landslide mass propagation into the water or a seismo-technical displacement at the bottom of reservoir (time-depended boundary problems), (3) hydrodynamic pressure at the dam under vertical seismic oscillatory actions (short-term prediction and estimation of the risk hazard due to the extreme waves impact), (4) determination of the kinematical and geometrical parameters of landslide and seismotectonical movements, (5) working out the applicability criteria of theoretical methods proposed, and (6) simulation of waves in the reservoir created by the world's

highest Enguri arch dam (H=271.5 m) in Georgia, estimating the risk of disaster and environmental impact assessment (EIA).

The hydrodynamic processes considered and the character of their impact will be described on the basis of mathematical modeling. Solving of the corresponding boundary value problems numerically might require the transference to the curvilinear coordinates and using the transformed equations for numerical integration. Analytical solutions might require the use of integral transform.

In the project, EIA methods will be developed that include a number of computational techniques, computer programs, practical recommendations, etc. The assessment of the adverse environmental impact caused by natural (earthquakes, landslides) and man-made disasters will be assessed.

The results of this project will serve as a reliable basis for making appropriate and rapid management decisions for technical, economical and social needs to ensure reliable operations of hydraulic works and to prevent (or minimize) ecological hazard to adjacent regions. The results would contribute to the scientific and engineering literature that is applicable to regions of critical importance in Georgia.

Project Description:

1.11 Introduction

What's the problem?

The importance of the problem under consideration in the project is stipulated by the following: at design and operation of hydro-projects in mountain and seismo-active regions is urgent to carry out reliable and accurate prediction of high (extreme) waves parameters in reservoir caused by natural (earthquake, landslide phenomena) and man-made disasters in order to make environmental impact assessment (EIA) of the waves and reservoirs monitoring purposes, to ensure safe operation of the dam and to minimize (or eliminate) extreme waves adverse (or catastrophic) effect on adjacent regions. Also, the development of the special "protective" structures to mitigate the intensity of extreme waves processes at dam site and upstream zone of reservoir is of high importance.

1.12 Literature Search

What are other people doing?

The generation of large devastating waves in natural and artificial reservoirs of mountain regions may be caused mainly by the rapid landslide mass impact or seismotectonical deformations at the bottom of reservoirs. These waves, which may be called landslidegenic and seismogenic (or impulse) waves are similar to tsunami waves, however, as opposed to them, they possess a number of specific properties concerning their transformation, interference, etc [1, 6, 7, 38, 40, 46].

History knows many cases of generation of gigantic impulse waves in reservoirs, their overtopping of dam crest and transformation along up- and downstream resulting in tremendous fatalities and property damage. The catastrophe in the River Viont Valley (Italy, 1963) is but one example; a mass of rock of about 250 mln. m^3, moving at 25-30 m/sec slid in the deep reservoir. The resultant overtopping wave of 70-99 m devastated the populated area of its downstream, causing heavy loss to both life and property [1, 38,40). Similarly, numerous instances of large seismogenic and landslidegenic waves have been observed in many natural reservoirs (lakes, fiords, bays) all over the world (Alaska, Switzerland, Norway, USA, Japan, Peru, etc.) [1, 38, 40, 51, 53].

The reservoirs created by high dams have significantly changed the natural strain-stress state of their bank slopes, intensified the filtration and rheological processes, significantly increasing probability of large landslide and landfall phenomena [30-33].

As shown in analysis [38] seismic movements of the ground in the type of oscillations will cause seismogenic waves on reservoir water surface of not high amplitude (with the exception of resonance condition, when the seismic progressive wave is propagating along the reservoir bottom). On the other hand, waves arising during earthquakes and caused by primary residual deformations or seismotectonic displacement (STD), may be of considerable amplitude [22, 38, 46, 55]. Therefore it is important to predict the height and period (and in particular, the possible duration of the water level maximal rises at dam site) of such tsunami-like waves when design dams (especially high earth dams) or in their operation in seismic zones with complex geological and tectonic conditions [42, 43].

The above mentioned problem has particular interest for the Caucasus region and for many other countries (such as Italy, France, Greece, Romania, Turkey, USA, Canada, China, India, the South America countries, etc.), which are characterized by high seismicity and complicated geological conditions considering in addition, that a number of deep reservoirs and high dams are located there. Obviously, it is vital to predict the extreme wave's environmental impact accurately enough to carry out the proper engineering procedure and implement urgent measures to minimize or eliminate the potential hazard [14, 15, 38].

In mathematical modeling of wave processes in reservoirs, mainly the following two approximate theories are used: 1. the small-amplitude wave (SAW) theory, wherein fluid is assumed to be ideal, incompressible, whereas motion to be potential (or non-rotational), governing equations and boundary conditions being linear; 2. the shallow water (SW) theory, using the non-linear equations wherein water depth is assumed small relative to certain characteristic measurement (e.g. the wavelength); the essential assumption, however, is that the component of water particles acceleration along the vertical axis is negligible and therefore the pressure yields the law of hydrostatiscs [38, 39, 47].

A large number of theoretical and experimental works were committed to the important problem under study. In the first theoretical papers [5, 41) two-dimensional (2D) extreme waves were described based on the SAW theory. Further investigations on mathematical modeling of the waves were developed in Georgian Institute of Power Engineering and Power Structure (GIPEPS) mainly on the basis of SAW theory [6-13] and in other scientific centers in USA, the USSR, Norway etc. using primarily the SW theory [24, 37, 44, 52]. In that case however, waves process simulation will be appreciable in general, only for relatively shallow water basins, as the horizontal velocity in this case is accounted constant [47]. Some works are concerned with probabilistic approach to forecast extreme wave processes [21, 48, 49, 54].

In some works the main parameters of extreme waves are assessed on the basis of the empirical relations [25, 45] or the approximate procedures [28].

Also a number of physical tests were performed on the models of real fragments of reservoirs or lakes as well as on hydraulic flumes in Austria, Switzerland, Norway, Bulgaria, USA, the former USSR, France and etc [38, 50]. In particular, R.L. Wiegel and D. Camotin carried out model studies of seismogenic oscillations of Hebgen Lake (Montana, USA) [55, 38].

D.D. Davidson and B.L. McCartney were investigated in the model of the part of reservoir (on the scale 1:120) the waves which might be generated by two large landslides near the gravitational Libby dam (height=120 m) (Montana, USA) [38].

E. Neuhauser with the Tyrol Hydroelectric Co. studied landlsidegenic waves in the model of Gepach reservoir (1:500) with boulder dam (height=115 m) (Austria) [38].

In Technical University of Norway J.Eie and G. Soldenberg et al were studied such waves in the models (1:500) of two lakes [38].

M. Towson and Y. Kaya were simulated waves in Lake Botnen created by the landslide [50]. Also, V.M. Liatkher and A.H. Militeev (from "NIC Hydroproekt" in former USSR, Moscow) were modeling one-dimensional wave flow caused by the landslide {37].

B.N. Ostroverkh (Ukraine Institute of Hydromechanics) and T.L.Gvelesiani (Georgian Technical University) carried out mathematical modelilg of landslide waves in Getik reservoir (Armenia) (see J. "Hydrotekhnicheskoe stroitelstvo". Moscow, № 12, 1989). T.L. Gvelesiani have a variety of works on extreme waves generation (are pointed in Reference and in p. 1.15)

G. Jinjikhashviili (the Israel electric Corp.) is the coauthor of number of articles dedicated to landslide waves researches [8, 14, 29].

A. Chait (NASA, John H.Glenn Research Center, USA) studies wave oscillations in water basins and is a practitioner in large scale computational fluid dynamics [23].

The most comprehensive experimental investigation of plane and spatial wave processes have been carried out by A. Huber of the federal institute of technology (Switzerland, Zurich) [25, 26].

The main objectives of above mentioned numerous theoretical and experimental investigations were caused by necessity to obtain the reliable results for designing of different dams in regions with complex geological conditions and for development of corresponding preventive measures from possible hazards, which might be caused by the extreme hydraulic (waves) actions.

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1.13 Purpose and Objective

What are we going to do?

The problem of investigations is related directly to design and operation of hydro-projects in mountain and seismo-active regions when it is urgent to carry out reliable and accurate prediction of high (extreme) waves parameters in reservoir caused by natural (earthquake, landslide phenomena) and man-made disasters in order to make environmental impact assessment (EIA) by these waves and reservoirs monitoring.

So the primary objective of the project is developing the new refined technique based on mathematical modeling for the explicit description of whole processes of high (extreme) waves motion caused by landslides or earthquakes in mountainous reservoirs including the reliable prediction procedures of environmental impact, exerted by that waves, in order to prevent or eliminate potential hazards to adjacent regions, as well as to ensure adequate secure conditions for hydropower plants operation. The special "Protective" structures to mitigate the intensity of extreme waves processes at dam site and upstream zone should be worked out too.

As was mentioned above in spite of a wide variety of the above investigations connecting with the problem under study, a number of problems are far from being solved completely. Therefore, part of the experimental results, as well as the observation data can't be explained well enough by the existing theoretical approaches.

Considering these aspects in the project a number of hitherto unconsidered problems using the hydro and geodynamic methods are developed; they are concerned with: extreme waves overtopping the dam crest and probability of such events; 3D wave processes in reservoirs caused by a large landslide mass propagation into the water or a seismo-technnical displacement at he bottom of reservoir (time-dependent boundaries problems) (Fig. 1 and Fig. 2); hydrodynamic pressure at the dam under vertical seismic oscillatory actions (Fig. 3); short-term prediction and estimation of the risk hazard due to the extreme waves impact; determination of the kinematical and geometrical parameters of landslide and seismo-tectonic movements; working out the applicability criteria of theoretical methods proposed; simulation of waves in the reservoir created by the world's highest Enguri arch dam (H=271.5 m) (Georgia) and estimating the risk of disaster and environmental impact assessment (EIA)

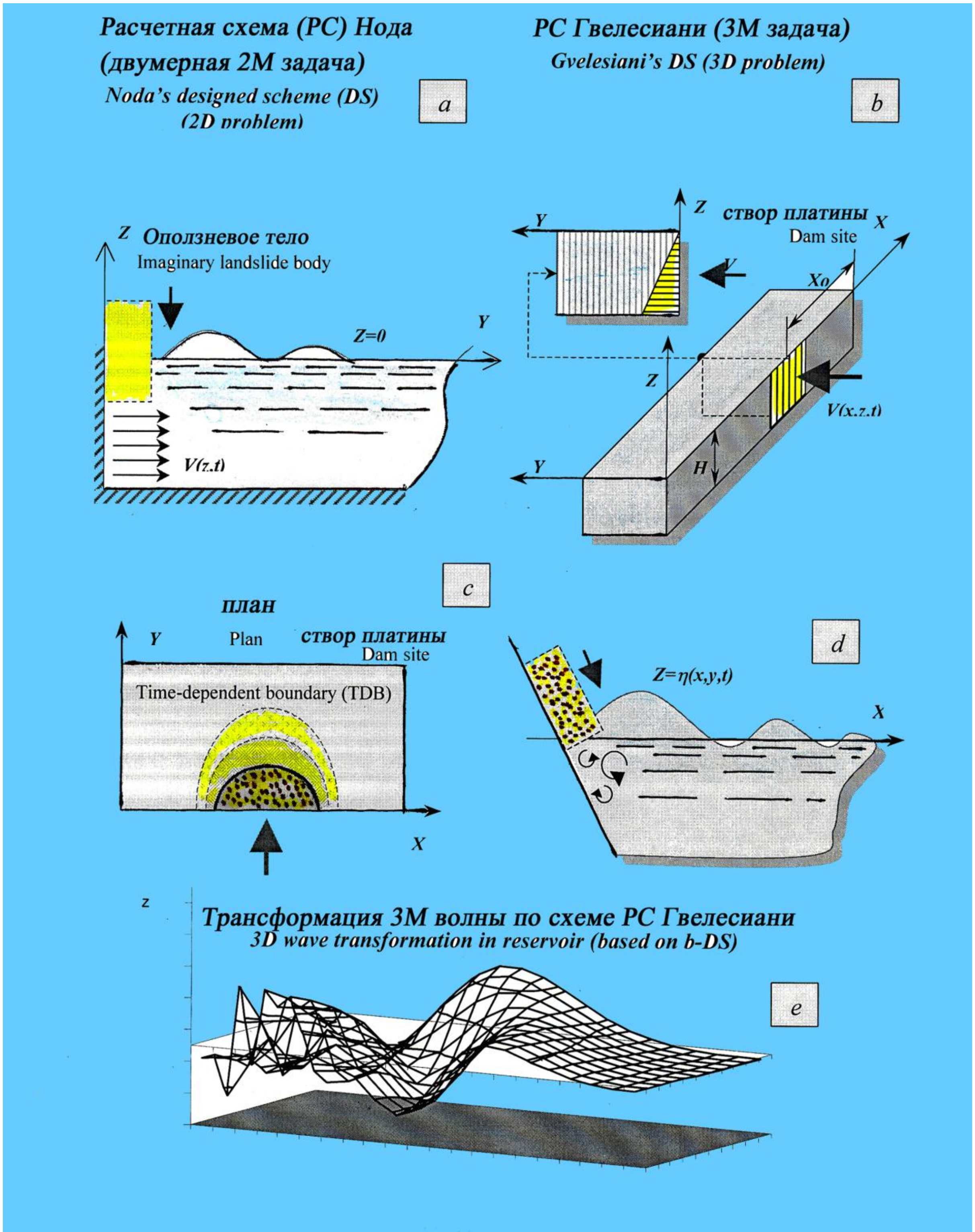

Fig 1 Design schemes of landslidegenic wave generation

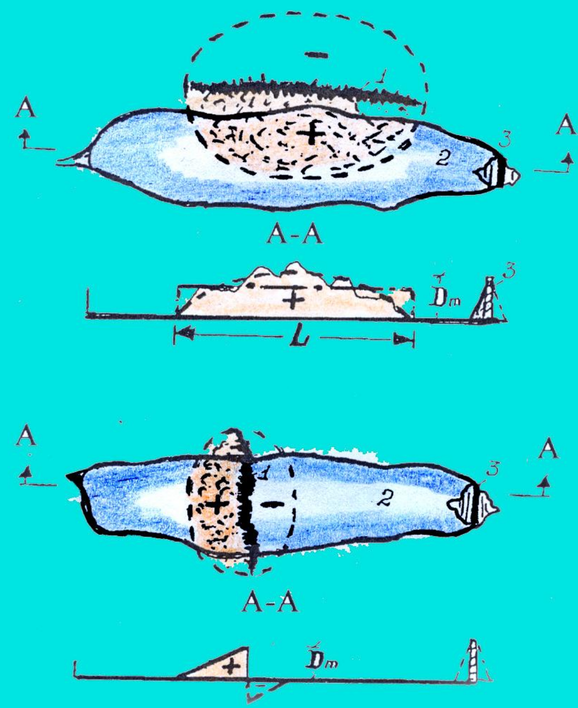

Fig.2. Seismotectonical deformation (STD) at reservior area
1 - fault line 2- reservoir 3 - dam

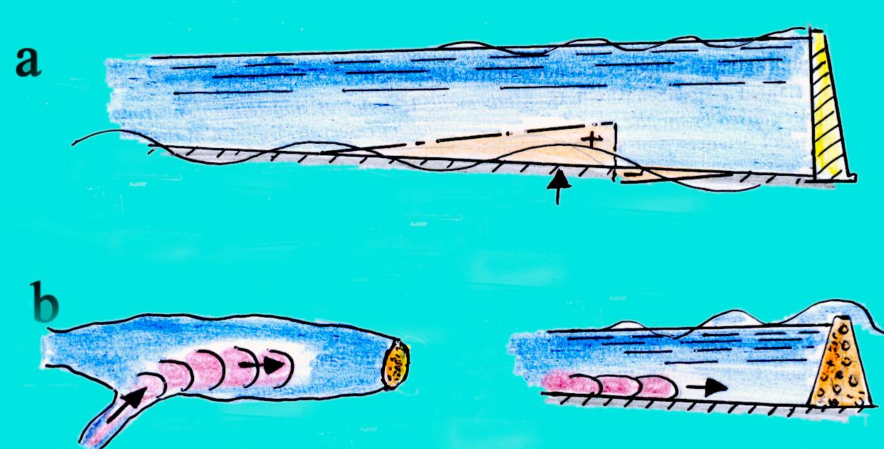

Fig. 3 Desine schemes a) seismogenic waves generation due to:
1 - an earthquake (seismic) wave propagation
2 - ST deformation (uplift) at the bottom of reservoir
b) waves caused by a movable mud flow.

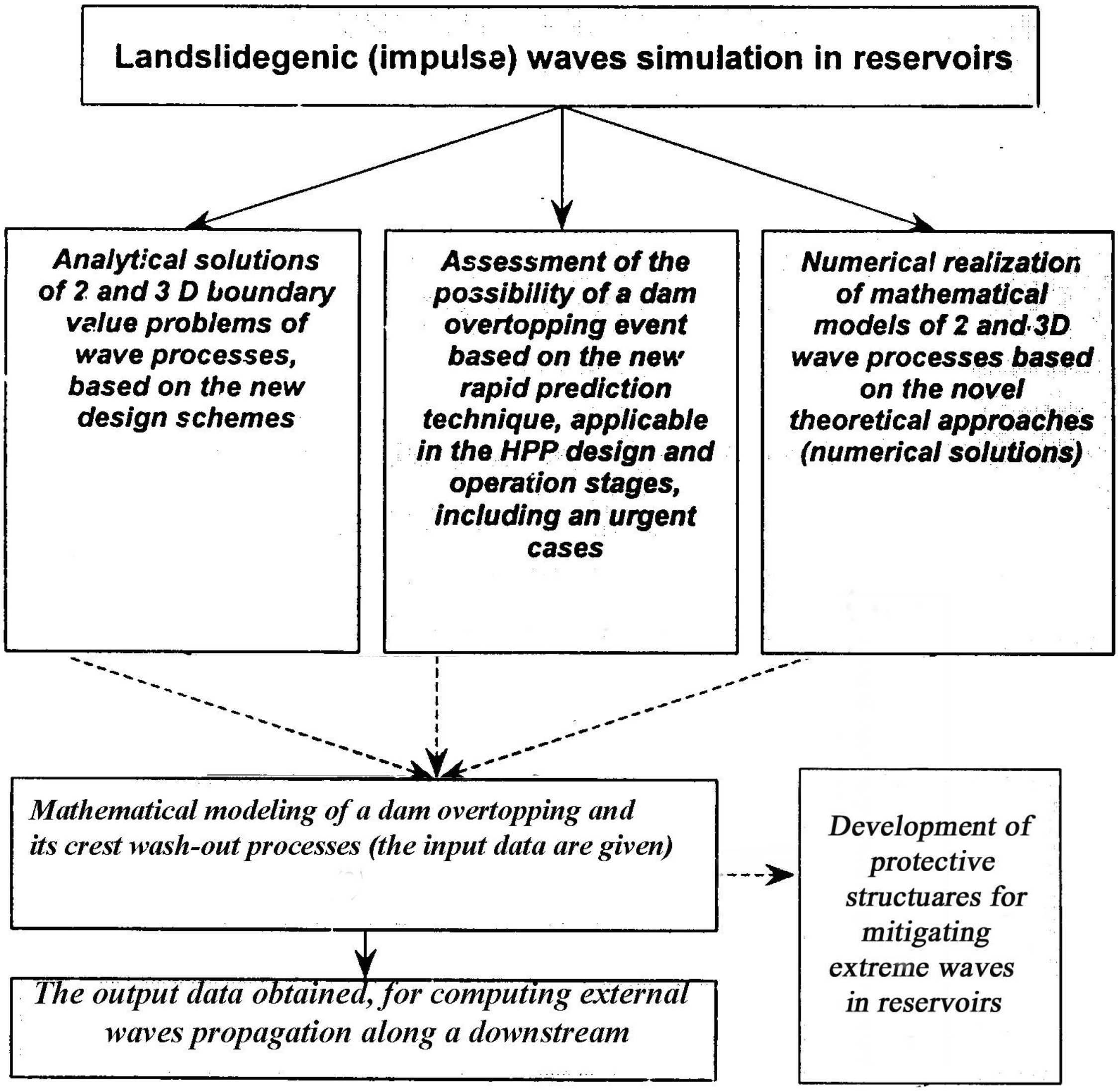

Fig. 4. The problem solution synthesize information

1.14 Expected Significance

What's new?

In spite of a wide variety of the above investigations (see 1.12), a number of problems are far from being solved. The calculation of extreme waves may be carried out based on the long waves theory using numerical methods, for one- or two-dimensional (in plan) cases. As a rule, in this case an expensive computational procedure requires much time and the accuracy of obtained results unknown in advance. In addition the results can be applied only to a specific case, inasmuch as the vertical component of wave oscillations velocity is not considered, the error of computed data would be considerable (especially, if the waves are not long, e.g., in the case of the most dangerous quick landslide phenomena).

In the project the more efficient and complex method based essentially on the new analytical solution of the general three-dimensional boundary value problem on waves of any length combined with numerical methods (if reservoir has a complex shape) is developed. As a result a number of new hitherto unconsidered problems on extreme wave's processes and their impact character will be solved (see 1.17). First of all, the essentially (lawsuit) of the complex hydrodynamic (waves) phenomena under study will be revealed and the general analytical dependencies (formulas) and corresponding graphic material will be developed. The limits of their practical applicability will be estimated too. So the results can be used easily for any dam which is under design or operation considering different actions of extreme forces (earthquake, landslide, mud flow etc) which are expected for given hydraulic works region.

The new prompt (express) technique mainly for forecasting hydrodynamic environmental impact in emergency and informing of inhabitants potentially exposed to the danger will be carried out.

Also, two types of original technical facilities (structures) for preventing (or mitigating) extreme wave's impact (on dam, bank slopes, up- and down-streams) and possible negative (or catastrophic) consequences are proposed.

1.15 Organization, Qualification and Staffing

Who are we?

The research program of the presented project is realistic and feasible, taking into account the mandatory nature of two research teams (Team 1 and Team 2) and corresponding experience and remarkable professional skills of the researchers. In particular Professors, Doctors of technical Sciences, Academicians of the Georgian Academy of Energy and Georgian Engineering Academy F. Khelidze, T. Gvelesiani and Z. Tsikhelashvili are participated in Team 1 of the project (see references).

Here it is noteworthy to add that the results of Prof. T. Gvelesiani's investigation were employed in assessing of the ecological safety of the deep Sarez Lake (in Tajikistan) regarding the large potential landslide hazard, as well as in design and construction of number of high dams (among them are unique ones) in the various states and regions: Saiano-Shushenskaia (Power 6400 MW, height 240 m) in Russia, Rogun (3600 MW, 335 m) in Tajikistan, Irganai and Miatli (in Russia, Dagestan), getik (in Armenia), Jinvali (in Georgia), etc.

Also, T. Gvelesiani's research results have been included in number of the State Standards and Buliding Codes (Norms) and Guidances. The book [38] have been published in Moscow by the famous publisher "Atomenetgoizdat" and was the first book devoted to the problem of waves generation in reservoirs under earthquake effects.

T. Gvelesiani two books published in 2009-2010 in Israel (by order and financial support of Simbiotic Ltd, Tel-Aviv_ and Tbilisi (In Russian) [23, 22] are closely connected with the problem under consideration.
T. Gvelesiani was a manager of different Projects (in particular, since 2003) which were carried out essentially in the frame of Georgian hydro-works rehabilitation and Economical development programmes (funded by World Bank, Soros Foundation, NATO, Director of Ltd "Enguri HES" etc).

T. Gvelesiani and Z. Tsikhelashvili are the coauthors of the Investigation (Patent/Ident №11748/01-2010-03-31 issued by "Sakpatent") which is related to the protective structures floating on the water surface for damping of high waves.

G. Khelidze is working essentially in the fields of mathematical modeling of large volume landslides (see ref.). He is the coauthor of the book [34]; he was the managed of a number of a Projects funded by Georgian Ministry of Power Engineering and Derectors of different private HPP-s ("KazbegiHES", "LajanuriHES", "MicrosioniHES", " ZhinvaliHES" etc) (see Ref).

Z. Tsikhelashvili is the coauthor of two books ("The control of innovative processes" Tbilisi, "Technical University", 2009 and [42]). Last years he was managed two Projects on sewage water purification, funded by USAID and Georgian Technical University.

G. Berdzenashvili is director of BSC (Bussines Software Consulting, www.bsc.ge) (established in 2003 and is an exclusive distributor of Dutch Holding Exact Software in Caucasus). "BSC" today is a leader in implementation of various accounting systems (Financial accounting, Stock accounting etc). G. Berdzenashvili was participated in mathematical modeling of different unsteady wave's motion in up- and down-streams of HPP-s.

All members of Team 1 know Russian and English.

Expert of participant country-Azerbaijan (from Team 2) is Dr. A.S. Mammadov from Azerbaijan "Sukanal" Scientific research and Design Institute. His scientific activities: research of hydraulic structures and their physical modeling, solving various hydro-ecological and hydrological problems etc.

He is the author and coauthor of more than 80 articles and 25 inventions and patents published mainly in Russian journals. He was manager and technical expert of number of projects funded by Azerbaijan State Budget, Director of Sheki HPP, Islamic Republic of Iran State Budget, UNDP/SIDA etc.

F.A. Imanov (Team 2) Doctor of Technical Sciences, Professor, Head of a chair of Hydrometeorology of Baku State University is hydrologist and water resources specialist in Azerbaijan and the region with over 312 years of experience in hydrometeorology, environmental management, information system etc. As an expert on legal and institutional analysis and policy implementation for water resources and environment conservation

Projects of UNDP/SIDA, EU TACIS, NAT. Com. of Intern. Hydrological Program of UNESCO and etc has prepared national reports. He is an author of many articles and books on water resources.

1.16 Expected Results

What will be done in the framework of this project?

In the project new refined techniques based on mathematical modeling are developed, that is intended for the explicit description of whole processes of high waves motion in reservoirs under extreme conditions including the reliable prediction procedures of environmental impact exerted by that waves and working out the special hydraulic constructions against them in order to prevent or minimize potential hazard to adjacent regions, as well as to ensure adequate safety conditions for hydroelectric power station operation. A wide range of factors determining the complex hydro – and geodynamic processes in mathematical modeling will be considered.

The project results (new computer programs, refined computational methods, protective constructions, etc), have great potential for application in design, construction, operation and control of reservoirs, dams and other hydraulic structures in mountain and pre-mountain seismoactive regions for evaluation and mitigation of environmental risks and the EIA caused be extreme waves, potentially dangerous to human life and safety.
The practical Instructions (Manual) employable for the monitoring of reservoir and the assessment of extreme waves possible adverse effects (on the dam and adjacent environment) will be the significant component of the project's applied results and intended principally for use developers and EIA practitioners and other "user groups" (dam design departments, companies which are responsible for the HPP operation safety, state departments concerned with environmental protection of water resources, etc).

Demonstration of the project results applicability on the prototype (the highest arch Enguri dam) will be of great interest to hydraulic engineers and researchers [42].

The results will define the proper management decisions concerned with arising of technical, economical and social problems. In particular, preventive (remedial) measures against the potential hazards may include: the warning of population about possibility of a dam failure, a large wave dam overtopping event or its propagation along a downstream; the determination of the "secure" wave level in reservoir, when the potential landslide is; the assessment of necessary landslide mass removals (either completely or partly); the estimation of dam crest elevation or choosing the suitable site of a dam when it is designed in the geologically complicated region, etc. Similar protections and remedial measures can be proposed against possible, artificial landslide, triggered by a relatively easily performed terrorist act or in war condition (an explosion of unstable rock masses at the bank slope of reservoir that amounts to the effects of mass destruction weapons).

In any case above mentioned management decisions should be carried out combining proper cost-effectiveness evaluation and feasibility study. In this case the application of theoretically well based exact waves forecast methods to be carried out, will lead to significant economical profit in comparison with tentative assessment based on the existing rough procedure [45]. For example, a computing "secure" freeboard height or volumes of necessary earthworks (on unstable landslide mass removal) using exact methods will be given much less values (therefore less required expenditures) than those estimated by rough methods. The profit may amount to several hundreds of thousand $ or more. As for such issue as ensuring the population safety against waves possible impacts, obviously, it does not lend itself to any economical evaluation and corresponding preventive activities must be carried out in any cases [53, 54].

Since, the corresponding research results will be an essential base and effective tool serving to support optimal and reasonable decision in design, construction and operation of hydraulic power plants (HPP), companies which are in control and responsible of the HPP operation safety, should be particularly interested in the application of above mentioned results (especially considering the current trends of world hydropower development that is characterized by use as necessity, of profitable riverhead sites located often in geologically complex mountainous regions). The results will be important in solving corresponding coastal engineering as well as in shore protection problems

1.17 Scope of Activities

How will the investigation be organized?

The scopes of activities for solution of the landslide and seismogenic wave's generation in reservoir and environmental protective complex problems are presented by the following tasks and subtasks.

1. Forecast of extreme geodynamic events in the region of hydraulic works;
   1.1 modeling of a landslide body motion;

1.2 Assessment of the seismo-tectonic deformation (STD) parameters at the reservoir areas (Fig. 2 and Fig. 3,a);

2 Mathematical modeling of landslide-generated (landslidegenic) waves (generation, transformation, run-up and their impact on bank slope and dam, etc) in reservoir caused by large landslide mass entering into it within considerable distances (the moving-boundary problem) (Fig. 1,c);

2.1 Development a proper approximate analytical solution;

2.2 Problem solving by numerical method;

3 Tsunami-like waves in reservoirs due to the seismo-tectonic displacement at its bottom considering the water basin complex configuration (Fig. 3,a);

4 Development of methods for forecasting of dam overtopping process by extreme waves;

4.1 overtopping when extreme wave maximum amplitude is higher than the dam freeboard (method 1);

4.2 Iterative method for forecasting the parameters of wave overtopping process (velocities, discharges to downstream etc.) after wave's setup at dam face (method-2)

5 Investigation of dam reliability aspects considering the probabilistic character of extreme waves impact;

6 Mathematical modeling of high waves generation near a dam site;

7 Determination of both the dynamic hydro-pressure distribution along a dam upstream face (or bank slope) caused by seismic wave propagation in the ground along the bottom of reservoir and the proper resonance criteria (Fig. 3.a);

8 Working out of the applicability criteria of the presented computation methods (based on comparison and analysis of theoretical and experimental results);

9 Developing of techniques for short-term prediction of possible maximum heights of extreme waves (water level rising) at the site of dam (or bank slope) and the instruction on the prediction of hydrodynamic effects on the environment and the proposed mitigation measures;

10 Working out the protective constructions for mitigation extreme waves impact on a dam and the upstream zone of reservoir;

10.1 Calculation of wave loads on protective barrier (wall) placed on the crest of dam;

10.2 Waves loads on floating structure fastened by wires with the bottom of reservoir;

10.3 Laboratory research of floating structure;

11 Simulation of extreme waves generation in the reservoir created by the world highest arch Enguri Dam (in Georgia) situated in geologically complex region with high seismic activity; risk from exposure of the project (HPP) to natural disasters;

12 Final project report.

All items specified have to deal with the elaboration of the appropriate design schemes, algorithms and computer programmes.

A wide range of yet unsolved problems proposed to develop (3D overtopping and hazard of this event; high waves generation near a dam site; extreme waves short term prediction technique; mitigation of adverse effect etc.) are directly linked with the objectives listed above.

1.18 Technical Methodology

How will the science be done?

Methodologically the research on the project chosen to reach the objectives will be developed involving modern and advance technologies according to the following stages:

- Working out new design schemes and formulation of the corresponding 2D and 3D boundary value problems.
- Solving this problems using analytical (integral transforms) and numerical (FE, FD) methods. In some cases, the transferring to curvilinear coordinates will be used and the transformed equations will be integrated numerically.
- Using probabilistic approaches to the system under study.
- Working out the applicability criteria of developed theoretical methods.

- Using experimental laboratory methods for studying in hydraulic flumes the efficiency of constructions to mitigate the intensity of wave's processes.