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**DAM BREAK FLOODRISK AND SAFETY MANAGEMENT AT DOWNSTREAM
VALLEYS**

A PORTUGUESE INTEGRATED RESEARCH PROJECT

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Dams, like “all structures, will be broken in the end - just as all people will die in the future. It is the purpose of the medicine and engineering to postpone these occurrence for a decent interval”.

(J.F.GORDON)

1. INTRODUCTION

The presentation describes a research project now under development in Portugal funded by the NATO Science for Stability Programme. This particular project whose title is **Dam Break Flood Risk Management in Portugal**, code NATO PO-FLOODRISK PROJECT. The project began in 1994 and will end in the fall of 1999. The research institutions are the following ones:

- Laboratório Nacional de Engenharia Civil (LNEC) or Civil Engineering National Laboratory;
- Instituto Superior Técnico (IST) or Technical Superior Institute

The project has the following supporting institutions:

- Instituto da Água (INAG) or Water Institute, the Portuguese water and dam safety authority;
- Electricidade de Portugal (EDP) or Portuguese Electricity, the main power company of Portugal;
- Serviço Nacional de Protecção Civil (SNPC) or Civil Protection National Service, the Portuguese agency for coordination of civil protection actions.

The presentation includes the objectives and concepts that inspire this research work, the project structure and developments and the expected contributions.

The environmental safety and the social behaviour under risk stress are topics three decades, as the result of a few dramatic dam accident in the world, the dam safety

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regulations introduce some procedures related to downstream protection, including inundation maps, zoning, emergency and evacuation plans. In very populated valley with large cities the implementation of these procedures will not be easy should a crisis occur. Within this context a group of researchers planned, in 1993, this NATO project.

2. GENERAL OBJECTIVES

At a national level the project pretend to improve the Portuguese operational implementation of the dam safety regulation published in 1990. At a scientific and technical level the aim is to develop new concepts and methodologies for an integrated dam and valley risk management.

The following four general objectives of the project were chosen in order to inspire the research work:

- To improve the engineering capability for dam-break flow analysis and prediction on real complex situations, as well as, to improve the use of social sciences in dam risk management.
- To develop methodologies and guidelines for dambreak flood risk management in Portugal, as a first step towards a new integrated flood safety system based on structural and non-structural measures, including public participation, and on advanced information support.
- To implement new advanced information technologies applied to hydraulic engineering analysis and land-use and safety management techniques.
- To create a new concept for operational crisis control and integrated dam safety management and also to contribute to the improvement of the Portuguese dam safety regulation and land-use management in risk-prone areas.

Each of the actors should have a part of the global safety responsibility. The valley development and the land-use policy downstream a built dam can modify the initial risk level. This need to be accepted by local authorities on behalf of the public.

3. EMERGENT CONCEPTS

- The Integrated Dam and Downstream Valley System (DDVS)

The DDVS includes the dam-reservoir system and the downstream valley system including the inhabitants, human feelings and public participation.

In the valley an adaptative land-use management, based on flood zoning, and efficient civil protection procedures are fundamental techniques of risk management.

- The Shared Downstream Risk Level (SDRL)

The shared responsibility towards the risk management is a new concept to be implemented between dam owners, authorities and public (Figure 1).

These three main actors will try to reach a downstream risk level accepted and shared by them. The authorities will impose constraints and regulations to dam owners expecting to receive from them a safe design and operation. The public and the media have now a strong influence on dam owners and authorities during the main phases of

a large dam lifetime. They expect to receive information, local and global benefits, as well as, a better protection from accidents or incidents.

This shared responsibility will need a better understanding of dam safety and risk preception and of what is an effective protection against an abnormal flood.

The NATO project develops in the contex of an integrated methodology for dam break floodrisk and safety management at downstream valleys is supposed to include:

- Computational modelling and simulation systems
- On-line multimedia databases
- A Geographical Information System (GIS)
- Applied social sciences techniques, strongly dependent on local and regional cultural characteristics and human behaviour

The integrated dam safety concept is now supported by three pillars:

- Technical-operational
- Monitoring
- Emergency and risk management

The first one includes the dam design, construction and exploitation and will try to minimize the failure probability. The second one gives the opportunity to observe and control the dam behaviour. The third one includes the planning and organization along the valley and all emergency procedures in order to anticipate and mitigate the downstream dangers should a dam accident occur. The objective of the project is to develop new methodologies for this third aspect.

4. PROJECT STRUCTURE

The NATO project is organized in five sub-projects (Figure 2):

- **Sub-project 1** - Hydraulic analysis and computational simulation
- **Sub-project 2** - Dam and reservoir safety analysis
- **Sub-project 3** - Social impact of dam break risk
- **Sub-project 4** - Computer aided decision support system
- **Sub-project 5** - Integrated emergency and training system

In **Sub-project 1**, dam break flood computational models were developed for natural irregular valleys (one-dimensional and two-dimensional models) based on the MacCormack-TVD high resolution numerical scheme. This technique allows the numerical simulation of significant flow discontinuities as those due to a bore advancing through the valley after a sudden dam burst. Large instabilities, as well as, numerical fluctuations are strongly attenuated or even eliminated. To validate the computational models a set of experiments were executed in an experimental test facility at LNEC (Figure 3). Another topic under study is concerned with the insteady sediment transport during a dam-break flood. For field works and tests on experimental area was selected as a case study: the Arade valley in Algarve, near the coast in south of Portugal, where two dams are built (an earth dam and a concrete arch dam).

In flood-plains the 2-D model can give a more accurate solution and this will be very important in what concerns the inundation mapping (Figure 4). The experimental is being modelled by a large physical model where, in the near future, special

hydrodynamic problems will be studied as well as tests for validation of computational models.

Sub-project 2 will develop design and risk criteria for practical dam-break analysis, as well as, the dam rupture scenario for flood simulation, including hydrologic conditions, breaching and dam data and recommendations according to dam safety regulations. These criteria as well as the dam-break flood simulations will make possible to have inundation maps for risk management and social impact of risk. These studies includes the following topics:

- Public perception and valley risk vulnerability
- Sociological analysis and characteristics guidelines
- Planning tools for land-use management
- Public participation studies

The contribute of the social research group (**sub-project 3**) to the process of dam safety and emergency planning is the following one:

- Description of the population in demographic, economic, housing and social terms.
- Knowledge of dam break flood risk perception in order to help on the promotion of safety management and on the risk communication.

The tasks developed to achieve the first goal include the description of physical and social aspects of human occupation, along the Arade experimental valley, in flood prone areas in terms of:

To achieve the second goal, the tasks developed for assesement of public perception of dam break flood included the collection of information on public perception, public preparedness and adjustments in a sample of the target population:

- State of population (number, structure and density)
- Description of households (number, structure and density)
- Sociographic characterization (economical status and educational level)
- Housing conditions (number buildings, building typology and number of family buildings)
- Exploratory interviews to people living in the experimental valley
- Content analysis of interviews and data statistical analysis
- Construction of questionnaires to be applied to a representative sample of population at risk.

The theoretical perspective undertaken in this analysis is multilevel and can be summarised in four points:

1. Lay conceptions for risk

The perception of floodrisk and dam failure risk (a low probability high consequences risk) seems particularly relevant.

2. Continuous exposure to uncontrollable threat modifies risk estimations

It is therefore expected that residents living under high objective risk will minimise their probabilities of damage in case of dam break.

3. Risk perception is not isolated from other socially shared beliefs and representations

These beliefs and representations make sense within the general conceptions of the environment and it is expected that risk perception should be related to some more general conceptions of the dam, the science and responsible to prevention.

4. Social roles of the different protagonists in risk management frame

It is expected that farmers, engineers, decision-makers and the public present different interests and perspectives in risk discourses.

The survey focuses this global perspective and the consequences of exposure to dam break risks and is intended to understand the following issues:

- How does the population in the valley think about the dam failure risk?
- How are the dams perceived by those residents?

The results present some challenge in terms of risk communication and opens some perspectives towards its content:

1. As dam failure risk is perceived as a much more dramatic, uncontrollable and unfamiliar risk than a normal flood risk, it is more difficult be accepted by population. The flood warning system to be created should then be developed for floods in general, dam failure being a particular and extreme case of flood. This strategy would have several other important consequences: it would prevent damages in case of natural floods or dam spillouts, and the population could have more opportunities to learn preventive behaviour.

2. Risk communication should not be conceived as a oneway strategy. In order to promote effective responses to warning systems, the decision process of the individuals must be understood and the residents should be informed about the seriousness of the risks they face and their possibility of response in adequate time. To fulfill these goals in case study, where the population is living at risk for more than 40 years, direct communication is particularly desirable. Furthermore, a local committee of residents in risk areas could help to improve the dialogue between the experts and the public, and prevent avoidant or hypervigilant responses.

3. Given the striking differences in flood and dam risk perception from the residents near the coast and near the dam, the communication strategy should be distinct in the two sites. Floods have different characteristics in the two areas, and they should be addressed separately.

4. Rural/urban distinctions are also important both in our results and the literature of warning response. However, as the differences relate mainly to the age and degree of literacy of the subjects, they only affect the communication channel and not the content of message.

Another aspect included in **Sub-project 3** is the land-use management decision system. The study is concerned with:

- Study of the interface between risk management and land-use planning techniques.
- Development of methods to be used by local and regional authorities integrating flood risk planning in valley management.

- Development of risk awareness among land use planners and authorities that are responsible for location of infrastructures and public services and improve the application of these techniques.

In **Sub-project 4** a decision support system is developed including:

- a dam safety database (Dam Map Genovator);
- a G.I.S. development and implementation (DamInfo);
- an integrated architecture for a decision system.

DamInfo gives water managers and civil protection agents an easy access to dam related data. *DamInfo* makes decisions on how to exploit the dam and on which measures and actions to take in an emergency situation much easier and more technically supported.

Dam Map Generator helps the project team to create automatically new maps as well as to run dam break models and visualize their results.

Finally **Sub-project 5** will produce:

- Integrated crisis management guidelines
- Downstream valley safety guidelines
- Field exercises applied to the case study - Arade River

5- VALLEY VULNERABILITY

Vulnerability is one of the major concepts in valley risk management as safety factor is important for dam design. Vulnerability can be defined as a measure of the level of exposure and of damage susceptibility towards the dam-break flood.

A global index should include both the physical vulnerability, as well as, the socio-economic vulnerability. The level of vulnerability should be obtained for each sub-zone downstream of the dam.

The physical vulnerability should include a quantification of the dam-break flood impact as function of variables like the following ones:

- maximum depth (D)
- maximum flow power ($V \cdot D$)
- maximum depth gradient ($\frac{\Delta D}{\Delta T}$)

The socio-economic vulnerability will be a weighted function of several characteristics factors:

- Social
 - Families (number of members)
 - Individual (age, education)
- Property

- Buildings
 - Economic activities
- Strategic Infrastructures
 - Power and water networks
 - Hospitals
 - Warning and Emergency System (effectiveness)
 - Civil Protection Response (effectiveness including training)
 - Psycho-social (public perception)

The global valley index obtained from the inundation map can be an indicator of valley situation in what concerns land-use planning, crisis management, warning evacuation planning, emergency plan and training exercises.

6 - IMPORTANCE OF DAM BREACH MECHANISM

In the context of the Interagency Dam Breach Workshop and of the activities of the NATO Project, a better knowledge of the breach mechanism is very important. In what concerns the earthfill dams there are a few computational models for simulation of the physical process. In engineering practice the BREACH model developed by D. Fread is the most popular.

Based on Kast and Bieberstein (1997), the breach models can be classified as follows:

- Type A:
the breach outflow is calculated as a worst-case-scenario for all types of dams. It is assumed the breach has the size of the whole dam from the beginning of the event.
- Type B:
the breach outflow is calculated with a breach of a chosen and fixed shape and size (a technique also applied to concrete dam breaches).
- Type C:
the models take into consideration the time-dependent process development of the breach in an earthfill dam. The breach enlargement is calculated as a function of a variety of parameters taking into account different aspects like breach hydraulics, sediment transport, geotechnical stability, etc.

The last group of models (type C) can still be sub-divided into three categories:

- Parametric models (e.g. DAMBREAK model of D. Fread and HEC - 1 model)
- Physical-parametric models (e.g. Lou's model, BREED model or BREACH model)
- Stochastic models (Granoulis and Meon models)

The more developed models (type C models) try to describe the course of a dambreak as exact as possible and take the delaying influence of the erosion process during a dambreak into consideration. However, due to the complexity of the process, the resulting breach outflow hydrograph is still not very accurate. A sensitivity analysis is still needed. These models have typically a time step different from the one adopted in flood routing models. The choice of the breach model can depend on the objective of study:

- to simulate a more accurate outflow for flood mapping and for a risk assessment analysis;
- to support a crisis management (including a potential evacuation action) during a dam incident with a threat of dam overtopping or piping;
- to reproduce a dam accident with failure and opening of a breach,

A more accurate breach modelling, in an earthfill dam, can attenuate the peak discharge and to modify the inundation map.

However, it is still difficult to have design criteria for the extreme envelope conditions. For risk management at downstream valleys, the inundation maps and the risk zoning need to be rather conservative. A better understanding of the breach incaption and formation can be useful for the warning system and evacuation planning. Design criteria based on systematic physical and mathematical modelling can improve the capability of dam break simulations. For concrete arch dams a complete and sudden breach is typically considered. For concrete gravity dams a partial break is a more realistic model. However a sound criteria is still lacking.

A relatively large breach makes more important the **inertial head effect** on the outlet law. This topic was studied within the NATO project context. The quasi-steady behaviour is accepted in orifice and weir modelling but during a sudden dam breach, the hydrodynamic response of the weir formed in the breach is sensitive during a few time on the inertial head. In fact the net head on the breach will be:

$$H = H_S - H_I$$

with

$$H_I = \lambda \frac{L_i}{gB_d H_r} * \frac{dQ_b}{dt}$$

where H_S = steady - steady head; H_I = inertial head; L_i = reservoir length under the hydrodynamic influence of the breach, B_d = dam span; h_r = reservoir depth upstream the dam; g = gravity acceleration; Q_b = outflow discharge; λ = a non-uniform effect correction coefficient.

This inertial head will allow a more easy simulation of the Ritter problem with 1-D computational codes. In real cases the inertial effect will be important for very fast breach and large breach width (VISEU, 1994). The influence of H_I will be greater during the first instants after the dam break (Figure 6) modifying the outflow law.

A better knowledge of the breach mechanisms will be very useful in order to work out effective plans for a disaster or crisis management/control. The dam break delay due to

a gradual breach inception can be vital for a suitable alarm and warning systems at downstream valley.

It is expected that the Concerted Action on Dam-Break (CADAM), now in progress in the UE, will develop the knowledge of dam break mechanisms and modelling.

7- EXPECTED PROJECT CONTRIBUTIONS

From this NATO project some general contribution to the improvement of safety valleys downstream dams are expected, as well as some answers to critical questions:

- Better modeling techniques for hydrodynamic analysis. How better it will be needed in engineering practice?
- More effective dam safety regulations in what concerns the valley protection. How good are in the present?
- Better integration of socio and psycho-social variables into the risk management process. It will be possible the compatibility between hard and soft applied sciences?
- A contribution for an integrated risk and crisis management based on computer aid techniques. How far we need to go without falling in overkilling techniques?

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