Centre d'Ingénierie Hydraulique

THE NEED OF A RESEARCH AND DEVELOPMENT PROJECT ON « DAMS AND EARTHQUAKES » FROM THE WORKING GROUP OF THE FRENCH COMMITTEE

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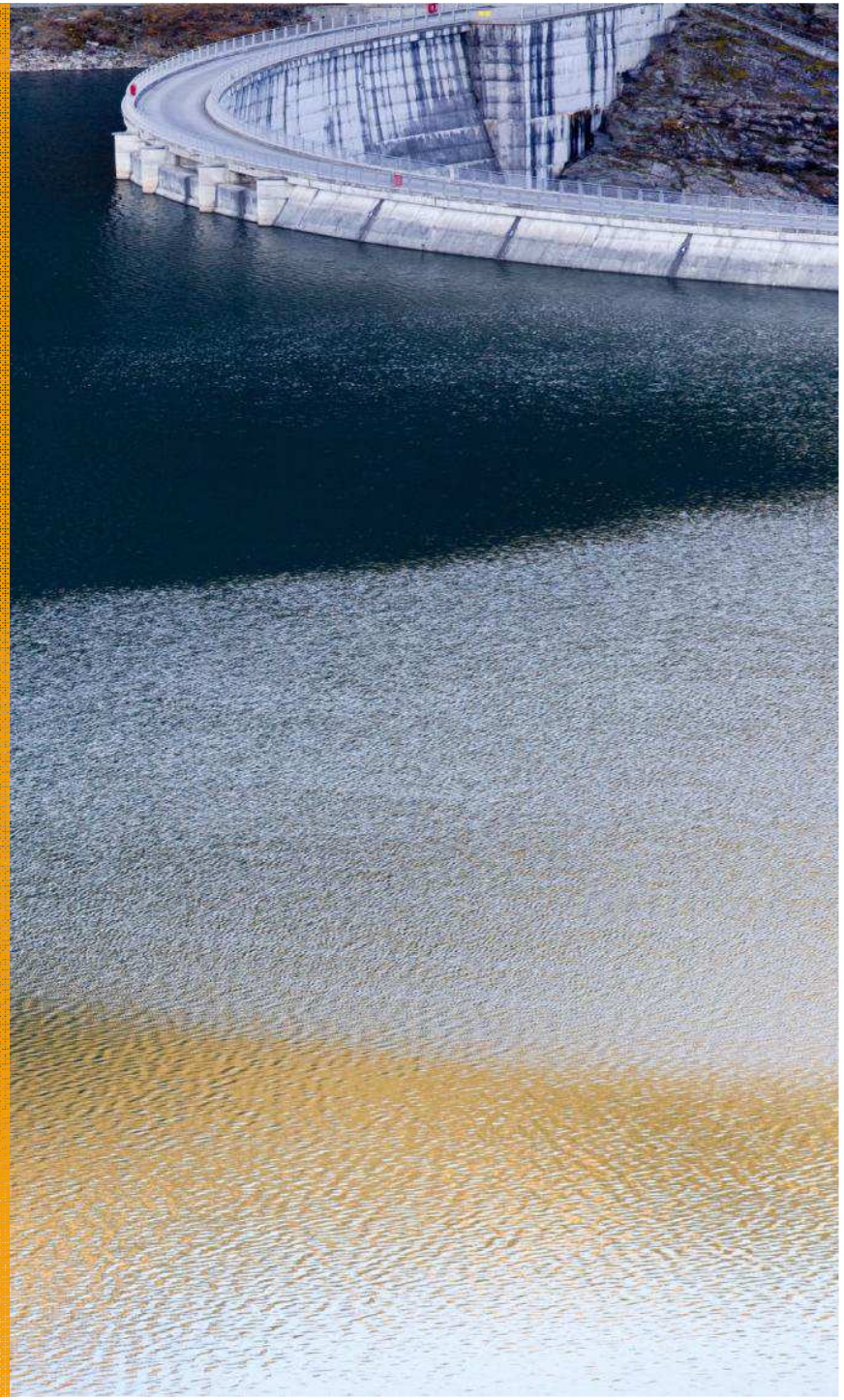


SUMMARY

CONTEXT

- **2010 New temporary recommandations by a group of experts :**
  - Accelerations will be doubled
  - Almost all dams must be calculated again
  - Dams generally behave much better than expected by the calculation.
  - encourages research efforts to exhibit and quantify the hidden safety margin.
- **2011 Failure of Fujinima dam during the Tohoku Earthquake**
- **2014 Project of a new regulation for hydraulic structures including seismic stability (take up most of the recommandations)**

CFBR has suggested a National Project for Research & Development on « Dams and Earthquakes ».

OBJECTIVES

- **Combine the objectives of safety with the necessities of economic performance passing by a just estimation of the safety level and the implementation of measures of risk reduction.**

- **3 mains objectives :**
  - Improve the robustness of the methods, analyses and modelling to reduce the conservatisms inherent to the current practices,
  - Identify the dominating physical phenomena, to improve the adequacy of the methods to the intrinsic characteristics of the works and to their seismic context,
  - Develop advanced methods to verify the resistance of the safety components (gates of the spillways or the bottom outlet).

STATE OF THE ART AND LIST OF THE SCIENTIFIC AND TECHNICAL BARRIERS

- **40 partners representing dam owners, private engineering and investigation companies, academic institutes and the regulatory Authorities.**

- **5 themes to classify the barriers :**
  - Characterization of the seismic hazard
  - Experimental characterization of the dynamic properties of the materials and the structures
  - Numerical methods
  - Qualification of modeling and field of application of simplified methods
  - Dynamic behaviour of gates and others safety devices

Barriers for the characterization of the seismic hazard

- Probabilistic and deterministic methods
  same safety level? UHS or conditional Hazard Spectrum?
- Instrumental approach : the use of in situ measurements
- Numerical approach
  dam-foudation-reservoir interaction, valley-shape effect, dike on the hillside
- Reference motion for dams
  significance of free-field for dams, high frequencies, very stiff rock
- Spatial variability
- Topographic effect
- Vertical component
- Representative accelerograms for dynamic time-analysis
  how to choose natural accelerograms ? Nocivity index?
- Slope instability
  better understanding of the triggering of instabilities

Barriers for experimental characterization of the dynamic properties of the materials and the structures

- New laboratory tests for the dynamic properties of material
  difficulties to test rockfill or soils with very large particles
  dynamic behaviour of mass concrete and of the interfaces (damping)
- Liquefaction with laboratory tests
  undrained conditions with regular equivalent cycles, undisturbed samples, saturated conditions, frequency of the cycles and viscosity,
  influence of the rotation of the stresses, of the anisotropy
  understanding the post-liquefaction behaviour
- Difficult diagnosis of dikes (detection of weak zones) and rockfill dams
  cost of the intrusive methods, testing the capability of the geophysical methods according to the dimensions of the weak zone,
  mechanical behaviour of up- and downstream walls in dry stone
- Lack of data on the dynamic behaviour of the large dams
  calibration of the models
  Permanent instrumental survey

Barriers for numerical methods

- Improvement of constitutive models for embankment dams
  influence of the anisotropy on the cyclic behaviour
  influence of the succion on the elastic modulus
  robustness of complex models
  simplification of the calibration of complex models
- Other numerical integration methods (FEM # DEM)
  no validated model for the cyclic behaviour of rockfill
  multi-scaled approach (DEM for the complex behaviour of granular material associated to FEM for the whole structure)
- Advanced numerical methods for concrete dams
  accessibility of the numerical methods for regularization (softening) and of mesh evolution for cracks

Barriers for the validity range of simplified methods

- Simplified methods to reduce the cost of the seismic analysis
  how to taking into account non linearity (liquefaction, cracks) without FEM?
- Simplified method to assess the post-seismic settlement
  lack of intermediate methods (empirical formula vs FEM with elastoplasctic models)
- Lack of validation of pseudo-dynamic methods :
  for example the Sarma Hynes-Griffin & Franklin method taking into account the foundation of embankment dams
  checking the assumptions, expand the number of seismic motions
- Question of validity of old simplified methods for concrete dams

Barriers for the dynamic behaviour of gates

- No real experience feedback
- Seismic design of gates:
  how to evaluate the hydrodynamic pressure due to the vibration of the system « dam+gate » or « pipe+gate »
  seismic input : vertical component? Sloshing effect? influence of the seal? Stiffness of anchoring system
  Definition of criteria (operability- integrity)
- Numerical model
  are the method used for concrete dams valuable for gates?
  range of the model ? Boundary conditions?
- Lack of in situ measurements
  necessary to calibrate any modelisation
- Need of analytical models
  very usefull for thousand of gates in France

The potential structures of the Research Program

- The identified scientific and technical barriers previously listed by theme are distributed in research axis in order to improve the modeling of three domains :
  - Concrete dams
  - Embankment dams
  - Gates

- The fourth axis dealing with seismic hazard is largely treated by other R&D projects (SIGMA Project,...).

Research axis for concrete dams

	Themes	Action
B1	Laboratory tests	Direct shearing tests of the contact concrete/bedrock
B2	**Shaking table**	Behaviour of 2 concrete blocks submitted to strong shaking (physical phenomenon, damping, modeling with available tools)
B3	**In situ mesasurements**	Instrumentation of different dams to capture ambiant noise and ambiant seismicity
B4	Improving numerical tools	Modeling radial damping Predict permanent displacements Better introducing of the input signal
B5	Simplified models	Pseudo-dynamic methods

Research axis for embankments

	Themes	Action
R1	In situ evaluation of damping	
R2	Comparaison of different methods for seismic hazard evaluation	
R3	**Locating weak zones on dikes**	Testing different geophysical investigation methods (MASW, H/V, CCASW, Sisprobe (intercorrelation of ambiant noise measures) Characterization of the non saturation with a geophysical method on small dikes
R4	Cyclic behaviour analysis with laboratory tests	Large shearing box on shaking table for rockfill Cyclic DSS vs CTX for post-liquefaction resistance
R5	Constitutive models	Improving the modelisation of liquefaction and post-liquefaction behaviour Testing a mixed DEM/FEM for liquefaction taking into accouent non saturation
R6	Qualification of the models on failure examples	**Reduced rockfill dam on the shaking table** Small scaled centrifuge tests (?)
R7	Validation of simplified methods	Development and validation of simplified methods (real cases/numerical simulations) Pseudo-dynamic method taking into account the foundation, the pore pressure built-up

Research axis for gates

	Themes	Action
V1	Improving the state of the art	Data basis
V2	Evaluatig the existing methods and understanding the main phenomena	Understanding the physical phenomena on simple cases (1 spillway gate, 1 lockgate, 1 gate of a pipe)
V3	Improving the robustness of the design methods	Analysis of the methods (with the constructors)
V4	**In situ evaluation the dynamic behaviour of the gates**	In situ testing on a gate (accelerometers on the gate) In situ testing in a pipe (dynamic pressure along the pipe)
V5	Definition of design criteria (integrity, operability)	
V6	Development of simplified methods	Numerical parametric studies with acoustic elements and added masses
V7	Validation of simplified methods	Development and validation of simplified methods (real cases/numerical simulations)

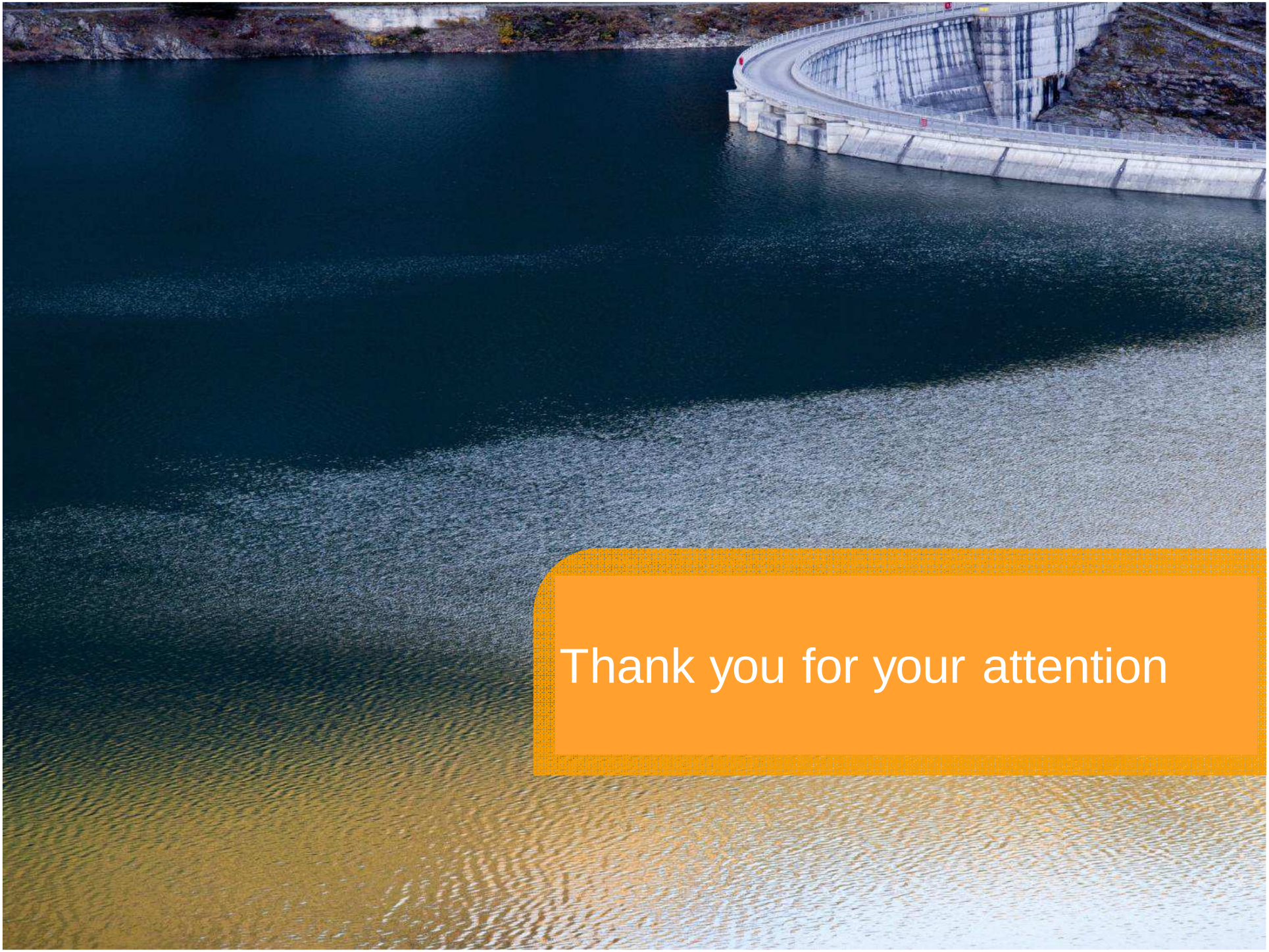
CURRENT STATUS OF THE PROJECT:

- **Almost 30 active partners**
  - 8% owners
  - 54 % private companies
  - 38% academic partners

axis	action number	1	2	3	4	5	6	7	total
concrete			1	3	4	4			12
embankment				4	3	5	2	6	20
gates					1		1	1	3
seismic hazard									0

CURRENT STATUS OF THE PROJECT:

- **Opportunity : October 2014**
- **Feasability : May 2016**
- **Technical and financial arrangement until June 2017**
- **Submission : July 2017**


Thank you for your attention