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# French Guidelines for Structural Safety of Gravity Dams in a Semi-probabilistic Format

Paul Royet<sup>1</sup> and Laurent Peyras<sup>1</sup>

<sup>1</sup> Irstea (formerly Cemagref), 3275, Route de Cézanne – CS 40061 - 13182 Aix-en-Provence Cedex 5 - France  
E-mail: [paul.royet@irstea.fr](mailto:paul.royet@irstea.fr), [laurent.peyras@irstea.fr](mailto:laurent.peyras@irstea.fr)

## Summary

In January 2006 the French Committee on Dams and Reservoirs – FrCOLD - issued provisional guidelines for structural safety of gravity dams. It was the first attempt to produce a semi-probabilistic limit-state method for the design of hydraulic works, in a format similar to the Eurocodes.

After 5 years of a progressive implementation of those guidelines, FrCOLD decided to produce an upgraded and enriched version of the guidelines. This task was undertaken beginning of 2011 and fulfilled mid-2012 through a FrCOLD project conducted by a working group representing the French engineering industry and related government agencies. This paper accounts for the work done over one and half year, discloses the feedback gained from the recent engineering practice and details the structure and the content of the document to be published end of 2012. It is arranged according to the limit-state format: design situations and associated loading combinations, geological model, characteristic strength values, limit states and corresponding verification analyses.

With other guidelines already issued (Structural safety of embankment dams and dikes, Hydraulic works and seismic safety) or under production (Safety of dams during floods), the major aspects of dam safety will be covered, allowing for introducing the main requirements for dam safety in French regulations in a very near future.

## Introduction

At the end of the 20<sup>th</sup> century, starting from the double observation that French practices in justification of gravity dams were heterogeneous and international guidelines available also showed significant differences between them, the French Committee of Dams and Reservoirs (FrCOLD) decided to draw up its own guidelines. The work was undertaken in three steps.

The first step undertaken in 2000 consisted in (i) a review of French practices and of the leading international recommendations on the subject, and (ii) examining the feasibility of a limit-state stability analysis method [1].

The second step undertaken in 2004 had a clearly operational focus and aimed at producing guidelines for the structural safety of gravity dams. This task was completed end of 2005 and provisional guidelines for the structural safety of gravity dams were issued in January 2006 [2]-[3], answering to a double objective: to harmonise French practice and to adopt a limit-state analytical format. As mentioned above, this document was provisional and FrCOLD had agreed to a probationary period of a few years to take advantage of lessons learned from its implementation.

Four years later, and this is the third step, FrCOLD decided to revive the working group with members of the previous WG but also with new members. The WG gathered representatives of the best French engineering consulting companies and national bodies involved in hydraulics engineering (see acknowledgment). The WG was active from end-2010 to mid-2012.

The outcome is an enriched set of French guidelines for the structural analysis of gravity dams [4], with an operational status.

## Feedback from the FrCOLD2006 guidelines

The first task undertaken by the working group in late 2010 has been to share the lessons learned from the implementation of these interim guidelines in the various consulting companies involved.

Although some companies have applied document upon its release, it is only recently that the use of the FrCOLD 2006 guidelines become widespread in the entire profession. Users derive a general feeling of satisfaction and point out:

- clarity, consistency and rigor made by the process of justification to limit states,
- clear definition of project situations,
- the interest of the notion of characteristic value of resistance and the justification process,
- their agreement on the hydrostatic loading situations.

When asked whether the FrCOLD 2006 guidelines are more or less secure than the various past practices, users have difficulty deciding, which probably reflects a global

conservation of levels of security in relation to their past practices.

## Dams in Relation to Eurocodes

The gradual involvement of Eurocodes in construction computation did not significantly help develop the principles of hydraulic work design. Indeed, although in theory nothing stands in the way of using Eurocodes for construction computation, Eurocode 0 (EN 1990) stipulates that, for the design of special construction works (nuclear installations, dams, etc.), other provisions than those in EN 1990 to 1999 might be necessary. Consequently, Eurocodes are not integrated computation rules for hydraulic works, and the project designer will have to seek professional guidelines for his design. Also, Eurocode 7 (EN 1997-1), introducing limit-states for embankment hydraulic works: critical gradient, suffusion, piping, etc., limits its scope only to small dams. And gravity dams are of course out of the scope of Eurocode 7.

In practice, it is noted that, today, none of the French engineering consulting companies uses Eurocodes for gravity dam design.

Nevertheless, the design procedure provided by Eurocodes is of great interest as a general framework for structural design of hydraulic works. This procedure, that we adopted in all the French guidelines for structural safety of dams, includes the following steps:

- Defining design situations,
- Defining limit-states to be taken into account,
- Assessing values for loads and defining loading combinations,
- Assessing values for soil properties,
- Designing limit-states based on limit-state requirements.

Such steps were also included in deterministic practices pertaining to hydraulic work design although they were not necessarily properly standardized in the computation notes and practices were relatively heterogeneous.

Eurocodes bring in the concept of characteristic value, which does not usually appear in deterministic computation notes for dams: the  $G_k$  characteristic value of a  $G$  load (respectively,  $R_k$  for  $R$  strength) is a **cautious** measurement or estimate of load intensity (of strength intensity, respectively). In Eurocodes, such cautiousness in measuring the parameters is taken into account by a 95% fractile (or 5%, depending on the positive or adverse nature) of the considered load or strength probability distribution. Using statistical methods may only be performed when data come from sufficiently homogenous identified populations or when enough feedback is available. To this end, the spatial variability of parameters

on the volume of soil or rock ruling the limit-state, the test data scattering and the statistical uncertainty related to the number of tests should all be taken into account.

In a number of fields, including hydraulic works, it is only seldom possible and relevant to resort to statistics. Cautious measurement therefore should rely on an expert assessment produced from available test results or from guideline values found in the literature. The characteristic value is then a cautious and proficient assessment of the material load or strength causing limit-states to appear.

## Scope of FrCOLD2012 guidelines for gravity dams

These guidelines apply to the justification of the stability of gravity dams in the French context. This document is intended to be used in the design process of new dams and in the diagnosis and reinforcement of existing dams. For structures already in service, it is recommended to take into account the history of the dam and the available information: field data, results of survey and monitoring, tests, etc..

Dams in the scope of the guidelines are dams on bedrock (good or bad quality). Gravity dams (or levees of gravity wall type) built on alluvial foundations needs further justification. Thus, the document does not address the mechanisms involved in differential settlement and internal erosion.

Mobile dams on rivers (BMR) are, in the absence of specific technical guidelines, in the scope of the FrCOLD document. However, the use of these guidelines for mobile dams requires special attention from the engineer and adaptation to each case of the design situations and calculation methods.

Additional requirements may also be necessary in case of specific structures like:

- Dams built for the correction of mountain streams (also called in French "RTM dams") that are subject to actions not described in this document (debris flows, hyper concentrated flows, etc.)
- Levees of gravity wall type that are subject to the actions of the sea (waves, flood, etc.)

## General approach for structural stability of gravity dams

In the guidelines, we examine successively: design situations, actions and their combinations, resistance of materials, limit states and limit state conditions (Fig. 1).

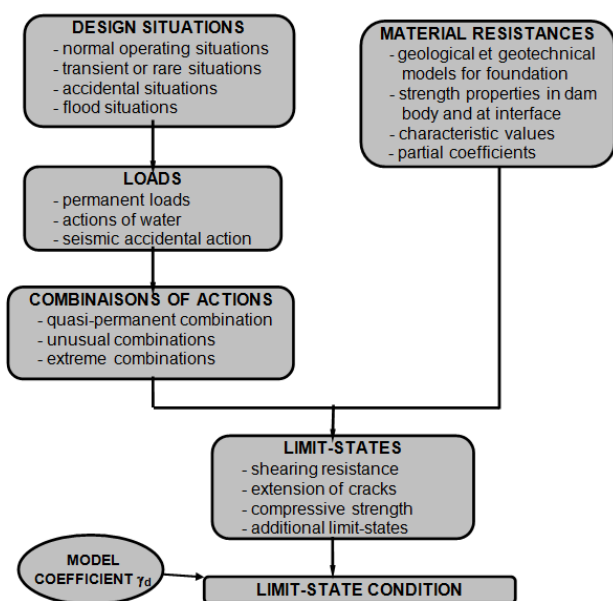


FIGURE 1: GENERAL APPROACH FOR STRUCTURAL STABILITY OF GRAVITY DAMS

## Design situations

Design situations (section 1 of the guidelines) are classified into several categories differentiated by the time interval during which the distributions of all data (actions, resistances) are considered as constants or by the probability of occurrence of the considered situation (Table 1):

- normal operating situations. They refer to normal operating conditions of the structure (typically the normal water level - NWL),
- rare or transient situations. They refer to temporary conditions of operation (e.g. end of construction) or to probabilities of rather high occurrence during the lifespan of the structure (e.g. frozen reservoir or operating basis earthquake - OBE),
- accidental situations. They refer to extreme conditions applicable to the dam or to low probability of occurrence during the lifespan of the structure (e.g. maximum credible earthquake - MCE),
- flood situations. They are introduced in a specific way, given their importance in the case of hydraulic structures. Flood situations include themselves three sub-categories:
  - o Unusual flood situations (dedicated to the justification of dams for flood mitigation),
  - o Exceptional flood situations (design flood corresponding to the attainment of the maximum headwater level - MHL),
  - o Extreme flood situation (beyond which the integrity of the structure would not be

ensured).

The intensity of seismic action and the return period of floods are defined regarding the category of the dam in a French classification from A to D depending on the height of the dam and the volume of the reservoir [5]. Table 2 presents the requirements for the return period of the design flood [6]. There is such a table for extreme situations, including combination of floods with possible failures of the spillway.

TABLE 1: MAIN DESIGN SITUATIONS

Categories of situations	Examples or remarks
<b>Normal operating situation</b>	Normal water level (NWL) in the reservoir and related d/s water level
<b>Transient or unusual situations</b>	End of construction Reservoir empty Operating basic earthquake(OBE)
<b>Flood situations</b> Unusual flood Design flood Safety check (or extreme) flood	Dams for flood control Max. Headwater Level (MHL) Hazard level
<b>Accidental situations</b>	Maximum Credible Earthquake (MCE) Accidental situations related to external hazards (sliding or avalanche in the reservoir)
<b>Situations related to the failure or unavailability of a component (or combinations of events)</b>	Depending on the likelihood of the situation examined, considered as unusual situation ( $P > 10^{-3}$ to $10^{-4}$ per year) or as accidental ( $P < 10^{-4}$ per year)

TABLE 2: RETURN PERIOD FOR DESIGN FLOOD OF GRAVITY DAMS

Class of the dam	Return period (years)
<b>A</b>	1000 to 3000*
<b>B</b>	1000
<b>C</b>	300
<b>D</b>	100

(\* 1000 years for existing dams, 3000 years for new dams)

## Loads (or action of loads)

Loads are divided into three categories:

- Permanent loads: weight of the structure, sediment pressure, action of a downstream shoulder, action of pre-stressed anchors;
- Variable actions of water, including u/s water pressure, uplift pressure under or in the dam body, hydrodynamic action on d/s face and ice pressure on the u/s face (those two last aspects being new compared to FrCOLD2006);

- Accidental seismic action (including that of water).

Permanent actions are taken into account in the calculations from their characteristic value: it is a conservative estimate of the intensity of the action and therefore incorporates a margin of safety on the intensity of permanent actions. Guide values are given for characteristic value of specific weight of different materials (conventional concrete, RCC, masonry) and of sediment pressure.

For variable actions of water, the representative values are directly selected in different design situations by examining levels of filling of the reservoir and the resulting intensities of actions. The uplift pressure diagram can be derived from results of monitoring measurements if available.

Finally, accidental seismic action is derived from the design earthquake considered and includes related action of water in terms of upstream overpressure (taken into account with the Westergaard or the Zangar methods).

### Combination of actions

Combinations of actions are grouped into three categories which will allow defining the set of partial factors associated with them:

- Quasi-permanent combination;
- Unusual combinations;
- Extreme combinations.

Eight typical combinations are detailed, not systematically relevant for all dams, but presented as a framework for the designer. A special category is related to situations of failure or unavailability of a safety component of the dam (e.g. gates on a spillway, pump for drainage network, etc.)

### Example: Uplift pressure

The assessment of the uplift pressure load is a matter of determining the diagram of the uplift pressures acting in the dam body, at the dam-foundation interface and in the foundation. This diagram sets the magnitude of the uplift pressure load applied either on horizontal sections in the dam body or at the dam-foundation interface or in the rock joints in the foundation. The uncertainty on the magnitude of the uplift pressure load arises from the variations of the intrinsic properties of the site, the materials and details tending to reduce uplift pressures (foundation rock bedding, permeability of materials, grout curtain performance, drainage system design, etc.). French practices were particularly varied on this point and substantial work was needed to arrive at a common proposal.

In general, FrCOLD2012 [4] suggests considering that variations in the uplift pressures in the foundations and the dam body keep pace with the changes in reservoir level without any significant time lag. In the seismic situation, it is assumed that the uplift pressure diagram is not affected by earthquake accelerations which are transient and very brief.

If there is no engineered arrangement for reducing infiltration into the foundation and into the dam body, uplift is assumed

to vary linearly, giving a trapezoidal uplift diagram with 100% uplift pressure at the upstream side and uplift equal to tail-water level on the downstream side.

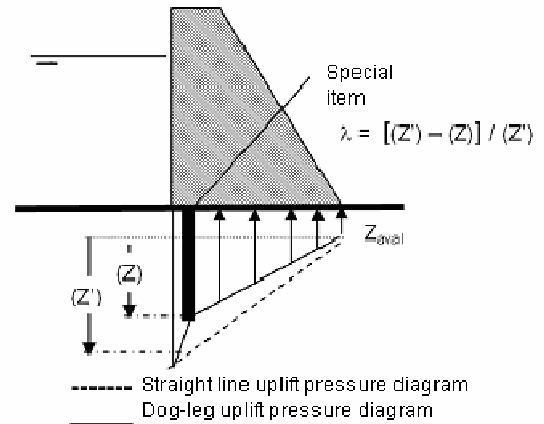


FIGURE 2. REDUCTION AND DISTRIBUTION OF UPLIFT PRESSURES

Engineered items such as grout curtains in the foundation and drainage curtains in the foundations and dam body intended to reduce the uplift pressure diagram are included in the form of a reduction factor  $\lambda$ . Using the notation of Figure 2, the reduction factor  $\lambda$  is defined by the following equation:

$$\lambda = (Z' - Z) / Z' \quad (1)$$

On the basis of an international bibliography and a review by the European Commission on Large Dams [7], the guidelines propose values for the uplift reduction factor  $\lambda$  which incorporates the following principles (Table 3):

TABLE 3. RECOMMENDED REDUCTION FACTOR  $\lambda$

Item	Recommended reduction factor $\lambda$
<i>in foundation</i>	
Foundation without drainage curtain (with or w/o grout curtain)	$\lambda = 0$
Drainage curtain in foundation	$\lambda = 1/2$ to $2/3$
Drainage curtain in foundation with unfavourable dip or geology	$\lambda = 1/2$ or less
<i>in dam body</i>	
Dam body without drainage	$\lambda = 0$
Drainage system in dam body made with homogeneous material	$\lambda = 1/2$ to $2/3$
Upstream impervious membrane with under-drainage	$\lambda = 1$
Maurice LEVY facing	
CVC* upstream facing with drainage	$\lambda = 2/3$
CVC upstream facing without drainage	$\lambda = 0$

\* CVC: conventional vibrated concrete

- Although a grout curtain effectively reduces uplift, it is recommended that it be ignored if there is no monitoring system to check its performance,
- Drainage systems are the most effective and reliable means of reducing uplift pressures.

If there are cracks in the dam body, FrCOLD2012 [4] suggests adopting the following assumptions (Figure 3):

- If the crack does not extend beyond the drainage curtain, then it is assumed that there is full uplift in the upstream part. The reduction factor  $\lambda$  applies where the crack intersects the drainage system with a linear distribution down to the downstream hydrostatic level,
- If the crack extends beyond the drainage curtain, full uplift is assumed to the end of the crack, followed by a linear distribution down to the downstream hydrostatic level. This is a conservative assumption that can be relaxed if it can be shown that the drainage system is sufficiently effective to reduce uplift despite the cracking.

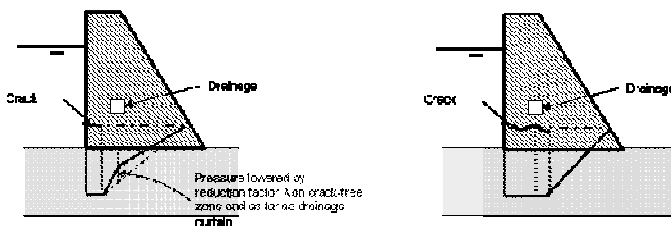


FIGURE 3. DIAGRAM OF UPLIFT PRESSURES IN THE BODY OF A CRACKED DAM WITH DRAINAGE

## Strength properties of materials

Strength properties of materials (section 2 of the guidelines) are taken into account in the calculations from their characteristic value: it is a conservative estimate of the value of the resistance of the material and therefore incorporates part of the safety on resistance characteristics.

In Eurocodes, this caution in estimating parameters is taken into account by a fractile 95% (or 5% depending on the favorable or unfavorable nature of the action) of the distribution law of resistance considered.

The evaluation of test results by statistical methods can be performed when the data come from populations identified sufficiently homogeneous and a sufficient number of observations are available. For this, it is necessary to take into account the spatial variability of parameters, the dispersion of test data and the statistical uncertainty associated with the number of tests.

When the use of statistic methods is not possible because of the lack of data, the conservative estimate is then appealed to expert judgment, based on the results of available trials or from guideline values from the literature; in this case, the

characteristic value corresponds to a conservative expert estimate value of the resistance of the material.

## Strength properties of the foundation

The formalization of strength properties of foundation materials for the justification of a gravity dam includes two steps:

- The geological model, whose objectives are to provide the information necessary to assess the quality of the foundation of the dam: its tightness, resistance and the risk of differential settlement and internal erosion in the rock;
- The mechanical model of the foundation, whose objective is to define a framework for representing properties of strength and deformability of the foundation, in order to evaluate its behavior and security vis-à-vis the various limit states to be considered.

The guidelines provide methods for establishing the geological model and defining the mechanical model. For resistance characteristics of the foundation, models derived from Barton [8] and Hoek & Brown [9] works are promoted, as illustrated in Figure 4.

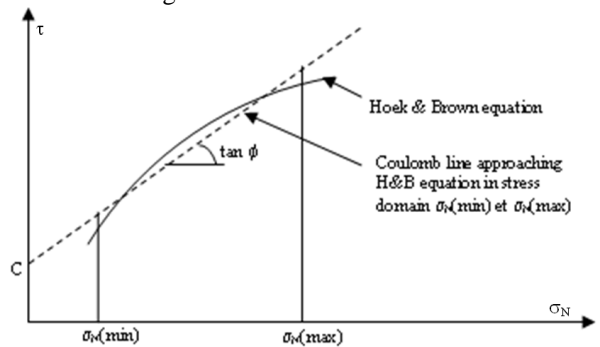


FIGURE 4. COULOMB LINE APPROACHING HOEK & BROWN EQUATION FOR DETERMINING C AND  $\phi$  IN THE FOUNDATION

## Strength properties at the dam-foundation interface

The mechanical strength of the dam-foundation interface depends not only on the characteristics of the weakest of these two materials. It also depends on the quality of treatment of the rocky foundation, the quality of the preparation and the geometry of the bottom of the excavation (in general complex geometry stepped to ensure the best possible anchor).

The dam-foundation interface is rarely a simple plan, but rather an area, a few meters thick (depending on the contact geometry and thickness of bonding treatments). The interface is therefore not limited to a strict contact between dam and foundation.

The surface on which stability calculations are performed will be chosen based on these elements.

In the case of an existing dam, high quality boreholes are



recommended to investigate the contact between the dam and its foundation and to collect samples for laboratory shear tests.

A specific section is developed on how to consider the resistance of passive reinforcement bars in a cautious approach.

### Strength properties inside the dam body

The characteristic value (denoted  $R_k$ ) of a material constituting the dam body (CVC, RCC, masonry) is a conservative estimate of the value of the resistance of the material controlling the phenomenon considered in the limit-state.

The extent of the dam body that governs the behavior of the structure vis-à-vis a limit state is much greater than that involved in a laboratory or in situ test. Therefore, the value of the property that controls the behavior of the structure is not the value measured locally, but an average value over a certain area or within a certain volume. The characteristic value is a conservative estimate of this average value. It cannot result from a single statistical computing and must appeal to the expert judgment.

### Example: Resistance of dam body made of RCC or conventional concrete.

The resistance is controlled by the mechanical parameters along the joints. What matters is not the local value or the average value obtained on all joints. Rather it is the average value of the property along the joint that has been the least well done. The characteristic value corresponds to a conservative estimate of the average value of the property along this joint. In the case where measurements are available, the statistical calculation must be conducted with care to identify and qualify the worst joint.

If tests are always recommended to determine the characteristic values, guide characteristic values are also suggested in FrCOLD, 2012 [4], that can be used in preliminary order-of-magnitude studies.

## Limits states

The stability of gravity dams is verified for different limit states, that is to say, for various negative phenomena against which the designer looks for protecting the dam:

- Lack of shearing resistance;
- Excessive extension of cracks;
- Lack of compressive strength.

Some dams require justification for additional limit states, such as:

- Bearing capacity of the foundation;
- Resistance to uplift;
- Erosion of the downstream toe by overflow.

All those limit states are described in the guidelines with their respective limit-state requirements (except the last one which

is not so formally stated). Two examples are given in next sections.

### Limit-state requirements

For each limit state, the French guidelines indicate the limit state requirements (Section 3), which involves:

- Actions taken into account by means of characteristic values for permanent actions and using representative values corresponding to design situations for actions of water;
- The strength properties taken into account by means of the characteristic values. Each characteristic value is weighted by a partial factor - noted  $\gamma_m$  - supporting the uncertainty in the knowledge of the property. The set of partial factors adopted introduces a differentiation according to the design situations;
- Model coefficient - denoted  $\gamma_d$  - supports all uncertainties not covered by considerations on the knowledge of the properties of resistance, especially hydraulic model uncertainty and limit state model uncertainty. In practice, the model coefficients were obtained by conventional calibration, the principle of seeking the best equivalence between the security levels of the semi-probabilistic method proposed and those resulting from traditional deterministic practices, so as to fit as reasonably as possible the previous standards. Thus, the model coefficient plays the role of fitting between deterministic and semi-probabilistic criteria.

### Mechanical modeling principles

Two approaches are described:

- A simplified 2D modelling, considering the dam body as a solid whose stresses comply with Navier hypothesis. This type of modeling is used to calculate the extension of a crack and study the ultimate limit-states requirements along predefined surfaces;
- Finite element modeling with 2D or 3D geometry (as appropriate) of the dam and the foundation. This type of modeling is used to calculate the stresses and strains at any point of the mesh. The stress field along a fracture surface can then be used as input to an ultimate limit-state calculation along this surface. The calculation of the extension of a crack is also possible if the computer code includes an appropriate module.

The possible surfaces of rupture considered are usually horizontal surfaces like dam-foundation interface and concreting joints. However geology and topography main impose inclined surfaces, especially in foundation.

### Example one: Excessive extension of cracks

The condition of non-extension of cracking is written:

$$\sigma'_N(x) > -f_{tk} / \gamma_{mft} \quad (2)$$

where:

- $\sigma'_N(x)$  the normal effective stress at abscise x along the shear surface;
- $f_{tk}$  the characteristic value of the tensile strength of the material investigated (in practice, the dimensioning is the value at the concreting joints);
- $\gamma_{mft}$  the partial factor affecting the characteristic value of the tensile strength of the material depending on the combination of actions considered.

Using the 2D Navier mechanical model, the normal effective stress at the upstream face of the dam is:

$$\sigma'_n = \frac{N}{L} - 6 \frac{M}{L^2} \quad (3)$$

where:

- N the normal component of the resultant of the actions being applied to the section considered;
- M the moment of this resultant relative to the center of the section;
- L the width of the section.

The cracked length of the section named  $L'$  is calculated by an iterative process, in which full uplift pressure is introduced in the cracked part of the section.

The limit-state requirements are as follows (Table 4), along dam-foundation interface and inside dam body:

TABLE 4. LIMIT STATE REQUIREMENTS FOR CRACK EXTENSION

Combination of actions	Limit-state condition
Quasi-permanent	No crack ( $\sigma'_N(0) > -f_{tk} / \gamma_{mft}$ )
Unusual	Crack opening limited to the drainage curtain Or extending to less than 25% of the shear surface in absence of drainage

The partial coefficient affecting the characteristic value of the tensile strength of the material is taken at 3 in all cases.

*Nota:* we do not impose a limit state condition of crack opening for extreme combinations of actions. However, including these combinations, calculations of crack expansion are necessarily made:

- To feed in the calculation of shear resistance,
- To assess the maximum length cracked (to take into account in assessing the stability after an extreme situation).

### Example two: Lack of shearing resistance

The limit state condition for shearing resistance is written:

$$[C_k / \gamma_{mC} \cdot L' + (N-U) \cdot (\tan\phi)_k / \gamma_{mtan\phi}] > \gamma_{d1} \cdot T \quad (4)$$

where:

- $C_k$  and  $(\tan\phi)_k$  are the characteristic values of cohesion and tangent of the internal friction angle of the material,
- $L'$  is the length of the uncracked section calculated as described above,
- N and T are the normal and tangential components of the

loads acting upon the section considered, arising from the load combinations considered,

- U is the resultant of the pore pressures on the section considered, depending on the load combinations considered,
- $\gamma_{mC}$  and  $\gamma_{mtan\phi}$  are the partial factors to be applied to the characteristic values of the shear strength of the materials, depending on the load combination considered,
- $\gamma_{d1}$  is the model factor for shear strength limit state.

Partial factors  $\gamma_{mC}$  and  $\gamma_{mtan\phi}$  weighting the shear strength parameters of the materials are given in Table 5. Partial factors  $\gamma_{mft}$  weighting the tensile strength are given in Table 6 (tensile strength of the foundation is always considered as null).

TABLE 5. PARTIAL FACTORS APPLIED TO SHEAR STRENGTH PARAMETERS

Partial factors $\gamma_{mC}$ & $\gamma_{mtan\phi}$	Quasi-permanent combination $\gamma_{mC-qp}$ & $\gamma_{mtan\phi-qp}$	Unusual combinations $\gamma_{mC-rare}$ & $\gamma_{mtan\phi-rare}$	Extreme combinations $\gamma_{mC-ext.}$ & $\gamma_{mtan\phi-ext.}$
Dam body	<b>3 &amp; 1.5</b>	<b>2 &amp; 1.2</b>	<b>1 &amp; 1</b>
Dam-foundation interface	<b>3 &amp; 1.5</b>	<b>2 &amp; 1.2</b>	<b>1 &amp; 1</b>
Foundation	<b>3 &amp; 1.5</b>	<b>2 &amp; 1.2</b>	<b>1 &amp; 1</b>

TABLE 6. PARTIAL FACTORS APPLIED TO TENSILE STRENGTH

Partial factor $\gamma_{mft}$	Quasi-permanent combination $\gamma_{mft-qp}$	Unusual combinations $\gamma_{mft-rare}$	Extreme combinations $\gamma_{mft-ext.}$
Dam body	<b>3</b>	<b>3</b>	<b>1</b>
Dam-foundation interface	<b>3</b>	<b>3</b>	<b>1</b>

TABLE 7. MODEL FACTOR  $\gamma_{d1}$  FOR SHEARING RESISTANCE LIMIT-STATE

Combinations of actions	Model factor $\gamma_{d1}$
Quasi-permanent	1
Unusual	1
extreme	1

## Conclusion

FrCOLD2012 guidelines for gravity dams benefited from feedback from the application of interim recommendations FrCOLD2006. Feedback reveals a good take-up of these new recommendations by engineering consultancies and public institutions. Setting partial factors prevents from disturbing



the usual safety levels obtained by conventional deterministic practices. This standardized method is now being routinely used for gravity dam safety reviews and design of new and remedial works.

Drafted by a working group whose members are representative of the French dam engineering profession, it has brought French practice into line on a common basis. It provides a standard reference for calculating loads and strengths, covering various design situations which must be examined and the limit states to be checked with acceptability criteria.

FrCOLD2012 adopts a semi-probabilistic limit state format similar to the Eurocodes, with characteristic values for loads and strengths, design situations and limit state conditions. In this way, they offer an integrated approach to the design review and its analytical support. The proposed analyses distribute safety among partial factors which are used to weight strengths and model factors which take charge of uncertainty in the limit state model. These factors substitute for the deterministic global factor, in common use in the previous century.

The recommendations introduce the important concept of characteristic value of strength. This allows a more rigorous procedure of expert judgment and/or statistical justification of the strength parameters, backed up by laboratory and field tests. This approach is an incentive to perform tests in order to improve our knowledge of these characteristic values and to avoid setting over conservative values because of there being too few test data or insufficiently justified strength parameters.

It fits into a coherent set of professional guidelines concerning dams and dikes:

- FrCOLD, 2010. Guidelines for the justification of the stability of embankment dams and levees - Interim Recommendations, June 2010, 114p.
- MEDDTL, 2010. Seismic risk and safety of hydraulic structures - Report of the Working Group, November 2010, 279p.
- FrCOLD, 2013. Recommendations for the design of spillways of dams, forthcoming.

In a very near future, French regulation will integrate those guidelines, giving them a mandatory frame.

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