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Directive on the Safety of Water Retaining Facilities

Part C1: Design and construction

Note: This document is a preprint of Part C1 of the Directive on the Safety of Water Retaining Facilities (revised version, 2014-2016).

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Contents

Appendices

1. Introduction

Part C1 of the Directive deals with all aspects of the structural safety of water retaining facilities (Articles 5 and 6 of the Water Retaining Facilities Act and Article 2, section 1 of the Water Retaining Facilities Ordinance), with the exception of special load cases relating to flood (cf. Directive, Part C2) and earthquake (cf. Directive, Part C3). Part C1 applies to all types of water retaining facilities, regardless of their dimensions, purpose and operator, in the context of:

- the preparation of a new project and construction of a new water retaining facility;
- alteration of an existing water retaining facility;
- safety analysis of an existing water retaining facility.

The implementation of the guidelines contained in this part of the Directive must take account of the characteristics of the water retaining facility concerned while complying with the provisions of the Water Retaining Facilities Act (hereinafter, WRFA) and the Water Retaining Facilities Ordinance (hereinafter, WRFO).

2. Procedure

2.1. Planning approval (Article 6, WRFA)

The construction of a new water retaining facility and the modifications[1] of an existing facility require the prior approval of the supervisory authority responsible for the aspects relating to technical safety. The documentation of relevance to technical safety that has to be submitted by the applicant is described in section 3.3.

If approval in accordance with legislation other than the WRFA should be required (for example, a cantonal construction licensing procedure), in line with the principle of procedural coordination the planning approval must be granted by the relevant cantonal or federal authority. The applicant is required to enclose all the necessary documentation related to technical safety with the application to the relevant licensing authority.[2] The licensing authority is responsible for requesting a report on the aspects of technical safety from the supervisory authority. It must incorporate the conclusions drawn by the supervisory authority, together with the resulting requirements ("conditions"), into its global decision ("planning approval").

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[1] Section 6.1 of Part D of the Directive specifies the relevant works.
[2] A distinction is made between "supervisory authority", which is solely responsible for ensuring compliance with the technical safety requirements as specified in the WRFA and WRFO, and "licensing authority", which is responsible for granting construction licences ("planning approval"), taking all the relevant aspects into account (for example, protection of the environment), one of them being the outcome of the examination of the aspects of technical safety by the supervisory authority.

If no additional approval is required in accordance with legislation other than the WRFA, the applicant submits the application directly to the supervisory authority, which examines the submitted documentation and grants the requested planning approval as long as the stipulated technical safety requirements are met.

It is advisable for applicants to contact the supervisory authority at an early stage in order to define the fundamental requirements for the project, as well as to draw up a plan for the direct submission and the review of the technical documentation. This will speed up the processing of the application following its formal submission for approval.

2.2. Influence of underground structures

In underground and excavated structures (especially tunnels) beneath an existing water retaining facility, drainage effects can give rise to deformations of the abutments, and these deformations can cause internal stresses in the dam. Depending on the prevailing situation (type of underground structure, hydro-geological circumstances, type of dam), this can threaten the safety of the water retaining facility.

Before an authority may take a decision regarding an underground structure, it has to consult the relevant supervisory authority (Article 9, WRFA), which has to decide from case to case whether it is necessary to examine the influence of the planned underground structure on the safety of the water retaining facility in question, and whether measures may need to be taken in order to prevent an uncontrolled discharge of water from the facility. The procedure described in **Appendix 1** serves as a guideline for this purpose.

2.3. Safety analysis of an existing water retaining facility

The operator is required to carry out a technical safety analysis of the entire facility or its components (dam and its foundations, reservoir, auxiliary installations of relevance to safety), in particular to:

- take account of changes in the state of the art in science and technology relating to water retaining facilities;
- take account of changes with respect to the assumptions made during a previous safety analysis, also those related to changes in the utilisation of the facility;
- comply with an order issued by the supervisory authority.[3]

[3] Operators who contest an order or conclusion communicated by the supervisory authority may request a substantiated ruling indicating the applicable remedial procedure.

If they are of the opinion that one of the conditions cited above applies and a corresponding safety analysis is thus required, the qualified professional and experts must include a comment to this effect in their safety reports.

The results of safety analyses that have been carried out in accordance with the *2002 structural safety basis document* and the *2002 directive* remain valid and do not have to be repeated due to the publication of this revised Directive.

3. Utilisation agreement, project basis and application for planning approval

3.1. Utilisation agreement

An utilisation agreement describes the owner's intended use of the facility, together with the conditions, requirements and general regulations relating to its planning, construction and use. The elements that are necessary for understanding the objectives and operating conditions of the water retaining facility, together with those incorporated into the assessment of technical safety, must be communicated to the supervisory authority. The utilisation agreement and any subsequent updates form an integral part of the archive material that must be submitted by the operator by not later than the time at which the facility is put into operation (Article 22, paragraph 2b, WRFO). For existing water retaining facilities, these elements may be included in other technical documentation (for example, dam monograph).

The elements concerned include:

- declaration of the purpose of the facility (primary and secondary uses, stating the corresponding operational objectives[4]);
- location of the facility (on maps and with a description of the dam and auxiliary facilities, the reservoir, the catchment area);
- the local conditions (topographic, geological and hydrological conditions, situation with respect to natural hazards);
- the design fundamentals (type and dimensions of the dam);
- special legal requirements and background technical documentation (including the requirements in accordance with the relevant legislation governing water retaining facilities and the issued licence).

3.2. Project basis

The project basis defines the specific technical data relating to the water retaining facility. It takes the form of a technical description for the implementation of the utili-

[4] For example, return period of natural hazards against which the water retaining facility is designed to protect the population, or installed capacity of a hydropower plant.

sation agreement, with specific reference to the facility concerned. The elements that are of significance in terms of technical safety have to be incorporated as an integral part of the plans, static and hydraulic calculations and other safety checks into the planning approval dossier to be submitted to the supervisory authority. Applicants are advised to ask the supervisory authority to confirm these elements before they prepare the detailed plans and safety assessments. This includes:

- the hydrological fundamentals and the applied methodology for demonstrating sufficient protection against floods;
- the level of earthquake hazard and the applied methodology for demonstrating sufficient protection against earthquakes;
- special safety studies relating to the location of the facility and the facility itself.

3.3. Documentation required for the planning approval of a construction or modification project

The documentation to be submitted to the supervisory authority for planning approval of a construction or modification project must contain all the technical details that demonstrate that the facility concerned is designed and will be constructed in accordance with the current state of the art in science and technology so that its safety is assured for all foreseeable load and operating conditions. All subsequent changes relating to the technical safety of the approved project must be submitted to the supervisory or licensing authority for approval.

The details to be submitted by the applicant are based on the elements listed in Table 3-1, adapted to the specific characteristics and dimensions of the project concerned:

1. Technical report (elements of the utilisation agreement and project basis)
1.1 Basic elements
1.1.1 Description of the construction / modification project (retaining structure, reservoir, auxiliary installations)
1.1.2 Objectives (purpose and type of use, envisaged duration of use)
1.2 Situation and background conditions
1.2.1 Existing structures and infrastructures
1.2.2 Topography, geomorphological framework
1.2.3 Underground conditions (foundations, reservoir): geology, tectonics, geotechnology, hydrogeology
1.2.4 General seismicity of the location
1.2.5 Natural hazards (including landslides, rockfalls, mudslides, avalanches, icefalls, outbreaks from glacial lakes, sedimentation, risk of subsidence in karstic landscapes)
1.2.6 Hydrology (catchment areas, water catchments, precipitation intensity, run-offs)
1.2.7 Reservoir filling curve, maximum operating level, storage height, storage capacity
1.2.8 Sedimentation and sediment management concept if the facility is subject to the influence of sedimentation
1.2.9 Construction materials (sites and quarries, properties)

1.2.10 Other project-related requirements and restrictions (for example, nearby buildings, including underground structures)
2. Structural analysis, safety assessment
2.1 Components of the structure
2.1.1 Structural system (including the foundations, secondary installations and reservoir banks): type, dimensions, other construction details
2.1.2 Structural design (joints, zone of contact between concrete and rock) *)
2.1.3 Properties of dam material (results of tests, including properties included in the verification) *)
2.1.4 Properties of foundation material, planned injections, drainage facilities
2.1.5 Construction method
2.1.6 Auxiliary installations of relevance to safety
2.2. Verification of structural safety
2.2.1 Calculation fundamentals; individual loads, combined loads
2.2.2 Modelling, calculations
2.2.3 Verification of static stability of the dam (overall stability, internal load-bearing capacity, including the foundations)
2.2.4 Stability of banks, impulse waves *)
2.2.5 Earthquake safety (dam, reservoir, auxiliary installations)
2.3 Verification of flood safety and of relief and outlet works
2.3.1 Hydrograph of inflows and outflows (retention), specification of design flood and safety level flood
2.3.2 Dimensions of relief and outlet works (capacity, freeboard and hydraulics), danger level
2.3.3 Specification of flood level for the construction site
2.4 Emergency planning
2.4.1 Inundation map (in the event of a dam breach)
2.4.2 Components of the alarm system
2.5 Instruments, surveillance concept, controls
2.5.1 Instrumentation and surveillance concept during operation of the water retaining facility *) and during construction work (description, diagrams)
2.5.2 Programme for testing of materials during construction work
3. Additional elements for the special case of modification of a water retaining facility
3.1 Binding with the existing structure, construction details at the interface between old and new
3.2 Surveillance of existing facility during construction work
3.3 Protection against flooding during construction work
3.4 Operational restrictions during construction work
4. Plans and construction programme
4.1 Situation, layout, elevations, cross-sections, structural details
4.2 Planned construction programme

*) As a rule, the supervisory authority may accept the submission of the details relating to these elements after it has granted its approval, though before the initiation of construction work.

Table 3-1: Elements of relevance to technical safety that normally have to be included in applications for planning approval

3.4. Duties of the supervisory authority in the framework of the licensing of construction and modification projects

The supervisory authority is responsible for examining the submitted documentation relating to technical safety (prevention of uncontrolled water discharge, management of residual risk), excluding all other aspects.[5] In particular, this includes verifying that:

- the submitted dossier contains all the documentation and details that it requires for verifying the technical safety of the planned facility – for this purpose it may refer to section 3.3;
- examining the structural measures necessary for ensuring technical safety are planned, including
    - the installation of a bottom outlet with sufficient discharge capacity (cf. Directive, Part C2);
    - measures to protect against acts of sabotage (cf. section 6);
- the design, safety analyses and planned construction method comply with the state of the art in science and technology (here it may refer to various parts of the Directive) – For this purpose it examines in particular
    - the suitability of the selected analysis procedure;
    - the correctness of the basic hypotheses;
    - the plausibility of the obtained findings;
- the arrangement of the various instruments (including the geodetic network) is appropriate;
- the installation of a water alarm system is planned (where necessary);
- the submission of additional documentations before and during construction has been planned.

The supervisory authority has to approve the project in accordance with section 2.1 if all the required documentation has been submitted and the technical safety requirements are met.

If necessary from the point of view of technical safety, the supervisory authority may, in the planning approval, specify certain requirements (“conditions”) that have to be met by the applicant. These typically concern the elements listed in **Appendix 2**.

The following points should also be noted (cf. Directive, Part D):

- planning approval does not represent a licence to commission and operate the facility;
- the operator is required to submit a programme for first filling, as well as gate regulations and emergency regulations that have to be approved by the su-

[5] Aspects such as choice of options for the construction project (insofar as these meet the applicable safety requirements), protection of the environment, quantities of residual and returned water, operation of power plant, workplace safety, do not fall within the remit of the supervisory authority.

pervisory authority; the approval of these items is a prerequisite for the granting of a commissioning licence;
- surveillance regulations drawn up by the operator and approved by the supervisory authority are a prerequisite for the operation of the facility.

3.5. Acceptance of construction work by the supervisory authority (Article 9, paragraph 3, WRFO)

Upon completion of the construction work, the supervisory authority has to check whether:

- the applicant has submitted all documentation relating to technical safety that has been specified in the planning approval or has been requested before, during or after construction of the facility;
- all the stipulated safety requirements ("conditions") have been fully complied with;
- construction has been carried out in accordance with the plans or (where applicable) the approved modifications.[6]

The supervisory authority is required to record its findings in the form of an acceptance report, which in turn is a prerequisite for granting a commissioning licence (cf. Directive, Part D, section 2.2.).

If the construction work has not been carried out in accordance with the approved plans (or, where applicable, the approved modifications), the supervisory authority has to decide whether a subsequent planning approval procedure is required regarding the identified irregularities. Here, in the same way as in the case of missing documentation or failure to comply with specified requirements, the supervisory authority may suspend the preparation of its acceptance report until the situation has been rectified, or specify a deadline in the acceptance report for the submission of the missing documentation.

4. Structural safety

4.1. Objective of structural safety

The main objective of structural safety is to ensure that the water retaining facility is able to withstand all foreseeable load and operational conditions so that uncontrolled and damaging discharges of large quantities of water can be prevented. It is the responsibility of the applicant and operator to take the necessary structural measures

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[6] Here, the duties of the supervisory authority are limited to a general assessment, without detailed inspections (for example, without measurements).

and provide the necessary evidence of structural safety. As a rule, this concerns the following elements:

a) diversion of flood water and sufficient discharge capacity of the relief and outlet works;
b) structural integrity of the dam, the auxiliary installations of relevance to safety, their foundations, and the reservoir during normal operation and following the occurrence of an extraordinary or extreme event (for example, an earthquake).

Verification of flood safety and compliance with the requirements on the discharge capacity of relief and outlet works are dealt with in Part C2 of the Directive and are therefore not addressed here.

4.2. Verification of structural integrity

Verification of structural integrity generally has to be provided for the overall limits of stability in line with the state of the art in science and technology:[7]

- overall stability of the entire dam or its components, or of auxiliary installations of relevance to safety (cf. section 4.6.6);
- ultimate capacity of the entire dam or its components, or of auxiliary installations of relevance to safety (internal stability, cf. section 4.6.7);
- ultimate capacity of the foundations (internal stability, cf. section 4.6.8);
- stability of slopes in the retention zone (cf. section 4.6.9);

For existing water retaining facilities, the circumstances that affect their safety (subsidence, cracks, clogging of drains, etc.) have to be taken into account when preparing the required verification, generally speaking in the form of initial conditions for verifying the structural integrity of the facility.

4.3. Load combinations

The individual load cases cited below usually have to be taken into account when preparing the verification of the structural integrity of a water retaining facility, if they are of relevance for the facility and the location in question. These have to be combined so that they represent the most detrimental loading. If other effects can influence the stability of the facility in a manner that cannot be ignored, or other load cases give rise to even more unfavourable results in the verification of structural safety, these have to be taken into account in accordance with the same principles.

[7] For the definition, see Part A of the Directive.

Combinations of load cases are classified and defined as shown in the table below:

Normal (Type 1)	Loads that act regularly on the facility.
Extraordinary (Type 2)	Loads that can arise, though not necessarily during the useful life of the facility. In such cases, minor damage may be tolerated. Safety installations (e.g. spillways and drainage systems) must remain operational.
Extreme (Type 3)	The most harmful loads for which structural safety must be verified (though it is assumed here that neither two simultaneous individual extreme load, nor a single extreme load in combination with an extraordinary load case, are likely to occur). In these cases, damage is permissible but must not give rise to any uncontrolled and hazardous discharge of water from the reservoir. However, as a rule intensified inspections and structural measures are required in order to reinstate an acceptable safety level.

Table 4-1: Load case combinations

Individual loads	Load combinations for gravity dams (concrete and masonry), weirs and arch dams, including abutments and foundations						
	Normal load combinations (Type 1)		**Extraordinary load combinations (Type 2)**			**Extreme load combinations (Type 3)**	
						Static	**Dynamic**
	Empty reservoir	**Full reservoir**	**Design flood**	**Ice**	**Avalanche or mudslide**	**Flood safety level**	**Earthquake**
Own weight [ii)]	X	X	X	X	X	X	X
Hydrostatic pressure, reservoir at maximum operating level [i)]		X		X	(X)		X
Hydrostatic pressure corresponding to flood level			X			X	
Hydrostatic pressure downstream (where applicable) [v)]	(X)	(X)	(X)	(X)	(X)	(X)	(X)
Sediment pressure upstream (where applicable)	(X)	(X)	(X)	(X)	(X)	(X)	(X)
Earth pressure downstream (where applicable)	(X)	(X)	(X)	(X)	(X)	(X)	(X)
Earthquake							X
Ice pressure				X			(X)
Pressure due to avalanche or mudslide					X		
	Other influences that have to be taken into account for gravity dams (concrete and masonry) and weirs [iii)]						
Uplift, reservoir at normal operating level [iii)]		X		X	(X)		X
Uplift, reservoir at flood level [iii)]			X			X	
	Other influences that have to be taken into account for arch dams [iv)]						
Temperature variations [iv)]	X	X	X	X	X	X	X

<u>Comments</u>

- i) **Normal operating level**: maximum operating level at reservoir with active operation; other facilities, relevant threshold for calculating the storage height in accordance with Part A of the Directive. An **intermediate level** also has to be taken into account if this leads to higher loads.
- i) **Own weight**: in the case of arch dams, the construction phases and joint sealing have to be taken into account in an appropriate manner.
- iii) **Uplift pressures** may in general be ignored in the verification of overall stability of arch dams, otherwise they have to be taken into account in the same way as for gravity dams.
- iv) Temperature variations may in general be ignored in the verification of the stability of gravity dams as there is no over determination of the global static system, otherwise they have to be taken into account in the same way as for arch dams. Temperature effects can also result in second-order stresses, especially in galleries and at the interface between concrete and rock.
- v) Downstream **hydrostatic pressure** has to be combined with upstream hydrostatic pressure in the most detrimental way.
- X Individual load that has to be taken into account in the load combination.
- (X) To be taken into account where applicable.

Please note	a) The other individual loads (cf. section 4.5) have to be taken into account as necessary, in the most detrimental way.

Table 4-2: Load combinations for concrete dams

Individual loads	Load combinations for embankment dams, including abutments and foundations							
	Normal load combinations (Type 1)		**Extraordinary load combinations (Type 2)**				**Extreme load combinations (Type 3)**	
							Static	**Dynamic**
	Empty reservoir (drained embankment)	**Full reservoir**	**Empty reservoir (upon completion of construction)**	**Design flood**	**Rapid discharge**	**Avalanche or mudslide**	**Flood safety level**	**Earthquake**
Own weight	X	X	X	X	X	X	X	X
Hydrostatic pressure at normal operating level[i)]		X				(X)		X
Pore water pressure at normal operating level[i)]		X			X [iv)]	(X)		X [iii)]
Hydrostatic pressure corresponding to flood level				X			X	
Pore water pressure corresponding to flood level [ii)]				X [ii)]			X [ii)]	
Pore water pressures before consolidation		(X)	X					
Earthquake								X
Pressure due to avalanche or mudslide						X		

Comments	i)	**Normal operating level**: maximum operating level at reservoir with active operation; other facilities, relevant threshold for calculating the storage height in accordance with Part A of the Directive. An **intermediate level** also has to be taken into account if this leads to higher loads.
	i)	**Pore water pressures in the event of flood:** adaptation is possible according to duration of flood and effectiveness of drainage system
	iii)	**Pore water pressures in the event of earthquake**: or in accordance with the details in Part C3 of the Directive.
	iv)	**Pore water pressures in the event of rapid discharge**: a reduction of pore water pressures is permissible for fills comprising well-drained material.
	X	Individual influence that has to be taken into account in the load case.
	(X)	To be taken into account according to the case.
Please note	a)	Load cases also depend on the type of embankment.
	b)	Generally speaking, **ice pressure** does not play a role in the verification of stability of embankment dams.
	c)	The other individual loads (cf. section 4.5) have to be taken into account as necessary, in the most detrimental way.

Table 4-3: Load cases for embankment dams (including abutments and foundations)

In addition, the following load combinations have to be taken into account for the **banks and slopes of the reservoir** if instability cannot be ruled out (in general, determined by a geologist).

- Normal load cases (Type 1) : Own weight **and**
  Hydrostatic pressure (full reservoir), uplift pressure (effect on smooth surfaces, joints, faults, etc.), and corresponding pore water pressures for underwater areas (maintenance of pore water pressure with absence of external hydrostatic pressure in the case of a rapid change of water level).
- Extraordinary load cases (Type 2) : Own weight **and**
  Hydrostatic pressure (reservoir at design flood level), uplift pressure (effect on smooth surfaces, joints, faults, etc.), and corresponding pore water pressures for underwater areas (maintenance of pore water pressure with absence of external water pressure in the case of a rapid change of water level).

- Extreme load cases (Type 3) : Own weight **and**
  (a) Hydrostatic pressure (full reservoir), uplift pressure (effect on smooth surfaces, joints, faults, etc.) and corresponding pore water pressures,
  Earthquake loading, or
  (b) Hydrostatic pressure (reservoir at **flood safety level**), uplift pressure (effect on smooth surfaces, joints, faults, etc.) and corresponding pore water pressures.

4.4. Description of individual loads

4.4.1. Own weight

The mean values of the density calculated with the aid of laboratory tests have to be taken into account for calculating the own weight of the materials. In the absence of laboratory tests, standard values may generally be obtained from the available literature.

4.4.2. Hydrostatic pressure

Hydrostatic pressure has to be taken into account with a specific weight of 10 kN/m^3.

4.4.3. Uplift pressure

Uplift pressures have to be considered in the verification of the stability of gravity dams and rock edges.

It is recommended to determine the uplift pressure on the basis of a flow calculation. Here the validity of the selected hypotheses can be verified by comparing the results of the calculation with the measured uplift pressure. Special attention has to be paid to situations in which the uplift pressure can be influenced by the circulation of water in the slopes.
If no uplift pressure measurements exist or if the facility is still in the planning stage, the following distributions of uplift pressure may be assumed (cf. Appendix 3):

- if there is no grout curtain nor drainage: triangular distribution (without the presence of water downstream) or trapezoidal distribution (with the presence of water downstream), with uplift pressures upstream and downstream equal to the respective hydrostatic pressure;
- if there is a grout curtain upstream, a reduction of the uplift pressure in its vicinity is only permissible if it is possible to verify its effectiveness and if this reduction has previously been confirmed by the supervisory authority. Otherwise no reduction may be taken into account;
- if a drainage system (drainage channel, borehole) exists: reduction of uplift pressure by a maximum of 50 percent in the vicinity of the drainage system [Obernhuber 2014, US Army Corps of Engineers 2000] (for faultlessly functioning drainage systems).

4.4.4. Pore water pressure

The intensity and distribution of pore water pressure in the interior of embankment dams, and possibly in the interior of gravity dams or dams made of highly permeable concrete (construction joints, etc.), have to be determined on the basis of a calculation of flow and equipotential lines while taking account of the properties of the fill (especially its porosity and permeability, including its anisotropy). For existing water retaining facilities, the assumptions on which the calculation is based must be verified by comparing the calculation results with the measured pore water pressures.

4.4.5. Variations in concrete temperature

The variations in the mean temperature of the concrete and in the temperature gradient in the cross-section of arch dams have to be taken into account for carrying out stress analyses. Here, as a general rule two conditions have to be observed: a “summer” and a “winter” status, in each case as the difference from the original temperature of the dam at the joint grouting[8]. The temperatures relating to these two statuses generally correspond to the long-term multi-annual averages for the observed season. Temperatures that deviate further from the multi-annual averages have to be taken into account depends upon the behaviour of the dam (for example, lifting of the upstream toe of the dam in a very cold winter, or compression of the abutment in a very warm summer).

4.4.6. Earth pressure and downstream backfill

Active, passive and at-rest earth pressures that have to be taken into account for the analysis must be determined from case to case.

4.4.7. Sedimentation

The effects of sediment pressure on the dam can generally be taken into account as a static load resulting from an increase in the volumetric weight of the water of 4 kN/m^3. This value may be changed due to the type of sediment and the loading velocity (dynamic influence). Generally speaking, additional sedimentation may be ignored if the layer of the sediment is thin in comparison with the level of the hydrostatic pressure[9] that is relevant for the calculation.

4.4.8. Earthquake loading

With respect to earthquake loading, it has to be proceeded in accordance with the instructions provided in Part C3 of the Directive as supplementary information to the ones provided in this document (Part C1).[10]

4.4.9. Ice pressure

The impacts of ice pressure have to be taken into account for concrete dams if no active system is installed that prevents ice from adhering to the surface of the wall (for example, air-bubble injection); pronounced water-level fluctuations (for example, daily filling cycles) have the same effect. Generally speaking, ice pressure plays a significant role in the upper part of smaller dams, but is negligible in large dams.
For dams with a vertical or slightly inclined cladding, ice pressure may be estimated as follows [ETH 2003], [Obernhuber 2014]:

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[8] If this temperature is not known for an existing dam, the predominant mean long-term temperature in the dam may be used.
[9] For example, a sediment thickness of 25% of the dam height generates a 2.5% increase in the overall horizontal static load in the two-dimensional case.
[10] For small water retaining facilities (Category III) a simplified demonstration of earthquake resistance may be prepared as described in chapters 7.1 and 7.2 in Part C3 of the Directive. The static safety factor incorporated in this simplified demonstration of earthquake resistance can be obtained analogously to the formula for normal loading (normal reservoir level) provided in section 4.6.6.1 as

$$FS = \frac{\tan\varphi \sum N + cA}{\sum T}$$

1) Estimation of ice thickness in accordance with

$h = 0.035\sqrt{\left|\overline{T_L}\right| t_w}$ [m], at least 0.3 metres up to a height of 500 metres above sea level and 0.8 metres above 2,300 metres above sea level (linear extrapolation in between these heights).

$\left|\overline{T_L}\right|$ is the absolute value of the average of the minus temperatures during the cold weather period considered (in degrees C) and t_w is the corresponding duration (in days). Temperatures and the duration of cold weather periods represent mean annual values, calculated on the basis of an evaluation of meteorological data from a nearby measuring station (at a similar altitude).

2) Total ice pressure is estimated by multiplying the ice thickness by a pressure equal to 200 kN/m^2.

4.4.10. Avalanches

A distinction is made between an avalanche that collides directly with a dam constructed for protection against avalanches, and an impulse wave caused by an avalanche surging directly into the reservoir.

Avalanche colliding with a dam
If an avalanche could collide with a dam designed to protect against avalanches, the exerted pressure on the structure is that of an avalanche with a return period of 300 years. Here, the pressure (q_f) has to be defined in accordance with the information in the specialised literature, for example [Salm et al. 1987, Gebäudeversicherungsanstalt des Kantons St. Gallen 1999, Schleiss & Pougatsch 2011) for a ground avalanche

$q_f = 0.5\, c_d\, \rho_f\, v_f^2$ [kN/m^2]

where v_f = avalanche velocity [m/s], c_d = 2 to 3 (resistance coefficient) and ρ_f = 0.3 [t/m^3].

If there is also a risk of any individual objects (for example, trees) hitting the dam, the corresponding pressure should be added to the q_f value.

Impulse waves

If it is possible for an avalanche to surge directly into the reservoir, the resulting impulse wave and associated overflow risk have to be estimated on the basis of a return period of 300 years for the avalanche. If the danger level in accordance with Part C2 of the Directive could be exceeded, structural or operational measures have to be taken (for example, construction of a parapet, or temporary or permanent increase in the size of the freeboard).

The procedure according to [Heller et al. 2009] permits the calculation of the wave height at the dam (including determination of the impact zone, the speed and duration of the wave), as well as the applicable forces for the static calculations.

4.4.11. Mudslides

For mudslides, the same considerations apply as for avalanches, cf. [Salm et al. 1987, Gebäudeversicherungsanstalt des Kantons St. Gallen 1999, Heller et al. 2009, Rickenmann 1995, 1999, 2008, 2016, Bergmeister et al. 2009, Schleiss und Pougatsch 2011]. The pressure can be calculated using the following formula:

$q_f = 0.5\, c_d\, \rho_f\, v_f^2$ [kN/m^2]

where v_f = velocity of mudslide [m/s], c_d = 1.5 to 2.0 (resistance coefficient) and ρ_f = 1.8 [t/m^3].

4.5. Other individual influences

4.5.1. Anchors

Pretensioned and passive anchors permit providing the necessary stability, if the standard safety requirements are not fully met. Their effect has to comply with the applicable SIA Standard 267 [SIA 2013a, 2013b].

New (especially pretensioned) anchors have to be designed and installed so that it is possible to measure their force and inspect their condition.

In the case of new dams, for normal load case combinations the safety factor without anchors (dam and abutments) must not be less than 1.0.

The use of anchors for the stabilisation of slopes must meet the standard requirements for soil and rock mechanics. Here, special attention must be paid to creep behaviour and stress relaxation [SIA 2013a].

4.5.2. Moving loads

As a rule, moving loads are not of relevance for the stress analysis of dams and may be ignored. Otherwise, moving loads originating from road traffic may be taken from SIA Standard 261 [SIA 2014] and added as either normal or extraordinary loads (cf. section 4.3).

4.5.3. Accidents involving ships

Accidents in which ships collide with dams can have serious consequences for weirs with sluices. Here, collisions have to be taken into account as extraordinary loads (cf. section 4.3).

4.5.4. Chemical swelling of concrete

In the event that, in an existing dam, swelling of the concrete caused by a chemical reaction (primarily due to an alkali-aggregate reaction) should be detected, it is necessary to check for the associated internal stresses resulting from the over determination of the static system on a case-by-case basis (arch dams), as well as for any damage to the concrete itself (advanced stage of the reaction) and their possible influence on the safety.

4.5.5. Creep, shrinkage, stress relaxation and subsidence

Creep, shrinkage and stress relaxation of concrete gradually develop over time and give rise to changes in the parameters entering in the constitutive laws. These effects have to be taken into account if they could influence the stress status of the dam, either explicitly (constitutive law) or implicitly (adjustment of the global modulus of elasticity of concrete, rock, fill, etc.).

In the case of embankments, the project must include an increase in the height along the crest in order to ensure there is an adequate freeboard, including in the case of subsidence.

4.5.6. Aircraft colliding with a dam

This situation does not have to be taken into account (part of the residual risk).

4.5.7. Superstructures

Generally speaking, superstructures such as antenna masts are not deemed relevant to safety and are therefore not addressed in this Directive. However, it should be ensured that such installations do not cause local instability in the vicinity of their foundations.

4.6. Criteria for structural integrity

4.6.1. Basic principles

The criteria for demonstrating the integrity of the structure depend on the limit state for which the verification has to be carried out, and on the load combination (cf. section 4.3). In the framework of the verification, sensitivity analyses have to be carried out, in particular regarding the applied geotechnical properties and uplift pressures. The aim here is to highlight relevant parameters and more accurately assess the actual behaviour of the dam considered based on the status of knowledge of these parameters.

Verification has to be made in accordance with the concept of partial safety factors for loads and resistance as follows:

- **Loads**: As best estimate or average value if the calculation is made on the basis of a statistic analysis, or as median value if the calculation is made on the basis of several possible estimation models. No partial load factors are introduced.
- **Resistance**: Reduction of the characteristic resistance by the partial factors cited in section 4.6.5).

4.6.2. Categories of water retaining facilities

For verification of their structural integrity under static loading, water retaining facilities are classified into three categories with differing requirements in terms of extent of the verification and the necessary investigations. These are the same classifications as those used for the verification of earthquake safety (cf. Part C3 of the Directive).

The classification criteria are as follows:
- **Category I** = water retaining facilities that fulfil the criteria specified in Article 18, paragraph 1a or 1b, WRFO;
- **Category II** = water retaining facilities that have a storage height of at least 5 metres, fulfil the size criteria specified in Article 3, paragraph, WRFA and are not allocated to Category I;
- **Category** III = water retaining facilities that do not fulfil the size criteria specified in Article 3, paragraph 2, WRFA or have a storage height of up to 5 metres.

The three categories are depicted graphically in **Appendix 4** in terms of storage height and storage volume, in accordance with the definition cited in Part A of the Directive.

Water retaining facilities that are designed to protect against natural hazards and which retain only occasionally water are classified in Category III, regardless of their storage height and storage volume.

Lateral embankments of run-of-river facilities are allocated to Category III, subject to other more stringent requirements imposed by the supervisory authority, licensing authority for water rights or other authorities.

4.6.3. Determination of material properties

As a rule, the necessary material parameters have to be determined through representative field and laboratory tests. The 5% fractile[11] has to be retained for the resistance values. For existing water retaining facilities, the results of tests carried out during construction may be used. Due to the uncertainties associated with the determination of material properties, caution is always called for regarding the selection of the parameters.

Material parameters may also be determined through analyses of measurements of the dam behaviour if it can be demonstrated that a retro-analysis is suitable for determining the necessary parameters.

The uniaxial static compressive strength of the concrete (f_{cs}) obtained from cylinder, the dimensions of which depend on the grain size of the aggregates, and the uniaxial tensile strength (f_{ts}) obtained with the aid of the Brazilian Test on cylinder samples, the dimensions of which also depend on the grain size of the aggregates, have to be determined for the age of the concrete that corresponds to the time of the actual or hypothetical loading for which the analysis is carried out. Otherwise this should be done in a conservative manner.

For water retaining facilities in **Categories I and II** the tensile strength of the concrete has to be determined with the aid of tensile tests. If no such tests exist, tensile strength equal to zero should be entered in the calculations and verifications.

For water retaining facilities in **Category III**, the static tensile strength of the concrete (f_{ts}) in MPa can be estimated on the basis of the static compressive strength (f_{cs}) in MPa in accordance with the equation [Arioglu et al. 2006]:

$$f_{ts} = 3 / 8 \cdot f_{cs}^{2/3}, \text{ maximum 3 MPa}$$

For existing **Category III** water retaining facilities the material parameters can be obtained from the literature or derived from the data for similar structures. If the resistance values are determined in this way, a reduction factor of 1.2 has to be applied (including the angle of friction), while the cohesion has to be reduced by a factor of

[11] In the case of non-linear finite element analyses a mean resistance value may be introduced in the model (rule of behaviour).

2.0. The partial resistance factors have to be added to this reduction in accordance with section 4.6.5.

4.6.4. Modelling elements

For static loading the minimum requirements for modelling apply as shown in Table 4-4:

	Water retaining facility category		
Topic	**I**	**II**	**III**
Determination of pore water pressures (embankment dams)	2D finite elements or finite differences model	2D finite elements or finite differences model	2D model (empirical)
Determination of interior temperature (arch dams)	2D finite elements or finite differences model	2D finite elements or finite differences model	2D model (empirical)
Verification of overall stability, dams with essentially two-dimensional behaviour	2D Model	2D Model	2D Model
Verification of overall stability of other dams	3D finite elements model	3D finite elements model	2D model for each block
Verification of internal resistance, dams with essentially two-dimensional behaviour	2D finite elements model of dam and foundations	2D finite elements model of dam, coarse modelling of foundations	Modelling as simple beam (gravity dams) or analysis of sliding stability (embankments); coarse modelling of foundations
Verification of internal resistance of other dams	3D finite elements model of dam and foundations	3D finite elements model of dam, coarse modelling of foundations	Arch-cantilever modelling without torsion (arch dams) or analysis of sliding stability (embankments); coarse modelling of foundations

Table 4-4: Minimum modelling requirements

If the underground is modelled by 3-dimensional finite elements, its extent has to comply with the following minimum dimensions in dependency on the stiffness of the dam concrete and the underground [Fok K-L, Chopra A. K. 1985]:

$R_f > 1.0 \cdot H$ for $E_s / E_b = 1.0$
$R_f > 1.5 \cdot H$ for $E_s / E_b = 0.5$
$R_f > 2.0 \cdot H$ for $E_s / E_b = 0.25$

E_b: Modulus of elasticity of concrete
E_s: Modulus of elasticity of the underground
H: Height of the dam structure
R_f: Spatial dimension of the model of the foundation

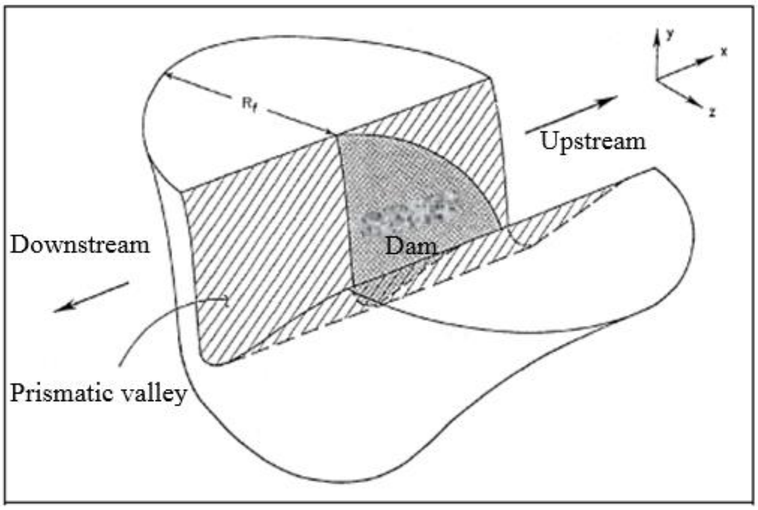

Figure 4-1: Delimitation of the 3D underground model [Fok & Chopra, 1985]

4.6.5. Partial resistance factors

The relevant partial factors can be obtained from Tables 4-5 and 4-6. These should be added as indicated in the sections that follow.

Load combination	**Overall stability (concrete and embankment dams)**		
	Sliding		**Uplift** **)
	Cohesion	Angle of friction	
	γ_{mc}	$\gamma_{m\phi}$	γ_{sf}
Normal	3.0.	1.5.	1.15.
Extraordinary	2.0.	1.3.	1.05.
Extreme static *)	1.1.	1.1.	1.00.

*) An "extreme dynamic" load combination must meet the requirements with respect to the prevention of uncontrolled water discharge in accordance with Part C3 of the Directive.
**) In the short term, after an earthquake until any necessary measures have been implemented (cf. Part C3, section 7.2, paragraph 2), the partial factor for the case of uplift must be 1.0 or higher.

Table 4-5: Partial resistance factors for overall stability (section 4.6.6)

Load combination	Stability of embankments, sliding		Stability of concrete dams, stresses	
	γ_{mc}	$\gamma_{m\phi}$	γ_{sc} *)	γ_{st} *)
Normal	3.0.	1.5.	3.0.	2.0.
Extraordinary	2.0.	1.3.	2.0.	1.5.
Extreme static **)	1.1.	1.1.	1.1.	1.1.

*) γ_{st}, Tensile strength (Brazilian Test) and γ_{sc}, compressive strength from cylinder samples, the dimension of which has to be defined on the basis of the size of the aggregates, cf. for example [Schleiss Anton J., Pougatsch Henri, 2011].
**) An "extreme dynamic" load combination must meet the requirements with respect to the prevention of uncontrolled water discharge in accordance with Part C3 of the Directive

Please note:

a) As a rule, no increase in compressive strength may be considered for the case of biaxial compression.
b) As a rule, the tensile strength at the interface between concrete and rock is zero and is 55% of the concrete tensile strength in the vertical and horizontal joints. If the construction joints were not prepared with care, the tensile strength to be entered at the level of the joints in the analyses and verifications is at most 40% of the tensile strength of the concrete [Obernhuber, P. 2014] and [iCOLD-EC, 2004a].

Table 4-6: Partial resistance factors for interior load resistance (section 4.6.7)

4.6.6. Overall stability

4.6.6.1. Sliding stability

The verification of sliding stability has to be carried out for the most detrimental potential sliding surface, taking account of the geological conditions of the foundations and the slope of the sliding surfaces. The corresponding safety requirement is met if:

$$\sum T \leq \left[\left(tg\,\varphi \sum N\right)/\gamma_{m\emptyset}\right] + \left[{}^{(cA)}/{}_{\gamma_{mc}}\right]$$

where

$\sum N$	=	Total of normal forces along the sliding surface[12]	A	=	Sliding surface
$\sum T$	=	Total of shear forces along the sliding surface	φ	=	Internal friction angle (residual value)
γ_{mc}	=	Partial resistance factor for cohesion	c	=	Cohesion (residual value)

[12] Including deduction due to uplift pressure

$\gamma_{m\phi}$ = Partial resistance factor for angle of friction

Cohesion may only be taken into account if it is in fact mobilisable. In order to take account of any uncertainties and the risk of a reduction or loss of cohesion due to movement, the residual value must be selected. Values φ and c also have to take account of the condition of the sliding surface.

If there is any uncertainty regarding the potential mobilisation of the cohesion or its magnitude, the value zero should be used for the verification.

These considerations also apply for the verification of sliding stability within the structure of masonry and concrete dams, for example along construction joints.

4.6.6.2. Rocking stability

It needs to be verified that no tensile forces due to rocking occur along the concrete-rock interface for the normal load combinations and remain limited for extraordinary and extreme load combinations, in accordance with the following criteria:

Normal load combinations (Type 1):	The resultant of the forces must lie within the **central third** of the cross-section (including deduction due to uplift)
Extraordinary load combinations (Type 2):	The resultant of the forces must lie within the **central two-thirds** of the cross-section (one-third each on both sides of the centre) (including deduction due to uplift)
Extreme static load combinations (Type 3):	The resultant of the forces must lie within **cross-section** (including deduction due to uplift)

In cases in which these criteria are not met, a detailed stability analysis has to be carried out, taking account of the gap in the contact zone. Here, structural measures should also be considered, for example in order to prevent water from entering the contact zone in the normal load combinations.

The zone which is not cracked must be able to accommodate for the forces with the partial factors as per Table 4-5.

4.6.6.3 Uplift stability

Uplift (or buoyancy) stability is defined as the ratio between the total of downward vertical forces (V_b) and upward vertical forces (V_h), and is verified if

$$V_h \leq V_b \gamma_{sf}$$

For “light” dams such as weirs and embankments, uplift stability (for example, a hydraulically-related uplift due to the cancelling of the effective stresses) has to be examined if there is little or negligible permeability in the geological layers downstream from the dam.

4.6.7. Internal load resistance of the dam structure

4.6.7.1 Embankment dams

The objective here is to ensure that the stability of the dam is maintained for all considered load combinations, with a safety margin against the occurrence of damage and in accordance with the partial resistance factors (Table 4-6).

Verification of the risk of internal erosion has to be carried out. Here the fact should be taken into account that rotting roots, nests or burrows of rodents inside the dam, which can create seepage paths, can cause damage to sealing systems, drainage facilities, filters, etc. The same applies with respect to scouring, for example on embankment dams with foundations in the immediate vicinity of a water course, which could deviate from its bed, or if there are overflow dams.

4.6.7.2. Concrete dams

Here the objective is to ensure that no damage to the concrete (formation of cracks) can occur that could result in local or overall instability for all load combination and with a safety margin in accordance with the partial resistance factors (Table 4-6).

In cases in which the stresses exceed the acceptable levels it has to be demonstrated that they can be redistributed. If this is demonstrated on the basis of a partial stability calculation (for example of one block), the partial resistance factors specified in Table 4-5 (“Overall stability”) have to be complied with.

In case of a possible crack formation, it is also necessary to ensure that no large quantities of water can be uncontrollably discharged and that no erosion can occur due to abrasion.

4.6.7.3. Weirs

Weirs have to be treated in a way similar to the concrete dams.

4.6.8. Foundations

The verification of stability of the foundations encompasses the following elements:

- **load resistance**: verification of the stress state in the foundations in accordance with the standard rules of geotechnical engineering, especially regarding contact between concrete and rock, and taking account of the partial factors cited in Table 4-6;
- **sliding or collapse**: in accordance with the standard rules of geotechnical engineering and rock mechanics, taking account of the partial factors as per Table 4-5 (applicable for sliding and rock edges);
- **scouring**: especially downstream from weirs, combined with the way the facility is operated. Appropriate (structural and/or operational) measures have to be taken if the stability of the facility is at risk;
- **erosion**: especially if there is any leakage or damage to the grout curtain, and if there are any cracks.

4.6.9. Stability of slopes in the vicinity of the reservoir

Here the objective is to ensure that no sliding, fall-out or other instabilities r that could give rise to an impulse wave in the reservoir can take place, that could damage the dam or cause an overflow, or which could directly damage the dam and its appurtenant installations of relevance to safety (including discharge works). Here the partial factors cited in Table 4-5 also apply. Special attention has to be paid to the case of rapid draw down.

If it is not possible to demonstrate this stability, the effects of potential instabilities and the resulting impulse wave have to be estimated. Where necessary, structural measures (for example, drainage of unstable zones, anchoring or nailing), monitoring (in order to detect any immediate danger) or operational measures (increase in freeboard) have to be taken on the basis of the assessment.

5. Special structural considerations

5.1. Vegetation on embankment dams

Slopes and crests of **new** embankment dams must be kept free from all forms of vegetation (trees, bushes, shrubs, etc.) which may:

- damage sealing elements due to the growth of roots;
- block drainage works;
- obstruct visual inspections of the slopes (detection of subsidence, instability, cracks and water discharge);
- attract burrowing rodents in channels and hollows, which in turn can result in damage to sealing elements and the creation of seepage paths;
- significant damage to the surface of the embankment due to ripped-out tree roots (as a result of trees being blown down by strong winds).

The only vegetation that is permitted on dams is a limited number of plants with short roots, as long as there are no roots within the required static profile.

For **existing facilities and the lateral embankments of weirs** the same requirements apply as those for new dams. Upon consultation with the relevant supervisory authority, a certain degree of flexibility regarding the implementation of this requirement may be acceptable, especially outside the required static profile.

In accordance with the applicable forestry legislation (Federal Forestry Act of 4 October 1992, RS 921.0 and the Federal Forestry Ordinance of 30 November 1992, RS 921.01), trees and shrubs on or in the downstream vicinity of dams (as a rule, in a 10-metre wide strip of land) are not classified as forest and are thus not subject to the provisions of the above legislation.

5.2. Structures on embankment dams

In order to ensure that the necessary visual inspections, and in particular geodetical measurements, can be carried out without obstruction, slopes and crests of embankment dams and their surrounding terrain (10-metre-wide strip of land) must be kept free from structures of any sort.

6. Protection against acts of sabotage (Article 6, paragraph 7, WRFA)

The objective here is to protect against acts of sabotage against water retaining facilities in which there is a high risk in the inundation zone (Article 11, paragraph 2, WRFA; Article 26, paragraph 2, WRFO). This concerns all water retaining facilities with a water alarm system (cf. Part E of the Directive). Where necessary, the supervisory authority may also order the implementation of protective measures in other water retaining facilities, as well as other measures, for example based on the danger analysis carried out within the scope of the preparation of the emergency regulations. It may also waive the imposition of the following measures if they only contribute to a minor extent towards the prevention of acts of sabotage, or if other equivalent measures have been taken.

- Access to the interior of the dam:
    - the access doors and gates to the interior of dams must meet the requirements of Resistance Class (RC) 4 as specified in EN Standard 1627:2011;
    - in principle, only authorised persons may have access to the interior of the dam. Measurement devices installed along the passageways must be protected against undesirable manipulation;
- Access to the control mechanisms of relief and outlet works:
    - access to the control units of relief and outlet works must be restricted to authorised persons only. Access to control mechanisms that are not located in a

dam or in a building that complies with Resistance Class (RC) 4 as specified in EN Standard 1627:2011, must themselves comply with this requirement.

- Access to outlet gates:
  - if it is easy to gain access to the outlet gates from the downstream side, this must be monitored (for example with the aid of sensors and cameras). In order to prevent false alarms, protective nets or lightweight barriers may be installed to prevent animals from entering the outlets without reducing the discharge capacity.

7. Dismantling of a water retaining facility

In procedural terms, the dismantling of a water retaining facility is equivalent to its modification. If the subordination criteria in accordance with Article 2, WRFA, are no longer met following the dismatling, the operator may request the supervisory authority to confirm the change of status. The water retaining facility in question will then no longer be subject to the provisions of the WRFA.

Reconstructing a water retaining facility after the original facility has been dismantled is equivalent to the construction and commissioning of a new water retaining facility, which is subject to the specified licensing procedures.

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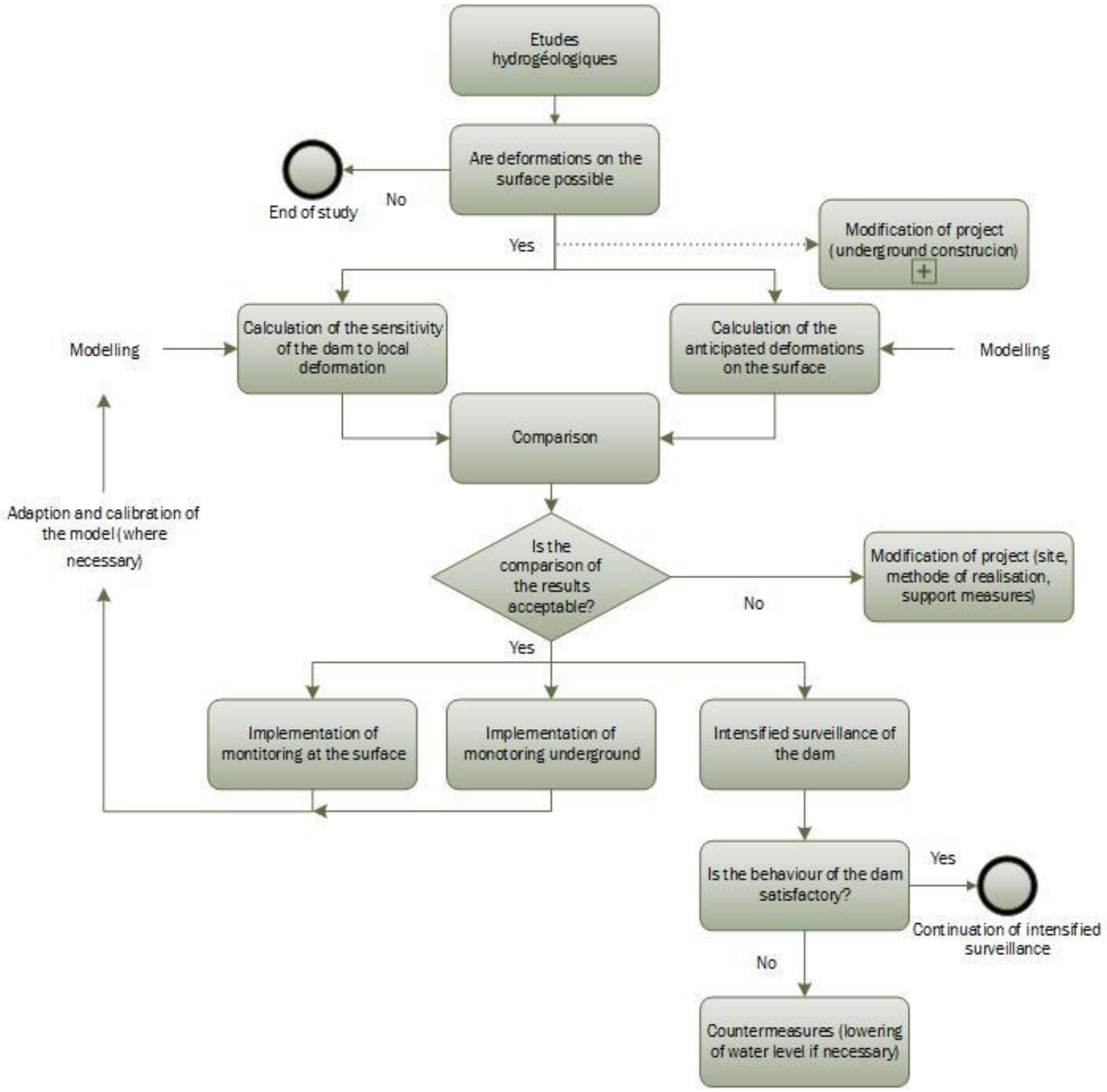
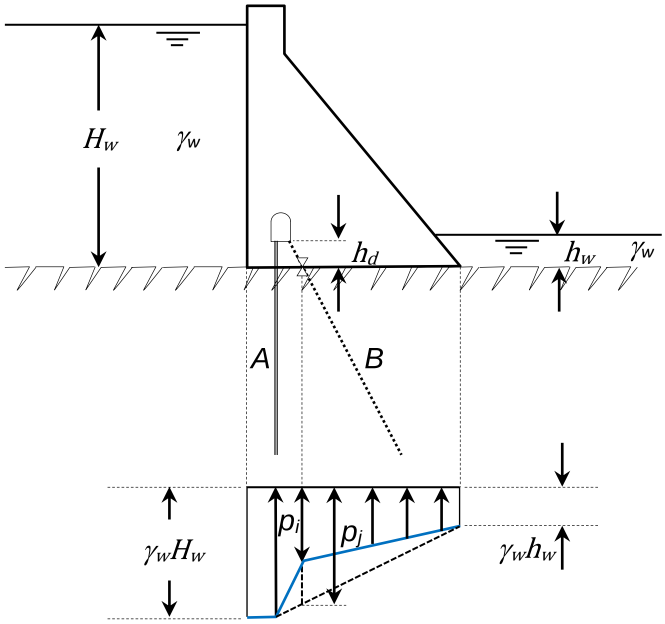
Appendix 1: Procedure for the prevention of harmful effects of nearby underground and excavated structures on the safety of a water retaining facility



Appendix 2: Typical requirements (“conditions”) to be met before, during and after completion of construction work

Requirements (selection only)
Prior to commencement of construction work
Written notification regarding the commencement of construction work
Confirmation through tests of the material properties assumed for the verifications
During construction work (cf. Article 6, paragraph 2, WRFO)
Updated planning of construction work and status of progress
Accompaniment of construction and injection work by a specialist (e.g. geologist or geotechnician)
Any applicable operating restrictions (during the modification of an existing water retaining facility)
Installation of a water alarm system
Communication of findings of inspections of construction and tests carried out on the materials
Communication of the results of injection work
Notification regarding special occurrences
Written notification regarding the completion of construction work
After completion of the construction work (cf. Article 6, paragraphs 3 and 9, WRFO)
Submission of a final report on the construction work, together with photographic documentation
Submission of the evaluation of the findings of inspections of construction and material tests
Submission of the plans of the structure “as built”
Submission of the geological plans and their interpretation
Submission of the evaluation of the inspections carried out during construction
In case of work on the relief and outlet works: results of function test (with discharge)
Requirements relating to modification work
Reference measurement prior to commencement of construction work (including complete geodetic measurement)
Protection of existing measurement equipment during construction work (in particular, geodetic measurement equipment)
Continuation of measurement programme, intensified where necessary; communication of results (to whom, how frequently)

Appendix 3: Standard forms of uplift pressure distribution



Key

A	Grout curtain
B	Drainage screen
	Measurement point in the interface
p_j	Pressure without drainage effect at interface
p_i	Pressure with drainage effect at interface: $p_i = p_j - k(p_j - p_m)$, where
	p_m = highest pressure between $\gamma_w h_w$ and $\gamma_w h_d$ (according to gallery level), and
	k = reduction coefficient (drainage screen)

Note:

i) On-site tests have to be carried out to ascertain that the distances between the drainage and the injection boreholes are sufficient for meeting the specified objectives.

ii) The above diagrams do not apply for special cases such as buttress dams and hollow gravity dams.

Appendix 4: Definition of the three categories of water retaining facilities