

Structural safety of dams, according to the new Swiss legislation

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ABSTRACT: The new Swiss federal regulation on dams applies to dams higher than 10 m or at least 5 m with a reservoir volume greater than 50,000 m³. Smaller dams are taken into account if they represent a specific danger for persons or goods. Since the new regulation became effective, the responsibility of the safety control of small dams belongs also to the States, the 26 Swiss cantons. The Federal Office for Water and Geology, together with canton authorities and representatives of corporate bodies, has prepared guidelines for the application of the new regulation. Specific guidelines are: criteria for specific danger, structural safety, seismic risk, flood control, monitoring and maintenance. The paper mainly presents the guidelines on structural safety. These guidelines is general enough to be applied to any kind of dam, whatever its size, type or function. They give indications on how to prepare an utilisation plan and a safety plan. These plans should help owners and engineers as well as the authorities to evaluate and to define measures to maintain dam safety at an acceptable level during its operating lifetime.

1 INTRODUCTION

The safety of dams in Switzerland is governed by the federal law regarding supervision of hydraulic structures of June 22nd, 1877. In its article 3(a), paragraph 1 which was introduced in 1953, the supervision of the federal authorities was established as follows: "The federal Council will ensure that the necessary steps will be taken with existing and future water storage installations to avoid, as far as possible, dangers and damages resulting from the existence of the installation, from insufficient maintenance or from effects of war".

One can see that safety has been comprehensively regulated and that even special threats that would arise in the event of war have been taken into account.

The executive decree stipulated in article 3(a), paragraph 3 of the same Law has been enacted with the so-called "dam-regulations" of July 9th, 1957. Apart from procedural, technical and organizational concerns, it governed in particular which dams came under the regulations. Accordingly, all dams were subject to the decree, and therefore were placed under the supervision of the federal authorities, which had an impounding head of at least 10 m over the low water level, or respectively over the existing terrain; or, if they had a storage capacity of more than 50,000 m³ at an impounding head of at least 5 m. In addition to that, the supervision could also be ex-

tended to dams which are below these dimensions and to weirs if public safety was concerned.

However, the latter criterion for enforcing supervision is more appropriate than setting minimal dimensions, as it is not the dimensions of the dam which are critical but the potential risk. The federal Council, who shared this view, decided to revise the decree completely. Finally, the new "dam-regulations" of December 7th, 1998 became effective in January 1st, 1999. Moreover, it is planned to update the old federal law and to substitute it with a modern law of supervision on safety of dams.

2 THE NEW SWISS LEGISLATION ON DAMS

The new "dam-regulations" introduced substantially three amendments. The first is a formal one, connected with the safety concept according to the current Swiss practice (see chapter 3). The second stipulates that all dams which, in case of failure may endanger lives or properties, will be subject to the decree (without limitation of the type of dam, its dimensions, and its purpose). Hence, all structures being able to retain water, sediments, snow avalanches and ice are subject to these regulations if they endanger lives or properties. The criteria for enforcing supervision are given in Figure 1. The third amendment states that the supervision of the smaller dams will be done by the authorities of the States, the 26

Swiss cantons, whereas that of the larger ones will stay as previously under the federal authorities.

Legislation

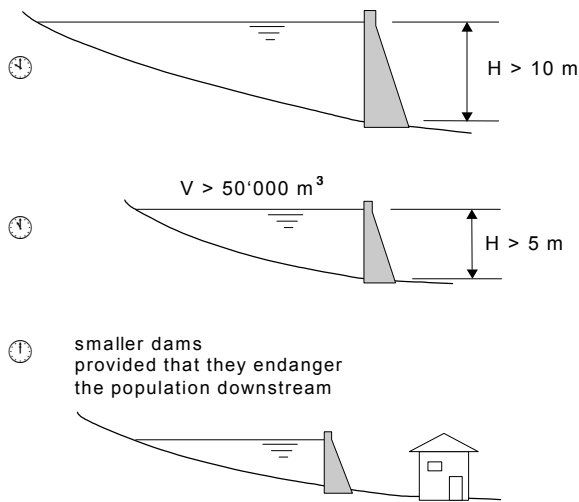


Figure 1. Criteria for dams to be subject to the regulations

3 THE SAFETY CONCEPT

The two requirements to guarantee the safety of dams are the minimization of the risk, and the best possible mastering of the remaining risk. To reach this goal a dam safety concept, based on three tenets, was established and consists in (1) the structural safety, (2) the monitoring and maintenance, and (3) the emergency concept (Fig. 2). The minimization of the risk calls for an appropriate design and construction of the dam (tenet 1), and that for all possible loading and operational conditions. This means that the design should be periodically checked to ensure that the structural safety is guaranteed according to the recent state of knowledge. However, a risk can be minimized, but never totally eliminated. It is therefore necessary to recognize as soon as possible a damage, a defect in structural safety, or an external threat to safety so that the measures to master the danger that occurred can be taken. In order to achieve this, regular checks of the condition and the behaviour of the dam as well as periodical safety evaluations are needed (tenet 2). The regular checks serve particularly in following the current behaviour, and the periodical safety evaluations in following the long-term behaviour as well as in verifying the structural safety.

In case of an identified threat to the dam the situation of danger is managed according to the emergency concept (tenet 3). It is important that measures to be taken have been prepared in advance as best as possible. These measures consist of a strategy and of preparation studies. They include the

determination of the potentially submerged area in case of dam break, the installation or specification of the alarming equipment, and the organizational measurements for ensuring the evacuation of the population. The emergency strategy defines three danger thresholds and specifies measurements accordingly, taking into account the possibility to master or not the event. Specific technical and operational measures as well as emergency actions are assigned to each danger level.

4 CRITERIA FOR SUBJECTING DAMS TO THE DECREE

The new regulation specifies that dams higher than 10 m or at least 5 m with a reservoir volume greater than 50,000 m³ are subjected to the decree. Smaller dams are taken into account if they represent a specific danger for persons or goods (Fig. 1).

The question comes from that definition for small dams: what do the legislator mean with "a specific danger for persons or goods". Specific guidelines have been prepared to answer this question for each particular case.

A specific danger exists if, in case of dam break, at least one habitation, or one working place, or a public building, a public camping place or a heavy traffic road is affected. The product of the water depth with the water velocity in case of dam break is to be compared with limit values given by the guidelines.

A dam break model analysis is then necessary for determining these parameters. Difficulties arise from the complexity of these models. Their heaviness and their costs are out of proportion for small dams, with reservoir capacity smaller than 50,000 m³. The guidelines refer to the principle of proportionality, and recommend in these cases very simple and low costs methods for determining the dam break flow parameters.

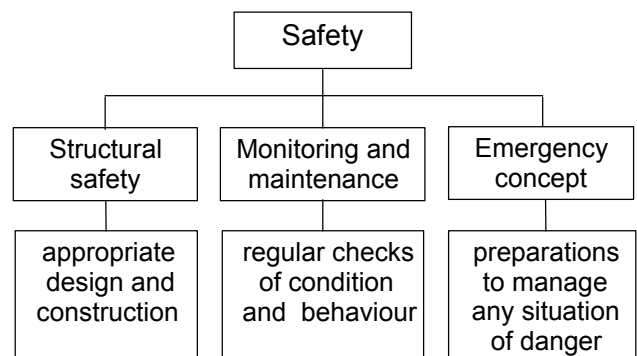


Figure 2. Swiss safety concept

5 GUIDELINES FOR PRACTICAL APPLICATION

The practical application of the new regulations and thus the safety concept call for guidelines. Their purpose is:

- To contribute to the interpretation and application of the different articles of the new regulations,
- To give a description of the actual state of practice in dam safety engineering in Switzerland, and
- To provide the 26 States authorities with the necessary means to exercise the supervision of the smaller dams.

The guidelines deal with five topics, such as:

- The decision criteria to define which dams will be subject to the new "dam regulations",
- The structural safety of dams,
- The safety of dams against floods,
- The safety of dams against earthquakes, and
- The monitoring and maintenance of dams.

These guidelines were recently prepared and are now about to be applied.

6 THE GUIDELINES ON STRUCTURAL SAFETY

The goal of these guidelines is to define a framework for the control of the structural safety of a dam and its reservoir.

It is assumed that safety against a risk is guaranteed when this risk is maintained under control with appropriate measures, and if it stays under a limit level of acceptance. Absolute safety cannot be guaranteed.

This definition comes from the introduction of the Swiss standard "Loads on structures", established by the Society of Swiss Engineers and Architects, SIA. This standard edicts the principles for the safety and the serviceability of a structure. It defines the principle of a utilisation plan and a safety plan. The loads and the combination of loads to be considered are also defined.

This basic document is self-sufficient for structures like buildings and bridges, but it is generally admitted that particular structures, such as dams, need a specific approach.

The guidelines on structural safety of dams give the framework for all the concerned issues. They are divided in 2 parts: the utilisation plan, and the safety plan.

7 THE UTILISATION PLAN

The utilisation plan is a document containing all the basic information concerning the using of the structure. This document is regularly updated during the whole project process, from the beginning of the de-

cision-making procedure, to the operation phase. Normally, most of it is defined during the general project phase.

The guidelines prescribe the following structure for the utilisation plan:

- A. Purpose,
- B. Base project documentation,
- C. Site conditions,
- D. Structural specifications,
- E. Project description.

7.1 Purpose

7.1.1 Main purpose

The main purpose of the work can be one of the three following types:

- Storage: for water supply, irrigation, hydropower, artificial snowing, etc.
- Protection: such as flood control, bed load retention, protection against avalanches (as these works have the possibility, under particular circumstances, to store water),
- Water level maintaining: for fishery requirements, recreation, fauna and flora preservation, landscape preservation.

Some dams are also multipurpose works.

7.1.2 Secondary functions

Other functions of the dam itself, or of a specific element of the dam, should also be mentioned, as they have a direct influence on the geometry of the dam, or on the loads:

- Roads, with in many cases bridges over the spillway crest,
- Cables, wires and pipelines, for water supply, telecommunication, energy,
- Pylons and masts,
- Fish facilities, as they are integrated in the dam itself,
- Specific devices for recreation, such as footpaths, pleasure boating facilities, etc.

7.1.3 Service life

The service life of the different elements of the structure should also be mentioned. It should not be compared with the amortization duration. Service life of a specific part of a work should be understood as the period during which no heavy rehabilitation works are necessary to keep the structure in operation. The effective life span of a dam can be much longer than the planned operating life. In Switzerland some dams are more than 130 years old and are still in operation. Maigrauge dam, for example, was build in 1872, and is nowadays being rehabilitated to extend its service life by 30 or 50 years (Fig. 3).

Service life can be very different from one part of a structure to another. It depends mainly on the kind of equipment, the material and the use of the me-

chanical parts. Service life of a concrete or an embankment dam can easily reach 100 years, but some elements, such as the gates and valves, should be changed after 40 to 50 years as the case may be.

Monitoring devices do not fall under the above conditions, as the technological evolution can make these equipments obsolete in a few decades, or even less. Replacing manual devices with automated monitoring allows to reduce significantly the human risk factor in the dam safety surveillance process.



Figure 3. Maigrange dam, 1872, before rehabilitation

7.2 Base project documentation

The complete legal, administrative and technical documentation should be mentioned:

- The legal framework: laws, decrees, guidelines, rules,
- The concession documents,
- Used standards, recommendations,
- Hydrologic and meteorological yearbooks, geological maps and documentation,
- Documents published by professional organisations,
- Technical reports, etc.

7.3 Site conditions

7.3.1 Geology

The main document referring to the site conditions is a document summarising the geological and geotechnical conditions at the dam site and in the reservoir. During the different steps of the project, this documentation becomes more and more precise and complete, integrating all the results of the investigations, the observations during construction (excavations, galleries, boring and grouting), and finally the analysis of the dam foundation behaviour during operation.

7.3.2 Hydrology

Hydrologic data that served as the basis for the definition of the parameters of the project are also precisely listed, and all the assumptions made and the

hydrologic models are described. During construction and operation, hydrologic data are recorded. The enhancement of the series permits to validate the assumptions and to check the safety against hydrologic hazard.

7.3.3 Environment

The description of the environment of the project is also a key element of the site conditions. Its description, and the protection and mitigation measures are elements of the environmental impact assessment. The requirements for this study are described in detail in the very complete Swiss environmental legislation.

The objects to be protected, and the mitigation measures have been defined during the concession negotiation phase. During the whole operation phase, it is useful to record in detail the measures applied, and to compare them with what was initially described in the preliminary phases.

7.4 Structural specifications

In the utilisation plan, the key structural specifications are summarised. The type of dam and the integration of all the appurtenant structures are described.

In some cases, the limit of the works to be included as an element of the dam is not easily defined. Many run-of-river dams not only contain the controlled weir and the hydropower station, but also very long upstream lateral dikes. The safety conditions of these dikes should be treated with the same attention as the dam itself.

7.4.1 Material

The quality of the different kinds of material used should also be described in the utilisation plan. Project specifications and material test results during the construction should be summarised. These data are essential for estimating the long term evolution of the mechanical characteristics of the material, and, if necessary, the correction measures to be taken.

7.4.2 Stability

Design criteria are also described in detail. The local and global stability criteria are mentioned. The load combination admitted for the design, and the assumed material and geomechanical parameters can be verified by means of the observed behaviour of the structure.

7.4.3 Floods

The evaluation of extreme flood discharge and volume is, during the project design phase, a most delicate task, as the hydrologic phenomena can in many cases only be estimated with statistical approaches. Overtopping during flood events is one of the most frequent reasons of dam accidents. The Swiss guide-

lines define 2 types of flood events to take into consideration for safety analysis:

- The design flood, which should be evacuated without any damage to the dam and the spillway structures, and with a remaining safety freeboard,
- The safety flood, corresponding to the extreme flood. The upstream water level can reach a so called danger level, so the general stability of the dam is guaranteed. In that case, it is accepted that some damage to the dam can occur, requiring some local restoring works.

Specific guidelines will be published in 2001 on safety against floods.

7.4.4 *Seismic hazards*

The criteria for the evaluation of safety against seismic hazards will also be mentioned. Specific guidelines will also be published in 2001 on that issue.

7.4.5 *Water level control*

The cases of first filling control, preventive lowering of the water level, and decommissioning should be analysed. These particular cases are key elements for the bottom outlet design criteria.

7.4.6 *Emergency plan for the protection of the population*

In the case of abnormal behaviour of the dam, or as a consequence of an extreme natural event (flood, earthquake), the owner has the legal obligation to prepare an emergency plan for the protection of the population.

This plan explains how the local monitoring is organized and what are the possible preventive operations to be taken, giving a description of all the available communication means, the alarm system, etc. For new dams, some elements of this emergency plan should be integrated in the project at a very early stage.

7.5 *Project description*

7.5.1 *Main characteristics*

In this section, all the main specifications of the project are summarized in a very condensed form, therefore all the necessary data useful for a rapid overview of the dam and its appurtenant structures can easily be reviewed:

- The dam: geometrical characteristics,
- The reservoir: typical water level, depth-volume curve, freeboard,
- The outlets: main specifications, operation restrictions, maintenance,
- The spillway: main specifications, operation rules, maintenance,
- The water intakes: main specifications, operation rules, maintenance,

- The hydrologic main parameters: runoff statistics, design flood and safety flood parameters,
- The geology: brief description of the foundation geology, of the reservoir geology, known geological instability, eventual landslides,
- The accessibility: description of the different access possibilities, in summer and in winter: roads, cable cars, distance and duration; helicopter facilities.

7.5.2 *Ancillary works*

The operation of the ancillary works is described in detail:

- Operation rules,
- Maintenance,
- Energy sources for engineering operation,
- Accessibility,
- Local and remote control,
- Annual check-up.

8 THE SAFETY PLAN

Drawing up a safety plan means that all possible risks have been examined and all measures required for ensuring safety have been defined. Remaining risks have been compared with the acceptable risks. These acceptable risks depend on the specific situation of each dam: type, geological conditions, environment, human presence and activity in the downstream area, etc.

The guidelines prescribe the following structure for the safety plan:

- A. Loads,
- B. Causes of danger,
- C. Critical situations,
- D. Design measures,
- E. Remaining risk.

8.1 *Loads*

During the design process, assumptions have been made for the definition of the loads on the structure. If possible, these assumptions have to be verified during the construction or the operation phases, for example:

- Earthfill and rockfill density in an embankment dam, which depends on the compaction and can only be determined during the construction,
- Uplift under a concrete dam. A probable uplift diagram is chosen for the design. The real uplift pressure can only be verified during operation with pressure cells and piezometers placed in the dam foundation. If the measured uplift is higher than the design uplift diagram, corrective measures should be taken (grouting, drainage boring).
- Temperature loads. In massive concrete structures, such as gravity and arch dams, temperature gradients and variations cause internal stresses. In

hyperstatic structures, such as arch dams, external loads may be induced by the reaction of the foundation and the abutments. The temperature conditions selected for the design should be verified with measurements during construction and operation.

- Exceptional loads. Seismic loads, extreme water level due to exceptional floods, ice load, exceptional dynamic load due to an avalanche or a landslide in the reservoir, have to be considered in the design.

The design parameters for all the loads should be recorded in the safety plan, to permit, at any stage of the life of the dam, to check if the design criteria are still fulfilled, or if specific measures are to be taken to maintain the residual risk at an acceptable level.

8.2 Causes of danger

In a preliminary risk analysis, all the possible causes of failure of an element of the structure should be listed, as well as all the imaginable damage caused to the structure.

This analysis permits to define all the critical solutions that should be considered for the design of a new dam or for the verification of an existing dam.

8.3 Critical situations

The decree stipulates that all the loads and all the predictable combination of loads should be considered. It means that all the particular operation situations have to be listed and the corresponding combination of loads analysed: extreme variation of the water level, revision of hydro mechanical equipment, failure of a particular outlet, no electricity supply, etc. The list varies from one dam to another and has to be developed specifically for the considered dam.

Each combination of loads is classified in the three following classes:

- Normal: combination of loads that can periodically occur to the dam,
- Exceptional: possible combination of loads, which have a low probability of occurrence during the lifetime of the dam. The dam should resist to these cases without damage, or with only limited damage to elements which have no relation with structural safety (for example the road surface on the dams crown, the water intake operation devices),
- Extreme: the most unfavourable combination of loads that can be applied to the dam. These cases are defined with physical limits of natural phenomena, such as the PMF event, the maximum possible seismic event, the crash of an aircraft. Some damages are admissible under these extreme load conditions, without altering the structural capacity of the dam. Some repair works

could be necessary to maintain the dam at the same level of safety after the event.

8.4 Design criteria

After defining and classifying all the critical situations, the guidelines propose to verify the stability of the dam and its foundation with the following safety factors:

- Normal cases: safety factor $SF = 1.5$,
- Exceptional cases: safety factor $SF = 1.3$,
- Extreme cases: safety factor $SF = 1.1$.

assuming a good knowledge of the different parameters intervening in this verification. Higher safety factors should be used if the statistical distribution of the values of one or another parameter is very wide.

Risk analysis is certainly a modern and more adequate way to ensure homogeneous safety analysis of a structure. The development of this approach for dam safety analysis and in particular for existing dams, will permit to evaluate the efficiency of a correction measure on the real safety of the structure with more accuracy. This matter is nowadays a theme of research. The potential and the hopes placed in risk analysis for dam safety analysis were demonstrated during a workshop organized by the Swiss Committee on Dams and the Federal Office for Water and Geology on this theme in February 2000.

9 CONCLUSION

The guidelines, which are nowadays based on a deterministic approach of dam safety assessment, are open to risk analysis, as it can demonstrate that in a particular cases, the remaining risk resulting from the risk analysis is acceptable. In the future, and following the first experiences made in Switzerland with risk analysis, design criteria will certainly be extended with limit values for the remaining risk. The way in that direction is still long, as it means that legislator must accept what is of evidence for engineers: dams, as other structures, are not risk free. A remaining risk always exists, but must be evaluated and kept under an acceptable level. A first step in that direction was made in the 1980s, with the development of the emergency concept as a tenet of the Swiss safety concept.

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