12th European Conference on Earthquake Engineering
Published by Elsevier Science Ltd., Paper reference 119

SWISS GUIDELINES ON THE ASSESSMENT OF THE EARTHQUAKE BEHAVIOUR OF DAMS

Working group for the preparation of the Swiss guidelines on the assessment of earthquake behaviour of dams

Federal Office for Water and Geology, Dam Safety
P.O. Box 957, CH-2501 Bienne, Switzerland

LOMBARDI ENGINEERING LIMITED

Mr. W. Amberg, Lombardi Engineering Ltd, Minusio CH
Dr. C. Bossoney, Stucky Engineering Services Ltd, Renens CH
Dr. G.R. Darbre, Federal Office for Water and Geology, Bienne CH (Chair)
Dr. J. Hammer, Federal Office for Water and Geology, Bienne CH
Dr. B. Otto, Nordostschweizerische Kraftwerke, Baden CH
Dr. J. Studer, Studer Engineering Ltd, Zurich CH
Dr. M. Wieland, Electrowatt Econo Ltd, Zurich CH

Published by Elsevier Science Ltd, All rights reserved
12[th] European Conference on Earthquake Engineering
Paper Reference 119 (quote when citing this paper)

SWISS GUIDELINES ON THE ASSESSMENT OF THE EARTHQUAKE BEHAVIOR OF DAMS

Working group for the preparation of the Swiss guidelines
on the assessment of the earthquake behavior of dams

Federal Office for Water and Geology, Dam Safety
P.O.Box 957, CH-2501 Bienne, Switzerland

ABSTRACT
The preparation of the guidelines on the assessment of the earthquake behavior of dams has been commissioned by the Federal Office for Water and Geology, Dam Safety, as supervising authority. They shall ensure that the earthquake assessment of the Swiss dams be performed on the basis of common criterions. The main goals are the protection of population downstream against loss of life and injuries and their protection against property damages and direct and indirect economic losses. These goals are fulfilled by requiring that, for a specific safety assessment earthquake, no failure with uncontrolled release of reservoir water occurs nor the dams sustain any damages that could jeopardize their integrity.

KEYWORDS
Earthquakes, dams, guidelines, safety.

1. INTRODUCTION

The Dam Section of the Federal Office for Water and Geology is the supervising authority for dam safety in Switzerland. In this capacity, it appointed a working group entrusted with the task of preparing guidelines on the assessment of the earthquake behavior of dams. The working group consisted of

Mr. W. Amberg, Lombardi Engineering Ltd, Minusio CH
Dr. C. Bossoney, Stucky Engineering Services Ltd, Renens CH
Dr. G.R. Darbre, Federal Office for Water and Geology, Bienne CH (Chair)
Dr. J. Hammer, Federal Office for Water and Geology, Bienne CH
Dr. B. Otto, Nordostschweizerische Kraftwerke, Baden CH
Dr. J. Studer, Studer Engineering Ltd, Zurich CH
Dr. M. Wieland, Electrowatt Econo Ltd, Zurich CH

Prof. D. Giardini, Dr. N. Deichmann and Dr. D. Faeh, of the Swiss seismological survey, were consulted by the working group.

The guidelines are subdivided in 7 parts whose content and underlying philosophy are outlined in this paper. The guidelines are presently available in a draft version which is being evaluated and discussed by the dam engineering community in Switzerland.

2. Guidelines

2.1 Part A - Fundamentals

The ultimate objective is to protect people, environment and property downstream from death, injury and direct as well as indirect economic losses. The aim of the guidelines is to implement this objective in dam engineering practice in relation with earthquake actions. In doing so, it is proposed to guarantee a similar level of protection at all dams. Defining the risk R as

$$R = P \cdot C \tag{1}$$

where P is the occurrence probability of an earthquake larger than the safety evaluation one and C is the consequence of dam failure, an "identical" value of R is accepted at all dams.

The safety evaluation earthquake (SEE), whose probability of occurrence is indicated later, serves as basis to the assessment. It is required that, under that earthquake, no uncontrolled release of reservoir water takes place and that safety relevant appurtenant structures and components (e.g. outlets) remain operational or can be brought back into operation quickly.

Dam classes

On the basis of equation 1 and keeping in mind the meaning of the safety evaluation earthquake, a larger probability of occurrence of the SEE may be accepted at dams with lower failure consequences and a lower probability required at dams with larger failure consequences. The failure consequences thus form the basis of the dam classification system reported in Table 1.

Simultaneously, larger modeling uncertainties are tolerated at dams with lower failure consequences (class 3 dams) and a more precise modeling required at dams with larger failure consequences (class 1 dams).

TABLE 1
DAM CLASSES

		Consequences		
		"Low"	"Medium"	"Large"
	Dam class	3	2	1
Probability of occurrence of SEE	Low	Required	Not accepted	Not accepted
	Very low	Accepted	Required	Not accepted
	Extremely low	Accepted	Accepted	Required

Class allocation

In the absence of any hard data related to the (potential) consequences of dam failure, the combination of dam height and reservoir volume of Figure 1 is taken as a substitute for class allocation.

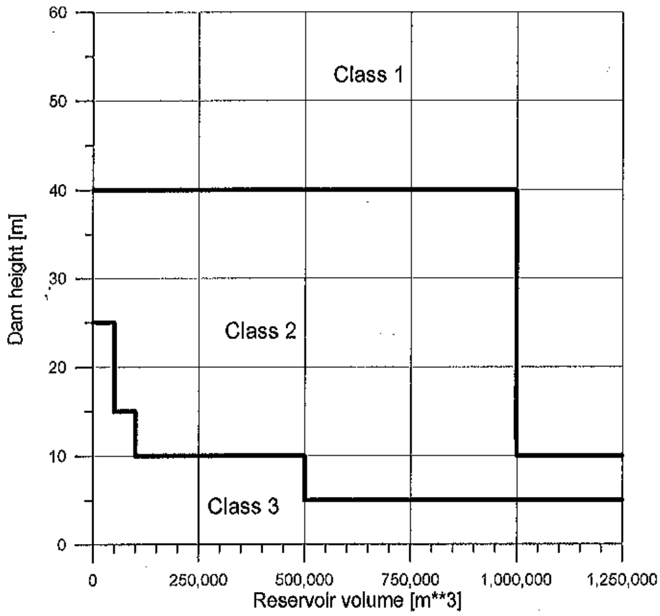

Figure 1: Dam classes

Dams which retain water on an exceptional basis (flood protection dams) are automatically assigned to class 3, irrespective of their height and reservoir volume.

Documentation and declaration of conformity

It is required that the assessment be fully documented. It shall contain a declaration of conformity personally signed by the lead engineer in which it is confirmed that the requirements of the guidelines are satisfied in full. In case the latter does not hold true, the extent to which this is not the case and what remedial measures have been taken must be indicated, and the effectiveness of these measures demonstrated. The purpose of this declaration of conformity is to emphasize the responsibility of the engineer in such an assessment.

Qualifications

It is also required that the lead engineer possesses the appropriate knowledge and experience to carry out the assessment. This is translated into the following required qualifications:

- For dams of classes 1 and 2: Documented technical education and experience in dam engineering, in dam safety and in earthquake engineering;

- For dams of class 3: Education as a civil engineer with documented experience in hydraulic structures.

Further considerations

Under this approach, damages that do not result in uncontrolled release of water nor to non-restorable functionality of safety relevant appurtenant structures and components are accepted.

There are also no serviceability requirements (operational basis earthquake – OBE), although it is in the interest of the owner of targeting one. It is in fact very unlikely that a dam that can not operate any more after a "light" earthquake event (OBE) will fulfill the SEE requirements.

It is stressed that the objectives and requirements put forward in the guidelines are minimal ones. They can be replaced by ones that are demonstrated to be equivalent or more stringent.

2.2 Part B – Safety evaluation earthquake

The existing seismological information form the basis of the probability-based definition of the safety evaluation earthquake (SEE). It is given by a set of response spectra and effective peak accelerations (rock outcropping) for various probability of exceedance (return periods).

Probability of exceedance

The exceedance probability is given for a reference time span of 100 years. It is expressed through the associated return period of Table 2.

TABLE 2

SAFETY EVALUATION EARTHQUAKE

Dam class	Reference time span	Probability of exceedance	Return period
1	100 years	1 %	10'000 years
2	100 years	2 %	5'000 years
3	100 years	10 %	1'000 years

Peak acceleration

The peak accelerations are read from intensity maps combined with an appropriate intensity-acceleration relation. The vertical component a_v is taken as 2/3 of the horizontal component a_h.

Response spectra

The response spectra are those of Eurocode 8. They apply both for horizontal and vertical directions.

Time histories

Appropriately scaled earthquake records or/and synthetic records are used in time-domain analyses. They must be compatible with the relevant response spectrum.

In accordance with EC8, the strong-motion duration T_s of synthetic records must satisfy

$$T_s[\text{sec}] = 10 + 50\left(\frac{a_h}{g} - 0.1\right) \quad ; \quad \text{min.}10\,\text{sec} \tag{2}$$

When a time domain analysis is conducted, at least 3 sets of stochastic independent time-histories must be considered, whereas the strong-motion duration may vary by ± 5 seconds in 2 of them. Each set is composed of 3 components (2 horizontal and 1 vertical, 3-D analysis) resp. 2 components (1 horizontal and 1 vertical, 2-D analysis).

2.3 Part C – Embankment dams

Assessment

The analysis procedure pertinent to dams of classes 2 and 3 is reported in the flow chart of Figure 1. Additional investigations are required at class 1 dams, in particular with respect to the embankment materials.

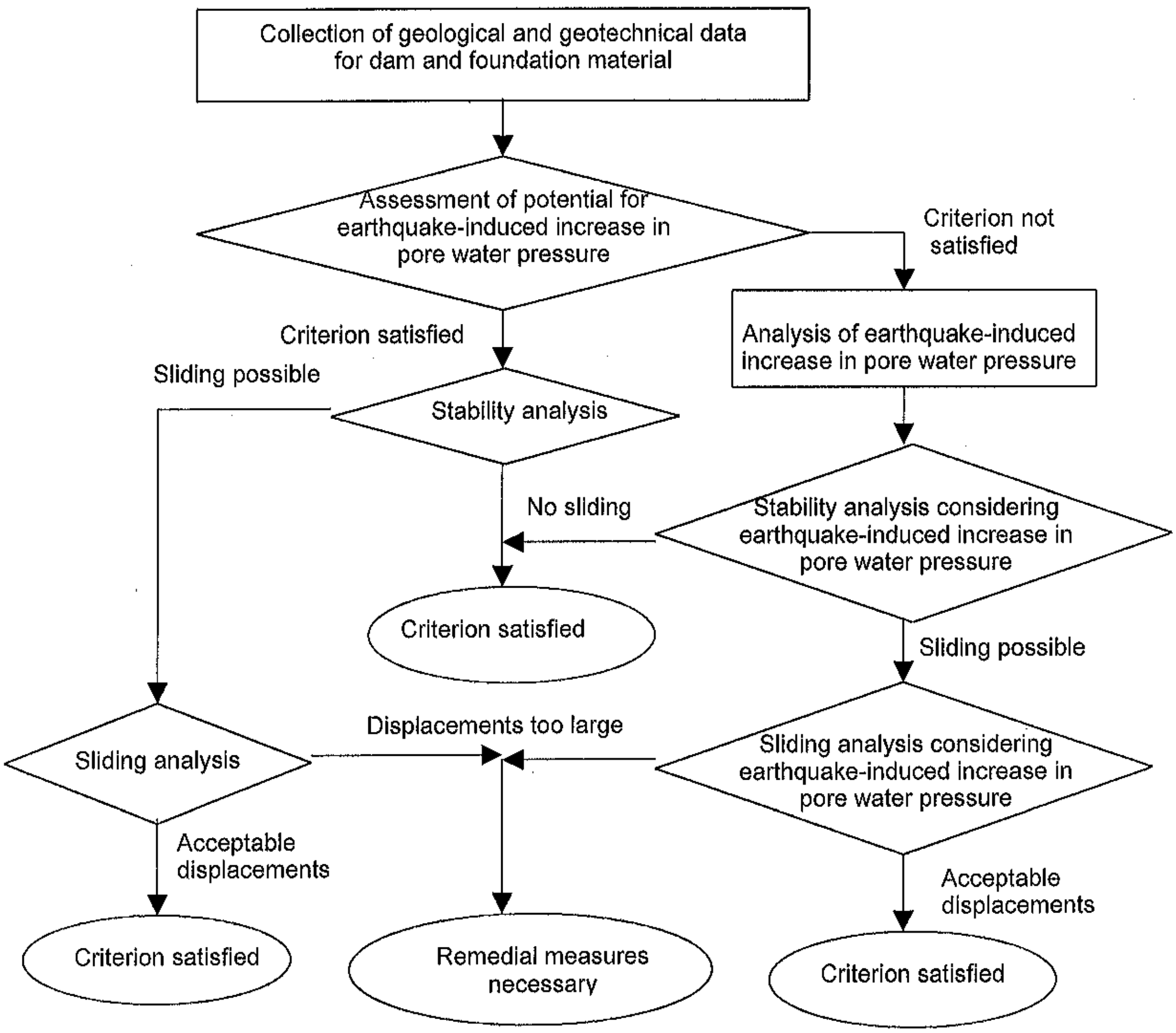

Figure 1: Analysis procedure for embankment dams of classes 3 and 2

The assessment is based on a two-step analysis. At first, the stability of individual dam parts is systematically evaluated. Is the stability not guaranteed and sliding possible, then a sliding analysis is performed in a second step. It must then be demonstrated that specific displacement limits are satisfied and the overall dam stability guaranteed. It must in particular be demonstrated that the freeboard remains sufficient (no dam overtopping) and that the drainage and core layers be able to fulfill their intended purpose.

Modeling requirements

Modeling requirements depend on the dam class according to Table 3.

TABLE 3

MODELING REQUIREMENTS FOR EMBANKMENT DAMS

	Material properties and investigation methods	Modeling and calculation methods
Class 3 embankments	Static properties *New dams*: From tests *Existing dams*: From construction documents or cross comparisons	Simplified stability analysis with equivalent earthquake load, horizontal action alone Simplified calculation of sliding displacements if necessary
Class 2 embankments	Static properties, possibly dynamic properties *New dams*: From tests for static properties and cross comparisons for dynamic properties *Existing dams*: From construction documents for static properties (from tests if none available), from cross comparisons for dynamic properties	Simplified stability analysis based on modal analysis (1 mode, response spectrum), horizontal and vertical excitation Simplified calculation of sliding displacements if necessary
Class 1 embankments	Static and dynamic properties *New dams*: Static and dynamic properties from tests *Existing dams*: Static and dynamic properties from construction documents (from tests if none available)	2D static and dynamic FE-calculations for dam response Simplified stability analysis based on calculated dam response (horizontal and vertical excitation) Simplified calculation of sliding displacements if necessary

2.4 Part D – Concrete and masonry dams

Assessment

It is required that both a stress and a stability assessment be performed, as well as additional assessments related to appurtenant structures and components, foundation and reservoir banks. The analysis flow-chart is reported in Figure 2 for class 2 and 3 dams, additional investigations being again required at class 1 dams.

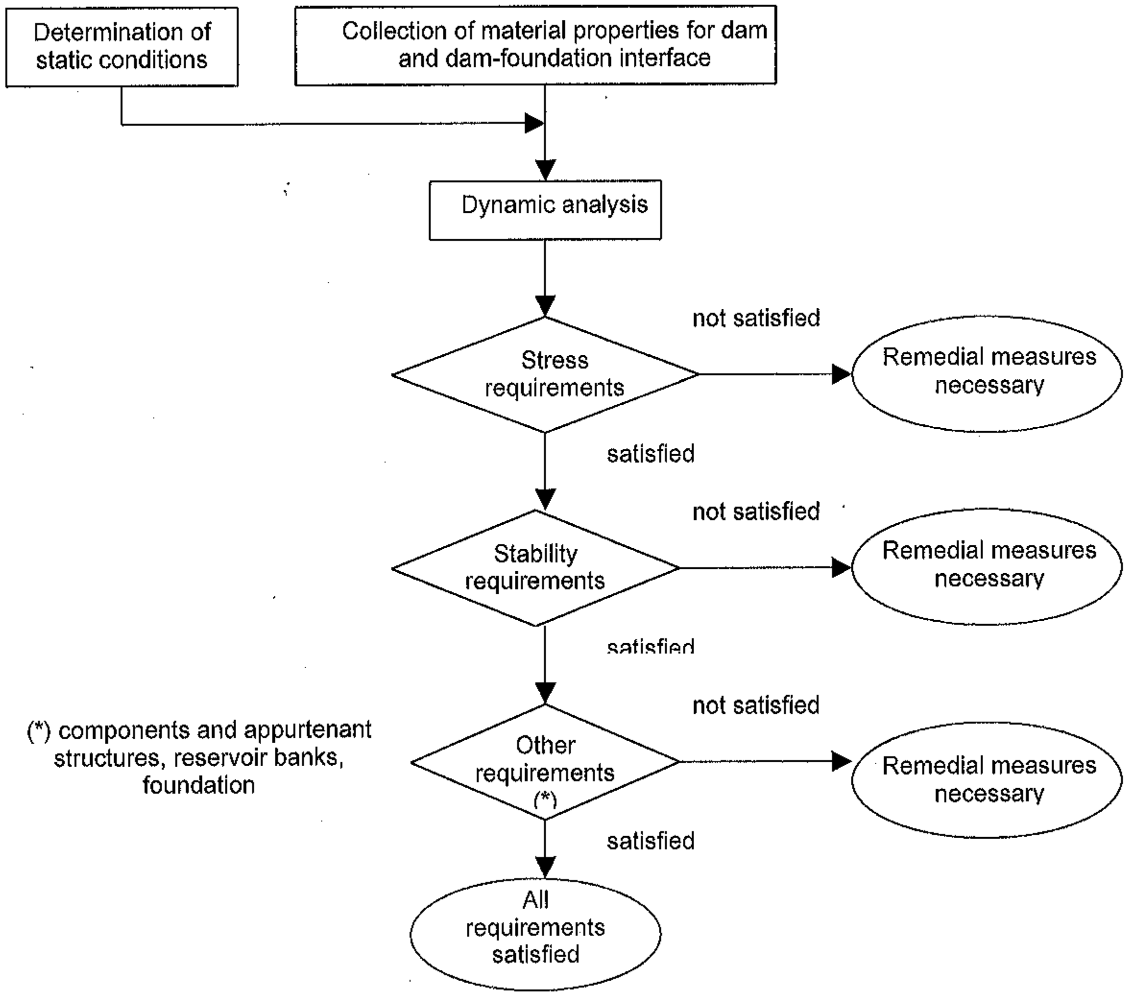

Figure 2: Analysis procedure for embankment dams

In the stress analysis, the stresses (or stress resultants) stemming from the combined static and dynamic loads are compared to material strength. In case of overstressing, it must be demonstrated that stress redistribution can take place and that no local instability will occur. Overall aspects such as overturning and sliding are investigated in the stability analysis.

Modeling requirements

Modeling details are again set as a function of the dam class according to Table 4.

TABLE 4
MODELING REQUIREMENTS FOR CONCRETE AND MASONRY DAMS

Dam class	3	2	1
Dynamic properties	Empirical	Modeling	Modeling
Modeling	*2D dam*: Beam model or analytical *3D dam*: Arch-cantilever or finite elements *Foundation*: Rigid *Reservoir water*: Entrained mass (incompressible)	*Dam*: Arch-cantilever or finite elements *Foundation*: Springs or finite elements (massless) *Reservoir water*: Entrained mass (incompressible)	*Dam*: Finite elements *Foundation*: Finite elements (massless) *Reservoir water*: Entrained mass (incompressible)
Materials	*Dam*: Linear visco-elastic, characteristics from cross comparisons *Dam-foundation interface*: From cross comparisons *Foundation*: Rigid	*Dam*: Linear visco-elastic, characteristics from dam-specific static tests *Dam-foundation interface*: From cross comparisons *Foundation*: elastic, characteristics from cross comparisons	*Dam*: Linear visoc-elastic, characteristics from dam-specific static tests *Dam-foundation interface*: From cross comparisons *Foundation*: elastic, characteristics from cross comparisons
Methods of analysis	Pseudostatic or modal analysis (1 mode, response spectrum)	Modal analysis (several modes, response spectrum)	Time history analysis
Necessary assessments	Stresses Dam stability Foundation integrity Components and appurtenant structures Reservoir sides	Stresses Dam stability Foundation integrity Components and appurtenant structures Reservoir sides	Stresses Dam stability Foundation integrity Components and appurtenant structures Reservoir sides

2.5 Part E – River dams

River dams are composed of an under-water structure with or without a large over-water structure (e.g. tall piles supporting a service bridge with heavy machinery). They can further be constructed in masonry, concrete, reinforced concrete, steel. This variety in structural system and material led to the explicit recommendation to use third party guidelines, respecting at the same time the fundamental philosophy of uniform risk and the resulting dam classification (and thus return period and modeling details).

2.6 Part F – Strong-motion instrumentation

Strong-motion instrumentation does not only provide important data for research purposes, it also has practical benefits. In particular, a post-earthquake investigation can be decided upon based on the effective site motion rather than on a highly approximate estimate and the dam behavior during the earthquake can be reconstructed. The installation of at least 3 strong-motion instruments at all class 1 dams is thus required (1 in the free field, 1 at the crest, 1 at the dam base). Instrumentation of other dams is optional, provided they do not show any abnormal behavior or have any safety defects.

2.7 Part G – Post-earthquake controls

Objective and principle

The objective of post-earthquake controls is to identify quickly damages or changes in dam behavior so as to be able to take the necessary steps to protect population and property downstream.

The extent and the urgency of the controls are specified on the basis of the earthquake motion observed or estimated at the dam site. The associated limits are set individually for each dam. For those in which at least 3 strong-motion instruments are installed, the intervention level is set on the basis of the comparison between the accelerations measured at the site and the SEE peak acceleration a_h. For those dams that are not instrumented, the levels are set as a function of the estimated earthquake motions at the dam site (estimated site intensity). This is summarized in Table 5.

TABLE 5

INTERVENTION LEVELS FOR POST-EARTHQUAKE CONTROLS

Intervention level	Control	Measured a_{max} (in rock / along abutment)	Measured a_{max} (on / in dam)	Estimated MSK intensity
1	Next regular safety check	> 10% a_h	> 20% a_h	IV
2	Within 24 hours	> 25% a_h	> 50% a_h	V – VI
3	Immediately	> 50% a_h	> 100% a_h	≥ VII

Extent of control

The requirements regarding the extent and content of the post-earthquake controls are essentially those specified by the International Commission on Large Dams.

3. Final comments

The guidelines presented here were prepared over a one-year period and the final draft completed in year 2000. They have been complemented by application examples prepared for actual class 3 dams (both gravity and embankment dams). The guidelines are still in an evaluation phase and have not yet been formally introduced.

The guidelines are largely a formalization of the recent dam engineering practice in Switzerland with regard to the assessment of earthquake safety. Three new main elements have however been introduced:

- The concept of uniform accepted risk with resulting dam classification and, thus, differentiation in probability of exceedance for SEE and in modeling detail;

- Compulsory strong-motion instrumentation of class 1 dams;

- Specification of urgency and detail of post-earthquake controls based on the comparison between site motions and safety assessment earthquake.