A need to reassess dam safety

Climate change is only one of many natural and man-made hazards which are changing with time, and must be taken into account in dam safety assessments. **Martin Wieland** explains why there is an urgent need to evaluate the seismic safety of existing dams

Above: ***IWP&DC*** **would like to congratulate Martin Wieland for receiving an Honorary Member Award from the International Commission on Large Dams in 2022**

IN CONNECTION WITH THE discussion of climate change, it can be concluded that dams are structures, which are directly affected by these changes. If nothing is done, then the safety of dams may decrease. However, if current safety practice of the dam industry is followed, this is not necessarily the case. Climate change is only one of the many natural and man-made hazards which are changing with time, and must be taken into account in the safety assessment of dams, and which dams must be able to withstand safely.

It must be kept in mind that the ultimate goal of dam safety is that people living downstream of both a new and an old dam should feel equally safe. This implies that old and new dams must both satisfy the same minimum safety criteria. This is particularly a problem for the earthquake safety of large dams, as the seismic design criteria and seismic safety criteria have undergone important changes since many of the existing dams were built. This is, for example, true for dams built or designed against earthquakes before 1989 when ICOLD published its first guideline on the Selection of Seismic Parameters for Large Dams. Because of these developments, it is not known if older dams comply with today's seismic safety criteria. As all dams should satisfy the current seismic safety criteria at all times, there is an urgent need for the seismic safety evaluation of dams that were not designed according to today's safety standards. The minimum design and safety criteria, which must be satisfied, are those published by ICOLD. They represent the state-of-the-art practice.

From the observation of dams damaged by strong earthquakes the following conclusions may be drawn:

- Dams are not inherently safe against earthquakes. Because of the satisfactory behaviour of dams during earthquakes, several engineers and owners may be of the opinion that a dam, which has survived for say over 50 years without any earthquake damage, is safe against earthquakes. This is a misconception, especially in areas of low to moderate seismicity, where strong earthquakes occur rarely.
- The simple pseudo-static analysis and design method is not a safe method for dams with a large damage potential. This has already been known since the 9 February 1971 San Fernando earthquake in the US. Although the pseudo-static method is outdated, or even wrong, it is still used today.
- All dams, both new and existing ones, must satisfy the present seismic design and safety criteria, which are different from those used during the design of most dams.

Today's seismic safety criteria not only apply to the dam body but also to safety-critical elements like gated spillways and low-level outlets, which must be operable after strong earthquakes in order to keep the water level in the reservoir at a safe limit, or to lower the reservoir level to increase the safety of the dam. Moreover, the stability of slopes, whose failure may create impulse waves in the reservoir that could overtop the dam crest, or block the intakes of spillways and low-level outlets, must be checked for the ground motions of the safety evaluation earthquake.

Risk classification

An important issue is the risk classification of dams, which may vary for different countries or organisations. Risk classification is the main factor that governs the seismic design and safety criteria. As a result, the seismic safety criteria of similar dams may differ in different countries. There are also new safety requirements that concern electro-mechanical and hydro-mechanical engineers, as well as geologists and geotechnical engineers involved in slope stability analyses, who may not be familiar with the current seismic safety concepts for dams.

There are many dams that have been built without taking into account earthquakes or which were designed against earthquakes using the obsolete pseudo-static analysis method. Therefore, it is not known if these dams satisfy today's seismic design and safety criteria.

There are many reasons why the seismic safety of both water storage and tailings dams needs to be reassessed:

- New information on seismic hazard (ground shaking, mass movements) and/or seismotectonics is available.
- A dam has been subjected to strong earthquake shaking.
- New seismic design criteria are introduced.
- New seismic performance and safety criteria are introduced.
- New dynamic methods of analysis are introduced, such as nonlinear dynamic analysis methods.
- Certain dam types and poorly designed, constructed and maintained dams are vulnerable to earthquakes.
- The seismic vulnerability of a dam has increased due to dam modifications, ageing, etc.
- Changes in the risk classification of dams.
- The seismic risk has increased, e.g., due to the increased number of people living downstream of a dam and/or due to economic development, etc.

These comments, which are related to seismic hazard and seismic safety, apply equally to the other hazards including those due to climate change. Because of changes in hazards, design and safety criteria, and in the risk classification of dams, periodic dam safety reviews are mandatory. If important changes have taken place, a safety re-evaluation may be necessary. In the case of earthquake safety, this may be needed every 20 to 40 years. Among the natural hazards, the seismic hazard and seismic safety criteria have undergone the greatest changes over the last few decades. Safety evaluations are primarily the responsibility of the dam owners.

Steps for re-evaluation

The basic steps for re-evaluating the seismic safety of embankment dams are as follows:

- Determination of the seismic failure modes of the dam due to different types of seismic hazard.
- Ground shaking hazard: Determination of the main parameters of the safety evaluation earthquake ground motion (i.e. acceleration response spectra, peak ground acceleration (PGA), duration of strong ground shaking).
- Estimate of dynamic material properties based on static and dynamic laboratory tests or information taken from the literature.
- Dimensional finite element model of the dam-foundation system using, e.g., the equivalent linear method.
- Assessment of pore pressure build-up (liquefaction analysis for certain foundation conditions or materials in hydraulic fill dams).
- Calculation of permanent displacements of potential sliding masses along the dam slopes by, e.g., the Newmark sliding block analysis.
- Seismic settlement analysis (rough estimates can be made using empirical relations).
- Estimation of the freeboard reduction during the safety evaluation earthquake.
- Assessment of internal erosion hazard due to damage to the fine sand filter or to the water-proofing membranes etc.
- Seismic safety assessment based on the results of the earthquake analysis.

For concrete dams, the basic steps are given below:

- Determination of the seismic failure modes of the dam due to different types of seismic hazard (see subsequent Section).
- Ground shaking hazard: Determination of the main parameters of the safety evaluation earthquake ground motion, which are the basis for dynamic analyse.
- Estimate of dynamic material properties of mass concrete and foundation rock.
- Modelling of joints whenever necessary.
- Dynamic analysis of a two-dimensional or three-dimensional finite element model of the dam-reservoir-foundation system.
- Dynamic stability analysis of concrete blocks separated by joints and/or cracks.
- Dynamic stability analysis of dam abutments.
- Seismic safety assessment based on the results of the earthquake analysis.

These dam analysis steps are applicable to the ground shaking hazard. For other earthquake hazards such as mass movements, fault movements, ground displacements, liquefaction, etc., other methods may have to be followed.

In general, a screening would be needed in order to identify the dams with the largest seismic risk that have to be checked first.

Above: **Today's seismic safety criteria not only apply to the dam body but also to safety-critical elements like gated spillways and low level outlets**

Seismic re-evaluations

The ICOLD Committee on Seismic Aspects of Dam Design has encouraged member countries to carry out seismic safety evaluations of their existing dams. Usually, dam owners and operators are reluctant to perform seismic safety checks unless there are laws and regulations, and a dam safety organisation with the authority and means to ensure that the rules are followed. A thorough assessment of the design criteria is usually done when the dam owners are applying for a new concession for their project or are selling a dam. Again, the perception that a dam that was considered safe at the time of construction will remain safe forever, is a dangerous misconception.

For example, if proper seismic re-evaluations would be carried out the dams that are vulnerable to static liquefaction could be identified and actions taken.

The main conclusions are as follows:

- The dynamic analysis methods and the technology for designing and building dams that can safely resist the effects of strong ground shaking are available.
- Dams are not inherently safe against earthquakes.
- As most dams built prior to 1989 when ICOLD published its seismic design criteria of dams, were designed to resist earthquakes using analysis methods, and design and safety criteria, which are outdated and no longer compatible with the latest ones published by ICOLD in 2016, the safety of these dams is unknown and it must be assumed that several do not satisfy today's seismic safety criteria. Therefore, dam owners especially those of older dams must start with seismic safety checks of their dams.
- Seismic safety evaluations have to be carried out periodically during the long life-span of large dams, e.g. every 20 to 40 years.
- New information on the seismic hazard and new developments in the seismic design and safety concepts of large dams may require a re-assessment of the seismic safety of dams.
- Seismic safety evaluations include the dam body, gated spillways, low-level outlets, abutment wedges and reservoir slopes where mass movements could either block intakes of the spillway or low-level outlets or create impulse waves in the reservoir that could overtop the dam. ●

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Martin Wieland is an expert in dam safety and earthquake engineering based in Switzerland. Since 1999, he has been the chairman of the International Commission on Large Dams' Committee on Seismic Aspects of Dam Design, a technical committee created in 1968 with representation from 34 member countries.

In 2022 he received an Honorary Member Award at ICOLD's World Congress which was held in France. The award was established in 2000 and is given to experts who have made outstanding contributions to the development of dams in the world, or have made great achievements in the field of dam engineering.

ICOLD was founded in 1928 and is one of the oldest international professional organisations. There are 104 member countries and more than10,000 individual members.