Monitoring of dams in operation - a tool for emergencies and for evaluation of long-term safety

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SYNOPSIS. As the number of new dam projects dropped during the late 1980's, the focus shifted from construction to operation of dams in Norway. In this process, the importance of emergency warning and monitoring of long-term behaviour was realized and resulted in a guideline for monitoring and instrumentation in 1996. After 7 years, the guideline has been revised and this paper summaries the content of the revised guideline [NVE, 2003]. Some Norwegian dams have a dam break warning system and a brief history of this system is also described.

INTRODUCTION

Traditionally, monitoring of Norwegian dams has been limited to the initial filling and the first years after commissioning. Surveillance of long-term performance was generally not systematic and limited to random inspection of dams.

The need for monitoring of long-term performance was visualised when the guideline for inspection and reassessment was introduced in 1994 [NVE, 2002]. According to the guideline, a reassessment is required about every 15th year, which includes a detailed evaluation of the dam and appurtenant structures. An element of the reassessment is an evaluation of the long-term performance of the dam, in order to compare the theoretical and the actual behaviour.

In 1994 a guideline on emergency action planning was also published [Svendsen, Molkersrød and Torblaa, 1997]. The guideline was a result of increasing focus on emergency planning and how to reduce the consequences related to an abnormal situation. It is evident that early warning is important to prevent worsening of the situation and to reduce the consequences.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

The realization of the importance of instrumentation to monitor long-term behaviour and for the purpose of emergency warning resulted in a guideline for monitoring and instrumentation in 1996. During 2003, the guideline has been revised and this paper summaries the recommendations of the revised guideline. Some Norwegian dams also have a dam break warning systems, and a brief history related to this system is also included.

LEGAL FRAMEWORK

The practice of public supervision with dams in Norway started in 1909. After almost 100 years, the regulatory authority has been transferred to the Norwegian Water Resources and Energy Directorate (NVE) which reports to the Ministry of Petroleum and Energy.

The Dam safety regulations [NVE, 2000a] represent the legal basis for public supervision and safety control of dams, spillways and hydraulic structures (called watercourse structures as a collective term). More detailed specifications and technical safety recommendations are specified in guidelines. The structure of the regulations is given in figure 1, below.

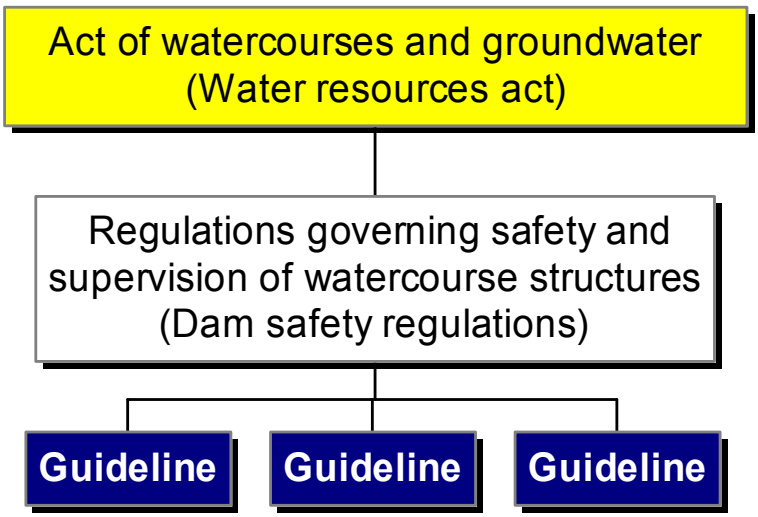

Figure 1: Structure of the legal framework

The guidelines give recommendations on how to fulfil the regulations but do not set any direct requirements. Guidelines are developed and managed by NVE and can easily be revised and amended. The Dam safety regulations and the Water resources act include general requirements and therefore needs a formal approval from the highest level in the administration, a process that is very time-consuming and complicated.

All together, 20 different guidelines are planned [Midttømme, 2003]. Eight of these have been issued, whereof two has been translated to English. The English versions of the regulations and guidelines are available on NVE's Internet site; http://www.nve.no-> English pages-> Safety and supervision-> Legislation

Classification of dams

The regulations define 3 different consequence classes [NVE, 2000b] and requirements for instrumentation are dependent on the classification of the dam. Each class is defined on the basis of the number of houses affected by a dam break, as shown in Table 1. Environmental and economical consequences shall also be assessed as an element of the classification.

Table 1: Classification of dams – definition

Consequence class		**Affected housing units**
Class 1	Low hazard	0
Class 2	Significant hazard	1-20
Class 3	High hazard	More than 20

PLAN FOR MONITORING

A plan for monitoring is important as a basis for the surveillance. A monitoring plan can be part of the inspection program for the dam, since an evaluation of the collected data often is an element of the inspection procedure.

The plan for monitoring will normally contain the following elements:

1. Overview of the different types of instrumentation on each dam.
2. Description of the different measurements that are being carried out and frequency of the readings.
3. Background on the choice of instrumentation or reasons for lack of instrumentation when this does not coincide with the guideline.
4. Description of the location of each individual monitoring device
5. Specifications on the different instruments.
6. Description of the accuracy of the instruments and expected errors in the recorded monitoring data.
7. Plan for calibration of the instruments where necessary.
8. Plan for testing, inspection and maintenance of the instruments.
9. Limit values to initiate actions in case of an emergency.

Limit values are important to give a warning in an emergency situation. The values are worked out as part of the Analytical Phase, which forms the basis for development of an Emergency Action Plan [Svendsen, Molkersrød and

Torblaa, 1997[3]]. Limit values will specify when to intervene and can for example be defined as;

- water level where access to the gatehouse or gate is interrupted
- water level when overtopping of the core will occur
- maximum expected load that the structure can withstand
- normal or largest acceptable leakage

MONITORING AND INSTRUMENTATION

Generally, the need for monitoring and instrumentation will depend on the dam type and consequence class. The number of instruments and their location must be assessed according to the dam type, height and length; the state of the foundation; normal reservoir levels, reservoir size and other factors in the reservoir area.

It is important that the instruments are reliable, accurate and easy to read off. Care must be taken when installing the instrument and the location must be chosen in order to ensure a correct and adequate reading of the monitoring data. For example, the water level sensor should not be located so that gates or spillways can influence the readings. This should be obvious, but experience show that it is not always taken into consideration, fore example in cases where the gates or spillways are seldom in use.

Recommendations for instrumentation of dams in Norway to monitor long-term behaviour and to provide emergency warning are given in the guideline for monitoring and instrumentation [NVE, 2003]. The guideline also specifies the frequency of the readings. Additional instrumentation and other frequencies than recommended by the guideline will need to be evaluated, dependent on the dam in question.

MONITORING OF LONG TERM BEHAVIOUR

Monitoring of long-term behaviour is generally limited to monitoring of the following elements:

- Leakage
- Pore pressure
- Deformation

Leakage

Variations in the recorded leakage will give an indication on the performance of the dam. Decreasing leakage can indicate increasing pore pressures as a result of poor drainage, while increasing leakage may indicate deterioration of elements within the dam or foundations that will need further investigations. Measurements of leakage should be recorded together

with water level in the reservoir, precipitation and snow melting, as these factors may influence the readings.

Continuous measurements of leakage are of importance to detect sudden changes in the leakage that may not be determined by a measurement now and then. This is of particular interest for embankment dams, but also for concrete dams founded on soils or rock with weak zones.

Pore pressure

Pore pressure measurements of the foundation will generally be required for dams founded on soils or rock with weakness zones. Additional monitoring of pore pressures can prove necessary, particularly on high concrete dams. However, as a result of the glacial history of Norway, the foundation often consist of hard, resistant and durable rock, and potential monitoring will need to be evaluated in each separate case and this is therefore not a general recommendation. Measurement of pore pressures is recorded together with the water level in the reservoir.

Deformations of concrete dams

Measurements of deformations are particularly recommended for arch dams and dams where alkali aggregate reaction (AAR) are detected or suspected. Deformations should be recorded together with measurements of water level and concrete temperature. Measurements of cracks must also be considered, however, this will be based on an individual assessment of the dam in question.

Deformations of embankment dams

Generally, settlements of the crest will be measured at least once every year. Annual levelling of moraine- and asphalt concrete core is also recommended. In this way any sudden changes in settlement can be detected and a more detailed evaluation can be carried out.

In addition, horizontal and vertical deformations of bolts are measured about every 5th year. Suggested distribution of deformation bolts are given in the guidelines. The need for a more detailed survey may be required to identify local deformations that will not be recorded within the grid of deformation-bolts, e.g. deformations caused by beaching or internal erosion. For this purpose, detailed topographic mapping can be made on basis of aerial photographs or sonar. A picture of sonar mapping is shown in figure 2. Sonar may give a better level of detailing than aerial photographs, but will be limited to the upstream face.

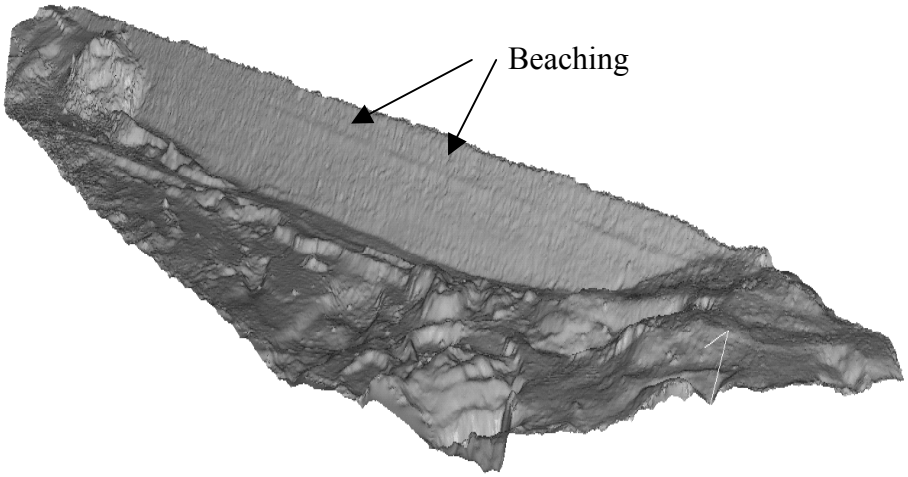

Figure 2: Topographic mapping of the upstream face of an embankment dam (Photo: Artec Subsea AS)

Evaluation of the monitoring data

The monitoring data must be analyzed and evaluated continuously and presented graphically so that both long term and short term tendencies are visualized. Some examples of graphical presentations are illustrated in the guideline [NVE, 2003[1]].

The monitoring data need to be assessed and commented on the basis of the following elements:

- Accuracy of the monitoring data.
- Possible changes in trends.
- Factors that may have influenced the measurements.

MONITORING FOR EMERGENCY WARNING

Instrumentation for the purpose of emergency warning is generally limited to monitoring of water level and leakage. Monitoring of the reservoir water level is recommended on all high hazard dams and dams with gated spillways. Monitoring of leakage for emergency purposes is limited to embankment dams with a central core of moraine and asphaltic concrete or dams founded on soils or rock with weak zones.

Where monitoring for emergency warning is required, a continuous reading and transmission of the data is necessary in order to detect any development of a possible abnormal situation.

In some cases, abnormal situations have not been detected as the instrumentation did not work properly. In such cases a surveillance camera on the dam site would have been useful. A camera on site can also reveal additional information that is not necessarily detectable by instrumentation alone and may be of particular use when the control centre is at another location than the dam.

DAM BREAK WARNING SYSTEMS

Some Norwegian dams also have been required to have a dam break warning system installed. [Martinsen, 1995]. This is not included in the guideline for monitoring and instrumentation, as the dam break warning system is only required on some particular dams.

The first formal warning system of dam failure was established during the Second World War. It covered nine river basins, and was based on the use of telephone or radio at the dam itself, and cars along the main roads with alarm sirens. After the war, this system was abandoned.

In some river basins, dam failures could cause disasters of enormous dimensions, in terms of both loss of lives and material damage and in 1966 a working group for dam safety in emergencies was set up. In 1971, the group concluded that a modern warning system should be developed. The decision was based on the following main factors;

- Even though the likelihood of dam failure is relatively small in times of peace, the possibility of it occurring as result of natural reasons, technical damages or damage caused by terrorism or sabotage should not be ignored. The system should therefore also be operated in times of peace.
- Dams constitute targets for attack in times of war. The primary motive for attack would usually be to exploit the destructive effect of the breach wave in the area below.
- In the event of a dam failure, loss of life can be very extensive. A good warning system allows even people living very close to the dam, to be evacuated.

These arguments, combined with a strong local political pressure, led to development of an electronic warning system for dam failure in two river basins.

The dam owners were requested to install and operate the warning systems, as well as the communications and transfer of the warning signals to a first reporting point. From this reporting point, the Civil Defence services assumed responsibility for installing and operating the system of sirens, and

for communication between the first reporting point and the sirens themselves. In this way the warning was transferred to a large number of sirens throughout the river basin.

The warning system is based on two different electronic monitoring systems:

- Four single current electric circuits built into the dam. When one circuit is broken it will be detected.
- Downstream the dam, there are four independent floats that measures the water level, and a warning signal is given at a previous defined water level.

To avoid unnecessary warning, the warning system is only activated if a dam break is indicated by at least three of the independent systems.

CONCLUSIONS

The guideline for monitoring and instrumentation [NVE, 2003] is valuable as a basis to determine a minimum of instrumentation for Norwegian dams. However, an assessment of each individual dam should always be made in order to determine the need for any additional monitoring, or in some cases the need for reduced monitoring compared to the guideline.

The guideline gives recommendations on what to do, when and where. However the human factor should not be forgotten, as instrumentation and monitoring is just a tool on the way to achieve better dam safety. Just as important as the actual instruments are how they are operated and how the monitoring data is analyzed. Valuable information may drown in an enormous amount of data. Further, improper analysis of the data may not reveal information that could have been detected. These factors may prove to be the real challenges when monitoring a dam and should not be overlooked.

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