

# **Dam Safety**

December 1992

## **Summary Report**



Norwegian Water Resources and Energy Administration  
Water System Management Association  
NORWAY



## **THE NORWEGIAN WATER RESOURCES AND ENERGY ADMINISTRATION**

The Norwegian Water Resources and Energy Administration (NVE) is a governmental body responsible for the management of Norway's water and energy resources for the optimum economical benefit of the nation. An objective for NVE has been to obtain this at the lowest possible cost to the environment and with the highest possible safety to the public.

NVE's Dam Safety Section NVE-T approves designs and construction plans and supervises dams and other river works in order to ensure public safety. Today more than 2500 dams are monitored by the section. The section drafts regulations and guidelines for construction and operation of such works. To maintain and develop knowledge within dam technology, hydrology and hydraulics, NVE initiates and takes part in a variety of studies and research projects.

## **THE WATER SYSTEM MANAGEMENT ASSOCIATION**

The objective of the members of Water System Management Association is power production through water system development. The majority of the country's power companies and development and owner associations are members.

Above all the responsibilities of the Association include matters of legal, economic and technical/scientific nature relating to the planning and operation of hydro-electric power stations and storage dams. Some examples are legislation and concessions technical operating experiences environmental questions, hydrology, and the coordination of the research and development for which the Association is responsible.

The Association reviews matters of common interest for its members, and advances these matters towards the authorities.

**Photo: Kilen Dam, Sira-Kvina Power-Company**

# **DAM SAFETY**

# **SUMMARY REPORT**

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ENERGY ADMINISTRATION**

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MANAGEMENT ASSOCIATION**

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## **SUMMARY REPORT**

### **Dam Construction and Safety**

Modern dam construction in Norway started about the turn of the century when the exploitation of our water-power resources gained momentum. Masonry and concrete dams were predominant in the early stages while large embankment dams came on the scene on a large scale after 1950. During this time Norwegian dam construction technology has maintained high standards, and the dams have attained a favourable reputation as far as quality and safety are concerned.

The water reservoir behind a dam represents an enormous potential of energy capable of provoking a catastrophic situation in the case of dam failure.

It will be a matter of course to everybody involved in dam construction and operation, that safety standards of the structure are high enough to render inconceivable the idea of dam failure.

Nonetheless we know that dam failure catastrophes do occur, and it has happened in our time and in technologically highly developed countries. No large scale accidents have been caused by dam failures in Norway. There has nevertheless been a series of failures on smaller dams below 15 metres in height.

A dam can never be considered as an absolutely safe structure. However, realizing that risk-factors are present makes it possible to strive for reduction and elimination of individual factors, so that total risk can be kept to acceptable levels.

During the period of extensive hydropower exploitation the country has undergone in recent decades, the perception of dam safety was largely related to planning and construction, where calculation methods, loads, material properties and design were the key words. But dam safety also depends a great deal on how dams are controlled, operated and maintained, and to what extent different incidents and situations emerging during the operation phase are perceived and prepared for. This was the reason that the Norwegian Water Resources and Energy Administration

(NVE), in 1987 initiated a cooperation project together with the Water System Management Association (VR) and the dam owners on dam safety.

The report "Risk Analysis for Dams" was issued in 1987 as a result of a preliminary project, while the main project commenced by establishing a Board of Supervisors in the autumn of 1988. The Project Manager started his work in April 1989, and from then on the practical work was launched. The project was terminated in 1992.

The Board of Supervisors consisted of:

- \* Chief engineer Bjarne Nicolaisen, NVE (president).
- \* Chief engineer Jan Daleng, VR.
- \* Professor Dagfinn Lysne, the Hydraulic Institute of the Norwegian Institute of Technology (NTH).
- \* Chief engineer Thorleif Hoff, the Norwegian Energy Corporation (Statkraft).

The Project Manager was Civil Engineer Svein Larsen.

On the basis of actual conditions, the project has made recommendations on how to promote dam safety during the operational phase. Various questions relevant to dam safety in the operational phase were likewise examined, phenomena related to the ageing of the dam, to diversion of floods, overtopping, leakages, security in the functioning of flood gates and preparation for emergency situations. Data on actual operational experience, statistics on dam failure and risk-evaluations have also been surveyed.

### **Target Groups**

- \* All categories of dam owners represented by the persons responsible for planning, building, operation, inspection and maintenance of dams.
- \* Consultants assisting the dam owners.
- \* Public authorities with administrative responsibility for dam safety.

- \* Public authorities with responsibility for rescue operations during disaster situations.

### **Reports from the Project**

The following reports have been issued by the Project:

Main Report

Summary Report

- |                                 |  |
|---------------------------------|--|
| Report no 1:                    | Ageing and Safety of Concrete Dams.                    |
| Report no 2:                    | Emergency Planning for Abnormal Situations.            |
| Report no 3:                    | Security of embankment dams against leakage failures.  |
| Report no 4:                    | Obstruction of Spillways.                              |
| Report no 5:                    | Overtopping of the impervious core in embankment dams. |
| Report no 6,<br>Parts I and II: | Functional Security of Flood Gates.                    |
| Report no 7:                    | Alkaline Reaction in Concrete Dams.                    |

#### **Report no 1: Ageing and Safety of Concrete Dams**

This report describes the construction of concrete dams in Norway in a historical context, and traces their technological development. Various types failure are reviewed and safety consequences evaluated. The different types of dams are described in terms of design, stability, safety and rehabilitation.

Characteristically damage to concrete dams appears clearly on the surface and visible to the naked eye. Rifts, cracks, water percolation, limestone washing, larger or

smaller fractures and erosion are among the most common forms of damage.

How serious is such damage, will it have consequences for dam safety, how will it develop in the future, and what kind of measures are required? Could there also be an internal degradation, not visible on the surface? Such questions arise naturally, and these matters are evaluated and conclusions presented in the report now issued. Briefly it can be said that concrete dams should not spring any major surprises on us from a safety point of view.

As mentioned already these dams readily disclose their weaknesses, and there will generally be ample time to consider appropriate measures before damage has reached unacceptable levels. Damage will usually be put right for aesthetic and economic reasons well before it has discernible impacts on safety.

#### **Report no 2: Emergency Planning for Abnormal Situations.**

Two examples of emergency planning are presented in this report. The examples have not been worked out in detail as far as size and layout are concerned and are should be regarded as merely parts of a process. The idea is that dam owners should receive impulses and ideas to work out corresponding plans for own installations through these examples.

All emergency planning should be adapted to prevailing conditions at the individual dam owner's site and to the consequences of dam failure. Planning will be important primarily to those dam owners responsible for dams where the consequences of failure are large.

Emergency planning for dams bearing in mind critical natural events constitute an integral part of the total, and the scope of the work should incorporate activities like:

- dam owner's current programs for operation, inspection and maintenance of his dams;
- emergency planning related to war-



situations, sabotage etc. for the dams;

- the general emergency and rescue operations planning the for major accidents;
- dam owner's emergency planning for other types of installations like power plants, factories etc.

### **Report no 3: Safety of embankment dams against leakage failures.**

In Norway there have been several incidents of internal erosion causing increased leakage of embankment dams. This phenomenon also figures in international dam statistics as among the most frequent causes of damage and failure.

In Norway, however, the rockfill dam is the most common type of embankment dam, but failures and serious damage typically occur in earthfill dams.

Leakage occurs frequently at the initial inundation of the reservoir. Relevant questions are whether such leakage also can develop in older dams, where abnormal conditions have not been noted previously, how leakage will develop, and how the safety risk can be reduced by investigations and appropriate measures at the dam site. The report deals with all these questions.

### **Report no 4: Obstruction of Spillways.**

This report reviews the results of model tests designed to reveal conditions leading to obstruction of permanent spillways. An attempt is also made to define and isolate those forces which impact on the debris in case of accumulation.

A complete evaluation of a spillway's diversion capacity should include an analysis of the situation at the obstruction. The analysis should answer the following questions:

- What are the consequences of an obstruction of the spillway?
- What types and amounts of debris can be

expected to arrive?

- What potential is there for diverting or halting the flow of debris?

The report will assist answering the above mentioned questions.

#### **Report no 5: Overtopping of the Impervious Core in Embankment Dams.**

An investigation should be carried out into the capacity of embankment dams to withstand collapse when the reservoir's water level overtops the impervious core. This should be done in connection with PMF-analyses and emergency planning.

The report contains guidelines and advice for the undertaking of such an investigation.

It should be noted that appraisal of various failure mechanisms (erosion, slides) can help decide what is the maximum water level a reservoir can sustain.

Norwegian rockfill dams with a reinforced dam toe of boulders can withstand large flood water levels. There are, however, also some dams in Norway where downstream slope protection and the dam toe consists of earth, gravel or mixed tunnel rocks/ quarried rocks. Such dams will withstand only smaller floods, and reinforcing of the dam toe should be considered in such dams.

#### **Report no 6: Functional Security of Flood Gates.**

Spillways that do not function as designed can cause dam failure, and it is necessary to ensure that spillways with sluicing devices have an adequate functional security.

Analysis of functional security can be performed as part of this exercise so as to determine diversion capacity at different degrees of gate operation failure.

The report demonstrates, with examples, how such analyses can be undertaken. The potential for operational and sluicing failures are explained together with various measures which

can be taken to improve functional security. The report is divided into two parts for practical reasons.

#### **Report no 7: Alkaline Reaction in Concrete Dams.**

The recognition that alkaline reactions can cause damage to concrete is relatively new in Norway, even although such reactions have been known over a period of many years. An extensive research project on alkaline reactions has been going on at SINTEF FCB (The Norwegian Centre for Industrial Research in Trondheim)(?) since 1989. Extracts of the conclusions from the research project as of 1st January 1992 are presented in this report (Part 1).

Data is scarce on how large expansions have been caused by alkaline reactions in different structures in Norway. It has been possible to reconstruct the historical rate of expansion at Votna dam by carrying out regular deformation measurements since the dam was built. This material is presented in part 2 (Grøner). It is concluded that the expansion of the concrete over the last 10 years amounts to a total of about 0.4 per mille, and that the present expansion rate is about 0.06 per mille annually.

Norwegian research on alkaline reactions has so far focussed, to a very limited degree, on the effects of reactions on forces and loads in different types of structures and on what effects this has for safety. This is reviewed in part 3 (Grøner).

The effects can be summed up in four parts:

- The structure undergoes deformation which can cause blocking of gates, jamming of outlets etc.
- The structure will crack at the surface, opening up for penetration by other destructive processes.
- The properties of the concrete regarding permeability, elasticity and resistance to pressure, strain and section strength will be altered.

- The internal expansion of the concrete leads to additional strain in thereinforcing, concrete and cables. The effects are different from expansion caused by temperature.

The expansion of the structure caused by alkali can be of the order of 0.5 per mille, and this alone results in considerable additional strains in the reinforcing. Expansion will cause additional strains for different types of structure, and a complete review of this can be obtained through analysis of the structure in question.

### **Responsibility and Division of Work**

The dam safety promotion work can be divided into two main parts:

The first part concerns tasks directly related to a dam construction project. The other comprises a general part which benefits indirectly the safety promotion work in each individual project.

There is a natural link between the two parts, as experience from individual dams influences and forms the background for the contents of the general part, concerning laws and regulations as well as standards and experience.

On the other hand the contents of the general part will form the basis for safety promotion work connected to each individual dam project.

To-day, two main parties are responsible for dam safety:

- \* The dam owner.
- \* The Safety and Emergency Planning Department of NVE (NVE-T).

A crucial factor in dam safety is that the distribution of functions, tasks and responsibilities is well known and acceptable to both parties. Under these circumstances the actual distribution of functions is often found not to correspond with formal



arrangements. Dam safety can be threatened if this is allowed to go too far.

### **Safety Promotion Work for the Individual Dam Project**

The individual dam owner plays the main part in dam safety promotion work because:

- \* The individual dam owner shall see to it that dam safety is maintained at a satisfactory level for all dams in his ownership.

NVE-T's role is dictated by its specific objectives:

- \* NVE-T shall on behalf of the public control the dam owner and verify that the level of safety of his dams is adequate.

An important element in dam safety promotion work is to develop standards for adequate safety levels. Both parties are responsible for this independently of each other.

### **General Safety Promotion Work**

NVE-T has the main responsibility for laws, regulations and the Norwegian Dam Regulations Part II. These should, however be developed and maintained in close cooperation with the dam owner organizations, the dam owners and other agencies in the water management sector (consulting engineers, research institutes, suppliers and contractors).

All agencies in the sector participate in development and maintenance of informal guidelines, standards and experience, but the main responsibility lies naturally with the dam owner organizations and NVE-T.

### **Quality Control**

The water management sector and NVE have jointly initiated a system of Project Quality Control, to formulate guidelines for contents and functions of a quality control system. The guidelines will be presented in mid 1993.

To-day a comprehensive set of regulations exists within the field of dam safety. Here the standards dam owners must comply with during planning and construction of the dam have been established. Quality control systems which can contribute to the realization of these standards are clearly important elements. Defining the dam owners' and NVE-T's functions and roles in this supervisory task will be a prominent part of the Quality Control Project.

Regulations governing the activities of the dam owner during the operational phase are insubstantial. The dam owner assumes responsibility for dam safety during the operational phase, but the implications of this are dealt with to a limited degree in the present regulations. For a quality control system to work more detailed specifications will have to be set out in a set of operational rules for dams.

This should be achieved under the established system of regulations, and not through rules for quality control. Quality control does not comprise the establishment of specific requirements to be complied with, but rather as the development of a system to guarantee that the requirements will be followed.

Quality control in its original concept also implies that the supervising agency (NVE) shall shift its activity from the control of dams to control of the dam owners' quality control systems.

The possible consequences for dam safety of this change should be more closely evaluated before it is adopted as the official system for control. Our largest dams represent a disaster potential so vast that NVE should presumably make independent security assessments here on a periodic basis.

An evaluation of NVE's inspection strategy within a future quality control system should be made under the Quality Control Project. NVE should use a term different from "Quality Control" for its strategy, in case future inspection systems do not correspond with other inspection agencies' quality control systems. This should be done in order to avoid misunderstandings.

## **Risk Analysis Methods**

Use of risk analysis methods in dam safety work offers a sounder basis for the assessment of dam-associated risks rather than traditional methods for safety promotion.

Calculations of dam failure waves and the consequences of dam failure were previously prepared by the previous Defence Electric Power Organization (KSFN) now the Emergency Planning Section of NVE-T.

The dam owners themselves should assume responsibility for making such analyses. It is not expected, however, that the dam owners will assume this task until NVE-T clarifies the situation.

## **Evaluations of Dam Failure Capacities**

Dam safety has traditionally been analysed and expressed through design standards and design loads. Safety related to individual events can be given a more explicit expression by analysis of failure situations, as individual dams may possess different abilities to support impacts in excess of the design standards.

Assessment of failure capacity should be standard for all new structures. Assessments should be undertaken for existing structures depending on the what the consequences of dam failure might be.

## **Safety related to impact, classification systems for dams**

In Norway it is estimated that about 2500 dams possess dam structures or reservoir of sufficient size for them to be subject to NVE-T's inspection.

These dams vary from 2 metres to 140 metres in height. There are reasons to believe that failure at one of our large dams with great damage potential would represent a disaster of the worst imaginable dimensions in Norway. Failure at one of our smaller dams could,

however, occur without causing any major damage. It seems evident for these reasons that all safety precautions for dam constructions should depend on the damage potential of a failure.

The purpose of a classification system will be to group individual dam structures into different categories, so that similar standards could be established for dams within each of these categories.

### **The Need for Changes in the Dam Regulations**

The need for change in some of the regulations has been revealed in different aspects of the project work. The results are presented in Annex 1 as "Proposed Changes in the Dam Regulations." It should be stressed that the project has not made a complete revision of the dam regulations with possible amendments in mind.

NVE should initiate such a complete revision of the dam regulations, and as a next step propose amendments to them. The work should be carried out in cooperation with the water management sector. Development of regulations, rules and recommendations for the operational phase (the Dam Regulations Part II) should be the main task.

### **Need for Rehabilitation**

The following possible needs for rehabilitation of our dams can be listed on the basis of safety considerations:

- \* Changes/removal of bridges over permanent spillways.
- \* Increased capacity of cross sectional area of tunnels and shafts at spillways.
- \* Construction of crests on older embankment dams, or, alternatively, construction of concrete parapet walls.
- \* Construction of dam toes made of boulders on existing embankment dams.



- \* Improve upstream slope protection on embankment dams.
- \* Increase spillway capacity on gated dams.
- \* Installation of several independent reserve systems for operation of flood gates.
- \* Reconstruction of older wooden flashboard dams.
- \* Rehabilitation of concrete dams.
- \* Rehabilitation of wooden and steel frame dams.

### **Dam Safety during the Operational Phase**

The dam owner is responsible for adequate safety at his dams.

Dam safety means assurance against an uncontrolled and damaging outflow of water (arising from operational errors or dam failure) or against damage to the reservoir by water levels higher than anticipated.

In order to meet his responsibilities the dam owner should work out, carry through and control programmes for the activities he assumes to be necessary for safety during the operational phase. The extent and content of the programmes shall be adapted to the type of dam, safety level and the consequences of dam failure.

The dam owner shall establish an organization with relevant professional competence and finance to enable him to carry out the above mentioned tasks. Some tasks will call for in-house capacity, while for others outside expertise will have to be hired. The dam owner's schemes for promotion of safety must be adapted to the structure, size and specific capabilities of his organization. The need for outside assistance will emerge as a part of the total picture.

The dam owner's programmes must also be conceived so as to provide the basis for NVE-T's inspection.

**NVE-T's Inspection**

- \* NVE-T is responsible for monitoring that the dam owner fulfils his safety obligations.

NVE-T can impose different degrees of monitoring. NVE-T should adopt a monitoring strategy geared to the consequences of dam failure. Dams where failure will have major consequences should be more intensively monitored by the NVE-T than dams where consequences are small.

**Planning and Construction Documentation**

Documentation clarifying all aspects of significance for the dam should exist from the planning and construction phases. It is of course important that documentation also covers all modifications added during the construction phase of the dam. Such modifications can be potential sources of damage or dam failure.

Documentation should exist in various forms.

For dams constructed before the introduction of the Dam Regulations, documentation may be very scarce in some cases.

The extent to which new documentation should be provided will depend on its usefulness and the need for it. Supplementary documentation should be restricted to a minimum for older dams with small failure consequences.

Dam safety is partly based on detailed, concrete public safety requirements, and partly on what the dam owner considers to be adequate levels of safety. The dam owner should see to it that proper documentation exists showing that all detailed, specific official safety requirements have been met.

NVE-T should establish a similar system in order to make a register of instructions given to and documentation received from the dam owner.

## **Operational Routines**

The purpose of the dam owner's current operations may comprise production of hydro-electric power or delivery of drinking water. Operational routines for these will be very numerous.

The concept 'operational routines' in this report, however, cover only activities connected to the dam's operational safety.

This comprises operational routines related to registration of water levels and flood diversion. The following operational routines should be included in the programme:

- \* Principal operational rules related to flood diversion.

The main requirements can in some cases be contradictory. Principal operational rules should set out the main flood diversion options open to those responsible for such situations.

The programme must be realistic and well conceived. Principal operational rules cannot cover every possible eventuality in detail.

It should be noted that one reason for the difficulties in setting out operational rules is contradictory demands in a flood situation. Setting out such rules reveal that demands are contradictory.

## **Emergency Planning**

The concept 'emergency planning' is a general one and can be applied in a variety of contexts. In the water management sector the concept used to be related to the work carried out by the former Defence Electric Power Organization (KSFN), which has now been transferred to the Emergency Planning Section of the NVE (NVE-TB). The purpose of its emergency planning was initially to secure an effective energy supply in war situations as well as under emergency conditions (periods previous to war).

A main aim of any hydropower company will be

to secure effective energy supply during periods of storm and bad weather. It must, however, be kept in mind that the hydropower company may also be responsible for dams with an extremely large damage potential in case of dam failure, and that the safety of these dams will be at risk in the same situations.

Only emergency planning for dam safety related to incidents caused by natural forces has been analysed by the project. It is important, however, that all associated emergency planning be coordinated.

### **How to Improve Dam Safety through Emergency Planning**

The dam owner can improve dam safety through emergency planning in the following ways:

- \* The dam owner's staff, administration and organization can, through participation in planning and by developing an operational emergency plan, better tackle critical situations and avoid dam failure and other unwanted incidents.
- \* Weak points can be detected through planning, and measures taken before potentially critical situations arise. Such weak points can take different forms as follows:
  - Technical design of construction.
  - Parts of the operational emergency plan.
  - Available resources for emergency situations.
- \* The dam owner presents his emergency strategy to NVE-T. This gives NVE-T an opportunity to evaluate his strategy in an overall assessment of the safety of the dam and to comment on potentially inadequate safety levels.

### **Inspection Routines**

Dam owners' inspections constitute an important part of the planning of construction safety. Inspections have always been undertaken, but the task has been performed in



a more systematic way after introduction of the Dam Regulations in 1981.

The current practice of inspections is largely satisfactory, and the Project has not found any reason to pay particular attention to this aspect in its work.

It has to be said, however, that underwater inspections and material analyses should be considered in many cases in addition to visual inspections.

The need for inspections, however, varies greatly, depending on the category of dam, its general condition and its state of safety. This should be reflected in the inspection procedures.

### **Instrumentation**

Instrumentation of dams for measuring of deformations, pore water pressure, tensions, water percolation, temperature or other physical standards will form part of a dam owner's safety monitoring.

The dam owner should set up a program for his measurements. The program has to be adapted to the category of dam, age and condition. The program should have a clear concept and purpose behind the measurements. The measurements must be followed up and analysed by qualified personnel. The extent of the measurements should be revised at intervals of 10 to 20 years. The need for measurements will decrease after the first 10 years of the dam's life span.

The need for new measurements should also be assessed in connection with any damage or irregular dam conditions. Special requirements for measurements can arise with very old dams, and technological developments give rise to new opportunities for measurements.

The purpose of dam instrumentation is generally to record the state of the dam, and constitutes a part of the strategy to preserve safety of the construction.

Instrumentation also has a place in the

programme for operational safety. The purpose of such instrumentation is to record the water level in the reservoir, the position of gates and other technical details regarding the operation of gates.

### **Safety Considerations**

The overall security of a structure vis-a-vis a threat or a load consists of the original security dating from the time of its construction and the change in this over its life-span.

Inspection routines and instrumentation practices can reveal changes in the state of the structure, but this, in isolation, cannot give a correct estimate of the security situation. The dam owners must undertake risk assessments on the basis of current safety standards in order to complete the picture.

#### **The various risks or loads.**

Security assessments can be directed towards different kinds of risks and loads or as an assessment of total security. A number of such risks/loads were analysed in the dam safety project as issues related to individual elements of the structure.

The dam owner should clarify and give reasons for which revisions of security that are presumed necessary, and then discuss this with NVE-T.

The dam owner may perhaps find it difficult to understand that revisions are needed in some cases. It can be difficult to determine what is necessary or not. In situations like this what other dam owners are doing and established practice can give useful pointers on what to do. Changes in practice may, however, be hard to introduce.

A change in practice might be achieved by clarifying the benefits from and needs for safety assessments, and by emphasising the dam owner's responsibility to clarify the need (or lack of need) for such assessments.

NVE-T itself however should assess the need to revise safety provisions for specific risk situations (for example blocking of spillways or a slide in the substructure of arch dams). It should instruct, in a planned and co-ordinated manner, groups of dam owners to undertake such revisions where considered necessary.

### **Amendments to Regulations**

A change in practice so that the dam owner himself undertakes the revision of security to a larger extent can be achieved by introducing this into the regulations.

The present system is so conceived that the Dam Regulations deal with the following issues:

- \* What kinds of security assessments need to be carried out
- \* The current acceptable security level.

These regulations cover both planning and construction.

It can be decreed that documentation on security shall be submitted for previously constructed and approved dams in cases where the revised dam regulations contain paragraphs that are either new or imply substantial deviations from earlier practice.

### **Reporting of Damage and Accidents**

Reports on damages and abnormal incidents during operation and the follow-up of such irregularities constitute an important element of dam safety. Such reporting has several purposes.

- \* Adequate handling of the matter internally is guaranteed.
- \* It ensures that NVE-T is guaranteed details and influence on the matter
- \* It ensures that information on damage and accidents reaches a central register of dam safety.

Reporting of damage or abnormal situations should be done through three main routines as follows:

- \* Normal reporting governing inspection, operation and maintenance.
- \* Reporting of acute damages and irregularities.
- \* Reporting for damage statistics.

### **Registration of External Impacts**

The principal loads a dam is supposed to withstand are determined by theoretical calculations. Both the data sources and the theoretical model may, however, be subject to substantial uncertainty. Recording the load that a dam structure is really exposed to is important in detecting miscalculations in determining load factors.

The following story from Switzerland illustrates the importance of recording of large recurrent floods:

A dam was exposed to a great flood after 20 years of operation. The dam was overtopped, collapsed partially and 17 persons were killed. The size of the flood was calculated at three times the design flood. A closer review of the data showed, however, that the design flood had been exceeded six times altogether in the course of the 20 years life span of the dam.

The dam was afterwards rehabilitated and provided with a larger flood diversion capacity.

The recording of wind and wave data should be initiated for a sample of dams so that various districts are covered. NVE-T should coordinate the work and instruct a selected group of dam owners to undertake it.

### **Flood Safety**

Flood safety in this context denotes security against dam failure caused by flood. A failure



of this kind normally develops in the form of overtopping. Events of this kind have evolved at a number of dam failures, and overtopping by flood can be regarded as one of the major potential causes of dam failure. A failure can also develop from erosion in the flood channel.

From a purely technical point of view, overtopping can be caused by:

- \* Recurrent floods that are of larger than anticipated at construction (larger water flow, more debris, a more difficult situation totally).
- \* The dam cannot support predicted water levels.
- \* Spillways not having the prescribed capacity.

The reasons the spillway has less capacity than anticipated may be:

- Actual capacity of the spillway is smaller than calculated technically.
- The spillway has been blocked.
- Gates, flashboards etc. in the spillway have not opened as anticipated.

Analyses of dams' security against failure caused by large floods should contain assessments of all the aforementioned issues. Unfortunately flood and capacity evaluations have often been restricted to assessments of water flow through unobstructed channels. An extremely large flood is a catastrophe situation which has to be analysed specifically.

#### **Assessments of Safety**

It is recommended that dam owners undertake complete analyses of failure risks caused by floods for all new structures and all existing installations. The extent of the analyses undertaken should be related to the consequences of dam failure. In particular

this concerns analyses of obstruction

situations and of failures in operation of mechanical flood regulating equipment.

It is of particular importance that revisions are undertaken for installations that are vulnerable to increases in flood-loads. This will primarily concern:

- \* Installations comprising tunnel/shaft in spillways.
- \* Installations comprising gated spillways.

### **Spillway Analysis**

A spillway analysis should comprise the following elements:

- \* Evaluation of capacity.
- \* Evaluation of erosion.
- \* Evaluation of obstruction.
- \* Evaluation of operational safety for mechanical flood regulating equipment

### **Tunnel/Shaft/Spillway**

Installations where the spillway is composed of a tunnel/shaft system beneath a fixed spillway or gate, are installations with less than the normal security reserves. Better standards of security than originally used when the installation was planned could now be introduced.

A re-evaluation of the capacity of such spillways should therefore be undertaken in connection with a flood safety assessment.

### **Obstruction of Spillways**

Blocking of spillways by debris is common in flood situations. Landslides from steep slopes can cause accumulation of large quantities of trees with roots and branches in the river system, and reference is made to what happened at Palagnedra Dam in Switzerland. Tales from

the large flood "Storofsen" in Norway in 1789 say that entire parts of valley sides with houses, forest etc. slid down and into the river Lågen.

There are also examples from Norway where snow- and rock-slides have blocked spillways.

Obstruction is one of the most important risk factors and leads to the reduction of the predicted capacity of the spillway and eventually to dam failure.

An obstruction assessment should form part of an assessment of the risk from of accident from exceptional loads, and the first step should be to evaluate the consequences of a complete obstruction.

### **Operational Safety of Gated Spillways**

There is always a possibility that the capacity of the spillway will be less than predicted because of operational failures.

A complete analysis of the capacity of gated spillways must therefore include assessments related to failures during operation.

The Project has undertaken examples of such analyses and these are presented in Report 6, sections I and II.

#### **The purpose of the analysis.**

A functions and safety analysis of a gated spillway will be a part of several processes.

##### **\* Emergency plans.**

The analysis could be included in the emergency strategy and serve as the basis for action planning in case of operational failures.

##### **\* Reserve capacities.**

The analysis can clarify how the reserve capacities of the installation can be improved.

\* Technical design, organization.

The analysis can serve as a basis for decisions on changes in technical design or for planning of actions in flood situations.

\* Safety evaluation.

The analysis can contribute to a better overall picture of total safety related to overtopping. The total probability of overtopping will in general consist of two factors:

- The probability of overtopping with all gates open.
- The probability of overtopping with different kinds of functional failures.

The analysis can point to the principal types of functional failures and indicate levels of probability.

\* Operational regularity of energy production.

Concern for dam safety is the basis of the Project and the reason behind the proposed analyses of functional safety. Such analyses, however, can also help reduce operational losses in economic terms.

### **Design of Analysis**

An analysis should be undertaken by the operational staff who know the particulars of the installation, in co-operation with the experts (external or internal) who can view the issues in question in a fresh light. Some help from personnel skilled in analytical methods may be desirable for larger evaluation tasks.

### **Leakage from Embankment Dams**

International statistics indicate that cracks or damage caused by leakage are responsible a significant share of the accidents/problems related to embankment dams.

Incidents of irregular leakage have also occurred at Norwegian dam installations, and the dam failure at Roppa in 1976 was caused by a leakage.

International statistics nevertheless seem to confirm that no large rock-fill dams have failed even when big leakages have occurred. The main reason for this is that the actual leakages have been limited in scale, and that downstream dam-toe was able to divert the leakage without becoming subject to instability.

International statistics show that failure has occurred in a number of earth-fill dams where the cause was considered to be internal erosion. In most cases the failure occurred during the initial inundation of the reservoir. But failures have also taken place after many years of operation, which clearly shows that internal erosion can also develop over a long time.

In Norway there is also a substantial number of smaller earth-fill dams in addition to rock-fill dams. These are particularly exposed to failure by leakage.

It is recommended that the owners undertake assessments of the security of all embankment dams for failure caused by leakage. Such assessments should be standard in the construction of new dams. Thought should also be given to carrying out assessments for existing dams.

#### **Systems for registration of leakages.**

The reporting of leakages in dams is important for the timely recording of abnormal conditions within the dam.

The dam owner must establish a system of recording which serves the necessary purpose. Embankment dams, the failure of which could have significant impactss should possess systems for automatic registration of leakages, permitting the remote transmission of records.

Embankment dams that have experienced large and sudden leakages should also have such an

automatic, remote transmission system for recording.

The dam owner's system for recording of leakages should consist of reporting and assessment routines as well as the purely technical setup for recording data.

### **Overtopping of Embankment Dams**

Dam failures due to overtopping are amongst the commonest type of dam failure in the world.

This type of failure is also of such a nature that the probability for it occurring does not reduce with the age of the dam.

Assessments of safety in embankment dams should therefore comprise analyses of the resistance of such dams against failure from overtopping (ultimate state). Such analyses may be undertaken in a number of situations:

- \* As an assessment of the extent to which a dam can support current risk loads without failure. Risk loads could for instance be water levels higher than design flood levels as a result of estimated maximum flood or obstruction of spillway.
- \* Assessment of the water level at which the dam will collapse constitutes part of the emergency planning.
- \* A risk evaluation of dams will also comprise an assessment of the failure limit (ultimate state) for dams.

Analyses of overtopping should be undertaken for all embankment dams in order to determine the water level the dam can support without failure.

### **Ageing of Concrete Dams**

The concept 'ageing of dams' indicates that dams undergo changes over the years. The dam structure and the foundations will be exposed to forces of disintegration, which also can

cause changes in loads. The disintegration process can be slow or rapid depending on the character of the concrete and the foundations and the impacts these are exposed to.

Age in itself gives no indication of a dam's condition and safety. This can only be determined through assessment of:

- \* The dam's condition and safety when it came into use.
- \* The forces of disintegration to which the dam has been exposed.
- \* The speed of these processes and how far they have gone.
- \* The importance of the forces of disintegration for the functioning and safety of the dam.

#### **Discovering hazardous ageing processes.**

It is essential that the dam-owner discovers hazardous development so as to be able to initiate measures to combat hazardous ageing processes.

This has to be done through an inspection programme set up by the dam-owner. Frequently this programme will be restricted to visual inspection. Closer examinations will only be undertaken when visual inspections lead one to suspect that hazardous disintegration forces are at work.

It is recommended that more systematic investigation into conditions in concrete dams be introduced. Neither must those elements of the structure lying submerged for years be neglected. Underwater inspection by divers or video-recorder should be elements in a total inspection programme.

In order to obtain a comprehensive overview, dam owners as a group should monitor developments in a selected sample of Norwegian concrete dams. They could do so in co-operation with the Water System Management Association (VR) and in collaboration with NVE-T, through a systematic, permanent investigation programme.

### **Landslides and Reservoirs**

The potential for slides into reservoirs or in the river basin behind will affect dam safety. This can be because of the destruction to the dam that waves from a slide can cause, or by malfunctioning of spillways caused by slide material or debris dumped into the river system.

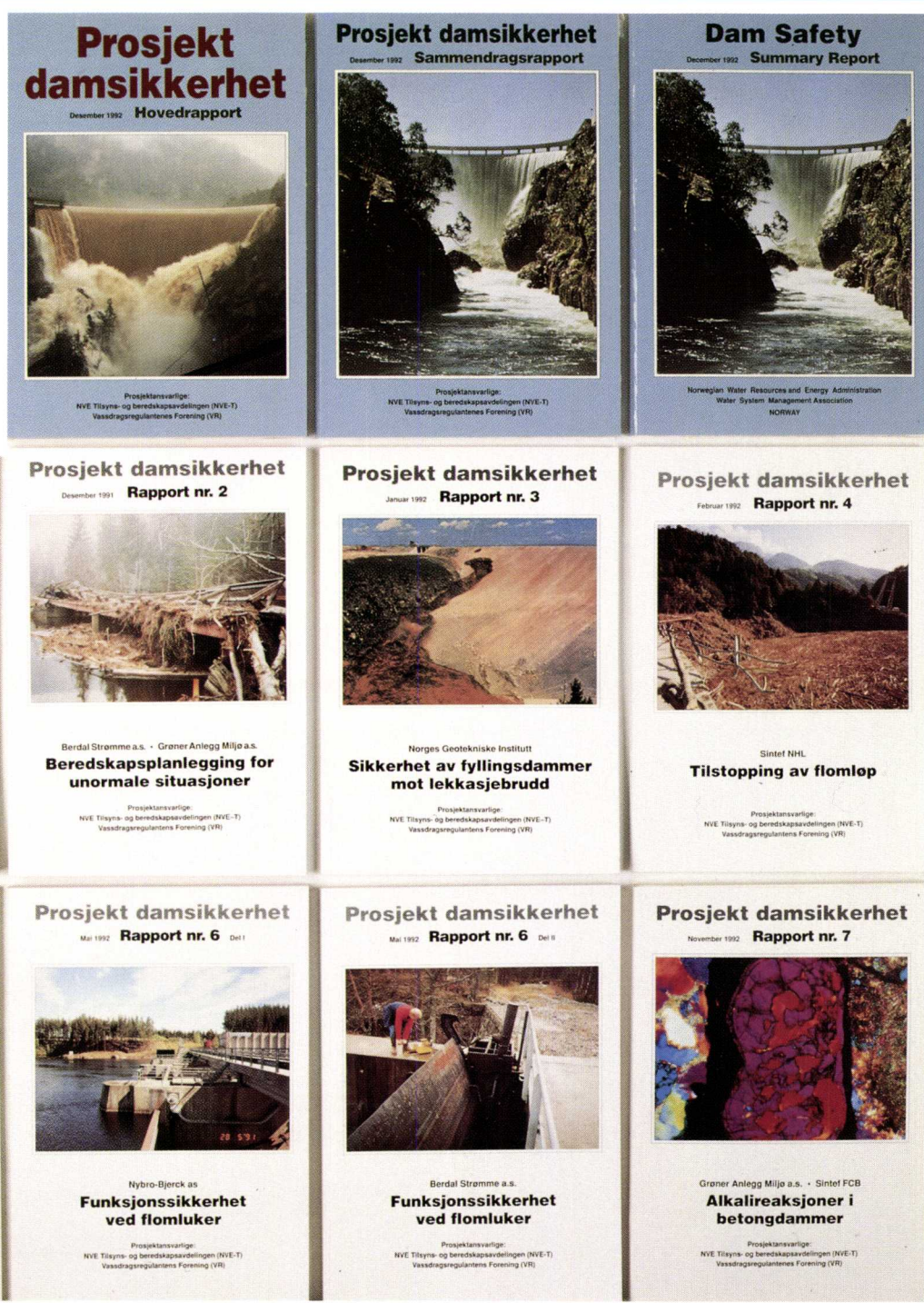
Loen and Tafjord are Norwegian examples of landslides which caused large waves. These slides could have caused dam failure with even greater destruction of life and property if they had slid into dammed reservoirs.

The slide of an entire mountainside into the reservoir of the Vajont dam in Italy is particularly well known. The dam withstood an 80 metres high wave over the crest, but some 2600 lives were nonetheless lost downstream.

The dam owner must assess the potential risk for slides while NVE-T (possibly in cooperation with dam owner's experts) draws the final conclusion on to what extent the dam must be able to withstand slides into the reservoir. Slides into the reservoir have to be considered as an exceptional load, so that dams where the consequences of failure are very great should be designed to sustain such extensive loads.



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