ICOLD EUROPEAN CLUB

European Working Group on "Management of Dam Incidents"

Preface

European ICOLD Working Group "Management of Dam Incidents" was established in Venice, Italy in April 2013. The objectives of the Working Group were to collect experiences and the best practices and improve the practices handling dam incidents.

The practices and legislation features were collected by sending questionnaire to European Club members on 15th of January 2015. Twelve (12) answers were received : Czech Republic, Finland, France, Great Britain (Wales), United Kingdom, Ireland, Italy, The Netherlands, Poland, Slovenia, Norway and Brazil.

The understanding of the subject was further discussed in the working group meeting in Helsinki, Finland on 25th and 26th of November 2015. The participants from Czech Republic, France, Sweden and Finland were attending the meeting. The report is work of several persons from different European countries. The report should be further developed, improved and updated, for instance the national incident data and case histories should be included in the report.

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1 Introduction

The dam owner's responsibility is to ensure safety in the construction, maintenance and operation of a dam and reduce the hazard and the consequences, which a dam incident or accident may cause. Dams are monitored and inspected in order to detect changes or abnormal behavior. The upgrading or the repair of dams can be carried out to improve the safety level and therefore lower the incident likelihood.

A dam incident may be caused e.g. by natural event (floods, landslides, earthquake), by aging of the dam foundation, by aging of the structure, by mechanical equipment dysfunction or by inadequate operational actions. The development time of a dam incident is variable, from days in case of floods in large river basins, to some hours in case of flash floods or minutes in case of an earthquake.

The seriousness of a dam incident, available time for and consequences of the dam failure as well the dam and the reservoir dimensions will have impact on which measures should be used. The crisis organization shall evaluate the alternative measures and their consequences. Are they some rapid repairs possible? What will be the safe water level in the reservoir? What will be consequences downstream, if the reservoir is emptied? Are there other tools to avoid accident and serious consequences for instance by opening side dam?

In case of a serious event the dam owner shall start the activities for the emergency repair. If the situation is critical the alarming of authorities, downstream residents, evacuations and rescue operations shall be started.

European ICOLD Working Group "Management of Dam Incidents" was established in Venice, Italy in April 2013 to study European dam safety practices and experiences to handle incidents. The study comprised the collection of the data on the dam safety legislation, the guidelines and the documentation related to the dam incidents, the training activities of dam incidents, the roles of the authorities and the dam owner, the safety arrangements practices and the analysis of the dam incidents and failures. The tailings dams are included in the scope.

The objectives of the Working Group are to collect experiences and the best practices and improve the practices handling dam incidents.

A draft questionnaire was sent for commenting on 11th of July 2014. The final questionnaire (Annex 1) was sent to European Club members on 15th of January 2015. Twelve (12) answers were received : Czech Republic, Finland, France, Great Britain (Wales), United Kingdom, Ireland, Italy, The Netherlands, Poland, Slovenia, Norway and Brazil.

Figure 1. **Participants of EWG meeting in Helsinki on 25th and 26th of November 2015: Jan Jandora, Patrick Le Delliou, Heli Nurmi, Michel Poupart, Anna Mayer, Miroslav Spano, Timo Maijala, Eija Isomäki and Juha Laasonen.**

A working group meeting was held in Helsinki, Finland on 25th and 26th of November 2015. The participants from Czech Republic, France, Sweden and Finland were attending to the meeting (Figure 1). The practices on the legislation, the emergency action, the roles of the authorities, training of the emergency situations and good practices were presented in the meeting. The draft content of the report was agreed in the meeting.

The terminology and the roles during the dam incidents are presented in Section 2 to understand the dam incidents. The results and findings of EWG Questionnaire are presented in Section 3. The entity "Management of Dam Incidents" is presented in separate and particular points in the dam safety legislation. The legislation itself varies a lot from one country to another, but the overall presentation of the management of dam incidents seems to be surprisingly similar. The studies on dam incidents are presented in Section 4.

Based on the national answers questionnaire and the discussions in the working group it was proposed to present "Management of dam incident" in two parts: the first part contains the measures to create conditions for manage the dam incident (Section 5.2) and the second part is the measures during the dam incident (Section 5.3). However the report shall be a live document, which is updated continuously.

2 Dam incidents and accidents

2.1 Discussion on incident terminology

2.1.1 Dam incident

An incident is an event that could lead to loss of, or disruption to, an organization's operations, services or functions. (Glossary of Terms, 2015). If not managed an incident can escalate into an emergency, crisis or a disaster. Incident management is therefore the process of limiting the potential disruption caused by such an event, followed by a return to task as usual.

A dam safety incident is an impending or actual sudden uncontrolled release or excessive controlled release of water from an impounding structure. The release may be caused by damage to or failure of the structure, flood conditions unrelated to failure, or any condition that may affect the safe operation of the dam. The release of water may or may not endanger human life, downstream property, or the operation of the structure. (Federal guidelines for dam safety, 2013)

In the work of the ICOLD Dam Safety Committee (Dam failure database) dam incidents are determined as follows: There are two types of incidents considered, which are failure (F) and accident (A). A failure is a catastrophic type of incident characterized by the sudden and uncontrolled release of impounded water. An accident is a lesser catastrophic type of incident defined by malfunction or abnormality outside the design assumptions and parameters which adversely affect a dam's primary function of impounding water. Such lesser degrees of incident can progressively lead to or heighten the risk of a catastrophic failure. They are, however, normally amenable to corrective action. Accidents related to safety appurtenant works (spillway, gates, bottom outlet) are included in the committee work.

One approach for the classification is presented by ICOLD: Dam failures (1995) and USCOLD: Lessons from Dam Incidents. USA-II (1988). The incidents have 4 classes: failures, accidents, damage during construction and major repairs. Each class has sub-classes.

- Failures *
  - F1 – A major failure of an operating dam which has involved complete abandonment of a dam.
  - F2 – A failure of an operating dam which at the time may been severe, but was of a nature and extend which permitted the damage to be successfully repaired and the dam again placed in operation.
- Accidents *
  - A1 - An accident to a dam which had been in operation for some time, but which was prevented from becoming a failure by immediate remedial work or operations, such as drawing down the pool.
  - A2 - An accident to a dam, observed during the initial filling of the reservoir, which caused immediate remedial measures, including such action as drawing down the water level and making repairs before placing the dam in operation.
  - A3 – An accident to a dam before it was placed in operation and before any water was impounded. Unusual settlement of a foundation, slumping and slides of the abutments, etc., after essential completion of the structure would be accidents of this type. It is not

intended to include the normal run of construction problems and movements which occur during construction operations.
    - A4 – Accidents or unusual problems encountered in the reservoir upstream of the dam which have occurred during operation of the project, but which have not caused failure or major accident to the dam structure.
- Damage during construction
    - DDC –Damage to partially constructed dam or to temporary structure required for construction prior to the dam being essentially completed. Failure of cofferdam or unplanned overtopping of partially completed dam are examples under this definition.
- Major repairs
    - MR – Extensive or important repairs to a dam that were required because of deterioration or to update certain features. Refacing of deteriorated concrete, repair of deteriorated riprap, or replacement of gages are examples under this definition.

With the exception of natural threats (floods, earthquakes, landslides..) most incidents appear with warning signs. If these signs are detected, there is often enough time to react and prevent the accident. In some cases there is very little reaction time for example in internal erosion.

2.1.2 Emergency action plan

In this document the emergency action plans refer to the plan developed by the dam owner. The emergency action plan is a plan of actions and measures to be taken in case of accidents and disturbances. The emergency action plan is mainly based on the results of the dam failure consequences (inundation maps). In many countries the emergency action plan is not required for all dams but for example only high consequence class dams only. The rescue service plan refers to the plan developed by the rescue authorities.

In some countries emergency action plans have different names like crisis management plans or calamity plans.

The purpose of an emergency action plan is to protect lives and reduce property damage. An emergency action plan presents the measures to be taken by the owner of the dam. The contents vary more or less from one country to another. The plan describes how to prevent accidents in case of disturbances as well as to prevent and limit damages at the dam. It presents how to protect humans, property and the environment against damage, and how to report an accident. The plan also presents the materials and equipment to be kept ready for urgent repairs or action in order to prevent an accident and the available staff. In addition, an emergency action plan for a tailing dam presents the type of the impounded substance, properties causing hazard, volume, contents and other special characteristics of the dam. Waste and tailings dams require plans for active measures to collect and process the impounded material in the event of a dam failure.

The emergency action plan may include: evaluation of the failure type and failure mode and modelling dam breach and flood wave propagation or these could be only included in hazard analysis. Definition of the hazard areas should be included as well as the contents of the hazard to human life, property and the environment. It should include instructions how to confirm the incident situation alert the authorities and

warn people, how to begin with emergency repair work. Organization in case of an emergency (persons in charge) and the roles are usually presented.

Emergency action plan should be updated every five year. This applies especially to such parts of the emergency action plan that are important when taking the rescue action, for example communications and warning. However the updating is not included in the legislation in all countries.

Emergency action plan gives also the basic information to rescue authority of the possible extend of the emergency. And it also helps them to develop the rescue service plan. The dam owner (operator) and the rescue authority will have their own emergency action plans.

2.1.3 Response units in a dam incident

Typical actors in a dam safety incident are the dam owner, dam operator, rescue authority/civil protection authority, dam safety authority and the police. Their roles in case of a dam incident vary.

In most countries the owner of the dam has the total responsibility of the dam. The dam owner develops and provides the emergency action plan in where he describes the actions to be taken in case of an incident or accident. The dam owner is responsible for notifying of the incident to the authorities. The dam owner's obligations during the incidents are variable. When the activities based on the emergency action plan are started the dam owner shall assist the rescue authority. The leading of the repair works may be the dam owner or the rescue authority depending on the situation and the legislation.

The rescue authority or the police will take the lead of the operations in the case of the emergency in most countries. The emergency may include the danger to the human life or the property.

The role of the dam operator during the dam incident is to regulate the inflow and outflow discharge and mitigate the consequences. Examples of duties may include opening spillway gates per a required sequence, opening or closing water intakes, as appropriate, or regulate the river discharge in the cascade. He should be familiar and trained to use of the emergency action plan. Instructions for the plant operations during the anticipated emergency should be provided.

Other actors in an emergency situation may be health authority, river authority and the army. Some country may have the governor of the province or mayor as the one in charge of the emergency situation. The various tasks and responsibilities of authorities and official establishments are primarily set out in the relevant law.

3 Results of EWG Questionnaire, 15th of January 2015 and findings during the European Group meeting on 25th and 26th of November 2015

3.1 General

The questionnaire on management of dam incidents was sent to European Club members on 15th of January 2015. Twelve (12) answers were received from Czech Republic, Finland, France, Great Britain (Wales), United Kingdom, Ireland, Italy, The Netherlands, Poland, Slovenia, Norway and Brazil.

The topics of the questionnaire were discussed in detail in the working meeting in Helsinki, Finland on 25th and 26th of November 2015. The findings of the discussions are included in this chapter.

3.2 European practices to handle dam incidents

3.2.1 General

The definition of a dam or hydraulic structure in the legislation is variable in different countries. In many countries the dams are classified based on the hazard they pose in case of the dam failure. If the consequences of a small dam are considered negligible, then they are excluded from the dam safety legislation in some countries. The definition of small dam may be different to ICOLD definition as well.

Table 1. Dam classification criteria in European countries and in Brazil.

	Dam classification according to				Remarks
	Geometric criteria		Failure consequences		
	yes	no	yes	no	
Austria	x			x	
Bulgaria	x		x		
Czech Republic	x(s)		x		(s) distinguished small and large dams
Finland		x	x		
France	x			x	
Germany	x			x	
Great Britain (England, Wales)		x	x		
Greece	x			x	
Iceland		x	x		
Ireland		x	x		
Italy	x			x	
Netherlands		x		x	
Norway		x	x		
Poland	x		x		
Portugal	x		x		
Romania	x		x		
Scotland		x	x		
Serbia	x		(x)		
Slovakia	x		x		
Slovenia	x		(x)		
Spain	x		x		
Sweden		x	x		
Switzerland	x		x		
Turkey	x		x		
Ukraine		x	x		
Brazil	x		x		Brazil's answer to the Questionnaire

In France, total number of the dams according to ICOLD definition is 500 and 2/3 of them are dams for hydropower. Most of the dams are more than 60 years old. Decree of the safety of dams specifies the general requirements for owners but does not set detailed technical rules. The consultant firms in France must be certified. The dam classification is based on the height and the reservoir volume. The authority can change the class, if there are important stakes downstream the dam.

The dam safety legislation in Czech Republic (CR) is guided by the Building Act, Water Act and Methodical Guides. The water retaining structures (water structures) are for instance the embankment (dam) higher than 1 meter and the reservoir volume more than 1 000 m^3. Military zones are totally separated to others. There are about 20 thousands of water structures divided into four categories in the CR. Categories are related to consequences of dam failure. Each water structure has to be supervised in range and periods defined by a dam safety decree. Demands to the dam reliability are also defined by a decree.

The Environmental Act and the Dam Safety Decree (2014) form the dam safety legislation in Sweden. In Sweden there are about 10 000 dams and about 200 are classified as high consequence dams. Consequence analyses prepared by the dam owners form the basis for the county administrative boards' decisions about dam safety classes. County administrative boards supervise dam safety. Municipalities (the rescue authorities) have large responsibilities during critical incidents.

There are approximately 4000 registered dams in Norway. 500 of these 4000 are classified as high consequence dams (classes 3 and 4). There is no separate dam safety act in Norway, but acts concerning the development of water resources and hydropower have included requirements about safety and supervision of dams for more than 100 years. Most important requirements with respect to dam safety are given in the Dam Safety Regulations issued in 2009 with legal basis in the Water Resources Act of 2000. Requirements for dam safety management systems are given in the Regulation for Internal Control issued in 2011.

Finnish dam safety is in the Dam Safety Act (2009), Dam Safety Decree (2010) and Dam Safety Guide (2012). The legislation is quite comprehensive and any revision is not scheduled. In case of an emergency, rescue authority take the lead, if human life is in endanger. In Finland, there are 441 classified dams according to the Dam Safety Act 2009. 120 of these classified dams are tailings dams or waste lagoons. The Dam Safety Information system includes information of all classified dams in Finland.

3.2.2 Dam safety authority

Almost every country that answered to the questionnaire has a dam safety authority. The dam safety authority controls the fulfilment on requirements and guides the owners of dams. In UK the dam safety is handled by a supervising and inspecting engineer.

The liability of the dam safety authority is varying. It seems that in Italy, the authority has larger liability of dams and in Slovenia there are three different bodies that supervise dam safety. Most dam safety authorities can issue guidelines, though not in Poland, Italy or Slovenia.

The same authority supervising watercourse dams, is supervising tailings dams also in Finland, Czech Republic and Norway. The legislation is same as well.

3.2.3 Methods to manage incidents through legislation

The instructions for the design and the construction of a dams is included in legislations (act, decree of technical framework) in all other countries except in UK (and Brazil). Classification of a dam, and obligation to keep the dam in a good condition are included into legislation in all countries.

The requirements for the monitoring and the inspections of a dam and the dam break hazard analysis are included into legislation in all countries. These vary from country to another as well. Emergency action plan lack from the legislation in UK and safety arrangements in Italy.

In most countries the dam owner has an obligation to inform about exceptional situations. In Poland informing is merely related to accidents (catastrophe). In the Netherlands the authority has to inform actual and expected problems.

A database of incidents has been created in Finland, France, the UK, Norway. It is thought to be created in The Netherlands (and Brazil).

The development phase of the dam safety legislation is variable. New legislation is under implementation in Sweden. In Wales (UK) the Reservoirs section of the Flood and Water Management Act has only been implemented and therefore new guidance will become soon. (Situation is quite same in Brazil.) In Poland it is necessary to introduce regulation and guidelines for performing controls of the technical and safety state. In Slovenia the legislation is scattered and there is an attempt to fix it. Most countries are pleased with the comprehensiveness of their legislation. However some minor modifications to the legislation are expected to be done.

3.2.4 Emergency Action

Emergency action plans are done in all countries. Some countries prepare the plans only for bigger dams and some do them only if the dam belongs to the high consequence class (based on the hazard). For example in Finland the emergency action plans are required for all consequence class 1 dams.

The content of the emergency action plan was quite the similar in all countries:

- list of contacts and responsibilities,
- list of possible failure scenarios,
- evaluation of the failure type and failure mode,
- modelling dam breach and flood wave propagation,
- defining hazard areas and hazard to human life, property and the environment,
- confirming the incident situation and giving an alarm,
- emergency repair work,
- organization in an emergency (persons in charge),
- securing the equipment and repair material,
- roles of dam safety authority and rescue authority in an emergency.

In most countries the responsibility of the dam owner was the very same:

- keep the dam safe,
- prepare the emergency action plan,

- alert the authority and warn the public and
- assist rescue authority (or other in charge).

Usually the dam owner will prepare the emergency action plan. In France the authority develops the emergency action based on the input from the owner (inundation map,..). In Italy civil protection document is prepared by the dam authority and the emergency action plan is set up by the civil protection authority.

The approval procedure of the emergency action plan is variable.

The emergency action plans in Czech Republic include 3 danger levels. The alarm and critical limits are specified based on the surveillance. In France an emergency action plans are mandatory for dams that are higher than 20 m and have a volume bigger than 15 hm^3. The documents are updated and training is held periodically.

For the large regulated rivers in Sweden the county administrative boards prepare regional plans for dam failures. The county administrative boards have exercises to train the coordination between responsible actors. The dam owners have responsibility for the exercises and testing their own emergency action plans.

When thinking of the emergency action plan, training the personnel for the emergency plays a huge role. Personnel must know the procedures set out in the emergency action plan. Emergency situations can be rapid and unexpected and therefore there might not be time to search and read the right measures during the situation.

3.2.5 The roles of the authorities and rescue situations

The responsibilities when preventing an incident and during an accident are clearly defined in Finland, Czech, France, Poland, the Netherlands, Italy and Norway.

The assistance of “rescue authorities” in planning rescue operations is determined properly in all countries.

The person, who is leading the operations in a dam safety emergency, varies from country to another. The leader of the operation can be the rescue authority, the head of the regional water authority, the authority in charge of the crisis management, the police, the governor/mayor, the civil protection authority, the county administration…

The role of the dam safety authority in an emergency situation is very similar in most countries. The dam safety authority has a role in the preparation of the emergency plans, but in a real situation he co-ordinates and assists, if needed.

3.2.6 Training of the emergency situations

Training to a dam safety accident is defined in the legislation in Finland (dam safety guideline), France (decree – every five years), the Netherlands (Act – every 4 years), Norway and Slovenia (and Brazil). Almost all countries have had exercises, excluding Poland (and the light exercises has been done in Brazil). In Sweden a guide for dam owner’s exercises and training of emergency situations has been prepared (energiforskmedia.blob.core.windows.net).

The co-operation during the dam incident can be tested and improved in the training of the emergency situation. For example in Finland there was a training of a high hazard levee arranged in 2014. The

participants in the training were rescue authority, dam owner, dam safety authority, authority responsible for the management of water resources and Finnish Environment Institute. Other parties like the police, communication division of the city and the road office were partially participated in the training. Main issues in the training were total management and rescue operations, the actions at the dam site and in the flood situation by the dam owner, and the management of the river and water system by the authority in charge. The field exercise and a desk study was arranged. Finnish environment institute prepared a flood forecast for the training event. The dam monitoring was not simulated. The training case was a dam leakage and the dam repair. As a conclusion of the training was that the co-operation and the roles between the participants were functioning well and the communications were successful. The videoconference communication was working fluently too. Everybody had a good attitude during the event.

The flash floods are a real problem in the Czech Republic and the training for floods is an important issue. The speed and volume of the flash floods that have already happened, has been unbelievable.

The exercises of the dam incidents have been found useful. They improve organizations and raise awareness. Something new is learned. The responsible person for the planning the exercise varies a lot from different authorities to dam owners - as do the participants in the exercise.

3.2.7 Good practices

It is important that the dam documentation is available and easily accessed during the dam incident. The storing of the dam safety documentation is set in the regulation in Finland, France, Italy, Norway and Poland. In the Netherlands documents are stored by the dam owner as well. In Slovenia it is important to document all the structural changes. In Czech Republic and UK there are no specified requirements for storing documents but the usual practice is to store documents on site.

The monitoring program for a dam is prepared in all countries. The requirements for dam monitoring are variable. The requirements in some countries are set based on the dam class like in UK. Some countries have set a framework on the objects that must be monitored.

The periodic dam safety inspection is considered more detailed dam safety inspection, where the documentation and data is analyzed. It may also include site investigations, if needed. The periodic inspection are carried out in every country. The periodic inspection is considered more through than annual inspection. However the period between the inspections is different in each country. The periodic inspections are arranged from five years to every 12 years. In most cases dam owners are responsible for the organizing the inspection. The dam safety authority is responsible of the inspection in Italy and independent inspecting engineer in UK. The annual inspections are arranged, if the interval between periodic inspections is long.

The high availability of the maintenance and operation personnel (24/7: 24 hours in a day and 7 days in a week) is set as a requirement In Czech Republic, Italy, the Netherlands, Slovenia and UK.

European databases on incidents has been created in Finland, France, UK, Norway and it should be created in The Netherlands (and Brazil). Database is public only in France and partly in UK and Norway. Incidents in tailings dams are included in the database in Finland, France, Poland and Norway. Finland and Norway publish a summary of the incidents in the internet yearly.

3.2.8 Measures to control adverse conditions

The main hazard in many countries is the flood situation, also at sea areas. In Nordic countries the ice (formation of frazil ice, ice jams and dams) increases the variety of the hazard. The dam owners are prepared for the gate operation by carrying out maintenance before the flood and winter period.

In France the measures to control adverse natural conditions (ice formation, landslides, earthquakes, flooding and rain) are hydrological (rain and snow) and hydraulic forecasts, visual inspection, dam surveillance and confirming the design condition, risk analysis.

In other countries measures contain hydrological monitoring (Czech, Slovenia, Brazil), water levels (the Netherlands) and hydrological monitoring + ice monitoring (Finland).

Norway has a national service for flood, land slide and avalanche warning based on a national grid of gauging stations and weather forecasts. The service is run by NVE in cooperation with other national state services such as the meteorological institute. In addition, many dam owners have their own forecasting models, based on local gauging stations. Dam owners are in general obliged to have a surveillance programme and instrumentation of different relevant parameters in order to detect any development of undesired events (deformations/damages to dams, floods, ice-jams, landslides etc.) as early as possible to avoid emergencies to develop

In Czech the hydrological monitoring is assured by Czech Hydro meteorological Institute. Experiences from last couple years is that the flooding may occur extremely fast. Therefore, the reaction must be fast. One of key measures is to ensure access to site for operating personnel who continuously monitor the situation and provide relevant information to crisis center and who is trained to operate by his own in case of loss of connection. Here, the access across valley my not be possible in case of flood situation. Also, a loss of power is quite often at such situation. Therefore, the back-up power station should be on site to be able to:

- ensure operation of gates and valves (manual operation is usually possible but not effective in case of rapid flood situation),
- gain data from monitoring system,
- recharge batteries of cell phones and laptops.

It is also important to have an independent heater on site.

Executive group for flood protection has been defined for all major flood-prone water systems (some dam owners are included) in Finland. Executive group may e.g. decide to slow the flow in river so that the ice cover would form, which prevents the formation of frazil ice. The flood situation is forecasted and monitored at Flood Centre (Finnish Environment Institute & The Finnish Meteorological Institute). Information is available to everybody at their web site.

National hydrometric networks in France are publicly operated by state agency or private and owned by some large companies. They are providing a real time data about rainfall and river flows, and through these data analysis specialized teams then issue rainfall and discharge forecasts. This information is used by operators for warning and anticipation. But the rule is to rely only on the measured data to operate the gates (using flood procedures, as already mentioned) and not on forecasted one.

3.2.9 Measures to control adverse situations (success stories)

Typical incident in the watercourse dam was overtopping or internal erosion.

There were only three answers of the typical accident in the tailings dam. In Finland these were piping, uncontrolled seepage and damage on dam structure, in the UK the erosion and in Slovenia landslides, leaking of substances to groundwater.

In France, UK, Norway and Slovenia the accidents are classified according to the severity.

There are several success stories from Czech Republic. Accidents have been prevented for example by improvement of the core permeability, reduction of the uplift, enhancement of reliability of appurtenant works and enhancement of spillway capacity.

There are other ways to control adverse situations as well. The written instructions are to secure the normal operation as well as the flood situation for all dams. The public safety has improved a lot during the past years. The user's information has been prepared: standard signs, specialized signs, surveillance and personal information.

4 Studies on dam incidents

Public information on the dam incidents are for large dam incidents by ICOLD (Bulletins 99, 109, 120), the dam incidents in the United States by USCOLD and the dam incidents in the UK by Defra. ICOLD bulletins address only dams responding to the ICOLD definition of “large” dams (height > 15 m, etc.). USCOLD, DEFRA and other databases or reports cover a larger scope with sometimes very small dams. This should be beared in mind when comparing figures given in the sections below.

Some European countries are collecting the documentation on the dam incidents and the information has been gathered in public database. Importance of database and incident documentation rises up when there is a need to learn and increase knowledge of handling dam incidents.

4.1 Bulletin 99 Dam failures. Statistical analysis

ICOLD's bulletin 99 "Dam failures - Statistical analysis", 1995, is based on the 176 cases of international dam failures. The Bulletin includes 25 European dam incident cases.

One finding of the data study was that the failure rate has decreased in the dams constructed before (2.2 per cent) and after 1950 (0.5 per cent). The highest failure rate was found in the dams built 1910-1920.

The failures of the embankment dams cover almost 80 % of the accidents and the remaining 20 % are referred concrete dams. The primary cause for the embankment dam failure is overtopping (Table 2).

Most failures have occurred for the newly-built dams (less than ten years). 70 % of the failures were during the first ten years after the commissioning and 45 % during the first year.

The most frequent cause of failure is overtopping, which constitutes 36 % of the failures (24 % of the concrete dam failures and 50 % of embankment dam failures).

The foundation problems (shear strength, internal erosion) were the primary cause for the concrete dam failure (9 primary causes out of 15). The overtopping was the second largest (4 out of 15 cases).

Table 2. The causes of the embankment dams failures.

	Primary cause	Secondary cause
overtopping	31 %	18 %
internal erosion of dam body	15 %	13 %
internal erosion in foundation	12 %	5 %

4.2 USCOLD, 1988. Lessons from Dam Incidents, USA-II

USCOLD's Subcommittee on Dam Incidents and Accidents has studied the dam failures in USA. The first volume of publication was released in 1975 and it was updated in 1988. Over 500 dam incidents were studied in the report.

According to the report it has occurred 62 major failures (F1), which have led to the abandonment of the dam. Overtopping was the cause of 41,9 % of the failures. The total amount was 48,4 % of the failures, when the spillway problems were taken into account. The piping (internal erosion) was the second largest problem 25,8 %.

The number of severe incidents (F1, F2, A1, not the types of construction period) has been 229. Overtopping and spillway problems correspond 38 % of the incidents and piping approximately 20 %.

The results of the study are presented in Table 3 and Table 4.

Table 3. Incident types per cause (USCOLD, 1988).

Incident type	Foundation	Structural	Spillway	Overtopping	Piping	Sliding	Unknown	Total
F1	2	9	4	26	16	2	3	**62**
F2	3	4	12	23	10	7	4	**63**
A1	13	29	16	6	20	12	8	**104**
A2	4	3	1	0	4	0	3	**15**
A3	0	2	1	0	0	3	0	**6**
A4	2	0	1	0	0	3	3	**9**
MR	22	96	73	1	7	6	12	**217**
DOC	6	4	1	18	3	6	2	**40**
Total	**52**	**147**	**109**	**74**	**60**	**39**	**35**	**516**

Table 4. Percentages of the severe incidents (not the incidents of the construction period).

Incident type	Foundation	Structural	Spillway	Overtopping	Piping	Sliding	Unknown	Total
F1	3,2 %	14,5 %	6,5 %	41,9 %	25,8 %	3,2 %	4,9 %	100 %
F1,F2,A1	7,9 %	18,3 %	14,0 %	24,0 %	20,1 %	9,2 %	6,5 %	100 %

4.2.1 National Dams database (NDD) for UK, Defra, 2002

There are approximately 2700 dams in UK (from which 112 are British Waterways dams). The embankment dams are largest part, approximately 2100 dams. The dam incidents are collected in the database. The incidents for the embankment dams older than 5 years are presented in Table 5 and Table 6. The internal erosion was the main reason for the failures and serious incidents (58,3 %).

Table 5. The embankment dam incidents (dams older than 5 years) in UK.

Level	Description	Pre-1975	Post 1975
1	Failure	13	0
2	Serious incident (emergency drawdown)	58	13
3	Concern leading works	184	91
4	Concern leading to involvement by Inspecting Engineer	107	55
Total		362	159

Table 6. The cause of the incident for the two highest levels. The incident after 1975 are presented inside the brackets.

Failure mode	Failure (Level 1)	Serious incident (Level 2)	Total
Overtopping	7	12 (0)	19 (22,6 %)
Wave overtopping	0	3 (2)	3 (3,6 %)
Internal erosion	6	43 (7)	49 (58,3 %)
Slope instability	0	11 (3)	11 (13,1 %)
Appurtenant works	0	2 (1)	2 (2,4 %)
Total	**13**	**71 (13)**	**84 (100 %)**

4.3 Typical dam incidents in Europe based on EWG Questionnaire

According to the questionnaire there are many different kind of incidents in different European countries. In many countries the natural conditions form a considerable alternative as a common incident. For example in northern countries it may be rain and ice and in southern countries it may be earthquakes.

In Czech the common dam incident types are local defects on dam sealing (cores, lining), seepage defects (internal erosion), minor defects on mechanical parts of appurtenant works (valves, gates), local slope instabilities, at small dams some overtopping and internal erosion.

Most common incident types in Finland are the water above normal high level, the power failure and internal erosion. With tailings dams the most common incident types are internal erosion, uncontrolled seepage flow and damage on dam structure. Internal erosion has created quite a few close calls in Finland. Repair works have been made to prevent the accident.

Figure 2. **Dam safety incidents in Finland 1984-2015. (www.ymparisto.fi)**

In UK overtopping of small dams due to inadequate overflow facilities is the most common incident type. Internal erosion where dams have been raised at the interface of the new and old dam cores is common too. With tailings dams the most common incident type is the erosion.

In Norway the statistics is unavailable, but from known cases, the typical incident is damage during or after flood, and sometimes dam failures on smaller dams due to insufficient spillway capacity/freeboard. Some run-of-river dams have had problems with gate operation during floods (triggered by debris, lack of power etc), and some large embankment dams have had piping and sudden leakages. The embankment dams have mostly healed themselves, probably due to the standard design of Norwegian zoned rock fill dams. This design is a result of long-term experiences, technological development and favorable conditions (solid rock foundations and availability of good fill material).

The most typical dam incidents in Slovenia are malfunctioning of the gates, risk of overtopping and internal erosion. With tailings dams Landslides and leaking of different hazardous substances into groundwater.

In Ireland typical dam incidents relate to gate malfunctions, primarily during test operations and loss of communications. Others relate to seepages at embankment dams. With tailings dams probably typical issues relate to seepage and inadequate freeboard.

5 Approach to Management of Dam Incidents

5.1 General

The entity "Management of Dam Incidents" is presented in separate and particular points in the dam safety legislation. The legislation itself varies a lot from one country to another, but the overall presentation of the management of dam incidents seems to be surprisingly similar. One general shortcoming in the dam safety legislation is the missing requirement for the establishing the database for the dam incidents (notification of the dam incidents, collection of the dam incident documentation, open database).

Based on the answers of the questionnaire and the discussion in the working group it was decided to present Management of dam incidents in two parts. First part contains the measures to create conditions to manage the dam incident. This part contains the regulations in the legislation, introducing the good practices. The principles are presented in section 5.2 "Preparation to handle incident". The second part presents the measures during the dam incident are presented in section 5.3 "Dam incident handling". The case histories are included in the section.

The dam incidents may include different kind of situations and events from small device failures all to way to serious dam incidents, which in worst case may lead to a dam failure. The surveillance and analysis of the monitoring data may reveal the initiation of a failure mode, which can lead to the dam incident. The dam repair in this case can be designed and carry out before the actual dam incident occurs. Such a dam repairs are not discussed in section 5.3. The case studies are concentrated mainly in the cases, where the dam incident is acute and is considered serious.

5.2 Preparation to “handle” incident

5.2.1 General

This section describes the preparatory work, which is needed to establish base for handling the dam incident.

The purpose of the measures presented in this section shall provide safe operation of a dam and also early detection of possible dam incident.

Common experiences in the dam legislations and good practices are collected and presented in this Section.

5.2.2 Legislative background for the Management of the dam incidents

The base for the Management of the dam incident is the requirements in the legislation. Basic compulsory requirements are the safe design, construction, maintenance and operation.

The dam safety legislation shall have requirements for dam monitoring and inspections. The monitoring program shall be based on the dam condition and it should be preferably set individually for all dams. The one who prepares the monitoring program must have a good knowledge of the dam. Also the one who monitors the dam must know what he is doing and why. The monitoring data shall be analysed periodically and alarm limits shall be set.

The periodical inspections shall be carried out regularly. The monitoring data shall be evaluated and analysed. The visual inspection is carried out after the data analysis. The findings of the visual inspection, data analysis and its interpretation as well the dam deficiencies are presented in the inspection report. The inspection report shall contain an evaluation of the dam condition and the recommendations for the dam. Annual inspections shall be supplement for the periodical dam inspections.

The instructions for preparation of the emergency action plan shall be given in the dam safety legislation. The document will give understanding of critical dam failure modes and their consequences, how the rescue operations shall be planned, how the repair actions and the organizations are planned, etc. The approval of the emergency action plan shall be determined in the legislation. As well as the preparation there must be precise instructions on how to keep the emergency action plan up-to-date.

The dam safety legislation shall include the notification of the dam incident to the authority. Authority should collect all dam incidents in to an open data base. Knowledge is key to understanding and the ability to be prepared. Some dam owners are not willing to share their problems. Then the solution may be created by anonymous descriptions.

For the management of dam incidents primary suitable start arises from the legislation. The responsibilities shall be clearly defined:

- The dam owner shall be responsible for safe maintenance and operation of the dam.
- The dam owner must be obligated to assist the rescue authority (or other person in charge) during the dam incident.
- The dam safety shall be controlled and supervised in the manner that the dam safety requirements are fulfilled. The dam safety authority shall be appointed for acting person. Same authority can be responsible for tailings dams as well.
- The rescue authority must have sufficient knowledge of dam safety. His duties and authorities must be clearly defined.
- The roles during the dam incident shall be clearly defined. The practice, who leads the operation, is compulsory.

5.2.3 Good practices

The good practices, which make the dam incident handling easier, are the availability of the dam documentation, procedures of handling of dam incidents, skillful personnel, reliable spillway and emergency gates, use of public safety and training on dam safety.

The dam documentation shall be available and easily accessed during the dam incident. Information system in the internet makes monitoring and inspections easier. The communication is easier as same documents are shared and can be read by several persons at the same time. Dam safety database with good access for all necessary people is a helpful tool into incident management. Updating the database is important for the usefulness. The database should include relevant information of the dam, its maintenance, the hazard and the emergency actions. The information should be available for the dam owner, rescue authority, dam safety authority and others involved with the procedures in the country.

In an emergency situation internet based system might not work and therefore paper copies (dam safety files) must be available as well. Information system and dam safety files must be kept up-to-date.

The detection of incident is crucial issue for handling dam incident. There shall be a procedure for handling incidents. For instance a notice of the dam incident or abnormal change in the monitoring result shall be verified and evaluated. The emergency group may be formed and the actions will be selected based on the criticality of the incident: warning, alarming and evacuation. The criterions for notifying the dam safety authority shall be established. The operating personnel must have adequate knowledge when to inform about the results of the monitoring.

The skillful staff and operating personnel should be ensured by training to emergency situations. When thinking of the emergency action plan, training the personnel for the emergency plays a huge role. The personnel must know the procedures set out in the emergency action plan. The emergency situations can be rapid and unexpected. Therefore there might not be time to search and read the right measures during the situation. Training can be done as field exercises and as in desk study. Both are good and both improve the ability of the actors to play their role correctly in a real situation. Training may reveal dark spots in an emergency planning and generate improvements.

Reliable and safe operations of the spillway gates is crucial issue. The hoisting system of the gate shall be maintained before the flood and the winter conditions. The manual and automatic operations shall be tested. The functionality of the heating system shall be proved. The maintenance and operational personnel shall be accessible during the flood situations. The written instructions are required for normal operation and in case of flood for every dams.

The requirement to provide a bottom outlet with large reservoir and high consequence dams may be advisable. The need for the bottom outlet shall be evaluated with risk analysis. The bottom outlet is only way to lower the reservoir elevation and also the risk of failure and its consequences. However for very big reservoirs it is sometimes not practicable. Then the design must provide possibility to perform repair works, sometimes very important, very quickly. It means providing access galleries with sufficient sizes for grouting or drainage equipment, having in place specific agreement with contractors to intervene very quickly on the dam, stocking materials and spare part, etc.

The public safety has improved during the past years. The user's information has been prepared: standard signs, specialized signs and surveillance. The sharing of the information has increased. People are more informed and more alert.

5.3 Dam incident handling

5.3.1 Detection of incidents

The dam safety inspection together with the analysis of the monitoring data may detect the development of a dam incident. The data may show abnormal reading or trend. The repair works and upgrading the safety should then be planned and executed in due time.

The dam incident may occur without warning, if the dam surveillance and monitoring are not carried professional way. For instance the development of internal erosion will take time and the signs may be noticed beforehand. The surveillance personnel at the dam site may detect the dam incident or automated

monitoring data will show abnormal values in the instrument readings. The notice of the dam incident or abnormal change in the monitoring result shall be verified and evaluated. The emergency group may be formed and the actions will be selected based on the criticality of the incident: warning, alarming and evacuation. The criterions for notifying the dam safety authority shall be established.

The dam owner shall start emergency repair. The alarming, evacuations and rescue operations shall be initiated, if the situation is critical (Figure 2).

There are different types of the incidents. The seriousness of the incident varies. The notification of the incident can come from different sources: the maintenance personnel, the dam inspector, passer-by etc. The information of the notification shall be handled, also confirmed in some cases and distributed to the responsible persons and to authorities. Therefore there shall be instructions and procedures for handling dam incident information.

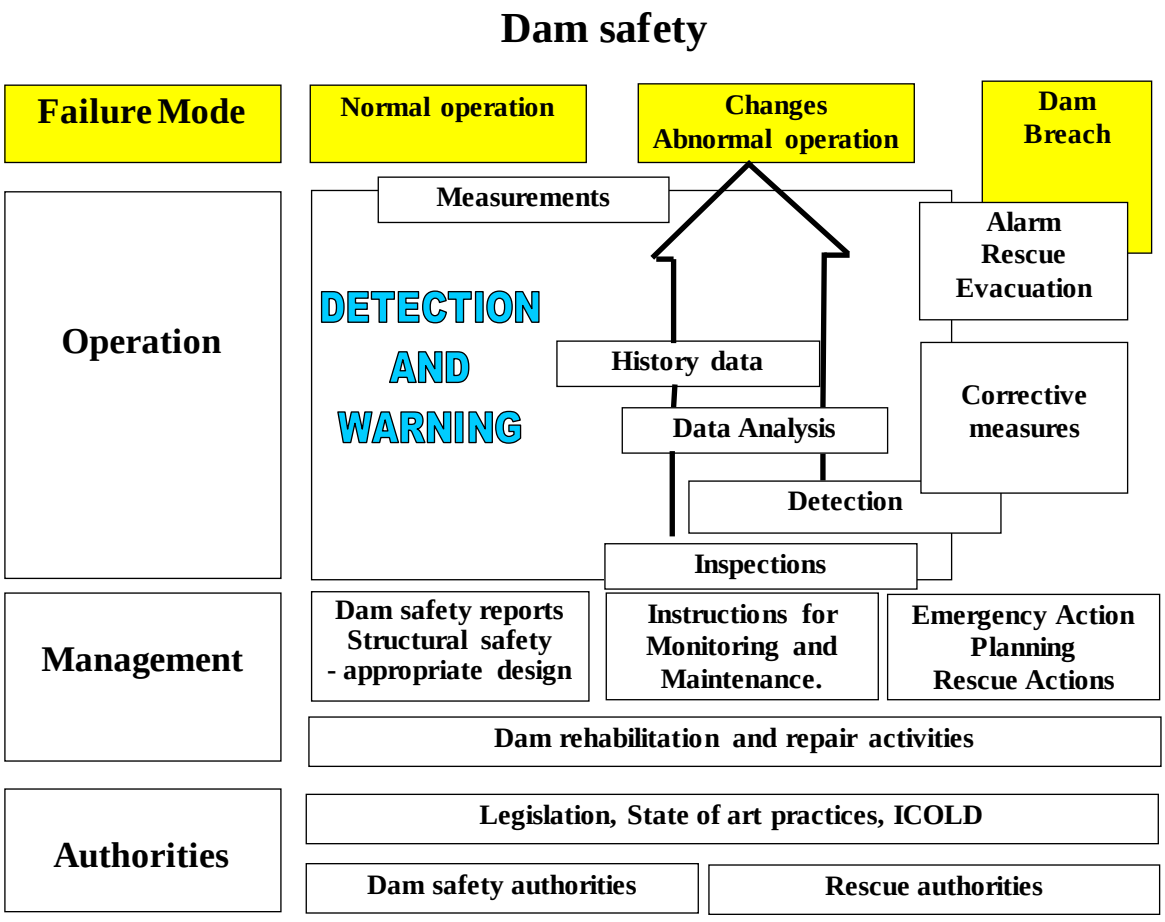

Figure 2. Dam safety process (Laasonen, 2014).

5.4 Construction measures/actions during the dam incident

Analysis may show a need for urgent repair works during an emergency. In such cases, it is possible to plan for such actions in order to do the necessary improvement works in due time, before the situation gets out

of control. The analysis may reveal what actions to plan for, and type of resources that may be needed (material, machines, personnel).

The actions/construction measures needed during an incident at an embankment dam may be, for example:

- construction of reverse filter
- filling the material in the dam
- emergency grouting.

5.5 Operating measures

The operating measures may be:

- draw down the reservoir
- reducing inflow to the reservoir (closing transfer canals into the reservoir/catchment, reducing or closing the outflow of upstream power stations).

The operating measures may require analyzing the situation and choosing measure from different alternatives. An example is a lightning strike to 10 kV causing a power failure in the city of Imatra in Finland. Five units out of seven were shutdown. The operator reduced the discharge at upstream hydropower plant from 550 m^3/s to 250 m^3/s. The operating personnel had two alternatives: start the units with DC-power or open the spillway gates with DC. It was decided to start the units.

5.6 Examples

Examples of incidents and repairs can be found in ICOLD-publications (congress-papers), technical journals etc. Here are some examples which were discussed during this work.

Repair of Bystricka masonry dam (height 27.4 m) in Czech, constructed in 1908-1912

Following deficiencies were found:

- deterioration and separation of the masonry face (cracks, degradation of joint mortar).
- increased seepage through the dam body and the foundation.
- loss of anchor capacity.
- limited operation capability due to the low capacity of the bottom outlets and
- critical situation during the 1997 flood.

The repair works included:

- renovation of masonry face,
- construction of new grouting gallery and grouting curtain,
- increased diameter to the bottom outlet and
- upgrading of the surveillance.

Figure 3. Bystricka masonry dam after the reapair.

Refurbishment of Plats dam, France (Hoonakker et al. 2013.).

The concrete arch dam was constructed in 1958. The pendulums showed abnormal behavior (upstream jamming on the Right Bank) in Summer 2003. The reservoir was drawdown for the inspection in 2005. Emergency measures started in the beginning of 2006.

The conclusions in 2006 were:

- The arch is very thin.
- The concrete has cut at the base (cracks through dam body).
- The phenomena has been irreversible.
- Important tensile stresses.
- High piezometric head at the downstream toe.

Figure 4. **Plats dam during the drawdown.**

The dam was strengthened by changing the arch dam to a gravity dam (RCC dam).

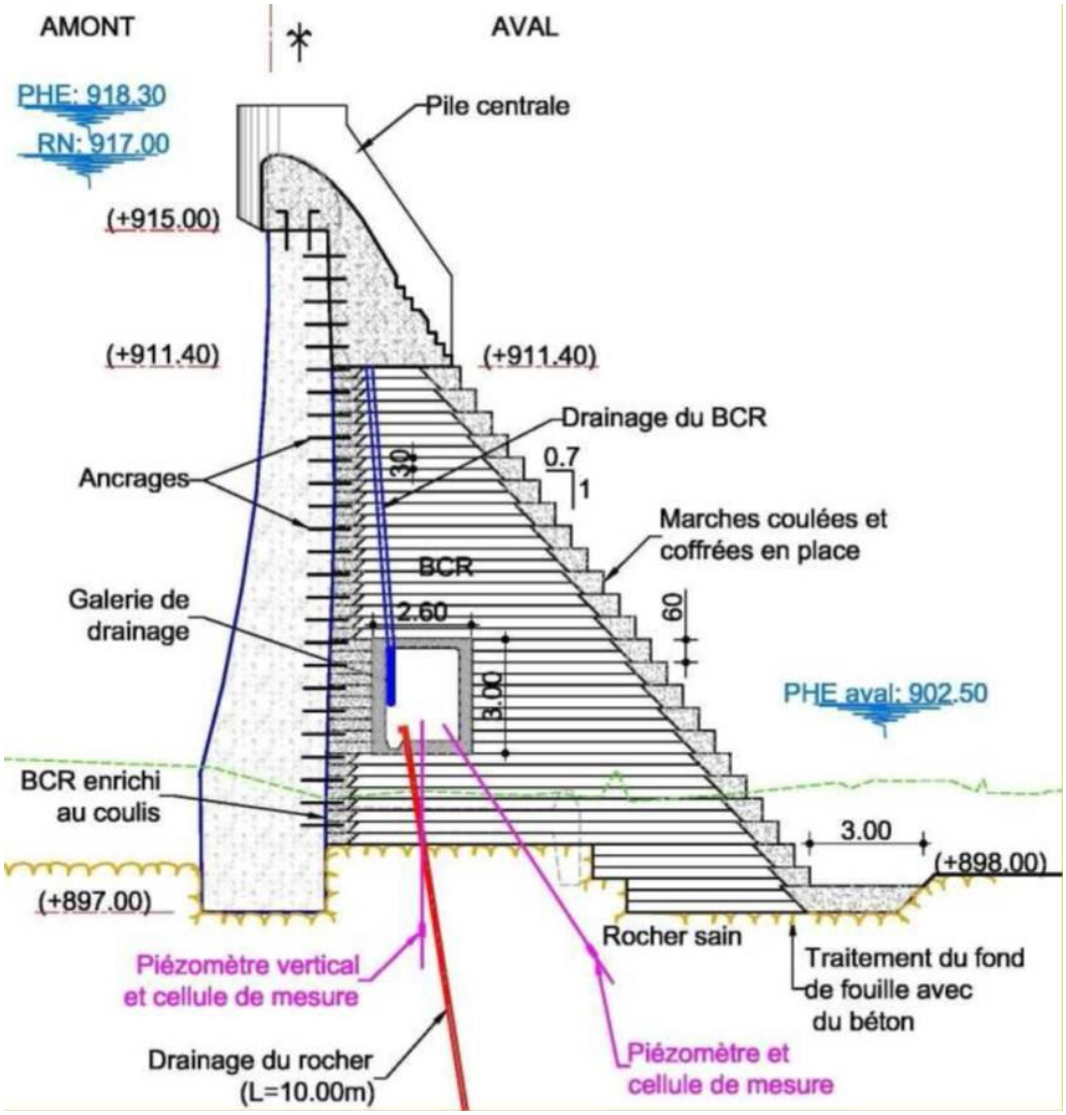

Figure 5. Plats dam after the rehabilitation. The section at central spillway.

The leakage at Uljua earth dam in Finland (Kuusiniemi et al. 1992.)

Uljua earth dam (13 m high, zoned earth fill dam), consequence class 1 dam, has been in operation since 1970. A clear leakage was observed during the first filling. The leakage was stopped by cement grouting. On 13th of May 1990, a muddy leakage was observed from rock fissures at the end of tailrace channel.

First measure was to start the lowering of the reservoir.

The site investigations were started to understand the dam incident:

- The geophysical investigations showed zones of anomalies at 30-40 meters north of the power station.
- Two sinkholes (3 m in diameter and 3 m deep) were found in the diving study at the upstream face. The tracer test showed the relationship between the sinkholes and leakage.

- The investigation boreholes were drilled at the dam crest. The boreholes were used later for the grouting.

A sinkhole appeared at the upstream face close to the place of grouting after two weeks of the first observation. The grouting unit and cement storage fell down to the sinkhole. The leakage was 100 l/s. First moraine load was dipped in the sinkhole after 45 min and the situation could be stabilized in couple of hours. A reverse filter, rockfill of 2 000 m^3, was constructed at the downstream face.

The rescue operations were prepared for the action and local population was warned by the authorities.

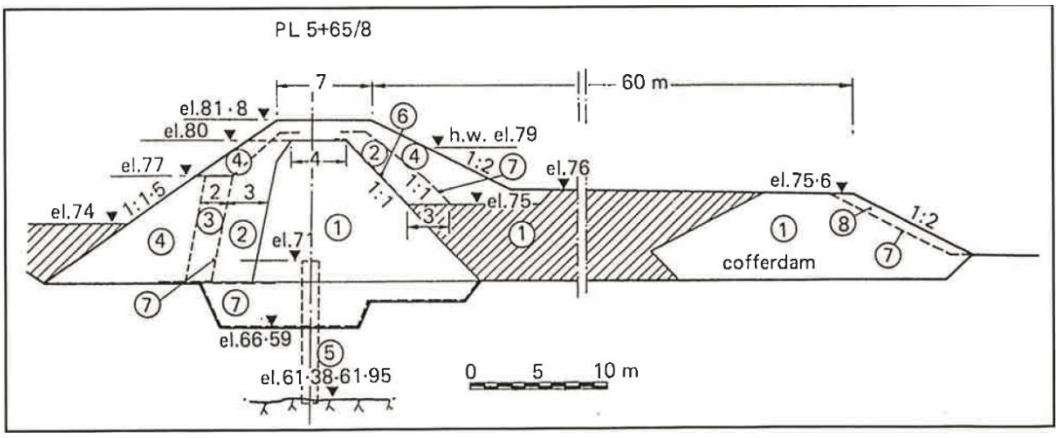

Figure 6. **The cross-section after the repair work, where 1=glacial till, 2=fine filter, 3=coarse filter, 4=dam shoulder, rockfill, 5=diaphragm wall, 6=bentonite mat, 7=geotextile, 8=riprap) (Kuusiniemi et al, 1992).**

The repair operations included (Figure 6):

- Emergency grouting (359 grouting boreholes, 950 ton cement, 5 ton polyurethane, 8 ton resin-type grout). The boreholes were drilled 10 m in bedrock. Three (3) grouting lines were done.
- The repair was done inside of the cofferdam was constructed and the repair was done.
- A partial diaphragm wall of 1.2 m diameter cast-in-place concrete piles was constructed.
- The area between the earth dam and cofferdam was filled with moraine (glacial till).

6 Conclusions

The dam incidents may include different kind of situations and events from small device failures all to way to serious dam incident, which may lead to a dam failure. There is not much time for planning actions during the dam incident. The routines shall be available and trained by the organization.

For understanding the current conditions in Europe, it was proposed to study and collect European practices and experiences on the dam incidents. European Working Group (EWG) on Management on Dam Incidents was established in 2013. The data of the National committees was collected by sending a questionnaire and 12 answers were received. The answers were studied and the results were discussed in working meeting in Helsinki in 2015.

The conditions to handle and manage the dam incident are set by the legislation. Basic compulsory requirements are the safe design, construction, maintenance and operation. The requirements are set for dam monitoring and inspections. The monitoring data shall be evaluated and analyzed. The periodical inspections shall be carried out regularly.

The instructions for preparation of the emergency action plan shall be given in the dam safety legislation. The responsibilities also during the incident shall be clearly defined.

The dam safety legislation shall include the notification of the dam incident to the authority and the dam incidents shall be collected to an open data base.

The good practices are supporting the legislation. Identified good practices are the availability of the dam documentation, the procedures of handling of dam incidents, competent personnel, reliable spillway and emergency gates, the measures for public safety and emergency training on dam safety.

The dam safety inspection together with the analysis of the monitoring data may show the development of the dam incident. The data may show abnormal reading or trend. Repair works and upgrading the safety can be planned and executed in due time if an emergency analysis is performed as part of the emergency planning process. The dam incident handling should be concentrated on the cases, where the dam incident is acute and is considered serious.

There are different types of incidents. The seriousness of the incident varies. The notification of the incident can come from different sources: the maintenance personnel, the dam inspector, public etc. The information of the notification shall be handled, also confirmed in some cases and distributed to the responsible persons and to the authorities. Therefore there shall be instructions and procedures for handling dam incident information.

The handling of the dam incident can be divided into the construction measures (hard measures) and operating measures.

7 Annex

Annex 1 Questionnaire

Annex 2 Answers from National Committees (and names of the responders)

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