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DISCUSSION ON THE MAJOR FLOOD WITHOUT DAM FAILURE AND ITS CONSEQUENCES INFLUENCE TO THE RISK ACCEPTANCE CRITERIA [(*)]

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1. INTRODUCTION

ICOLD, 1995, "Dam failures. Statistical analysis" lists 176 cases of large dam failures and 36% of the failures were caused by the overtopping (24% of the concrete dam failures and 50% of embankment dam failures).

USCOLD, 1988, "Lessons from Dam Incidents, USA-II", covers over 500 dam incidents, which are divided to failures (F1 and F2), accidents (A1, A2, A3 and A4), the damage during the construction (DOC) and major repairs (MR). Failure category (F1) is a major failure of an operating dam which has involved complete abandonment of the dam. 62 major failures (F1) have occurred. Overtopping was the cause of 41.9% of the failures and together with the spillway problems it covers 48.4% of the cases. The failure of a dam, which has been in operation for some time, has been prevented in 167 cases (F2 and A1) by reparation or immediate remedial work of operations, such as a drawdown of the reservoir. The overtopping or spillway problems have caused 34.1% of those incidents.

The dam incidents in UK are collected in the National Dams database (Defra, 2002). The incidents are classified in four levels: failure, serious incident (emergency drawdown), concern leading works and concern leading to

[(*)] *Discussion sur les crues importantes sans rupture de barrage et les conséquences pour les critères d'acceptation de risque.*

involvement by Inspecting Engineer. Thirteen (13) failures (all have occurred Pre-1975) and 71 serious incidents (58 have occurred Pre-1975) have taken place for the embankment dams older than 5 years. The internal erosion was most common cause (58.3%) for the failures and serious incidents and overtopping was cause in 22.6% of the cases.

Overtopping was the cause in three out of ten failures in Spain. Two embankment dams failed during the construction and one failure was caused by the problems of malfunctioning in the discharge works. Totally thirty (30) overtopping incidents has taken place. Twenty-three (23) concrete dams have overtopped and none of them failed. Eighteen (18) of the cases have occurred during the construction period (Berga, 1997).

The other side is the major floods without any dam failure. The spillway capacity has been adequate to discharge the high flood. The consequences will take place also in these cases.

The number of the global flood disasters has been less than ten times in the decade in the 1960's and 1970's and it has increased in 1980's and 1990's to 20 and 34 flood disasters in decade, respectively. Also, the economical and insured losses have been multiplied. The economic losses due to the flood disasters has been estimated to 25.5 billion US$ in 1980's and it was approx. 200 billion US$ in 1990's. Insured losses increased from 1.4 billion US$ to 7.4 billion US$ (Ashton *et al*, 2003).

220 major floods have occurred in Europe during the years 1980-2002. Over 9.4 million persons were affected and 3607 persons were killed by floods. The estimated damage was 117.4 billion US$ (Ashton *et al*, 2003).

Several questions arise from the dam safety and risk acceptance point of view, when above mentioned data is studied e.g.:

- Dam owner's liability to the consequences of the overtopping failure compared with major flood consequences.
- Dam hazard classification taking into account the flood risk.
- The liability questions, if dam owner is not responsible for the reservoir and river regulations during major flood and if a dam failure occurs.

2. SELECTION OF DESIGN FLOOD

ICOLD (1992) states that the selection of the design floods is governed by the degree of risk judged acceptable in the event of it being exceeded. This means that the consequences of the dam accident should be taken into account, when selecting the design flood.

The present trend in many countries is made a distinction between dam safety and works discharge capacity. In practical terms, this approach leads a two-level design based on two design floods and their corresponding spillway discharge capacities (ICOLD, 1992):

- *The "safety check flood"* often made equal to the Probable Maximum Flood. It is considered acceptable practice for the crest structure, waterway and energy dissipator to be on the verge on the failure, but to exhibit marginally safe performance characteristics for this flood condition.
- *The "design flood"* strictly representing the inflow which must be discharged under normal condition with a safety margin provided by the freeboard. It is usually taken as a percentage of PMF or a flood given probability of exceedence (1:100, 1:1000, etc.).

3. DAM RISK AND CONSEQUENCE ANALYSIS

A dam failure risk (R) is a measure of the probability (P) and extent of adverse effect e.g. consequences (C). The risk for class c can be presented as:

$$R_c = \sum \left(P_f * C_f \right) \qquad (1)$$

The probability of the hydrological risk can be much more easily determined than e.g. for the internal erosion. If a long period of flood data is available, a statistical analysis can be done and different return periods (probabilities) can be determined.

The routines exist for the estimations dam failure consequences. Following stages may be included in the study:

- Determination of the dam failure scenarios.
- Calculation of the breach hydrographs.
- Calculation of the flood wave attenuation downstream of the breach section.
- Determination of the inundation areas.
- Determination of the warning times for each river section downstream of the dam at different dam failure scenarios.
- Estimation the number of people at risk (PAR) for each failure scenario and each river section of different warning times.
- Estimation of the casualties with empirically based equations
- Sensitivity analysis (estimation of the uncertainty)

Several dam failure scenarios have to be studied e.g. overtopping risk, when the inflow exceeds the spillway capacity (one gate may also be out of operation, n-1 rule, if extensive debris flows are possible) and unexpected piping failure during "sunny day". Several models exist for the determination of the outflow from the breach opening. The flood wave attenuation can be calculated with one-dimensional hydrodynamic model or with two-dimensional hydrodynamic model, if detailed information is required in the vicinity of the dam.

The inundation areas are drawn in the maps (scales 1:20 000...1:50 000) using the calculated water elevations along the river. The structures (private housing, offices, schools, hospitals, etc.) under the flood risk can be determined from the maps and also some field studies may be required. The people at risk (PAR) can be estimated from the statistics of the municipalities (e.g. the population densities). The estimations may be required for different seasons (e.g. the permanent housing during the winter time, the population during the holiday season).

The estimation of the casualties may be done with the model of USBR (Graham, 2000), which is based on the study of actual dam breach cases in US during the period 1960 to 1980. The warning times, the population at risk and the number of the fatalities was investigated in each dam failure. The calculation of the loss of life (LOL) is based on the people at risk (PAR) and the warning times after the dam breach. The traveling time of the flood wave, the flow velocities and the water elevations calculated by the hydrodynamic model can be used in the determination of the coefficients of the model.

The fatality rate (fraction of people at risk expected to die) is determined by three factors: flood severity, warning time and flood severity understanding.

The flood severity categories are as follows:

- "*High severity*" is when the flood sweeps the area clean and nothing remains.
- "*Medium severity*" is when homes are destroyed but trees or mangled homes remain for people to seek refuge in or on.
- "*Low severity*" is when no buildings are washed off their foundations.

The warning time categories are as follows:

- "*No warning*" means that the media or official sources in the endangered area are unable to issue any warnings prior to the arrival of the flood wave.
- "*Some warning*" means officials or the media can start issuing warning 15 to 60 minutes before arrival of the wave.

- "*Adequate warning*" is those issued more than 60 minutes before the wave arrives.

Relative awareness of severity (flood severity understanding) is a function of the distance or time from the initial dam failure. The farther one is from the dam failure location, the greater the likelihood that the warning will be accurate. This is because there will have been reports on flooding in upstream areas, so that people can assess its damage potential and can adjust the warnings to reflect the actual danger. *The flood severity understanding categories* are as follows:

- "*Vague understanding*" means that the person issuing the warning has not been able to see the failed dam and flooded areas and, therefore, have only a limited picture of the actual magnitude of the flooding.
- "*Precise understanding*" means that the persons issuing the warning have a clear understanding of the situation due to observations of the flooding made by themselves or others.

The suggested ranges for fatality rate can be found in Graham (1999). The LOL-estimation has many uncertainties. The uncertainties are related to the cause of dam failure, the time of the failure occurs (day, night, day of the week, time of year), warning times and inability to precise determination of the fatality rate.

The human impact has a big influence to the LOL-figures as can be seen in the USCOLD statistics (1988). The dam failure could be prevented in 167 cases by reparation or immediate remedial work of operations, such as a drawdown of the reservoir.

The estimation of the economical losses is tedious work. The economical losses can be divided into commercial losses (e.g. reconstruction costs of the dam, loss of production) and societal losses (e.g. impact to private and public property, environment). It requires field work, where the risk objects are mapped at the inundation area.

4. SUMMER FLOODS IN SOUTHERN FINLAND, 2004

The summer floods 2004 at River Vantaanjoki in Southern Finland are presented to illustrate complicate consequences of a flood. The description is based mainly on the newspaper articles.

The catchment area of the River Vantaanjoki is 1685 km^2 and only 2.5% of that area is covered by lakes. The variation in flow is considerable. The mean flow (MQ) is approx. 17 m^3/s. The maximum flood flow (HQ) has recorded

317 m^3/s in 1966. There are times when the discharge is very low (NQ = 1.4 m^3/s), due to the small storage capacity of the lakes upstream. Any large dams are not situated in the river system.

Heavy rains in large area started in the end of July, 2004. The precipitation was over 100 mm during the week. Such amount of rain in Southern Finland has occurred in 1979. Summer flood flow was approx. 190 m^3/s, which was lower than the HQ.

The flood caused losses to the property e.g. the cellars of the houses were filled with the water.

The rainwater in the towns and the cities is collected in the same sewer system than the waste water. The extensive rainfall reached the capacity of the sewage treatment plant. Hundreds of thousand m^3 of untreated sewage water has to release in the river, which had 25-30 tons of phosphorus and 220 tons of nitrogen. The bacteria concentration was 1000 times higher than in normal situation.

Untreated water used the oxygen content in the river, which caused the fish deaths in the river reach of approx. 25 km. Untreated water was slipped in the water intake plant.

It can be seen in this example that the consequences of major flood or a dam failure may be complex and an exact estimation may be very difficult.

5. DISCUSSION ON THE FLOOD RISK VS OVERTOPPING RISK

5.1. DAM OWNER'S LIABILITY TO THE CONSEQUENCES OF OVERTOPPING FAILURE COMPARED WITH MAJOR FLOOD CONSEQUENCES

Australia and USBR have developed F-N diagrams (F: Probability of failure, N: Number of fatalities) as criteria for Risk Acceptance (Rettemeier *et al*, 2000). Typical areas in the chart are Unacceptable and Acceptable Risk. The tolerable risk, but not acceptable risk, is situated in between of abovementioned areas.

The high hazard dams should have a spillway capacity, which corresponds 1 000 to 100 000 year flood depending on the country's legislation. The discharging such a high flood will have some adverse consequence (loss of life, injured persons, economical losses) as discussed in Chapter 1: Introduction.

The consequences of the major floods are not considered to reduce the consequences of the overtopping failure and thus reduce the liability of the dam owner. If dam owner's liability is reduced, the basic compensation would be on the responsibility of the society. The question is juridical. The dam safety legislations and the guidelines do not take into account such a possibility and the dam owner has the obligation to keep the dam safe that they will not cause a hazard or have damaging effects on public or private interest.

5.2. DAM HAZARD CLASSIFICATION TAKING INTO ACCOUNT THE FLOOD RISK

The dams are classified according to the hazard risk. Some interesting questions may arise in the classification procedure.

If it is considering following case: the dam failure during the mean flow (MQ) or during design flood of lower hazard class (e.g. at 100-year flood) is not endangering the human life or health and the economical losses remain low. The consequences during the safety check flood with a dam failure causes human and economical losses, but the consequences may be same without a dam failure. How should the dam be classified?

A common sense says that the dam should be classified to lower hazard class, but the dam legislations do not give any clear answer.

What has to be the consequence difference that the dam is classified to the high hazard class?

5.3. LIABILITY QUESTIONS DURING MAJOR FLOOD UNDER EXTERNAL REGULATING INSTANCE

The river regulations are not always done by the dam owner. The authority or the river regulating company is responsible for the river and reservoir regulations. If this regulating instance is taking the power during the major flood and a dam failure occurs during some the liability questions, what is the dam owner's responsible.

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SUMMARY

Overtopping has been the most frequent cause for dam failure. The safety of the discharging facilities has been improved by studying UK incident statistics. All seven overtopping failures and all twelve (12) serious incidents have occurred before 1975. The safety feeling may be misleading, because on the other hand the number of the major floods has increased in the 1990's. Also the retiring of the dam safety personnel will reduce the dam safety level in the countries with developed hydropower capacity.

Major floods without any dam failure causes human and economic losses. In this paper is discussed, how the major floods and their consequences may influence the risk acceptance criteria? Several questions arise from the dam safety and risk acceptance point of view e.g.:

- Dam owner's liability for the consequences of the overtopping failure compared with major flood consequences.
- Dam hazard classification taking into account the flood risk.

- The liability questions, if dam owner is not responsible for the reservoir and river regulations during major flood and if a dam failure occurs.

RÉSUMÉ

Le déversement a été la cause la plus fréquente des ruptures de barrages. La sécurité des ouvrages d'évacuation a été améliorée par l'étude des statistiques anglaises sur les incidents. Tous les cas de rupture par déversement (7) et tous les cas d'incidents graves (12) ont eu lieu avant 1975. Le sentiment de sécurité peut être trompeur car le nombre de crues exceptionnelles augmente et, de plus, le départ en retraite du personnel de sécurité va réduire le niveau de sécurité des barrages dans les pays à forte puissance hydroélectrique.

Les grandes inondations sans rupture de barrage causent des pertes humaines et économiques. Dans ce rapport, on examine comment ces grandes inondations et leurs conséquences peuvent influencer les critères d'acceptation du risque, plusieurs questions émergent, notamment :

- Responsabilité du propriétaire du barrage vis-à-vis des conséquences d'une rupture par déversement, par rapport aux conséquences d'une inondation importante.
- Classement des risques dus aux barrages, compte tenu du risque d'inondation.
- Problèmes de responsabilité : si le propriétaire du barrage n'est pas responsable des règlements sur la retenue et la rivière, pendant une inondation et si il y a rupture de barrage.