New Developments in Dam Safety – Feasibility Evaluation on Risk Assessment

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ABSTRACT: The world wide discussion about dam safety leads to a change in the approach towards risk related problems. Basically two opinions can be viewed, the safety and the risk-oriented one. Traditionally dams are considered safe, because they have been built according to high technical standards. Today people become aware of the fact that all man made structures have a potential risk that has to be evaluated, assessed and managed. Thus the risk of dams is no longer neglected. This discussion about risk based dam safety leads to a new approach for German dams as well. Because of the varying cultural and legal background it is impossible to use a Risk Assessment procedure from another country without adaptation. On the basis of known Risk Assessment procedures a new procedure was developed for German dams taking the German background into account.

1 INTRODUCTION

Like all technical buildings also dams hold a potential risk of failure. One of the largest disasters in Germany was the failure of the Moehne Dam. It was destroyed 1943 due to extensive bombing. The reservoir was almost full and ran empty within few hours (RUHRVERBAND, 1988). The devastating extents of this failure are represented in figure 1. The disaster cost 1200 human lives and led to destruction of the downstream settlement. Unlike dam failure in many other countries this failure naturally did not effect the approach towards the risk of dams in Germany since the awareness of the risk is small compared to other war actions.

Figure 1: Möhne Dam Failure, World War II (RUHRVERBAND, 1988)

Different effects can lead to damage and cause the failure of a dam. Some examples are flood, earthquake, landslides and piping or static reasons. Operation incidents are important factors, which can be divided into incidents due to technical and those due to human failure. The flow chart of a dam failure is represented in figure 2.

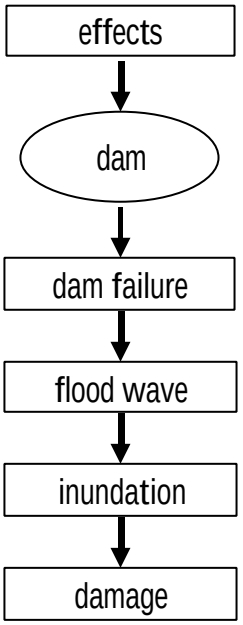

Figure 2: Flow chart for dam failure

The failure of a dam results in a flood wave. The hydraulic characteristics of this flood wave highly differ from a conventional flood wave in a river due to high precipitation. The sudden failure results in a wave with large energy and high flow rate, which suddenly floods the downstream settlement and causes large devastation.

The resulting damage encloses far away sections of the downstream settlements and can be very high for humans, economics and the environment.

The acceptance of the hazard potential of technical buildings is subject to change in the society permanently. While in former times humans accepted such disasters, today the awareness of risks is much higher and dams are regarded more critically. Since risk management is executed in many other technical areas, the question arises: how safe are our dams?

2 DAM SAFETY AND RISK

The present discussion about the safety evaluation of dams led world-wide, covers two different view points. Here the conventional safety-oriented perspective faces the risk-oriented perspective (figure 3). The safety-oriented perspective assumes no risk of failure, since a dam is built according to high design criteria. Consequently damage for humans, economics and the environment can be excluded with a degree of probability verging on certainty unlikely. However an absolute safety cannot be ensured technically. The risk-oriented view point takes a risk of failure into account. Thus the residual risk has to be determined, evaluated and managed even if failure seems unlikely.

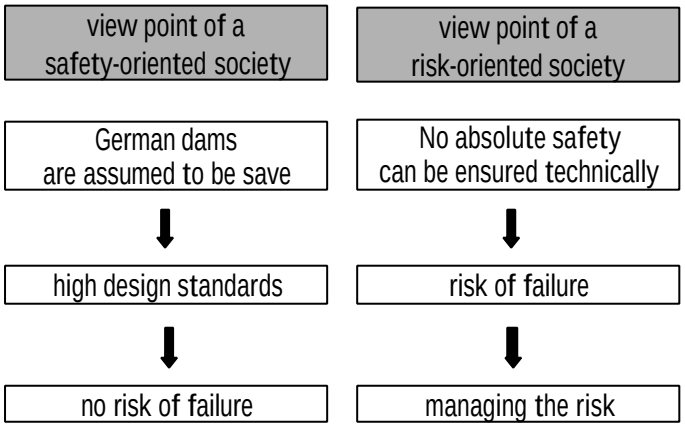

Figure 3: View Point of a safety and risk oriented society

The safety-oriented perspective was represented in Germany so far. But the world wide discussion about dam safety where dams are regarded more commonly under aspects of risk led to a reorientation. Therefore the aspects of risk are considered in the draft of the DIN 19700 section 11 dams (1999) – "the residual risk in consequence of exceeding the BHQ2 (equivalent to a flood with recovery period of 10.000 years) has to be evaluated –eventually considering the PMF. It should be met by technical and/or organizational measures."

The estimation and evaluation of risk are known from other technical areas (e.g. atomic industry) and the methods of risk management are often taken into account. The process of Risk Management can be divided into the areas Risk Analysis, Risk Assessment and Risk Management.

Figure 4 represents the context associated with Risk Assessment. The Risk Analysis as the first step is part of the Process of Risk Assessment. While the Process of Risk Assessment itself is part of the Process of Risk Management. The flow chart gives an overview of the fundamental terms and represents both the relationship of the individual steps (Risk Analysis, Risk Assessment, Risk Management) and their integration into the entire process (Process of the Risk Assessment, Process Risk Management).

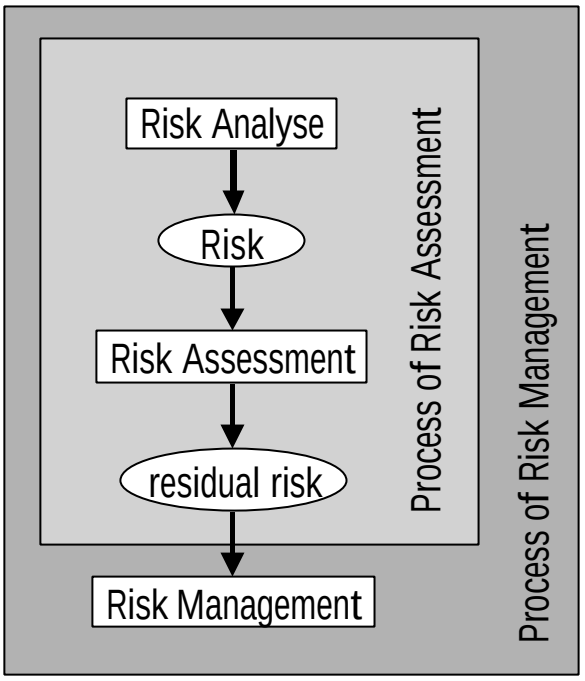

Figure 4: Risk Management Process

The risk of the dam is determined within the Risk Analysis. The risk is defined as the measure of the probability of failure and the severity level of unfavorable effects (ICOLD, 1998). Thus the risk is determined as the product of failure probability and extent of the damage (risk = probability of failure * extent of damage).

The evaluation of the risk comprises the consideration of alternative mitigation measures as well as the acceptance of risk. These aspects are formally referred to as Risk Assessment.

Finally the Risk Management covers the decision making for the development and conversion of a management plan as well as the monitoring of the implementation.

3 DAM SAFETY IN GERMANY

3.1 *Classification and legislative demands*

Germany has 311 dams which are listed in the ICOLD register of dams with a height over 15 m (SIEBER, 2000). In Germany there are uniform technical standards for dams, which are determined in the DIN 19700 (1986). The DIN 19700 (1986) classifies five types of dams (reservoirs, flood control storage basin, weirs, pumped storage reservoir, tailing dams), no matter the height or volume (table 1). According to the draft of the DIN 19700 (1999) dams are classified according to their type and size.

The building, operation and the monitoring of dams are regulated by the state water law of the individual state of the Federal Republic of Germany and depend on the state of the art. Most dams are subject to regulation of the individual state. According to the state water law in North Rhine-Westphalia all dams with more than 5 m height and a volume of at least 100.000 m³ are subject to regulation. Especially in North Rhine-Westphalia the technical and legal demands depend on the type of the dam (Table 1). RETTEMEIER & KÖNGETER (1998) provide an outline of the classification and the legal and technical requirements of dams in Germany.

Table 1: Dams Subject to Regulation in Germany

State Water Law (NRW) legal requirements	DIN 19700 technical requirements
$h \geq 5$ m and $V \geq 100.000$ m^3	all dams
type 1: dams and weirs	part 10: all dams
type 2: tailing dams (within waters)	part 11: reservoirs
type 3: similar safety measures as type1	part 12: flood storage reservoirs
type 4: flood control reservoirs	part 13: weirs
type 5: pumped storage reservoirs (upper reservoir)	part 14: pumped storage reservoirs
type 6: tailing dams (outside of waters)	part 15: tailing dams

The classification of dams limits the introduction of risk based dam safety approaches in Germany. Other countries which classify dams according to risk have a better understanding of the risk of their dams.

The German dams have been built and operated according to the DIN 19700 (1986) with high request on the structural design and the maintenance. Since the failure probability is assumed to be very small, dam failure has not been considered in general. Consequently the possibility of failure has been neglected and flood or emergency plans do not exist for any German dam. However inundation studies are absolutely necessary for the regulation and the estimation of risk.

3.2 *Risk Assessment in Germany*

The world wide discussion about risk based dam safety leads to a new approach for German dams as well. Because of the cultural and legal difference it is impossible to use a Risk Assessment procedure from another country directly. The Risk Assessment procedure that is presented in figure 5 has been developed by the authors on the bases of other known procedures as well as taking into account the German questions.

Risk Assessment is part of the Process of Risk Management. The Process of Risk Assessment covers Risk Analysis and Risk Assessment. The risk which is determined in the Risk Analysis is evaluated within the Risk Assessment. This context is already represented in figure 4, and all Risk Management procedures have those fundamentals in common.

Before a Risk Assessment can be executed the risk must be determined qualitatively or quantitatively. There are many investigations for the quantitative determination of risk, particularly with respect to failure mode analysis and their effects. In addition, the qualitative estimation is quite usual, especially if the statistical basis is insufficient. Here experts and risk analysts estimate the risk by experience.

While monitoring is part of the Risk Assessment (risk mitigation) in many countries, it represents a part of the risk analysis in Germany and can be used likewise for risk mitigation. In Germany the monitoring of dams is legally regulated, so it can be regarded as an important constituent of dam safety.

After the risk was determined, it must be evaluated whether it is acceptable in Risk Assessment. The risk acceptance depends on the hazard potential for humans, economics and environment. Here many different aspects take influence, whereby the most important point of discussion for German dams is acceptance with respect to human lives. Engineers alone should not come to the decision. Rather an interdisciplinary co-operation between engineers, sociologist, economist etc. is necessary.

If the risk is not acceptable, risk mitigation measures must be met. The risk can be reduced by modification of probabilities or consequences. Possible measures are e.g. extended monitoring, structural or operational changes, emergency planning.

The residual risk is evaluated with respect to the acceptance of risk and risk mitigation measures. Since cost as well as human demands need to be considered the risk evaluation should not only comprise cost-benefit analysis but also take non economic values into account.

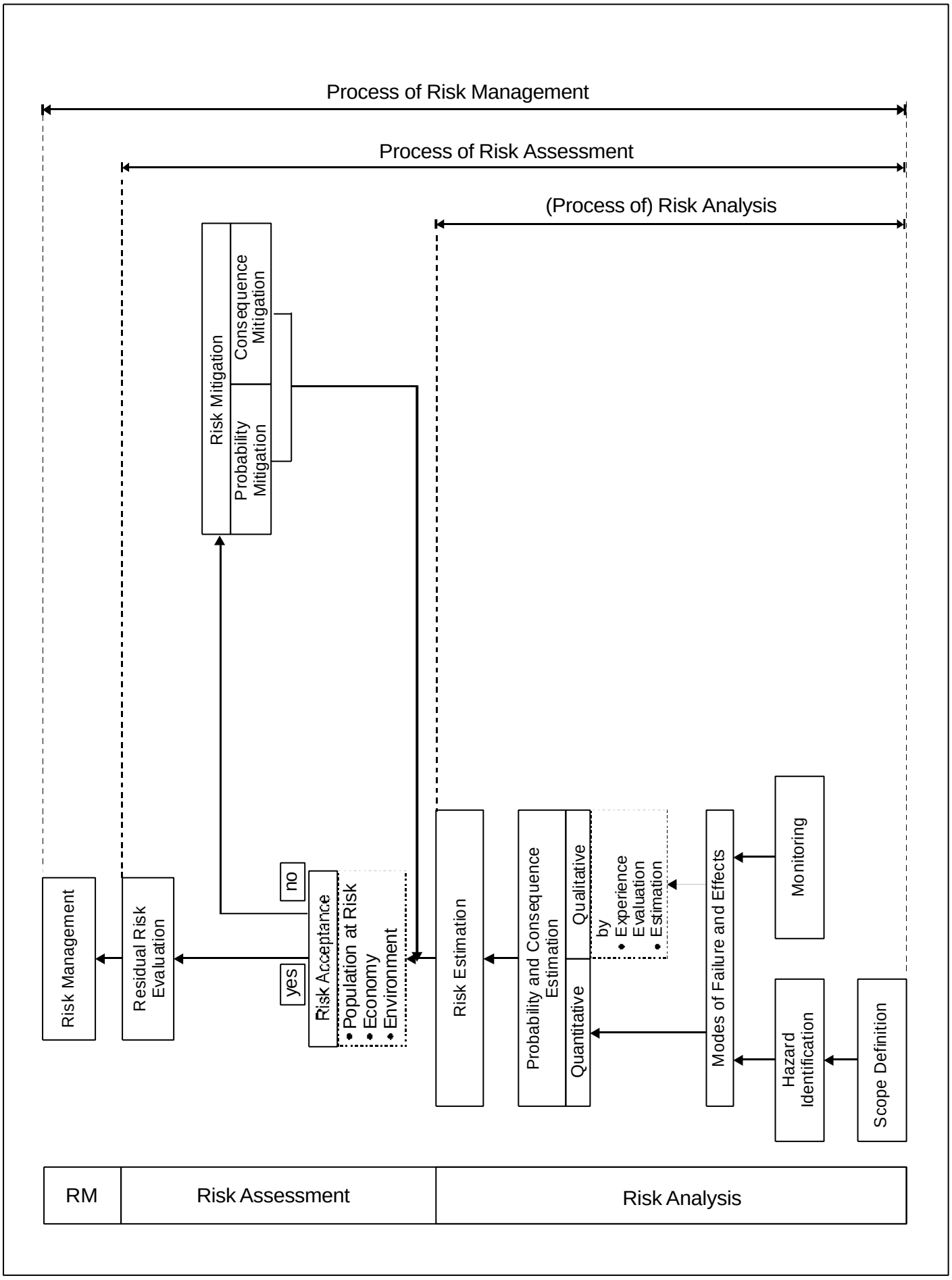

Figure 5: Risk Assessment procedure in Germany

3.3 *Risk Acceptance*

The acceptance of risk as well as acceptance limits are not yet discussed in public, documented or socially de-

fined neither for the loss of assets nor for human lives, in Germany. RIßLER (2000) provides a fair comparison of individual risk with risk of dam failure. This approach can influence the acceptance of dam failure but needs to be evaluated in more detail in the future.

For a first approach a F-N diagram was developed which can be used for German dams (figure 6). This diagram does not consider the individual risk. The main objective of this diagram was to provide a measure of acceptance for a validation of the procedure described in chapter 3.2 (RETTEMEIER, et al. 2000). The diagram is flexible and should be adapted for each dam.

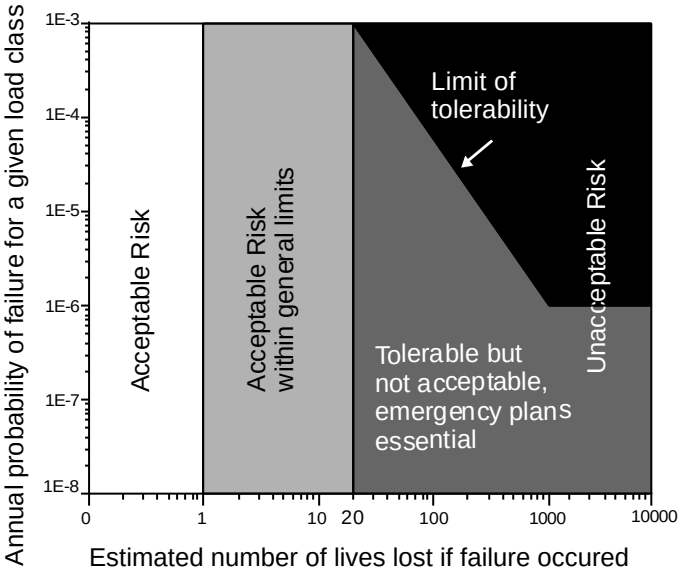

Figure 6: F-N diagram for Germany

First of all it can be noticed that a Risk is only acceptable if no one dies. Taking into account the insurance measure for catastrophe vs. misfortune, a failure with less than 20 dead persons is acceptable within general limits. All other Risks are unacceptable. This does not take into account the probability of failure (vertical limits). Only within the area of tolerable but not acceptable Risk the probability of failure is considered. In this case emergency planing is essential and should be used for risk mitigation. The range of the probability of failure is limited to 10^{-3} because of the design flood (required capacity of the spillway), according to DIN 19700 (1986).

The limit of tolerability curve is subject to change for individual dams. The range of the number of fatalities depends on the number of endangered population and should be increased if necessary. The trend of the 'limit of tolerability' curve can only vary in the value where the slope changes. This value depends for example on the number of people that can be evacuated in a limited time. The horizontal line is fixed to 10^{-6} according to IDEL (1986) for the "totally unlikely" risk.

4 FEASABILITY EVALUATION

The fundamental difference of the German Risk Assessment procedure compared to other procedures results from the approach to the question of dam safety under risk criteria. In many countries, where the Risk Assessment is applied, dams are classified according to their risk. Therefore Risk Analysis is an established factor for the design of dams. However dams are classified according to their type in Germany. So the risk of a German dam is unknown so far.

High request on the structural design led to the assumption that German dams have a very small risk of failure. It seems to be reasonable that dams in Germany according to IDEL (1988) and RIßLER (1998) have a probability of failure of 10^{-5} at the most. Especially for the load case flood the technical demands require a design "flood" for the spillway of a 1.000 year recovery period. Additionally a free-board is demanded that is large enough to ensure that a dam will not be spilled in case of PMF (DIN 19700, 1986).

Presumably a detailed Risk Analysis will not result in a wide change in the probability of failure for German dams. Still the risk cannot be neglected. The density of population and the industry downstream of dams result in a high potential of damage.

The presented procedure takes the German standards in dam design into account. It allows to prove the very high level of safety with respect to probability of failure (Risk Analysis). At the same time the emphasis is not drawn towards Risk Analysis with respect to the quantification the probability of failure. Instead failure modes are identified and their effects are determined. This information is essential for Risk Assessment.

While monitoring and surveillance is part of Risk Assessment in many countries, the German approach takes it into account in Risk Analysis. Germany has very high legal and technical standards in surveillance which directly contribute to the low probability of failure.

The draft of the DIN 19700 (1999) demands the evaluation of risk with respect to organizational and/or technical mitigation measures. The Risk Assessment is well suited to fulfill these requirements. The presented procedure assures the mitigation of risk (Risk Assessment) taking the German question into account. Since failure modes and effects have been identified within Risk Analysis, the Risk Assessment can focus on optimal mitigation measures. Thus the risk mitigation in the German Risk Assessment procedure comprises new failure mode and effects analysis which do not result in a new Risk Analysis.

Since the individual aspects (Risk Analysis, Risk Assessment, Risk Management) are regarded separately, a Risk Assessment can be executed without a detailed Risk Analysis e.g. if only the worst case complete failure is considered. Naturally different failure modes and inundation studies must be regarded, in particular for the risk mitigation, thus fundamental elements of the Risk Analysis have to be considered within a Risk Assessment.

The aim of this procedure, in particular the separation of the Risk Analysis and the Risk Assessment should be to encourage the forthcoming of risk based dam safety in Germany. Especially for existing dams a complete, detailed and quantitative Risk Analysis is very difficult if not

impossible. Thus in engineering practice an approach which does not emphasis on the probability of failure determination but focus on the damage with respect to failure modes and effects can provide a very good approach and lead to a reduction in risk. Consequently the demands of the DIN 19700 can be met on the level of engineering judgement.

5 CONCLUSIONS

It is our responsibility to minimize the hazard of technical buildings. Germany is constantly improving its design standards to meet public demands on dam safety. Still risk based approaches have not been considered so far..

The world-wide discussion on Risk Assessment as a tool for dam safety leads to new developments in Germany. The Institute for Hydraulic Engineering and Water Resources Management, Aachen University of Technology developed a Risk Assessment procedure, which is applicable to German dams. Hereby the new requests which result from the draft of the DIN 19700 (1999) can be met

A special feature of this Risk Assessment procedure is the context of Risk Analysis and Risk Assessment. The process of Risk Assessment contains Risk Analysis and Risk Assessment, which build on one another, but are final in themselves. So they can be treated separately from each other. The estimated risk, e.g. of the largest damage, can be considered for the Risk Assessment in the line with the demands of DIN 19700 (1999).

With Risk Assessment a tool is available, which allows a safety evaluation of dams with respect to risk on a practicably and economically meaningful basis. A implementation for German dams is technically possible. For the future work detailed inundation studies as basis of the damage assessment have to be carried out. The consideration of failure modes with appropriate load case combinations is an important issue that has to be considered for the forthcoming of Risk Assessment in Germany as well.

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