Portfolio Risk Assessment in Dam Construction

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ABSTRACT

The increasing focus on dam safety is a problem of major concern to technicians and entities responsible for designing, licensing, constructing and managing such structures. In spite of the growing experience in designing and building dams, as well as in using more appropriate materials, dam safety is increasingly an issue of debate among the international community. Dam owners, engineers and regulators who are responsible for the safety of groups of dams need to prioritize dam safety evaluations or funding for structural and non-structural risk reduction measures. Traditionally "downstream hazard" assessment, weighting schemes, and judgment have been used for this purpose. However, these have significant weaknesses and cannot be relied on to provide the basis for an effective and efficient program for managing and reducing dam safety risks. This paper describes the Portfolio Risk Assessment (PRA) approach, which the authors have developed and applied to several portfolios of dams. The approach is a tool for prioritizing risk reduction measures and additional evaluations. In addition, it provides valuable inputs to various business processes and for strengthening other aspects of a dam safety program. Significantly more cost effective and rapid rates of risk reduction may be achieved using this approach.

Keywords: Portfolio Risk Assessment**,** Project Management**,** Risk Management**,** Dam Construction

INTRODUCTION

The management of a project is a difficult and challenging task due to the many variables determining its final outcome. Although classic project management techniques addressing Scope, Cost and Schedule requirements are proven approaches to managing a project effectively, projects often run into trouble even when well-planned and sound controlled methods are employed. The American Society of Engineers believes the common reason is that threats to the projects are not clearly identified and actions to control these threats are not properly implemented. Consequently, project managers/project engineers must be consciously aware of potential threats to the success of their projects and take early, effective, and offensive actions against these threats. An effective risk management approach will provide engineers/managers with a needed management technique that will significantly increase the probability of success for their projects by addressing these problems, resulting in clear benefits to them and their customers. [1]

"At the moment, there is a growing public awareness of the potential risk for people, structures and property in the downstream valley. This concern led to the creation of a Dam Safety Committee within the International Committee of Large Dams (ICOLD), which defined a set of guidelines to be taken into account, during the design and construction phases

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of dams." (Dam-Break Flood Emergency Management System) At the national level, most western countries are also issuing similar guidelines. Although considered of low risk, incidents with dams may cause significant damage both directly and indirectly. Direct losses are usually easier to assess (assuming human lives are quantifiable), but indirect losses are difficult to measure and may take some time before the original situation is restored. Moreover, it is impossible to define a pattern for these damages. In some occurrences, such as the Baldwin Hills and Teton cases in the USA, very high costs are associated with a small number of casualties. Other examples, such as the cases of the South Fork Dam, in the USA, and the Verjont dam in Italy led to tragedies of more than 2,000 deaths (Ramos, 1995). Many other examples of dam accidents throughout the world can be found in the literature. [2]& [3]

PORTFOLIO RISK ASSESSMENT

The PRA approach is a tool for prioritizing structural and non-structural measures for reducing dam safety risks across a group of dams. It can also be used to prioritize further investigations and analyzes, and to give a basis for the evaluation of other dam safety activities such as, monitoring and surveillance, inspections, and emergency planning. Management, who are responsible for integrating dams into business processes, will find PRA outcomes useful for capital budgeting, insurance, legal liability and due diligence assessments, and business criticality evaluation and contingency planning. By effectively representing dam safety issues in these business processes, the likelihood that dam safety concerns will be addressed in a timely manner, and that risks will be reduced, can be expected to be increased compared with other approaches. [4]

After an initial PRA is completed, on-going benefits can be derived through periodic updating. In addition to being used by dam owners, one state regulator is incorporating PRA as a key element in a Business Risk Assessment approach to dam safety regulation (Watson 1998). The PRA approach is applicable and valuable whether safety levels are to be based on either a standards or a risk-based approach; and therefore using PRA does not commit the owner or regulator to a risk based approach for selecting safety levels. The authors have applied the approach to several portfolios of dams. We have also applied different versions of the approach to a larger portfolio using sampling process to make estimates of the existing condition of the entire portfolio and to obtain cost estimates for risk reduction across the entire portfolio. [5] &[6]

THE PRA PROCESS

Participants

For the success of a PRA, it is essential that it be undertaken through a partnership between the owner and the engineer (in some cases the owner and the engineer may be different departments within the same organization), with the assistance of an expert risk assessment facilitator. It is also important to obtain input from the regulator and other stakeholders in the dam safety decision. It is essential that the owner's senior management (executives and directors), who will ultimately be responsible for making dam safety decisions, are involved throughout the PRA process. At the outset of the process, management should help to define the overall business context, objectives, and business requirements for the PRA. Near the end

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of the PRA it is essential that senior management be involved with the integration of the PRA results into the owner's business processes. Experienced dams engineers should be committed to performing the PRA. They must be capable of making sound judgments based on the available information, relevant experience, and case histories. The facilitator should be skilled in leading a PRA Team, overseeing risk assessment aspects of the project, and advising on the integration of dam safety risk issues with business risk considerations. Operations and maintenance staff should be involved in the PRA process. [7]

Overall Approach

A PRA is usually based primarily on available information, without performing extensive additional analyses or investigations. The risk assessment itself is normally conducted at a reconnaissance level. Thus it should not be expected that a PRA will lead to "signing off" on any aspects of the safety of the existing dams which have not already been "signed off" as the result of previous work. Additional engineering studies will be needed to determine if remedial work (a risk reduction measure) is needed and to justify the extent of the work. The goal of additional studies should be to develop the normal level of confidence expected in current engineering practice. In the absence of that level of confidence there will be a greater dependency on professional judgment in the PRA. [8]
Some additional information is often needed to complete a PRA. A common example is the need for estimates of extreme floods or earthquakes where these have not been developed, or have been developed, but not using current practice. For the PRA, it should be sufficient to base such estimates on regionalized procedures which will involve less effort than design or final evaluation level estimates.
Since risk reduction measures are to be prioritized, it is desirable that there be consistency in the treatment of all dams included in the PRA. The priorities which are based on the PRA should be considered to be initial priorities. A PRA is a baseline assessment and should form the basis for a "living document" which will be updated using additional information becomes available. [8]

Steps in Performing a PRA

The following is a list of tasks that will be needed to perform as PRA:

1.0 Define overall business context and objectives for PRA
2.0 Agree business requirements for PRA
3.0 Perform engineering assessment of existing dams
- 3.1 Review available information
- 3.2 Conduct site visits
- 3.3 Review flood and earthquake loading and make regional estimates
- 3.4 Assess dams against engineering standards

4.0 Conduct risk assessment of existing dams
- 4.1 Identify significant failure modes
- 4.2 Develop risk models
- 4.3 Develop various reservoir relationships
- 4.4 Estimate system response probabilities
- 4.5 Perform dam break modeling and inundation mapping
- 4.6 Estimate failure consequences
- 4.7 Conduct existing dams risk analysis

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4.8 Evaluate existing dams against risk-based criteria

5.0 Conduct risk assessment of risk reduction alternatives

5.1 Formulate structural and non-structural risk reduction measures and develop cost estimates

5.2 Conduct risk analysis of measures

5.3 Evaluate measures against risk-based criteria

6.0 Integrate dam safety PRA results into business risk

6.1 Develop initial priority for measures

6.2 Estimate capital budget requirements for measures

6.3 Formulate Dam Safety Improvement Program

6.4 Integrate PRA outcomes into dam safety program and other business processes[9]

PRA ELEMENTS

Business Context, PRA Objectives and Business Requirements Context:

The current and evolving context of the organization (e.g. organizational mission, goals, and values; regulatory environment; public perception; etc.) which operates the dams must be understood if the PRA is to provide outcomes which will be of value and relevance to the organization. Understanding of the overall business context will help to define the PRA objectives, the degree of effort to be expended in various aspects of the PRA, and the format for presentation of PRA results.

It is important to identify related business and decision processes, including regulatory policies, practices and criteria, and the expected role of other stakeholders. Various business risk and dam safety criteria should be evaluated for potential use in the PRA, and agreement should be reached between the owner and the PRA team on the use of criteria and the format for PRA results.

Specific objectives should be defined for the PRA and may include some of the following:

- To provide a basis for evaluating or establishing an integrated Dam Safety Management Program
- To prioritize structural and non-structural risk reduction measures
- To identify the amount and disbursement of capital for risk reduction measures
- To understand the business risks associated with the owner's dams
- To satisfy due diligence requirements[10]

Risk-based Criteria

At this time interim risk-based dam safety criteria have been developed by ANCOLD (1994), the U.S. Bureau of Reclamation (USBR 1997) and B.C. Hydro (1993). While criteria developed by one organization should not be assumed to apply to another organization, these criteria can be useful for reference purposes. Generally these criteria focus on public safety. In applying life safety criteria from these organizations to more than fifty dams we have found that there is often little difference in the ratings that would be assigned by applying the different criteria. Additional criteria which relate to the business implications of dam safety decisions should be developed for use in the PRA. [11]

In addition to using risk-based criteria there appears to be a persuasive legal basis for including both ALARP (as low as reasonably practicable) and de minimize risk considerations in dam safety decision making. The basis for ALARP is that risks are "acceptable only if reasonable practical measures have been taken to reduce risks" (IAEA 1992). In practice this is commonly taken to mean that risks have been reduced to the point where it is no longer cost effective to reduce them further. The cost effectiveness of improving life safety [cost-per-(statistical) life -saved, CPLS] can be used to assess degree of ALARP justification for a risk reduction measure (Bowles et al 1996) [11].

The term, de minimize risk, comes from the Latin, "de minimize non curat lex" meaning the law does not concern itself with trifles (Short reed et al 1995). A significance in dam safety decision making is that "a dam owner may have a legal obligation to implement a relatively low cost fix (risk reduction measure), even if it is not cost effective" (Bowles 1998). The de minimize risk concept appears to be related to the common law construct of what a "reasonable" dam owner would do to reduce risk in a particular situation. It should be remembered, however, that under a common law system there is no guarantee that a safety decision made before a dam failure will be viewed favorably by a court the event. ALARP should always be evaluated when limit and objective values of risk-based criteria appear to be met by an existing dam or by a proposed risk reduction measure. De minimize risk should be evaluated when there appears to be no ALARP justification to proceed with a risk reduction measure[12].

Engineering Assessment of Existing Dams

An initial engineering assessment of portfolio dams is performed as part of the PRA. It is conducted at a reconnaissance-level against current engineering standards based largely on available information and professional judgment. Bowles et al (1997) define engineering standards to include "current state-of-the-art (or practice), meaning the generally accepted present-day approach to dam design, evaluation, and construction." A rating system, which was developed by RAC (SMEC/RAC 1995), has been found to be useful for the engineering assessment part of the PRA. The rating system is intended to minimize conservative biases which can be introduced into reconnaissance-level engineering assessments when insufficient information is available to make these assessments at a "sign off" level of confidence. While some measure of conservatism is desirable if the goal is to make a "final" determination of safety, too much conservatism can be undesirable in a PRA where a goal is to obtain a realistic appraisal of capital requirements for dam safety upgrades. Results of the engineering assessments are recorded using the following ratings:

- "Pass" (P) and "No Pass" (NP) ratings are given when sufficient information is available to make assessments with the normal level of confidence expected in current engineering practice

- "Apparent Pass" (AP) or "Apparent No Pass" (ANP) ratings are used to indicate the most likely outcome that is expected in the future when sufficient analyses and investigations have been completed to develop the normal level of confidence

Results of the engineering assessment may include the following:

- Engineering assessment ratings (P, AP, ANP and NP) for each dam for each loading (e.g. flood, earthquake, and static) -subsystem (e.g. emergency spillway, gate system, embankment, outlet works, and reservoir rim) category.

- Number of dams with each type of rating across the portfolio[13].

Risk Assessment of Existing Dams

Following the initial engineering assessment a reconnaissance-level risk analysis and evaluation is performed for each portfolio dam. A Failure Modes and Effects Analysis (FMEA) approach is used to identify most likely failure modes. Simplified event tree risk models are applied to estimate the probability of dam failure due to floods, including malfunctioning of spillway gates, and due to earthquakes. Static dam failure modes, due to such causes as piping, slope stability, and foundation failure, are typically estimated by adjusting historical failure rates.
Dam break and simplified flood routing are used to estimate the extent of inundation as a basis for the consequence assessment. Life loss and economic damages, including owner's business impacts, are assessed for flood and non-flood failure modes so that incremental consequences and risk can be estimated. Cascade failure modes and other common cause failure modes (Bowles 1987), which can affect more than one dam in the portfolio should be considered at an appropriate level of detail for the PRA. Probabilities and consequences associated with each type of failure mode for the existing dams are evaluated against the selected risk-based criteria[14].

Results from the risk analysis of existing dams may include the following:

- Probability of failure (/year)
- Incremental loss of life (lives)
- Incremental economic damages/financial liability ($)
- Probability of occurrence vs. incremental loss of life (life safety risk matrix)
- Probability of occurrence vs. incremental economic damages/financial liability (economic/financial loss risk matrix)
- Annual exceedance probability (AEP) vs. incremental loss of life (F-N charts)
- AEP vs. incremental economic damages/financial liability (F-$ charts)
- Incremental expected loss of life (lives/year)
- Incremental risk cost ($/year)
- Breakdown of portfolio risk by loading-subsystem categories

In the above list risk is characterized in various forms and not simply as an expected value (e.g. probability * consequences).
Risk analysis results for the existing dams are evaluated against risk-based criteria and the resulting ratings are presented. In some cases these ratings apply to individual types of loading [e.g. USBR(1997) Public Protection Tier 1 Guideline] and in other cases they apply to risk aggregated over all loading type [e.g. ANCOLD(1994) societal risk criteria]. Typically individual life safety risks would not be assessed as part of a PRA because the level of resolution of the assessment may not be sufficient to obtain a meaningful assessment. High risks should be identified for prompt evaluation of short term risk reduction measures such as operating level restrictions, increased monitoring and surveillance, and emergency action planning, early warning systems, and contingency planning[15].

Risk Assessment of Risk Reduction Alternatives

Structural risk reduction measures are developed and costed for each dam safety issue which does not satisfy either the engineering standards or the risk-based criteria. Structural measures should be developed to a reconnaissance level as logically separable construction packages. A single measure is usually developed rather than evaluating alternatives measures during the PRA since the resolution of the evaluation may not be sufficient for a meaningful comparison. For similar reasons, only complete fixes (i.e. to bring a dam to an engineering standards level) rather than partial fixes are typically evaluated in the PRA. The benefits of early warning systems (EWSs) can be evaluated in an indicative manner based on reductions in estimated life loss due to dam failure, as the result of assumed increases in warning time. In contrast, structural measures usually achieve life loss risk reductions by lowering the probability of dam failure. Event tree risk models should be adapted to represent each risk reduction measure. Results for each risk reduction measure can be presented in the same way as for existing dams and in other ways to convey information about the estimated amount of risk reduction. Examples of risk reduction information include the following:

- Changes in engineering ratings
- Changes in risk-based ratings
- Risk reduction vs. capital expenditures or time
- Cost effectiveness (i.e. risk reduction per $)

However, risk reduction is most usefully displayed after risk reduction measures are prioritized as discussed in the following subsection[16].

Prioritization of Risk Reduction Measures

A useful initial basis for prioritizing risk reduction measures is maximizing the rate of risk reduction. Such a criterion can be applied to the life safety, economic/financial or probability aspects of dam safety risk. The resulting prioritization can be used as the basis for development of a Dam Safety Improvement Program (DSIP) as discussed in the following section. The rate of risk reduction can be maximized by ranking measures in ascending order of cost effectiveness. An example of a measure of cost effectiveness for life safety risk reduction is cost per (statistical) life saved.

Risk reduction and residual risk can be characterized across the portfolio in the following ways:

- Probability of failure vs. cumulative capital expenditures for risk reduction measures
- Incremental expected loss of life vs. cumulative capital expenditures
- Incremental risk cost vs. cumulative capital expenditures
- Breakdown of portfolio risk reduction/residual risk by loading-subsystem categories
- Reduction in AEP of various levels of incremental life loss vs. cumulative capital expenditures
- Reduction in AEP of various levels of incremental economic damages/financial liability vs. cumulative capital expenditures

In a recent PRA, first priority was given to reducing life safety risks until a point of diminishing returns was reached, at about 98% of the standards-level life safety risk reduction, but only about 15% of the estimated total capital expenditures. When compared with the current prioritization for dam safety works, which was based on traditional

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"downstream hazard" assessment and professional judgment, this level of life safety risk reduction would not have been reached until about five times the capital expenditures which could be many years later. Second priority was given to reducing total economic/financial risks (i.e. direct and third party) in prioritizing remaining risk reduction measures.
Bowles (1995) reviewed traditional "downstream hazard" assessment from several countries and found internal inconsistencies in the approach. Also, because the risk (probability and consequence components) are not explicitly considered these inconsistencies can lead to inefficient risk reduction as demonstrated in the case history which was summarized in the previous paragraph. In addition, the traditional approach is frequently ineffective in providing a convincing justification for dam safety risk reduction measures, especially to non-technical managers[12].

APPLICATION OF PRA OUTCOMES

In the previous section we summarized the process which leads to development of the engineering and risk-based assessments of the existing dams and various risk reduction measures, and to the development of an initial priority for risk reduction measures. The application of other PRA outcomes is covered this section. The development of a Dam Safety Improvement Program (DSIP) is discussed in the first subsection. The use of PRA results in an overall Dam Safety Program (DSP) and other business processes are addressed under second subsection.

Development of Dam Safety Improvement Program

An important purpose of conducting a PRA is usually to provide a basis for designing a Dam Safety Improvement Program (DSIP). The goal of such a program should be to reduce risks associated with a portfolio of dams to tolerable levels, where "tolerable levels" may be defined using standards or risk-based criteria. In fact the visibility which conducting a PRA can give to dam safety issues within an organization, can create an opportunity to win senior management and Board support for addressing dam safety issues.
The principal elements of a DSIP are a) further engineering evaluations, and b) implementation of structural and non-structural (typically EWSs, but could include other measures such as relocating downstream residents) risk reduction measures. Evaluations should include engineering investigations and analyzes, including detailed risk assessments, of sufficient depth to achieve a "sign off" level of confidence in dam safety assessments and decision making, and to provide sufficient information for design of structural and non-structural measures.
The initial prioritization described in a previous subsection can provide a useful staring point for designing a DSIP. Such a prioritization should be reviewed and modified to consider practical resourcing issues associated with its implementation and various other factors which are driven either by internal business considerations (e.g. loss financing, business criticality, contractual obligations) or external factors (e.g. public protection/tolerable risk criteria, regulatory requirements, public perception, and environmental issues).

Risk reduction measures may be grouped following a "triage" process as a basis for establishing DSIP phases, as follows:

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- Group 1: Good justification to proceed - those measures that clearly have a strong Justification (e.g. as removing “unacceptable” risk ratings) which would not be expected to be affected by the uncertainties associated with the PRA.
- Group 2: Questionable justification to proceed - those measures for which justification to proceed is either moderate or uncertain and for which additional analyzes are needed to justify the decision on the appropriate level of residual risk to adopt.
- Group 3: Poor justification to proceed - those measures which have weak justification, even considering the uncertainties associated with the PRA.

We have also found it to be useful to identify “criteria thresholds” for use in formulating DSIP phases. Above a “criterion threshold” a particular criterion appears to be met by all portfolio dams. For example, a high priority phase might comprise all risk reduction measures which appear to be necessary to eliminate “unacceptable” risk ratings. We use such tentative wording to emphasize that the initial priority established based on the PRA is subject to confirmation and adjustment as the PRA is updated using the results of further investigations and analyzes. In fact, the opportunity for reduction of uncertainty (i.e. increasing confidence) should be a key factor in prioritizing additional investigations and analyzes.

In addition to prioritizing risk reduction measures and further engineering evaluations, it is necessary to decide what level of risk reduction will achieve an tolerable level of residual risk. As stated in the introduction to this paper, “The PRA approach is applicable and valuable whether safety levels are to be based on either a standards or a risk-based approach; and therefore using

PRA does not commit the owner or regulator to a risk-based approach for selecting safety levels.”

Bowles et al (1997) state that “the standards based approach can be thought of as a prescribed point on a continuum of different performance standards or design (evaluation) loading conditions. The risk based approach can be readily used to examine a range of these performance measures or loading conditions to evaluate the effects on reliability, consequences, cost effectiveness, and due diligence, of deviating from the standards based approach. In this way the risk based approach can be used to explore the appropriateness of a standards based approach.”

Thus, detailed risk assessment can be very valuable for assessing the justification for various safeties.

Bench marking information (e.g. cost-per-life-saved) is a potentially valuable to dam owners and regulators as they decide what level of risk reduction to target. At this time little such information is available to define what constitutes defensible ALARP or de minimize risk levels, for cases in which dam safety risk reduction measures are selected with the knowledge of this information.

Such information is available for other areas of public safety (e.g. OMB 1992). A dam owner who has performed a PRA, and who is implementing the highest priority phases of a DSIP, should consider sharing bench marking information with other dam owners so that each will be in more defensible position to justify the extent to which lower priority measures should be implemented.

It is sometimes stated that a risk-based approach should be considered because it might justify a less costly solution. We have evaluated several dams for which the opposite has been found to be true. These dams have been located in relatively densely populated areas with the result that estimated life loss is high for some sunny day failure modes and standard-based solutions do not appear to meet any of the currently proposed (life safety) societal risk criteria. In such cases combinations of structural and non-structural measures should be considered.

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Alternatively, this situation may raise the question as to whether a dam should continue to exist in such a location.
Thus detailed risk assessment should be an integral part of a DSIP to provide the information that is needed to make sound dam safety decisions. Bowles et al (1998) discuss the core role of dam safety risk analysis in an integrated dam safety program [16] & [17].

SUMMARY AND CONCLUSIONS

The portfolio risk assessment (PRA) process, using reconnaissance-level dam safety risk assessment procedures, provides a risk profile of a portfolio of existing. It can be used to assess the potential for reducing existing risks in a cost effective manner which can be expected to be more rapid than that which would be achieved using traditional dam safety project ranking procedures.
A PRA of a group of existing dams is based primarily on available information, without performing extensive additional analyses or investigations. As such it must be performed by experienced dam engineers. The resulting dam safety risk profile should become a "living document" which should be updated as improved information is developed and as risk reduction measures are implemented. Thus the PRA should be considered to be a baseline assessment with additional engineering work and detailed risk assessments programmed to confirm the need for specific risk reduction measures and their extent, to update the initial priorities based on the PRA, and to develop a "sign off" level of confidence, especially for any cases in which risk reduction is proposed to less than a standards level.
The PRA provides an initial prioritization of future dam safety investigations and potential structural and non-structural risk reduction measures. The basis for this prioritization is maximizing the rate of risk reduction through considering the cost effectiveness of risk reduction measures, and can be adapted to include considerations such as public protection, due diligence, business criticality, insurance, and the regulatory environment. Outputs from the PRA should be designed to provide information in a format that will be useful to the owner’s management (and Board) as they make important dam safety decisions. Outputs should provide a valuable basis for designing a dam safety improvement program regardless of whether it is proposed to use standards or risk-based approaches for justifying risk reduction measures. They should also provide a basis for integration of dam safety into the owner’s business processes such as project evaluation, capital budgeting, and loss financing.

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