RISK MANAGEMENT FOR DAM REHABILITATION PROJECTS

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ABSTRACT

Dam rehabilitation involves a wide range of design, construction, and operation risks, some of which are not encountered in new dam construction. These risks can have significant impact on project schedule and project budget. Owners, engineers, and contractors need to understand these risks.

Existing dams typically were designed in an era of design and construction standards that have been upgraded and changed. Modern standards will impact the construction approach taken and involve understanding the earlier standards. Knowledge of historical standards/practices as well as current design standards and construction methods is valuable for developing and designing rehabilitation components.

Construction records and as-built drawings are valuable when they are available. Rehabilitation projects often consist of older projects where as-built documents or construction records are not available. Where these records exist, many (most) times, they do not fully reflect the current conditions within the dam and appurtenant works, leading experienced practitioners to "expect surprises" both during investigation of the existing facility, as well as during construction. "Surprises" should be expected even when historical records of investigations, design and construction are available.

Unknowns, be they known unknowns or unknown unknowns, can be planned for by developing an approach for the design and construction process to identify potential issues/problems, or at least alert the designer and contractor of potential issues. A Risk-Based approach applied for the entire life of the rehabilitation project can be used to alert the parties of potential "surprises" and provide direction for mitigating issues as they arise. This type of approach is particularly effective when the process includes senior practitioners with decades of design and construction experience in all aspects of dams.

Minimizing impacts created by "surprises", particularly during construction, can result in an improved project meeting budget and schedule goals and design standards. This paper identifies and categorizes risk types salient to dam construction and provides a process that can be used by: Owners; Design Engineers; and Construction Managers, in planning, design, pre-construction and construction phases of dam related projects.

1. BACKGROUND

The dam safety profession is moving to a risk informed decision process that better prioritizes projects that have actionable failure modes with significant consequences. The goal is to reduce the risks to society and more efficiently utilize available funds. Assessments of the safety of dams are conducted using a risk assessment approach which provides input to risk informed decision making. The approach combines the evaluation of dam safety and consideration of engineering and construction guidelines, and evaluates the risk posed compared to tolerable risk guidelines. The former focuses on satisfying essential guidelines for a wide range of engineering considerations. The latter involves identifying credible and significant failure modes for a specific dam, quantifying their probabilities of occurrence and associated consequences, and evaluating the estimated risk of dam failure against applicable tolerable risk guidelines. Combining the two evaluation approaches and the breadth of understanding gained from both, well-reasoned recommendations are made for reducing risks to tolerable levels and to meet applicable guidelines. Achieving and maintaining tolerably low risk levels for dams typically requires structural measures in concert with an effective safety management regime, including staff training, operation and maintain, monitoring and surveillance, and emergency action planning.

Too often the project team is faced with construction or engineering challenges during both the design and construction phases and due to lack of integration of the design and construction phase teams, resolution of issues in either phase becomes problematic. Developing a systematic approach, with experienced people representing the design and construction disciplines can identify potential issues and mitigate them before they manifest themselves during the construction phase. This was the result that was identified during the investigations into the failure of Teton Dam. A key issue identified in that dam failure investigation was: "*contributing to the failure was the lack of interaction and communication between the design staff that designed the dam and the construction management forces.*" Construction personnel were not involved during the design phase and the engineering staff was not involved in the construction phase. This was the impetus for the U.S. Bureau of Reclamation to implement the "Total Design and Construction Process."

2. PROJECT RISK MANAGEMENT

The practice of dam construction and rehabilitation carries significant inherent risks that cannot be managed and/or mitigated by any one party. To manage risk reduction, the Total Design and Construction process provides opportunities for staging risk reduction actions identified using logically separable construction packages related to the risk items for consideration in the dam safety modification study phase. This approach also allows for prioritization of the risk items based on the degree of risk or urgency, at a specific project or among a portfolio of projects when an Owner owns multiple dams. The discussion below emphasizes the "Total Design and Construction Process" which strives to integrate design and construction teams throughout the design and construction phases for rehabilitation projects.

Formal Project Risk Management is the proactive practice of identifying risks, projecting their likelihood of coming to fruition, assessing their potential impacts, and developing mitigation plans. It has been demonstrated on past projects that proper management of risk helps identify appropriate project budgets and results in a higher quality project that meets stakeholder expectations.

3. IMPLEMENTATION OF PROJECT RISK MANAGEMENT FOR DAM CONSTRUCTION

Every project has a unique set of risks that could impact its scope, budget, schedule, and quality. Risk is categorized by three factors: risk event, risk likelihood, and potential impact. People normally equate risk with negative consequences; however, risks can present opportunities for positive results as well. The Project Risk Management process for dams generally consists of the following processes:

- Risk Identification and Categorization
- Risk Analysis
- Risk Mitigation
- Risk Monitoring and Updating

4. RISK IDENTIFICATION AND CATEGORIZATION

The first step in the project Risk Management process is to identify and categorize risks during the early stages of a project, preferably during the planning phase, but this process continues through completion of construction. The planning phase is an important phase of a dam project, because this is where most owners rely on project team to develop initial estimates of project scope, cost, and schedule. The owner typically uses project cost estimates to secure appropriate funding for design and construction of the dam project.

A typical risk identification and categorization process includes a formal project team workshop. This workshop is used by the project team members to identify risks from several sources including: lessons learned from similar projects, project team experience, understanding of the project, technical expert experience, current construction trends, and impacts to the current operation of the facility. The outcome of this effort is the development of a Risk Register which is discussed in more detail later in this paper. Risk categories generally consist of: Technical, Contracting and Construction, and Other. Some common risks identified in these categories include:

- Technical Risks
  - Hydrologic, seismic, geology/geotechnical, differing site conditions, structural design errors or omissions, weather, material shortages, etc.
- Contracting and Construction Risks
  - Inadequate bid period, selecting low bid; inadequate owner contingencies and funding; project team members (owner, engineer, contractor) with limited dam construction experience; shortages of skilled labor, equipment, materials, general services; pricing volatility; owner-requested changes during construction (scope creep); unexpected site conditions; inadequate quality control/quality assurance program; safety problems; incomplete or inaccurate schedule (precludes ability to identify issues); construction contract does not accurately describe work; inadequate information/schedule for contractor-required design items, etc.

- Other Risks
  - Team member turnover (personnel turnover); unexpected and/or extreme environmental requirements and/or regulatory demands; permitting delays; property access issues; public/political interruptions and/or work stoppage; security etc.

Risk analysis for projects is presented in various documents/publications and consequently this paper will not go in to detail. See References for select documents, including the USSD white paper *"Risk Management for Dam Construction", 2017.*

5. RISK ANALYSIS AND RISK REGISTER DEVELOPMENT

Once the risks have been identified, the next step is to perform risk analysis. The purpose of risk analysis is to quantify and prioritize the risks and allocate resources to address the risks that could potentially cause the most impacts to the project. To understand the seriousness of the risk, the likelihood of occurrence of the risk and its impact is developed. It is important when developing the Risk Analysis and Risk Register that the team consider the Total Design and Construction Process. The risk analysis team should include the owner, designer, permitting agent, and construction knowledgeable people.

A Risk Register provides an excellent tool to analyze and manage project risks. A Risk Register records the details of the risks identified at the beginning and during the life of the project, their grading in terms of likelihood of occurring and potential impact. In general risks are evaluated either qualitatively or quantitatively. Qualitative evaluation of risks is easier to perform and is best used for smaller projects or to perform initial evaluation of risks for larger projects.

The qualitative risk register describes:

- A unique identifier for each risk;
- A description of each risk and how it will affect the project
- An assessment of the likelihood it will occur and the possible impact if it does occur
- A grading of each risk according to a risk assessment table
- Who is responsible for managing the risk
- An outline of proposed mitigation actions
- A rough order of magnitude (ROM) estimate of the cost of the risk should it occur

SCHEDULE RISK REGISTER
LAKE ISABELLA DSMP

Color Code	Status	ID	Title	Meeting Date	Assignee	Time Horizon	Impact	Risk Prob	Mitigation Strategy
Red Alert Risk Items								**No of Risk Items in this Category:**	
Near Term								**No of Risk Items in this Category:**	
	Closed	1	Completion Borel Canal Cap	10/1/2018	Contractor	Near Term	High	100	Waiting for test Results
	Open	7	Crushing Plant	25/12/2018	Contractor	Near Term	High	100	Backward Pass & Weekly Schedule Reviews
	Open	5	Timely Completion of QA Lab	11/20/2018	Joint	Mid Term	High	80	Kleinfelder equipment calibration and validation
Mid Term								**No of Risk Items in this Category:**	
	Open	2	Service Spillway Abutment Wall	11/14/2018	Contractor	Mid Term	High	100	FDSJV to request demo prior 1st april/excavation submittal week of the 21st Jan
	Open	3	Start of Aux Dam Degrade	10/1/2018	Contractor	Mid Term	High	80	Backward Pass & Weekly Schedule Reviews
	Open	10	Mass Concrete	3/4/2018	Contractor	Mid Term	High	80	Weekly Discussion
	Open	9	Laberynth Weir	1/29/2019	Contractor	Mid Term	High	80	Discuss every week
Yellow Alert Risk Items								**No of Risk Items in this Category:**	
Near Term								**No of Risk Items in this Category:**	
	Closed	4	Construction of FG Extension	11/16/2018	Joint	Near Term	High	60	Waiting for test results
Mid Term								**No of Risk Items in this Category:**	
	Open	6	Construction Placement Window	8/1/2018	Contractor	Mid Term	High	60	Weekly Discussion
	Open	8	Dewatering Plan	8/1/2018	Contractor	Mid Term	High	60	Weekly Discussion
Blue Alert Risk Items								**No of Risk Items in this Category:**	
Near Term								**No of Risk Items in this Category:**	
Mid Term								**No of Risk Items in this Category:**	

COLOR INDEX

Probability	21 - 40	41 - 60	61 - 80	81 - 100
Impact	Unlikely	Possible	Likely	Almost Certain
High	Blue	Yellow	Red	Red
Med	Green	Blue	Yellow	Red
Low	Green	Green	Blue	Yellow
Resolved	Black	Black	Black	Black

TIME HORIZON

Near Term	[<=90 days]
Mid Term	[91 – 180 Days]
Far Term	[> 180 Days]

Page 1 of 1 *Tuesday, November 20, 2018*

6. RISK MITIGATION

The purpose of risk mitigation is to identify and implement a strategy to address moderate and higher risks identified. This is typically done by assigning a project risk owner who in collaboration with the project team develops a risk strategy to either avoid, mitigate, transfer, or accept the risk. Some risk mitigation strategy examples include: changing project scope to avoid or minimize risk, determining ways to transfer or share risks with the contractor such as adding bonus clauses or liquidated damages for critical milestones, and/or developing contingencies for the overall project budget for those risks that are out of a project team's influence. Contingencies are included in the Risk Register and are typically applied as "additional costs" needed to counter project risks that cannot be mitigated or are deemed as acceptable risks to take during project implementation.

Risk development, analysis, and mitigation should not be a one-time activity. The Risk Register should be considered a "living" document, that is reviewed by the risk team as the project evolves from the planning phase through the design and construction phases. And for many projects, post-construction risk analysis and mitigation can be important as well. A post-construction risk management program can be used to: (a) assure that stakeholder commitments have been met, (b) document lessons learned for future similar projects, and (c) update owners, policy makers (Boards and Councils) on the project status/outcome. This allows owners/policy makers to be more confident that a project is being effectively managed.

As discussed in the Background portion of this paper, the profession has recognized that the failure to properly address both risks and opportunities posed during the construction phase can result in serious economic consequences and loss of life. The resulting move by many entities towards a Total Design and Construction Process can be enhanced by including constructability reviews to supplement and inform the Risk Analysis team throughout the design phase.

Properly conducted constructability reviews are the integration of engineering and construction professionals in order to assess construction issues that may affect design. In most projects the review is performed to assure that the various elements of the project are buildable to the designer's intent. These reviews can result in design changes to simplify construction and reduce construction costs. However, as part of the Total Design and Construction Process, the project will benefit from the earlier involvement of construction professionals. There are four general areas or time frames when constructability reviews should be considered:

- During the development of engineering alternatives to address actionable failure modes
- During the feasibility design phase to aid in the selection of the preferred alternative
- During the completion of final designs of the preferred alternative
- During construction to address specific construction issues

Properly conducted constructability reviews will provide a more representative Risk Register during the design phase and following into construction, allowing the project team to adjust, fairly allocate risk ownership, and develop mitigation measures. An example of a project where constructability reviews were performed is summarized as a Case Study to illustrate these benefits.

7. CASE STUDY - ISABELLA LAKE PROJECT

This case study demonstrates the value of various approaches to constructability reviews that were successful in reducing overall project costs and identified risks to both the owner and contractor. The Isabella Lake Project is located approximately 1.5 km below the confluence of the North and South Forks of the Kern River in Kern County, California. The project consists of a 58 m high, 530 m long earth fill Main Dam across the Kern River, and a 30 m high earth fill Auxiliary Dam (Figure 1).

Figure 1 : Features of Isabella Lake Project near Bakersfield, CA

Isabella Lake Main Dam, Auxiliary Dam, Spillway, and Borel Canal had significant hydrologic, seepage, and seismic potential failure modes. The formulation of alternative Risk Management Plans (RMP) for the Isabella Dam Safety Modification Study was a multi-phased process over a 2-year period. Table 2 summarizes the dam safety issues associated the project and proposed engineering opportunities to address them.

Table 1 : Dam Safety Issues and Opportunities

DAM SAFETY ISSUES	OPPORTUNITIES
Hydrologic Overtopping and Erosion of the existing spillway	Increase Spillway Capacity with an Emergency Spillway, dam raise, line and treat the existing spillway
Seepage & Piping/Internal Erosion of the Main and Auxiliary Dam	Add Filters and Drains to the Main and Auxiliary Dam
Fault Rupture of the Auxiliary Dam	Add Filters and Drains to the Auxiliary Dam
Embankment Stability & Cracking of the Auxiliary Dam	Stabilize the Embankment & add Filters and Drains to the Auxiliary Dam
Structural Stability of Borel Control Tower & Conduit	Replace or Retrofit the Conduit and Outlet Control Tower

Engineering alternatives were developed and evaluated to identify the most suitable rehabilitation measure based on site constraints, technical feasibility and comparative cost. A list of the most suitable rehabilitation measures for each feature are summarized in Table 3.

Table 2 : Feasible Rehabilitation Measures to Mitigate each Potential Failure Modes

Rehabilitation Feature	Alternative Description
Emergency Spillway	-900-ft wide, straight crested Fusegate with a 4-ft dam raise -900-foot wide labyrinth spillway with a 16-foot dam raise
Auxiliary Dam Buttress	-80-ft wide downstream buttress the full width of the auxiliary dam with shallow foundation treatment -80-ft wide downstream buttress only over the fault zone area with shallow foundation treatment -100-ft wide downstream buttress the full length of the auxiliary dam with full depth foundation treatment
Borel Canal	-New tunnel through right abutment of auxiliary dam with control tower outside of shear zone -Retrofit existing canal -New tunnel connecting the main dam outlet works with 2 pumps
Main Dam	-Filter near dam crest with 4-ft dam raise -16-ft crest raise with full height filter and drain on downstream slope -4-ft dam raise with full height filter and drain on downstream slope
Existing Spillway	-Lining and treatment -Lining and treatment, anchor existing spillway, raise right wall 16-ft, retrofit intake tower for access with raised dam crest -Lining and treatment, anchor existing spillway, raise right wall 4-ft
Other Measures	-Retrofit main dam intake structure, control tower and outlet structure -Relocate Highways 155 and 178 to accommodate 16-ft dam raise

The six RMP's address different features of the project with alternate engineering solutions. Six RMP's (#1 through #6) were developed that addressed actionable failure modes and met risk reduction guidelines.

The six plans are summarized in Table 4.

Table 4 : Isabella Dam Rehabilitation Risk Management Plans

Feature/Mitigation Plan	#1	#2	#3	#4	#5	#6
Emergency Spillway						
900-ft wide, Fusegates with a 4-ft dam raise	X	X	X		X	
900-ft wide, labyrinth, with a 16-ft dam raise				X		X
Auxiliary Buttress						
80-ft buttress, full length of dam with shallow foundation treatment	X					
80-ft buttress, fault zone with shallow foundation treatment		X	X	X		
100-ft buttress, full length of dam with full depth foundation treatment					X	X
Borel Canal						
New tunnel right abutment, new control tower	X			X		
Retrofit existing canal		X	X			
New tunnel from outlet works with 2 pumps					X	X
Main Dam						
Filter near dam crest with 4-ft dam raise	X	X	X			
Full height filter/drain with 16-ft dam raise				X		X
Full height filter/drain with 4-ft dam raise					X	
Existing Spillway						
Lining and treatment	X		X			
Lining, treatment, anchoring raise wall 16-ft, retrofit intake				X		X
Lining, treatment, anchoring raise wall 4-ft					X	
Other Measures						
Retrofit main dam intake, control tower, outlet Structure					X	X
Relocate highways 155 and 178 for 16-ft dam raise				X		X

The Design team and the constructability review team developed construction schedules and analyzed sequencing of the proposed remediation measures. In addition, considerable time was spent reviewing construction cost estimates to ensure that production and cost assumptions were appropriate and supported by facts. As a result of the review refinements were made to the proposed construction method for the foundation treatment at the toe of the Auxiliary Dam along with the sequencing of the Borel Canal construction. The blasting assumptions for the excavation of the spillway were also evaluated and refined after receiving input from the blasting expert that was represented on the constructability review panel. The Constructability Review was judged to be extremely valuable by the Design team and resulted in a higher level of confidence in the various RMP's.

The results of this effort enabled development of a Risk Register that included the knowledge gained from the constructability review for the selected RMP implemented. In all projects, this initial Risk Register is to be updated throughout the project.

8. CONCLUSIONS

Rehabilitation of existing dams involves a range of design, construction, and operation risks, some of which are not encountered in new dam construction. These risks can have significant impact on project schedule and project budget. It is of critical importance that Owners, Engineers, and Contractors understand and communicate these risks during the design and construction phases.

The unknowns, be they known unknowns or unknown unknowns, can be anticipated by developing an approach through the design and construction process that may not fully recognized the appropriate issue/problem, but at least alert the designer and contractor of potential issues.

Minimizing impacts created by "surprises", particularly during construction, can result in a successful project meeting budget and schedule goals and modern design standards.

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