Tailings Dam Risk Mitigation Through Risk Informed Decision Making

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ABSTRACT

Given the risks potentially generated by a dam, produced by its probability of failure and additive cost of consequences, risk mitigation may be required. This paper shows how a proper Risk Informed Decision Making (RIDM) tool supports rational and sensible risk mitigation selection as requested by the Global Industry Standard on Tailings Management (GISTM). We use an anonymized case report to preserve confidentiality. To support rational risk mitigation roadmaps, first each possible single mitigative alternative and chain of possible mitigation steps are tested in comparison to the world-wide benchmark failures rate. Then each alternative's causality is split between Dam vs. Ancillary water system, including possible necessary creek protection to understand where optimum actions would be applied. This helps understanding where the mitigation sweet spot is and to evaluate the ratio between the annualized risk decrease and the mitigative CAPEX for each mitigation alternative. Furthermore, for each mitigation alternative and stage, the risk abatement "efficiency" can be evaluated. At the end the "optimal" roadmap can be selected considering constructional and regulatory constraints. The RIDM roadmap leads to select a defensible mitigation level (GISTM ALARP or better). RIDM fosters healthy and rational technical and risk perception discussion related to the level of risk mitigation that should be attained, based on GISTM ALARP. RIDM can also be used to foster healthy discussions with regulators and insurers as applicable and needed. The paper also discusses what the "legal test for negligence" adopted in some jurisdiction states and what different perception to risks means in terms of alterative selection.

INTRODUCTION

Given the risks linked to a dam, generated by its probability of failure and cost of consequences, mitigation may be required at present or during the closure and post-closure phases. In the past we have discussed how to quantitatively evaluate risks (Oboni 2021a), decide if a given dam constitutes a tactical or strategic risk (Oboni 2019a), and if mitigation is necessary (Oboni 2021b) based on explicit and formal definition of corporate and societal tolerance (Oboni 2016). The same quantitative approaches can be deployed to enable what-if scenarios and develop sustainable and efficient roadmaps (Oboni 2020) towards reduced risks. Let's note that in many aspects we preceded and exceeded the GISTM (GISTM 2020) requirements, especially if planning large portfolios mitigation during service or at closure. By focussing on assessing each alternative probability of failure (Oboni 2019b) and failure causality it becomes possible to understand how the dam system, i.e. the dam and ancillary structures, can be brought within or to better levels than the world-wide benchmark and within risk tolerance. One can also find the optimum ratio between the annualized risk decrease and the mitigative CAPEX for each mitigation alternative and/or stage. In general, the roadmap points to a defensible mitigation level (ALARP), as defined by GISTM (GISTM 2020). The results can also be used to foster healthy discussions with regulators, investors, insurers and the public. Let's note that GISTM introduces the notion of risk tolerance and acceptability when defining ALARP without actually offering any guidance. We opted for tolerance explicit formulation years ago (Oboni 2014 a b). Thus, the proposed quantitative approaches are compliant with GISTM and foster healthy and rational discussions between all stakeholders. Their deployment gives useful indications to select and optimize, if feasible from a constructional point of view, the phasing of the various mitigation stages during service life and at/beyond closure.

EXAMPLE OF A PRIORI DEPLOYMENT FOR MITIGATIVE DECISION MAKING SUPPORT.

Dam case story

The dam for this example is inactive and is parallel to a valley bottom. An unprotected creek runs at its toe and the bed is considered to offer sufficient protection against the 1/500 event. Beyond that flood, there will be progressive erosion of the dam toe. The dam was built with the upstream method. It has diversion ditches, drainage systems capable of carrying the 1/100 return. The area is not seismic and there is consensus the material is draining and not liquefiable. The spillway was reportedly designed for 1/500, but its present conditions do not allow to pass more than the 1/100 return flood. Due to past instabilities the dam was reinforced after geotechnical investigation, documentation, etc. Nevertheless, the estimated annualized system probability of failure (pf) of $1.07*10^{-2}$ (appx. 1.1%) per year places the dam well higher than the world-wide benchmark (Oboni 2013; Taguchi 2014) highest value. In other words, the dam is more hazardous than the world-wide benchmark. Estimated failure consequences C are evaluated at appx. 2B$ due to the presence of inhabitants, housing, infrastructure, river, and a relatively pristine environment downstream.

The owner and dam's EoR request

Given the pf and C the dam risk is corporately and societally intolerable in addition to falling in the "Extreme" consequences following GISTM. The dam also represents a corporate strategic risk following the tolerance threshold (not shown in this paper due to space limitations (Oboni 2014 b)). Thus owner and the EoR want to mitigate its risks and what-if mitigation scenarios must be produced to support risk informed decision-making. The EoR developed a number of possible mitigative stages increasing from minimal repairs to significant reinforcement of the overall system following six Alternatives (details omitted due to space limitation). The process consisted in systematically evaluating the risks for each mitigative stage, the related CAPEX and deriving risk abatement-mitigative investment graphs to determine the ALARP "point".

TAILINGS DAM MITIGATION RISK INFORMED DECISION MAKING

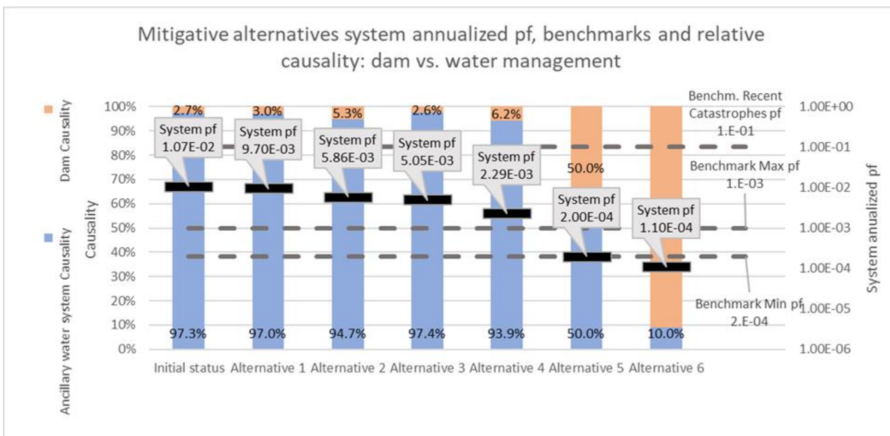

Figure 1 Causality of dam vs ancillary water system evaluation for different mitigations

Figure 1 displays each alternative's causality split between the Dam vs. Ancillary water system including the creek. These jointly cause the annualized System pf. The graph also shows that the ancillary water management facilities and the creek remain the preponderant failure causality for alternative 1 to 4 whereas alternative 5 and 6 would be driven by the dam's pf. As one can see, it is extremely difficult to bring this dam within or to better values than the world-wide benchmark (Oboni 2013; Taguchi 2014). The reason is simple: birth defects and nature of the materials. Furthermore, the dam will remain a strategic risk even in case of the most comprehensive mitigation implementation. The only way to make it nonstrategic would be to alter the system, i.e., for example alter the consequences of its failure. And of course, talking about consequences, if these are explicitly evaluated it is possible to express the risk and the associated mitigative costs for each alternative, allowing for risk estimates for each alternative, evaluation of risk differential and efficiency. Going back to pf, Figure 2 (left) shows the system pf cumulated decrease as a function of the mitigation alternative/stage. Note the minimal estimated advantage in pursuing mitigation beyond a certain stage (decision support comes later), unless it is mandatory for jurisdictional compliance. Remember, Figure 2 (left) shows the changes in terms of relative pf, and not in terms of risk. As stated earlier, if our quantitative approach had been deployed in parallel with the engineering studies risk-informed decision-making (RIDM) support to design would have been possible, i.e. the selection of mitigative alternatives and the return optimization (Oboni 2017). Once the risks are included together with the costs of each foreseen mitigative step, a true cost benefit analysis can be activated as shown Figure 2 (right). The crossing of the two curves, i.e. risk and mitigation cost vs. mitigation level, represents the “optimum”. The GISTM conformance documents (Figure 9 in that document) indicated that point as the ALARP point, but we would rather call it the lower bound of the ALARP range. In this specific example the GISTM ALARP appears with a mitigation level between stage 1 and 2, so mitigation stage 2 would be selected out of prudence if there were no jurisdictional compliance issues (e.g. seismic compliance) to be respected and no public perception considerations.

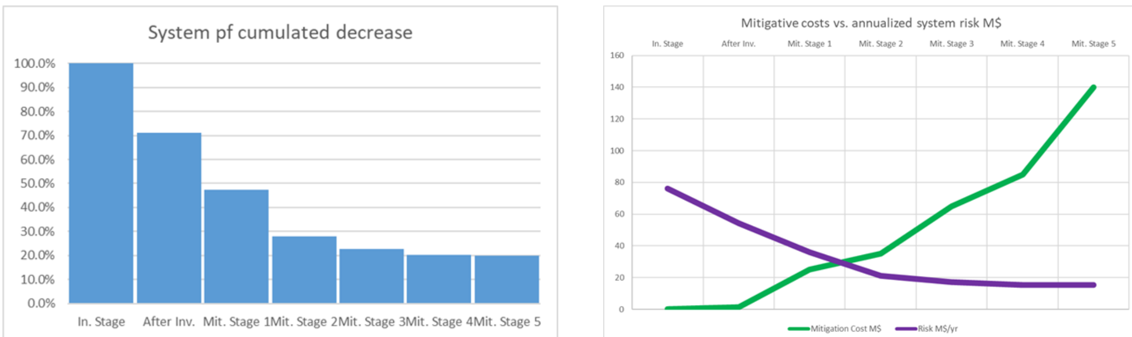

Figure 2 (left) Pf cumulated decrease **(right)** Risk and mitigation cost vs. mitigation level

As a side note, the crossing point corresponds to what the “legal test for negligence” adopted in some jurisdiction states (Oboni 2021 a). Following that test a company is not legally negligent if the annual mitigation expenses match at least the annualized risk generated by the considered facility. Indeed, following the “legal test for negligence” the negligence of the injurer (company) is determined by relations between the probability of injurious event (p), the consequences of the resulting injury (C), and the burden, or cost, of adequate precautions or mitigations (M); that means the injurer is only negligent if M is less that the product of p by C. In other words, a judge may deem a company negligent only if mitigative moneys M spent (CAPEX or per annum) are less than the annualized risks. However, the legal negligence test is not a critical test for an operation when confronted to risk perception and public reactions. Indeed we saw the SLO of many operations and companies being revoked (Boutilier 2014) as a result of more stringent pubic perception conditions (Berger 2011).

Perception discussion

The discussion boils down to: “is selecting mitigation stage 2 enough from a pure risk-engineering point of view, if we do not consider jurisdictional issues?” The perception of some stakeholder could easily be that the dam risks should be mitigated “anyways” to stage 3 or 4 or higher despite the high CAPEX of stages 1, 3 and 5 (Figure 3 (left)). In this example, the mitigation costs follow a steeper than linear evolution across the mitigative stages (Figure 3 left). As the paramount importance and benefits of building the knowledge base have already been shown in prior papers such as (Oboni 2021c) it is now time to focus on the other stages in order to answer the question above. Figure 3 (right) shows that after stage 2 the mitigation efficiency strongly decreases. The owner and the EoR could easily argue at this point that if there are no specific regulatory issues to be complied with, any mitigation beyond stage 3 would be too inefficient, which also corresponds to the reaching of the horizontal asymptote of the system pf (Figure 2). Indeed, as stated above, if stage 2 complies with the

GISTM minimum ALARP criteria and the legal negligence test, it is also true that the horizontal asymptote of the system pf is only reached at stage 3. Thus our deployment would offer a solid ground of discussion and negotiation (with the public and regulators, and, if applicable, with insurers) to state that stage 3 represents a possible choice for risk mitigation level. Going beyond stage 2 requires, based on the costs we have assumed for this example, a sharp investment increase for what seems a modest risk mitigation gain. Note, in some cases this reasoning could bring to propose different sequences (as possible and feasible) of the stages to seek better CAPEX allotment. Ultimately this deployment example, using assumed initial knowledge and mitigation costs, shows that our quantitative approach can be used in full conformance with GISTM to foster healthy and rational discussions between the stakeholders. The deployment can give useful indications to select and optimize, if feasible from a constructional point of view, the phasing of the various mitigation stages. It can foster healthy technical and perception-based discussion on the level of risk mitigation that should be attained, based on GIST ALARP concept, the legal negligence test and finally the mitigative stages "efficiency". The first stage in any mitigation approach will always be to build a solid knowledge base on the considered system. Building the knowledge base will reduce uncertainties and hence allow to approach the "base case" with more confidence.

Figure 3 (left) Stepped mitigation increase **(right)** Efficiency of the mitigation stages: Ratio between the annualized risk decrease and the mitigative CAPEX at each mitigation stage

CONCLUSION

We showed that one can use our quantitative risk assessment approach in full conformance with GISTM. The process gives RIDM indications to optimize, if feasible from a constructional point of view, the phasing of the various mitigation stages and alternatives. It can foster healthy and rational internal and external communication on the: i) RIDM level of risk mitigation, conforming with GIST minimum ALARP concept and beyond, ii) legal negligence test and finally the iii) mitigative alternative risk informed "efficiency".

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