A systemic look at tailings dams failure process

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ABSTRACT: Tailings failures are on the radar screen of regulators, engineers and the media at least since the mid 70s. The Authors of this paper have performed quantitative risk assessments of mines, often featuring multiple active tailings dams, for over 20 years and have reviewed numerous qualitative and semi-quantitative risk assessments (FMEA etc.), oftentimes paired with peer reviews and inspections. After each failure the mining community sees codes evolve and imposes tougher criteria and dam specifications while FMEA remains the common practice risk assessment methodology. FMEA lacks the finesse needed to predict the progress “toward zero failures” goal. The effects of today's risk mitigation programs will only slowly become visible because the world-portfolio will contain mitigated and unmitigated (legacy) dams. During that time the public will perceive at best a status-quo. It will be very difficult to evaluate progress, as factors such as climate change, seismicity and increase in population will further complicate the situation. Thus public outcry and hostility toward the mining industry, fueled by the diffusion of Information and Communication Technology will likely increase. In this paper we present a systemic approach of the “failure chain process” of tailings dams using a probabilistic causality analysis based on publicly available incident and accidents data from the last 60 years. The predictive model, geared toward filling the gap between common practice and “path to zero failures” requirements, accommodates data-mining analytics. The model “constructs” the probability of failure of a dam which is consistent with factual historical world-data. The causality of various factors entering in the dam's service life can then be individually discussed with a sensitivity analysis. We then show where and how mitigative actions can benefit the most with practical example. Attention is focused on Common Cause Failure (CCF) in operations, risk assessment, peer reviewing and inspections of tailings dams.

1 INTRODUCTION

The Report of the TSM (Towards Sustainable Mining) Tailings Review Task Force (2015) states in its preface: “... The tailings failure that occurred on August 4, 2014 at the Mount Polley Mine - owned and operated by Imperial Metals, a member of the Mining Association of Canada (MAC) - led the Board of MAC to ask: "Are there improvements in the tailings protocols under Towards Sustainable Mining (TSM) that could have prevented this tailings spill?” MAC's TSM initiative was developed starting in the late 1990s, after the Canadian mining industry faced an erosion of public confidence following a series of tailing spill incidents. In the face of these incidents, members of MAC embarked on a collective initiative to improve performances and ensure public and environmental safety. After years of development in consultation with communities of interest, TSM was officially launched in 2004.

In this paper we present a systemic approach of the “failure chain process” during the service life of dams. Investigations, Design and Construction and then Management, Monitoring & Water Balance control (e-IDC) of the dam are analyzed with a probabilistic causality analysis based on publicly available incident and accidents data from the last hundred years. The predictive model, geared toward filling the gap between common practice and the "path to zero failures" goal (Independent Expert Engineering Investigation and Review Panel, 2015), accommodates data-mining analytics. The model "constructs" the probability of failure of a dam which is consistent with factual historical world-data. The causality of various factors entering in the extended IDC process (e-IDC) and other elements in the dam's service life can then be individually discussed with a sensitivity analysis. We then show where and how extended IDC process mitigative actions can benefit the most, with practical example. Special attention is spent on Common Cause Failure (CCF) in operations, risk assessment and peer reviewing and inspections of tailings dams. CCF means that a "hidden" shared cause may lead parallel components to fail, annihilating the theoretical redundancy they have (or were designed for) (Mahesh, 2014).

2 PRIOR PAPERS ON PREDICTIVE PERFORMANCES OF TAILINGS DAMS

Past and future probabilistic failure behavior of tailings dams has been studied and published respectively in 2013, 2014 and 2015 at the Tailings and Mine Waste conferences (Oboni, Oboni, 2013; Oboni et Al, 2014, Caldwell et Al, 2015) to provide quantitative measures to the predictive performances and various mitigation measures and levels of risk of tailings dams. As this paper constitutes the logical extension of the prior ones it seems useful to summarize the previous steps.

At Tailings and Mine Waste - TMW 2013 (Oboni, Oboni, 2013) we attempted the first estimate of the rate of failure of major tailings dams and compared their risks to human life to well known social tolerance. After stating the limitations of the available data and the lack of clear definition of what constituted a major failure in commonly available statistics, we found rates varying between 10^{-3} (decade around 1979) to $2*10^{-4}$ (decade around 1999) major failures per dam year. In the same paper we showed quantitatively how, over time, multiple hazards hit would significantly increase the probability of failure of a dam and lead to intolerable future risks. The paper concluded "... Especially in the case of TDs located in areas where demographic pressure leads to settlements in the downstream areas, social and legal consequences of a failure will dramatically increase. This will particularly be the case if the methodologies used to perform the risk assessments prove to be in disconnect with the needs of our modern society."

The theme of the long term survivability of TD was further detailed at TMW 2014 (Oboni, Oboni, Caldwell 2014) where attention was focused on modeling the aging process of a geostructure as a series of discrete hits by hazardous conditions (these could be anything, from an earthquake to flooding, etc.). In that paper an attempt was drafted at multidimensional estimate of future consequences. The paper stated that "... Should the value of consequences increase, ... then the "excellent dam" would soon pose a societally unacceptable risk even for shorter terms. Any dam that starts its life with a small initial FoS or reduced standards of care (...) would see its risk evolve towards intolerable societal risks faster, even if its consequences of failure remain constant. ... the methodology developed in this paper enables us to "measure" and give a sense to a complex problem, to transparently compare alternatives, to discuss rationally and openly the survival conditions, or to evaluate the premature failure of a structure. The only way to slow down the increase of the probability of failure is to repair damage occurring as a result of each hazard hit, or to entirely avoid the damage. The second is generally "not feasible" for economic and constructional reasons. Risks, especially long term ones, can never be reduced to nil."

Finally, at TMW2015 (Caldwell, Oboni, Oboni, 2015) we were delighted to examine the result of a new study of tailings dam historic failures (Bowker, Chambers, 2015) which used detailed data and actuarial techniques to define historic rate of failures of tailings dams after attempting to define what constitutes "serious" and "very serious" TD failures. We stated that "... The common practice approach of using oversimplified consequence functions (with "and/or" clauses as just defined above) is often used in research papers because of scope/budget limitations, but should not be accepted for a rational world-wide approach to decision making and tailings risks management for an industry that has significant societal impacts like mining. Tailings accidents generate multiple direct and indirect consequences on the environmental, human, H&S, operational and reputational areas and we believe it is time for the mining industry as a whole to adopt a uniform consequence function.” Our paper concluded that “... It is comforting that the results of the “quick and dirty” 2013 (Oboni & Oboni) study reached globally comparable results to the 2015 (Bowker & Chambers) very deep and solid analytical approach. We note that the selection of the time frame has a large influence on the conclusions of the 2015 study and therefore we recommend these comparative studies to be performed with constant duration (for example decade by decade) to avoid the hazard of drawing misleading conclusions. “Averaging” over 70 years, during which so many conditions have changed, may indeed mask decennial spikes. To prove this it is enough to note that the accident rates have actually decreased by 15%-24% from the 1990-1999 to the 2000- 2009 decades using the 2015 study's own data.” The paper concluded “... We reiterate that the aim of zero tailings failures is impossible to achieve. Tailings dams will continue to fail. In fact, in the long term all tailings facilities will spiral toward significant increases of their probability of failure and when they fail the tailings will go to downstream rivers, lakes, and the ocean as they did at every failure to date. We have demonstrated that consequences are not necessarily correlated, in one way or another, with dam height or pond volume. As in many industries the “scary stuff” is not necessarily the riskier one. Our practice and research have shown that the probability of failure is, or will be, often way higher in smaller structures than in major ones, simply because more care is taken for larger structures than for “insignificant ones”. Examples like Stava or Bafokeng are there to show that “extreme” consequences can actually occur. We have also demonstrated that the rate of fatalities in the tailings “industry” lies way above the generally accepted “safe” thresholds for hazardous industries. The number of existing, operational, and closed tailings storage facilities around the world makes it necessary to prioritize the mitigation tasks, if we want to achieve a higher quality, be it at corporate or at national levels.”

3 DESIGN PROCESS AND COMMON PRACTICE RISK ASSESSMENT

After each failure the mining community sees codes evolve and imposes tougher criteria and dam's specifications (TSM Tailings Review Task Force 2015). Factors of Safety (FoS) are eventually increased by empirical consensus among experts, whereas risk assessment methods have generally remained unchanged over almost half a century.

The relation between FoS and the probability of failure is often misunderstood, together with the multidimensional nature of potential damages to the environment, infrastructure and human beings. Codes that allow designers to use, for example, FoS=1 under some pseudo-static seismic condition (CDA 2014, Table 3-5) actually accept that a tailings dam undergoing that seismic event would have the same chance of surviving/failing than a coin toss (p_f=0.5). If the considered quake has a probability of 1/100 then the estimate of the risk under seismic loading would be p_{fs}=0.5/100=5*10^{-3} times the consequences of the failure (annually), respectively 10^{-3} times the consequences, if the quake has a probability of 1/500 annually. These are certainly not safe conditions with respect to public expectation or published tolerance thresholds (Oboni, Oboni, 2013). FMEAs (PIGs) remain the common practice risk assessment methodology (Oboni, Oboni, 2012) despite their know limitation and misleading aspects (Chapman, Ward, 2011; Cox, 2008; FAA, 2002; Hubbard, 2009; NASA, 2007). FMEAs lack the finesse needed to evaluate or predict the suggested progress “toward zero failures”. Furthermore FMEAs do not help bringing any significant conclusion when comparing alternatives, cannot measure the efficiency of the (potential) mitigative measures implementation and compare them against themselves or even just determine if they are sufficient.

Finally, a significant number of risk studies we review do not start with a tailings system definition, its functional analysis and they confuse hazards, risks and consequences (Oboni et Al. 2016) leading to misleading results. It is for example rather common to see “insufficient FoS” considered as a hazard (or a risk), whereas such deficiencies are generally the result of deliberate human choices (excessive audacity, errors and omissions, insufficient efforts). In this paper we will take a rather extreme, but logical, line of thinking, stating that dams failures find, in the vast majority, their root-causes in human choices and not in natural events.

At the center of this reasoning there is the concept of credibility threshold. Many industries consider the limit of credibility at around 1/100,000 to 1/1,000,000 (10^{-5} to 10^{-6}) (Comar, 1987;

Wilson & Crouch, 1982; Renshaw, 1990), so it can be stated that any event above that limit is not an “Act of God” (or, following modern times buzz-words a “Black Swan”) and should therefore foreseen/planned for. We will also note that, reportedly, the vast majority of dam failures has occurred for other causes than “Black Swan” natural events, but again for “chains” of gradual deviances, which become “normalized” over time, stemming from investigations, design, construction, management and long-term monitoring.

4 FUTURE PERFORMANCE OF THE WORLD-WIDE PORTFOLIO

Given the nature of the structures under consideration, their construction time and expected service life and closure, the effects of today's risk mitigation programs will only slowly become visible because the world-portfolio will contain mitigated and unmitigated (legacy) dams. During that period the public will perceive at best a status-quo and the industry credibility and social license to operate (SLO) will remain at stake (Oboni, Oboni, 2014; Oboni, Oboni, Zabolotniuk, 2013).

It will be very difficult to evaluate progress. Factors such as climate change, seismicity (again, not necessarily “Black Swans”), increase in population and environmental awareness (consequence side of the risk equation) will further complicate the situation. Thus public outcry and hostility toward the mining industry, fueled by the Information and Communication Technology diffusion will likely increase and lead to prosecutions and larger fines. Due to the same influencing factors negligence and Force Majeure implications will certainly drastically change in the coming decades.

5 A SYSTEMIC LOOK AT TAILINGS DAMS FAILURE PROCESS

The elements described above show the need for a systemic approach of the “failure chain process” through Investigations, Design and Construction (IDC) of Tailings Dams and then service life Management and long term Monitoring, which we will call e-IDC (for extended IDC).

For the discussion in this paper we have opted for a probabilistic causality analysis. Publicly available incident and accidents data from the last hundred years were used. The predictive model is geared toward filling the gap between common practice and “path to zero failures” goal and accommodates data-mining analytics and future “lesson learned” that could make it possible to perform Bayesian updates (Dezfuli et Al. 2009) after the first estimates (after the a priori estimate).

The model has to include Common Cause Failure (CCF) (Stott et Al., 2010) in operations, risk assessment, peer reviewing and inspections of tailings dams, at least in a simplified way, for the sake of completeness and explicit inclusion of conflict of interest and complacency (Oboni et Al., 2013).

5.1 *The Reliability Model*

Engineering structures (and machinery, but also processes, including e-IDC processes) are systems consisting of a number of structural/physiological elements that can individually fail. The way elements are connected and their reliability X_j, where $X_{j_j}=1-p_{fj}$ define the reliability of the whole system (eq. 1,2). For a series system (eq. 1), failure of an element results in failure of the whole system. Reliability of the system is the product of the reliabilities of its elements. Equivalently, the system fails if any component fails.

Success:

$$\overline{X} = \prod_{1}^{N} \overline{X}_j \qquad (1)$$

A parallel system (eq. 2) is a redundant system that is successful, if at least one of its elements is successful.

Success:

$$\overline{X} = 1 - \prod_{1}^{N} (1 - \overline{X}_j) = \coprod_{1}^{N} \overline{X}_j \qquad (2)$$

For the e-IDC we have identified in Figure 1 four different functions (Geotechnical Investigations, Engineering, Construction, Management (including Water balance), Monitoring) constituting the chain of elements responsible for success/failure of a dam.

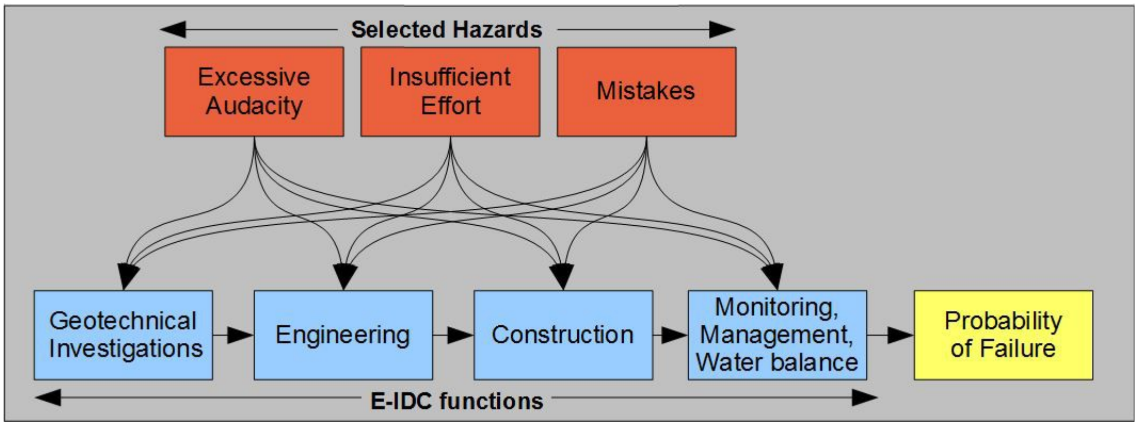


Fig. 1 Functional scheme of the e-IDC with the hazards selected for this study.

Various hazards are lurking on each element (Figure 1) such as, in the specific approach adopted in this paper: Insufficient effort, Mistakes, Excessive Audacity, etc. leading to a probability of failure p_f for each element evaluated using a reliability model (eq. 1,2). The chained elements can then be evaluated using, again, a reliability model (series (eq. 1) in the case depicted in Figure 1). The list of selected hazards should be discussed project by project.

Modes of failure previously identified in the literature (COLD, UNEP, WISE, USCOLD, and USEPA) due to the hazards selected in Figure 1 are (Fig. 2):

Slope Instability,
Earthquake and Mine Subsidence,
Overtopping,
Foundation,
Seepage and Structural.

5.2 *The data*

As pointed out in our prior papers, data on tailings failure is scarce, sometimes tainted by biases and censorship, and spread through various entities and databases of variable reliability (for example, notice in Fig. 2 the very large number of "unknown" causes). In prior papers we adopted a "quick and dirty" engineering approach to estimates, preferring to rapidly gain an understanding for the order of magnitude of the estimate rather than waiting to get very precise "true" numbers. We saluted the actuarial effort published in 2015 and were delighted to notice that our prior estimates had framed the more precise numbers with good agreement, although we commented on some unfortunately "forced" linear regressions drafted by various authors and to the tendency to use variable time intervals to jump to conclusions.

In this paper we ensure coherence with our prior, now proven correct, "quick and dirty" engineering approach, but decided to also include uncertainties by using two different sets of causal lists, namely those resulting from ICOLD 1994, respectively from a 1910-2009 compilation (Azam, 2010).

5.2.1 *Failures reported by ICOLD 1994*

For the sake of this study it was necessary to re-interpret literature data. Readily available literature generally reports Number of Failures vs. Cause of Failure (Fig. 2, Fig. 3) and is fraught by many “unknown causes” or statements like “unusual weather” that leave great space to conjectures. This study requires to attribute causality of the failures to the various phases of the e-IDC process, so that the model becomes amenable to analyses. Of course, should in the future detailed data on causality of failures become available, they could be readily included in the model and many assumptions made could be released/replaced.

Out of a total of 106 recorded failures (Fig. 2), 87 are from known recorded causes (column 1 of Table 1) which were re-interpreted as described in Table 1.

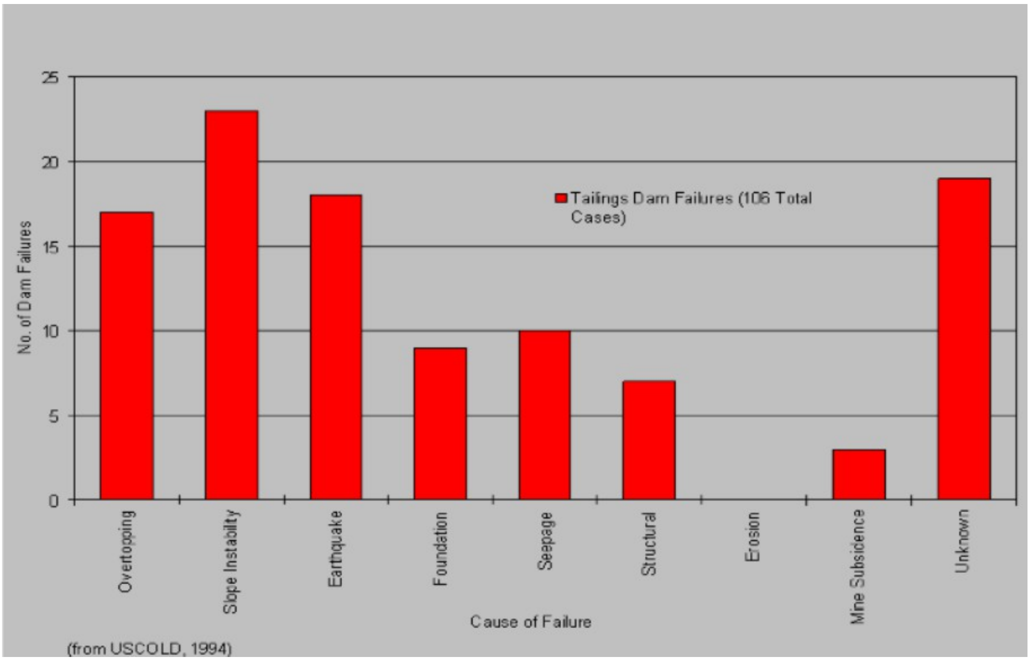
Table 1 Recorded cause of failure, attributed causality scenario and related recorded failures number (from USCOLD 1994, Fig. 1).

Recorded Cause of Failure	Attributed Causality Scenario	Recorded Failures Number
Slope Instability, Earthquake and Mine Subsidence	Engineering error & omission, excessive audacity	23+3+18=44
Overtopping	Poor management (mostly over in this example as a life time flaw rather than an initial one)	17
Foundation	Poor Investigation	9
Seepage and Structural	Poor Construction	10+7=17
		TOTAL = 87

5.2.2*Failures world-wide 1910-2009 data*

The data in Figure 3 are a compilation (Azam, 2010) from the following sources:

1. United Nations Environmental Protection (UNEP);
2. International Commission On Large Dams (ICOLD);
3. World Information Service of Energy (WISE);
4. United States Commission On Large Dams (USCOLD); and
5. United States Environmental Protection Agency (USEPA).



(from USCOLD, 1994)

Fig. 2 Dam Failures vs. Cause of Failure from USCOLD 1994.

The same re-interpretation described in the prior section was performed for the 1910-2009 data.

Out of 167 recorded failures 145 are from known causes, 22 from unknown causes, which were re-interpreted as described in Table 2.

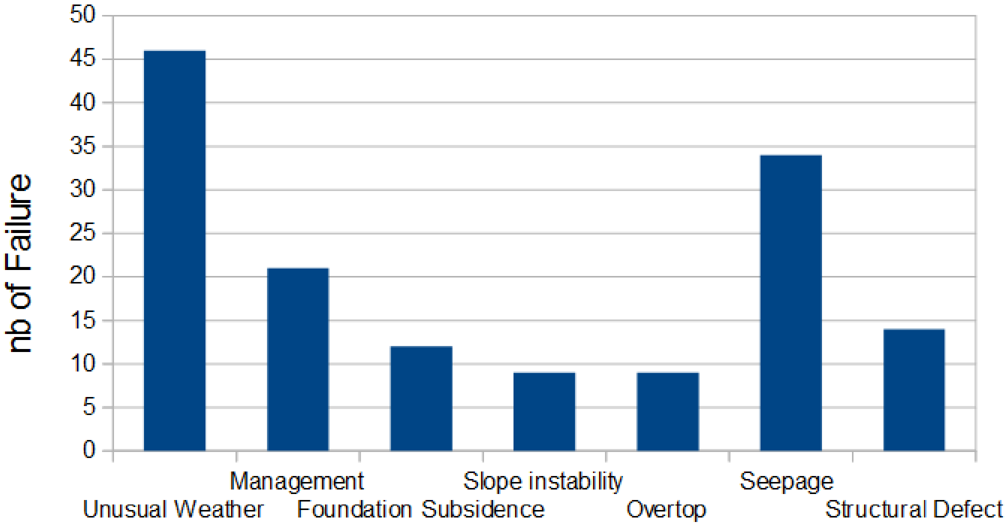


Fig. 3 A recent compilation of Number of Failure vs. Causes from various sources (Azam, 2010)

Table 2 Recorded cause of failure, attributed causality scenario and related recorded failures number (from Azam (2010), Fig. 2).

Recorded Cause of Failure	Attributed Causality Scenario	Recorded Failures Number
Slope stability	Engineering error & omission, excessive audacity	9
50% Unusual Weather	“	23; total of 2 lines= 32
Management	Poor management (mostly considered in this example as a life time flaw rather than an initial one)	21
Overtopping	“	9
50% Unusual Weather	“	23; total of 3 lines=53
Foundation Subsidence	Poor Investigation	12
Structural Defects	Poor construction	14
Seepage	“	34; total of 2 lines=48
		TOTAL = 145

5.2.3 *Attributed Causality Scenario relative split for initial flaws*

Using the data of Table 1, 2 it was then possible to define a relative (%) split of Attributed Causality Scenario stemming from project inception (Table 3).

For ICOLD (Table 1) overtopping had to be removed (as it was attributed to management during lifetime) leaving us with 70 recorded failures with “known” causes.

For world-wide 1910-2009 data (Table 2) we eliminated poor management for the same reasons as above. Quake remained in the counting because the design should be considered as faulty from the beginning with respect to that loading if the dam fails under seismic loading.

Table 3 Attributed Causality Scenario stemming from project inception.

Attributed Causality Scenario	ICOLD		World-wide 1910-2009 data	
	Recorded failures	Failures in %	Recorded failures	Failures in %
Poor investigation	9	13	12	13
Engineering error & omission, excessive audacity	44	63	32	35
Poor Construction	17	24	48	52
Total	70	100	92	100

We note a rather wide difference in the percentage split of causality, due to the database poor quality, requiring the study to proceed with both values to include uncertainties.

5.3 *The Mitigations Models*

In this study we considered two possible types of mitigations M1, M2 to be implemented during the e-IDC development, i.e. Independent Peer Review and Inspections described as follows:

M1: Engineering performance can be enhanced with an independent peer review (including sensible risk based decision-making procedures and risk assessment from project inception). Engineering and Peer Review become a parallel subsystem (eq. 2, Fig. 4) possibly fraught by Common Cause Failure (CCF).

M2: Monitoring, Management, Water balance function can be enhanced with Inspections paired to sensible risk based decision-making procedures and risk assessment from project inception. Again CCF has nefarious potential on this additional parallel subsystem (eq. 2, Fig. 5).

Adopting a very simplified approach to CCF it is possible to assume that insufficient rigor, complacency, conflict of interest, common excessive audacious approach in M1, M2 could reduce the expected positive result of any mitigation to nil.

Four levels of mitigation (Fig. 1,4,5,6) were studied:

A) Base case with no M1, M2, depicted in Section 5.1, Figure 1.

B) Base case with M1, i.e. independent peer review (including sensible risk based decision making procedures and risk assessment from project inception).

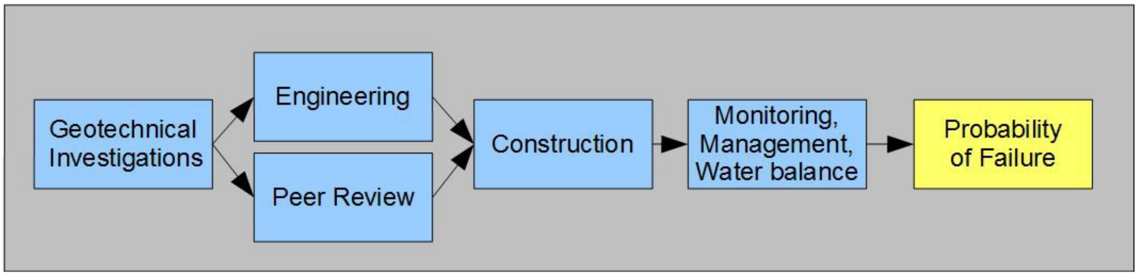


Fig. 4 In case -B- the base case is mitigated with M1=Peer Review during Engineering.

C) Base case with M2, i.e. Inspections paired to sensible risk based decision making procedures and risk assessment from project inception.

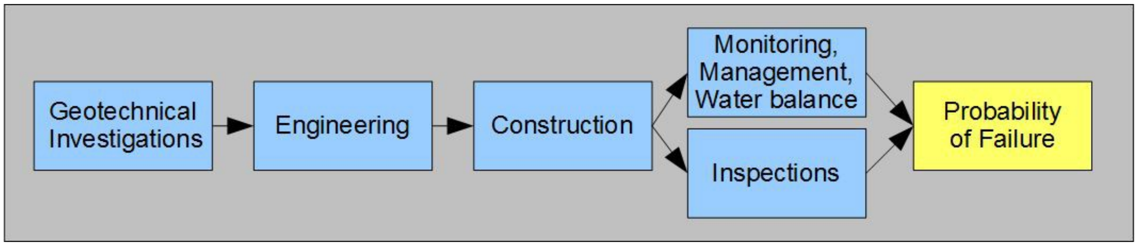


Fig. 5 In case -C- the base case is mitigated with M2=Inspections during service life.

d) Base case with M1, M2 (descriptions as above) implemented.

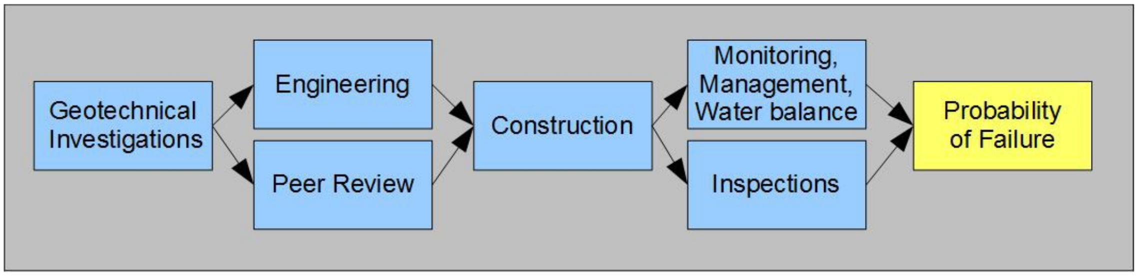


Fig. 6 In case -D- the base case is mitigated with M1=Peer Review AND M2=Inspections.

By using ICOLD and World-wide 1910-2009 data (Table 2, 3) and the various mitigation variants of the model described above it was possible to evaluate the probability of failure of the dam under the considered hazard selection for a selected average life span of 30 years. In order to perform the calculations one further step was necessary as the probability of each hazard hitting a function had to be determined.

The first framing was easy: all those probabilities lie in the range 10^{-2} to 10^{-4}. The higher value corresponds to a threshold where insurers generally shy away from insuring (thus any engineering/construction accident likely has a lower probability of occurrence), and 10^{-4} is a rate one order of magnitude above the higher bound of credibility (as engineering/construction accidents are unfortunately well into the credible realm).

The second framing required to calibrate the model based on the data derived causalities (Table 1, 2, 3). Finally the probabilities were annualized.

4.4 Results

4.4.1 *One dam, various levels of mitigation*

Figure 7 depicts the results of the analyses for the four levels of mitigation (Fig. 1,4,5,6) A,B,C and D. In Figure 7, the horizontal dotted/dashed lines “1979” and “2000” depict the framing estimates thresholds we published in the 2013 TMW paper (Oboni, Oboni, 2013). It is interesting to compare the results of the various mitigative levels (A,..D) to those thresholds.

The Base Case (A) and B: Base Case and Peer Review (including sensible risk based decision making procedures and risk assessment from project inception) have calculated probabilities of failure in the vicinity of 10^{-3}, i.e. the factual estimated rate we published in our prior paper (Oboni, Oboni, 2013) for the decade around 1979.

Case C: Base case and Inspections (over the life of the structure paired to sensible risk based decision-making procedures and risk assessment from project inception) leads to a value near to the mid-point of the values for 1979 and 2000, bordering with the higher estimate from the most recent data (Oboni et Al, 2015, Bowker, Chambers 2015), for the Serious and Very Serious failures.

Finally, Case D with Peer Review and Inspections reaches the lower bound of the interval, i.e. the value we published for the 2000, very similar to the lower estimate from the most recent data (Oboni et Al, 2015, Bowker, Chambers 2015) for the Very Serious failures.

Absent or botched mitigations M1 and/or M2 can increase the value of the probability of failure to historic high (decade around 1979) due to CCF.

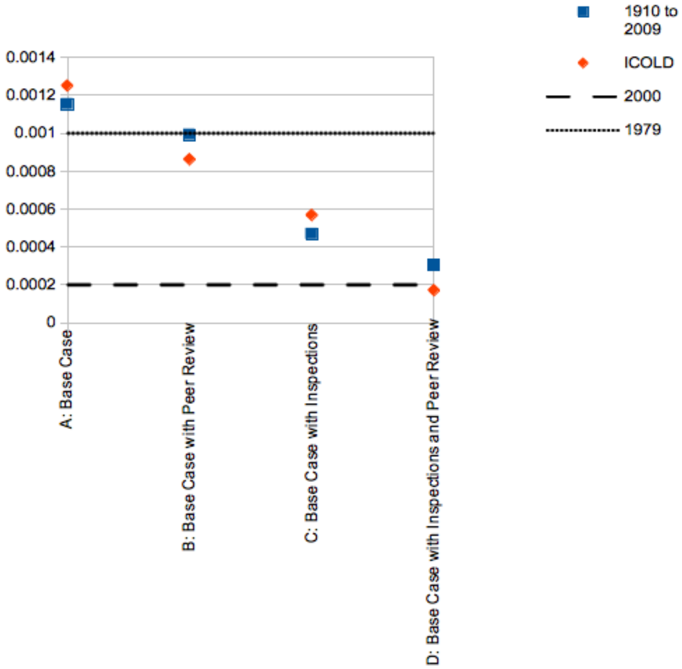


Fig. 7 Results of the annual probability of failures derived from the model for mitigation level A,B,C,D including attributed causalities (Table 2, 3) derived from factual data (Fig. 2, 3).

Based on this example, the biggest reduction in the probability of failure of the e-IDC chain is obtained through thorough inspections with sensible risk based decision-making procedures and risk assessment from project inception. Peer review has also a beneficial effect, of course, but smaller, probably because the most deviances and shortcuts intervene during the long term service life rather than during design. All together the implementation of both mitigation reduces the e-IDC chain probability of failure by almost one order of magnitude.

4.4.2 *Prioritizing risks in a portfolio of dams*

Notwithstanding the assumptions made, which could be perfected in a real-life portfolio study, the model is capable of reconstructing first estimates (a priori) of the probability of failure in good agreement with the last one hundred years of tailing dams failure history by looking at data (records) that should still be available for many structures, possibly in corporate, governmental or regulators' offices archives. Thus, based on an examination of those records it will be possible to determine, dam by dam, the first estimate of the probability of failure which, paired with each dam potential consequences (to be determined using a multi-dimensional consequence analysis), will give the total risk and finally a dam portfolio (corporate, national, regional) quantitative risk prioritization. That quantitative risk prioritization would be the first step of what the Auditor General for the Province of British Columbia recommends. "*1.10 Risk-based approach. We recommend that government develop a risk-based approach to compliance verification activities, where frequency of inspections are based on risks, such as industry's non-compliance record, industry's financial state, and industry's activities (e.g., expansion), as well as risks related to seasonal variations.*" (Bellringer, 2016).

These authors have already demonstrated (Oboni, Oboni, 2012) how to include societal and corporate tolerance into the risk prioritization techniques, shown how decision-makers focus can be enhanced rather than fogged-up by unclear risk assessments (Oboni, Oboni, 2016).

Given the public and corporate capital investments required to reduce future risks generated by dams, it is paramount to be able to address the riskier situations that lie above corporate and social tolerance first. In order to be able to use more efficient prioritization it will be necessary to define multi-dimensional tolerance levels, an exercise that has already performed from local to country-wide scale by these authors, but cannot be brought within the space of this paper.

6 CONCLUSIONS

Given the nature of tailings dams, their construction time and expected service life and closure, the effects of today's risk mitigation programs will only slowly become visible because the world-portfolio will contain mitigated and unmitigated (legacy) dams. During that period the public will perceive at best a status-quo and the industry credibility and social license to operate (SLO) will remain at stake (Oboni, Oboni, 2014; Oboni, Oboni, Zabolotniuk, 2013). It will be very difficult to evaluate progress as factors such as climate change, seismicity (again, not necessarily "Black Swans"), increase in population and environmental awareness (consequence side of the risk equation) will further complicate the situation. Thus public outcry and hostility toward the mining industry, fueled by the Information and Communication Technology diffusion will likely increase if transparent, rational, and defensible approaches to dam portfolio risk prioritization aren't swiftly implemented.

The presented model has been shown to "construct" the first estimate of the probability of failure of a dam which is consistent with factual historical world-data. As such it constitutes the support to any prioritization effort on a portfolio of dams or a first stab for a single dam.

The causality of various factors entering in the e-IDC process and other elements in the dam's service life can then be individually discussed/negotiated among experts and stakeholders with a sensitivity analysis allowing for better communication and enhancing transparency.

It has been shown where and how e-IDC process mitigative actions can benefit the most, if properly implemented, with a practical example. The potential effects of Common Cause Failure (CCF) have been described.

This methodical approach allows to determine in an economical, orderly, efficient way the relative a priori probabilities of failure of dams, based on archival data, expressed in ranges to include uncertainties. It is possible to use this approach for one dam or for a portfolio of dams.

Companies, governments, regulatory agencies dealing with large portfolios of dams need to be able to prioritize risks in order to develop credible and efficient risk reduction programs (Bellringer, 2016).

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