VIII-3. Construction Risks

Key Concepts

When a decision is made to reduce risks at a dam, a structural modification may be implemented to reduce the risk. Sometimes in these cases, a decision must be made to potentially temporarily expose the public to even greater risks during the time that it takes to construct the modifications. The term "construction risk" is used to describe this risk during construction. Construction risk can have different meanings, such as cost risk or schedule risk during construction. However, for this Best Practices document, construction risk refers to the failure probability, annualized life loss, individual risk or societal risk that exists during the period of construction when a dam is being modified. It is important to balance costs with efforts to minimize these construction risks. It is also important for the decision makers to understand these risks and the cost trade-offs.

Conditions that can lead to increased risks during construction include:

- Excavations that lower the crest of the dam which increase its susceptibility to flood overtopping.
- Excavations at the toe of a dam that increase its susceptibility to sliding instability by removing mass and allowing potential sliding surfaces to daylight in the excavation.
- Excavations that remove a portion of the downstream slope or foundation of an embankment leading to a shortened seepage path and increased susceptibility to internal erosion.
- Full or partial replacement of structural features, such as spillways, that results in a temporary decrease in the hydraulic capacity or structural stability of a dam.

In cases where construction risks are elevated in comparison to existing risks, timing can be everything. That is, the reservoir water surface elevation may drive the risk during construction and the likelihood of reaching various elevations may vary during the year. Thus, one way to minimize the temporary increase in risk during construction is to adjust the construction schedule so that the high risk activities occur when the reservoir is likely to be lowest. In addition, shorter construction durations limit the risk exposure.

Example: Excavation at toe of an embankment dam

Consider a case where potentially liquefiable materials exist under the downstream shell of an embankment dam in a highly seismic area. There is a major town 1 mile downstream of the dam that would be severely inundated if the dam were to fail. The reservoir typically goes through three stages each year: 1) filling during spring runoff (March through June), 2) falling levels during irrigation and summer water use season (July through October), and 3) a required drawdown during flood season (November through February). Risks associated with liquefaction of the downstream alluvium under the shell justify risk reduction action in the long term. The proposed modifications include excavating a portion of the downstream shell and a trench to bedrock at the toe of the dam to remove potentially liquefiable soil material. The trench will be backfilled with compacted cement-modified soil to improve foundation strength. A dewatering system is planned to remove water from the excavation during construction.

The normal maximum reservoir operating level is Elevation 2465, with the historical maximum at about Elevation 2470. The crest of the dam is at Elevation 2475. Reliability analyses (see section on Probabilistic Stability Analysis) were performed for slope instability with various reservoir water surface elevations, various levels of excavation at the toe of the dam, and groundwater levels corresponding to both a fully functioning dewatering system and failure of the dewatering system. The most critical condition was found to occur when the bottom 20 to 30 feet of the trench was fully open. The results for this condition are summarized in Table 34-1.

Table VIII-3-1 – Summary of "Reliability" Slope Stability Analyses

Reservoir Water Surface Elevation (ft)	Probability of F.S.<1.0	
	Dewatering System Fails	Dewatering System Works
2470	4.0×10^{-2}	2.4×10^{-6}
2465	2.0×10^{-3}	2.4×10^{-6}
2445	4.0×10^{-4}	2.4×10^{-6}
2425	2.0×10^{-5}	2.4×10^{-6}

For the conditions represented in Table VIII-3-1, the critical slip circles typically intersect the dam crest near the upstream slope, and there will be a dam remnant with some likelihood of retaining the reservoir. Therefore, the likelihood of this remnant breaching also needed to be assessed, and is obviously much higher under high reservoir water surface elevations. This case was found to be more critical than slip circles intersecting the upstream face below the reservoir level with near certain breach. With the dewatering system working, the results were not sensitive to reservoir water surface elevation. This is because the critical slip circles extended downstream into the zone where the water has been removed.

It was expected that redundant dewatering system components and back-up power would be required and that failure of the system would be unlikely, but since it had not yet been designed or operated, it was given about a 10 percent chance of failure. The likelihood of exceeding various reservoir levels (see section on Reservoir Level Exceedance Curves) varies with time of year, as shown in Table VIII-3-2.

Table VIII-3-2 – Reservoir Exceedance Probabilities

Reservoir Level (ft)	Exceedance Probability		
	March-June	July-October	November-February
2465+	0.012	0.0021	0.0002
2445	0.38	0.26	0.32
2425	0.80	0.62	0.39

The event tree (see also the section on Event Trees) used to evaluate potential slope instability is shown in Figure VIII-3-1. This figure shows the reservoir load range probabilities for the four-month period March through June. The mean results for all three seasonal load range probabilities are summarized in Table VIII-3-3.

Table VIII-3-3 – Annualized Results by Season from Event Trees

Season	Failure Probability	Loss of Life
March-June	4.66×10^{-5}	4.20×10^{-2}
July-October	2.02×10^{-5}	1.82×10^{-2}
November-February	1.99×10^{-5}	1.79×10^{-2}

Based on this assessment, the best time to construct the trench would be the winter season, followed closely by the summer construction season. However, it might not be possible to complete the trench construction in a four month window, and the winter season is expected to have more rainy days when work would have to be suspended. Therefore, four construction scenarios were estimated as follows; two starting times for the trench construction (July 1 and November 1), and two shift scenarios (one ten hour shift five days per week, and two eight hour shifts five days per week). Table 29-4 shows the durations for each of these four scenarios. To annualize the risks for each scenario, the number of months in each four month window is multiplied by the four-month failure probability. These numbers are then added and the sum is divided by 12 (months in a year). These results are also shown in Table VIII-3-4. Note that if the construction takes more than a year, the annualized risks must be portrayed year by year.

Table VIII-3-4 – Construction Durations and Risks

Scenario	Duration (months)	Annual Failure Probability	Annualized Loss of Life
One shift beginning July1	4.8	8.06×10^{-6}	7.26×10^{-3}
Two shifts beginning July 1	2.8	4.71×10^{-6}	4.25×10^{-3}
One shift beginning November 1	5.8	1.36×10^{-5}	1.23×10^{-2}
Two shifts beginning November 1	3.4	5.64×10^{-6}	5.07×10^{-3}

As can be seen from the results, beginning November 1 with one shift would put the annualized construction risks into the range justifying expedited risk reduction actions, whereas beginning July 1 and working two shifts would cut this risk by a factor of 3 and bring the construction risks into the range of the existing dam safety risks. The potential lost work days during the winter months increased the construction duration, and more than offset the advantage otherwise realized by winter construction. Thus, it makes sense to require construction of the trench during the summer months. Additional scenarios could be run in an attempt to optimize the construction, but construction schedules will always be uncertain, and broad ranges typically suffice.

Finally, a sensitivity study was performed looking at the reliability of the dewatering system, since examination of the event tree reveals that most of the risk stems from branches where the dewatering system fails. If the dewatering system could be made 100 percent reliable, the four-month failure probability for March-June drops to 3.00×10^{-7}, a reduction of nearly two orders of magnitude from the case of a 90 percent reliable system. Thus, additional efforts and specifications requirements are likely warranted to ensure reliability of the dewatering system and reduce the construction risks.

The above example was developed to illustrate construction risks associated with slope instability caused by an excavation at the toe of the dam. Additional potential failure modes also need to be examined. For example, there is an increased potential for piping or internal erosion (see section on Internal Erosion and Piping Risks for Embankments) as a result of excavating at the toe of the dam and shortening the seepage path. This potential failure mode would need to be evaluated in a similar manner. The dewatering system would need to be filtered to prevent movement of fines into the drains, and as such would likely play a key role in keeping exit gradients into the excavation low enough to preclude piping.

In addition, the example dam is being modified for seismic issues. If we were unlucky enough to have a major earthquake hit while the trench was open, major instability could result. The annual probability of this can be evaluated relative to the construction durations using similar methods to those described above. Once again, the dewatering system may play an important role in de-saturating potentially liquefiable foundation soils and keeping construction risks low.

Another approach to comparing construction risks to baseline risks involves looking at the risk exposure time. The instantaneous annualized failure probability (from the event trees) is multiplied by the duration to which it applies for each phase of the construction and the results summed over the entire construction project. This number is compared to the baseline risk multiplied the construction duration. The ratio of these two numbers (construction/baseline) gives the relative increase in risk that is being accepted during the construction. In this case, it is typical to also indicate the maximum instantaneous annualized failure probability (from the event trees) and the duration to which it applies.

Cofferdams

A key component of many construction projects is a cofferdam to protect the work area from flooding. Design of cofferdams requires the same risk considerations as any other water retention structure. Consequences need to be considered. Will failure of the cofferdam result in failure of the main dam, or just flooding of the work area? The trade-offs in cost vs. risk reduction need to be weighed. It is often advisable to involve the Decision Makers in the selection of design floods for cofferdams.

Accounting for Uncertainty

Typically, a range of estimates is made for each node on the event tree. However, since construction schedules will always be uncertain a priori, construction risk estimates typically focus on mean values in a relative sense to better understand the likely magnitude of increase (or decrease) over baseline conditions, to compare alternative schedules, and to focus on the key factors requiring attention in the specifications.

Decision Maker Involvement

Perhaps one of the most important aspects regarding construction risk is decision maker involvement. Designers of modifications to dams need to be aware of design and construction situations and timing that could result in an increase in risk to the structure and the downstream population. Sometimes it is necessary to accept a higher level of risk temporarily to gain the long term benefits of the risk reduction. However, the designer alone should not be the judge of what level of increased risk is acceptable, how long that risk would be present, and how much money should or should not be spent to mitigate those risks. A risk informed decision on construction risk can be made if all of the information is made available to the decision makers. There are many ways to deal with increased risk during construction, some of which involve additional funding to offset risks, and some involve the use of schedule adjustments and construction timing. All of the options should be evaluated so that an informed decision can be made.

Exercise

Estimate the annual failure probability for the above example, if construction of the trench in the example above begins on June 1 and takes six months to complete.

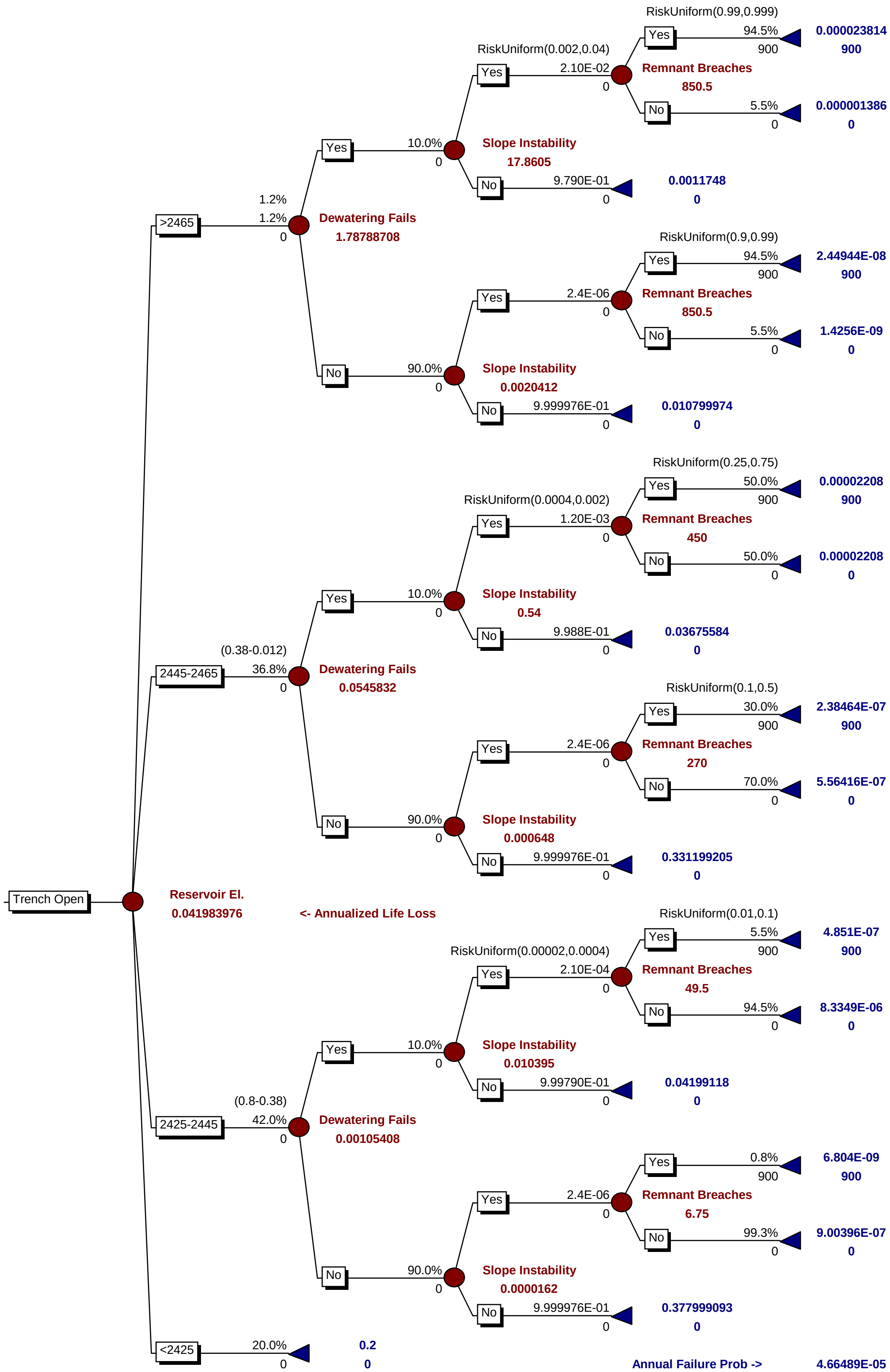

Figure VIII-3-1 – Event Tree for Seasonal Slope Instability Construction Risks