COMPREHENSIVE ASSESSMENTS: LESSONS LEARNED IN ROUND ONE

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ABSTRACT

In April 2022, the Federal Energy Regulatory Commission (FERC) implemented new regulations for Licensees to complete Comprehensive Assessments (CAs) for selected dams. As a simplistic definition, a CA includes a complete review of the project's records to look for and assign an estimated risk for potential failure modes. Typically, a CA includes a hydrologic hazard assessment, a seismic hazard assessment, a site visit from a team of experts (specialists in hydraulic structures, geotechnical, engineering geology, hydrology, structural, operations, human factors, etc.) and a "from scratch" Potential Failure Modes Analysis (PFMA). Then somewhere between 70 and 700 failure modes from the PFMA are screened and assigned a risk value (probability of failure and potential life loss) and assessed for risk reduction measures within a Level 2 Risk Analysis (L2RA). Navigating unfamiliar processes, terminology, and decision-making tools has been challenging for all involved. For consultants, initial uncertainty about the level of effort needed has given way to an expectation that the proposed scope of work will induce sticker shock in prospective clients.

While the goal of this paper is to help consultants and Licensees find potential cost saving approaches, the secondary goal is to optimize productivity so that the industry can properly staff all the comprehensive assessments expected in the coming years. In short, Licensees and consultants are both limited in labor availability and financial resources, so this paper suggests strategies to improve both utilizations.

INTRODUCTION

The term "Comprehensive" is sufficiently vague that Licensees and consultants have struggled to understand expected CA team composition, number of hours needed for review, and overall CA budget. The FERC regulations (see References Section) clearly expect that CA review teams shall thoroughly understand a project's history, potential design weaknesses, deteriorations due to project age, operational constraints, exposure to extreme floods and earthquakes, and risk of (often hidden) internal and foundation defects. However, FERC has said that they do not expect reviewers to redo original design computations or dive into great detail on most[2] topics. So, while some simplified

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[2] Hydrologic Hazard Assessment is one exception. This is a very detailed review of historical flows, discharge rating curves, and statistical methods to predict reservoir stage associated with extreme floods.

computations are necessary to verify assumptions, most consultants are not sure what level of labor is needed to acceptably complete a CA.

Licensees are also unsure of CA cost expectations. The author's firm (and many others) bid on the first round of CAs, and Licensees reported that CA costs widely varied among consultants. To gain a local perspective of costs and effort, the author was able to take part in multiple CA roles as bidder, Subject Matter Expert, Independent Consultant, and Facilitator. A regional perspective was gained at the Midwest Hydro Users Group's roundtable with both small and large Licensees. The October 2023 National Hydropower Association conference sessions and FERC's March 2024 presentation yielded perspectives from several large Licensees and FERC's Director Capka, respectively. The most voiced concerns by Licensees, consultants, and FERC staff center around a perceived shortage of trained risk experts, a large variation in CA bid prices, and confusion as to the baseline level of effort necessary to follow FERC guidelines. In short, this paper aims to document lessons learned and tips for improving efficiency on future CAs.

KEY FACTORS

A trifecta of well-prepared Licensees, experienced facilitators, and efficient subject matter expert preparation contributed to the author's success in completing two first round CAs. Note that the opinions in this paper are derived from two CAs that have been submitted and presented to FERC; three in progress; and three more in the planning stage. The author has seen a wide variety of Licensee preparations and three different facilitators and has worked alongside four different firms and many SMEs. A correlation exists between Licensee preparedness, facilitator style, and SME training and how efficient the overall CA process is.

Licensees

First, the extensive preparation and foresight of Licensees (dam owners and operators) lessens the CA team's time necessary to understand the project. Based on reviewing multiple Supporting Technical Information Documents (STIDs), several sections are critical to getting a new CA team familiar with the project. Assuming the Digital Project Archive format has already been established per the new FERC guidelines, the highest priority for the Licensee should be expanding Section 3 (construction history) with the best available scans of construction photographs, specifications, drawings, and field notes. In addition to a good timeline of month and year that project features were constructed, the Licensee should complete the following:

- First, go through the full history records and summarize all major project dates and repairs (embankment raises, seepage repairs, gate replacements, etc.) into a

chronological list. Often data gaps can be filled in by requesting state dam safety records. Many dams were built prior to the Federal Power Commission (established 1930) and predate FERC (established 1977), so early dam safety inspections were often the responsibility of the state's Railroad Commission, then later Public Service Commission staff, and usually after 1950 the Departments of Natural Resources would document inspections (this timeline varies by state). These state inspection reports often include notes on flood damage, embankment seepage, repairs, and dam safety concerns.

- A second priority for the Licensee is to scan all historic documents, including construction and repair photographs, drawings, reports, etc. and to label all these documents consistently. To aid in establishing chronology and also be searchable by report name and authoring firm, consultants often prefer a naming system like yyyymmdd_authoring-firm_report-title.pdf or something similar.
- A third priority is to write a narrative for events surrounding the top ten extreme events (floods, ice jams, earthquakes, droughts) and then digitize plant operating records (gate settings, headwater, tailwater, unit settings) for these periods. For example, such knowledge allows risk experts to appropriately assign risk of loading once they understand that the 1924 flood of record for a downstream USGS gage happened because a far-upstream dam failed and then the Licensee's operators scrambled to open all the project gates and draw down the reservoir in anticipation of a flood wave.
- And as a fourth but still important priority, the more common discrepancies seen by CA review teams include structure elevations and lengths. At a minimum, and prior to CA, confirm that accurate crest and deck elevations are available for each structure, accurately measure the maximum gate opening's lip elevation, and survey all embankment rims with plenty of crest shots. For those embankment dams with core walls, confirm the end location and top elevations of all core walls, either by non-destructive scanning in sensitive areas or by probing or test pit where safe exploration is possible. Having correct information upfront will avoid rework during the CA due to the team misunderstanding critical project features.

Facilitators

A well-trained facilitator is a key to an efficient CA. First, the facilitator must be very familiar with common failure modes in multiple engineering disciplines and have a plan to efficiently arrive at a final comprehensive list of brainstormed failure modes. The author had the privilege to work with a former US Army Corps of Engineers risk assessment facilitator who was very efficient at sorting, grouping, and screening an extensive list of brainstormed potential failure modes. The facilitator went structure by structure to look at the key areas for potential failure modes, such as under, over, through, and around seepage for embankments and global stability, local pier stability, trunnion, gate, and hoist for spillways. Then for each failure mode developed for normal pool, the facilitator asked if there was also a flood pool, winter ice, and seismic version that also needed to be tracked. A second facilitator had significant experience with Colorado dam safety screening assessments which rely on a list of possible failure modes (like that provided in FERC's Engineering Guidelines) and would work through a list of failure modes common to many dams elsewhere and expand on specific failure modes that applied to the dam in question. In short, both facilitators arrived at a comprehensive list

of brainstormed failure modes, but each facilitator had a unique perspective on the most efficient route to finishing the list. Second, the facilitator must be able to screen hundreds of brainstormed failure modes into a sorted list of remote, credible, damage state, etc. modes. A facilitator already familiar with the USBR[3] and USACE[4] best practices standards can quickly pose key questions to SMEs – such as whether soils could hold a roof for internal erosion or if two gates out of service mean that the headwater would rise during the maximum flood. This approach focused the SMEs on arriving at a definitive path for screening each potential failure mode. In general, the author noted certain facilitation strategies that improved the efficiency of the screening process, as follows:

- Aim to rule out first and then look for failure modes whose probabilities are too remote to matter. Remind SMEs to consider any best practices that could be cited to rule out failure. If it cannot be ruled out, would the chance of loading times the probability of failure be too remote to plot on the risk chart?
- Choose the failure mode that has the highest probability of failure as the starting point for discussion. Ask if other less-probable modes are too remote to carry forward.
- Look for quick screening opportunities – massive spill capacity probably will significantly lower the loading probability for flood-initiated failure modes. For example, if the loading probability is 10^{-5} then any failure that has less than 0.1 chance of progressing and leading to a consequence is too remote to discuss further. Seismic failure modes are another quick screening opportunity, and SMEs should come prepared to know what is the minimum seismic event that can cause damage progression.
- At the brainstorming stage, the FERC still requires a writeup for each candidate failure mode prior to ruling out or classifying as too remote to plot. Come prepared ahead of time with example text that can be quickly modified for each screened out mode.

Subject Matter Experts

The overall number, technical expertise, and risk experience of SMEs will also significantly affect the efficiency of the CA process.

- First, the cost of a CA will be highly correlated to the overall number of CA team members. Consultants are trying to convert technical experts to risk experts, and often too many staff are put forth at the expense of efficiency. A single expert in hydraulic structures who has been through a past risk assessment is probably far more capable of screening a hundred candidate failure modes quicker than three people with less risk assessment experience. When more than one SME is covering a particular field, SME to SME discussion may get far into the details during brainstorming. Although it makes sense to involve younger team members who are training for a future SME role, the process will be slower if multiple SMEs are offering competing opinions. In some cases, there are undeniable benefits to having two experts to cover the most important risk drivers on the project, but the initial team selection process needs to “right size” the number of SMEs. The author believes some experts are better suited to offering written opinions (and may prefer to do so anyway) or just being “on call” to remotely take part for a limited time on very focused topics.

[3] https://www.usbr.gov/damsafety/risk/methodology.html
[4] https://www.rmc.usace.army.mil/Reference-Center/Risk-Assessment/

- Second, technical expertise should be chosen based on the project's known high risks. Certainly, new potential failure modes are likely to arise during the CA, but in general, the Licensee and FERC already know the key risk drivers on a project. If corrosion of post-tensioned anchors and uncertainty with bedrock strength have been the critical potential failure modes on a project in past years, but the spillway has an abundance of flood capacity, the contributions of experts in structural engineering and geotechnical / geological engineering will be critical to the CA's success and those of the hydrology and hydraulics expert less so. In this case, a detailed study (as part of the CA) by a well-respected anchor corrosion expert may be the most beneficial way to acknowledge the risk upfront and be more prepared to efficiently discuss it during the risk assessment.
- Third, the risk experience of the collective industry is currently low. While the federal agencies have dedicated teams of risk experts who have significant experience, most consulting firms do not have a deep bench of SMEs with risk experience. The first CA that the author took part in was daunting in terms of learning the overall process, anticipating the level of detail needed for review, and identifying what should be done ahead of the PFMA and risk assessment to make the most efficient use of the Licensee's budget. After completing two CAs and starting another five, the author sees significant strides in use of time. Instead of scrambling to come up with answers and positions during the PFMA and risk assessment, the teams are coming prepared. For example, filter compatibility checks, seismic liquefaction screening, and rating curves with one gate and two gates out of service are done prior to the PFMA. The team comes prepared to talk about impacts if the friction angle drops three degrees or formerly neglected cohesion is accounted for in the computations. In short, risk experience is probably the one area that will certainly improve with time, and thankfully the FERC has supported industry training and has recognized that these initial risk sessions and comprehensive assessment presentations represent a learning curve.

SPECIFIC LESSONS LEARNED

While the key factors above set the stage for overall success, specific lessons learned may help Licensees and consultants reach common ground on price and efficiency expectations. The following are major findings and understandings for the process itself.

1. The largest efficiency gains are in the Licensee's hands.
    a. With a good facilitator aiding, the Licensee can probably plot the project's existing potential failure modes on a f-n chart to within two or three orders of magnitude. Based on this knowledge, key project risk drivers should become evident, and the Licensee can tailor the CA team solicitation efficiently to focus on known risk drivers.
    b. An accurate and well-prepared STID and Digital Project Archive are crucial because the team can read through it once, pull out the important information for each area of expertise, and proceed with computations based on the latest and best information available. The worst case for a CA is finding new information during the risk assessment that either forces

rework of earlier failure mode descriptions or creates confusion as to accuracy of what were thought to be final computations.

2. Key authors of the Pre-Inspection Preparation Report (PIPR) (ideally the key SMEs on the project) should visit the site between writing the Inspection Plan submittal and the PIPR submittal.
    a. An initial draft of the PIPR may have misunderstandings about operations, transitions between structures, and locations of critical equipment. A quick site visit by the primary PIPR author(s) will reduce misunderstandings and yield a better written PIPR.
    b. The Hydrology and Hydraulics SME should visit the site during spring runoff to witness flow patterns, population at risk flooding, etc. Taking photos during this time will help during the PFMA discussions when populations at risk, gate hydraulics, wave freeboard, and tailrace eddies are discussed. Also, the project operators should plan to collect photographic and other event-specific information (water levels on structures, locations of hydraulic jumps, restrictions on spillway flows, etc.) in the event of an exceptionally large runoff event that the SME cannot observe.

3. Write as much of the CA report (especially Sections 2 through 4) as possible during the PIPR and assign homework to fill in knowledge gaps. The more complete the PIPR is, the faster it is to identify critical project features, familiarize SMEs with the project, and demonstrate that the team is coming into the PFMA well prepared. Several “homework” assignments seem to arise for many types of dams.
    a. For geotechnical and geology SMEs, summarizing filter compatibility checks, checking for foundation homogeneity or common defects in bore logs, comparing soil characteristics (uniformity, gradation, etc.) to applicable ranges for progression from Best Practices, and checking for liquefaction susceptibility can be done at the PIPR stage so that conclusions can be used during brainstorming to screen quickly.
    b. For structural SMEs, doing simplified free body diagrams and verifying sensitivity of stability to parameter variations, checking reinforcement ratios in piers, quickly computing shear key strengths, and summarizing factors of safety for all structures are good examples of common homework. A structural SME should also have a good understanding of what earthquake loads commonly damage structures, how the magnitude of earthquake loads compares to the project’s maximum expected water and ice loads, and the strength of interlocking mechanisms between structures for post-earthquake stability (as well as structure racking).

c. For hydrologic and hydraulic SMEs, while the hydrologic hazard assessment tends to be completed for the project operating as expected, most of the potential failure modes will lead to questions about how quickly the reservoir can be drawn down, what happens to the headwater rating curve if one or two gates are out of service, and what stream power, shear stress, and velocity are applied to the spillway surface and downstream riverbed. Check for rim overtopping at the project onset, confirm normal and flood freeboard for all structures, embankments, and rim overtopping areas, and review downstream land use.
d. Do the seismic and hydrologic binning upfront in the PIPR. Then everyone knows what the bins will be for later use. For examples, the structures expert can estimate how a given bin range impacts the stability, a geotechnical expert can estimate how the tailwater for each bin impacts the toe seepage, and the hydraulics expert can look at substation and powerhouse flooding for each bin.
e. Create a draft review for all of the Licensee's plans listed in PIPR Section 8 so that any remaining questions can be asked during the field visit when the entire team of operators, managers, maintenance leads, and dam safety staff are available to review key questions about the Emergency Action Plan, Public Safety Plan, etc.
f. Assign the Licensee homework too. The Licensee should define their limit of financial damage (up to $10M per current FERC guidance) and come prepared with order of magnitude costs for gate replacement, unit replacement, etc. to figure out what items exceed the financial damage threshold. The Licensee should also identify other financial consequences associated with a prolonged lake drawdown or sudden lake drawdown.

4. Allow plenty of time for the inspection site visit but consider how the site visit information can be pulled into the PFMA discussions efficiently. For projects with significant geographical spread, consider taking all pictures with GPS-enabled cameras to set up Google Earth photologs and document key field measurements at the same time as the site inspection.

5. Plan more meeting space than you need and locate it efficiently.
    a. Book the meeting space as soon as the meeting is scheduled. Meeting spaces sized for fifty or more people are often reserved months in advance. Look for local catering options and the venue's ability to host working lunches.
    b. A working meeting with plans, photographs, specifications, SMEs, laptops, monitors, and projection capabilities requires more physical space

and more power/connection options than a standard conference room. In general, find a room that comfortably seats three times the number of attendees expected at the PFMA and L2RA, and provide at least one outlet strip for power to every two attendees. Provide a high speed and robust internet connection. Assume (whether expected or not) that someone will need remote participation and provide microphones and adequate speakers to allow for effective communication. The author has had great success using OneNote live file sharing for sketches and reference information plus Teams or WebEx to share the draft PFMA or risk assessment document. In addition to allowing remote participation, this allows attendees with vision restrictions to zoom in and see critical text.

c. Make sure the projector's screen is viewable for all, such that the text and images in the risk forms are readable by the furthest attendee. Consider having two projectors and two screens for large rooms.
d. In general, it seems that the most valuable communication for promoting group understanding of description, progression, intervention, and consequences is exchanged directly between the Licensee's team and SMEs. To minimize side conversations and the need for the facilitator to repeat statements for all to hear, seat Licensee staff and subject matter experts so they can look directly at each other and communicate more clearly. Suggest seating for FERC staff that allows them to see and hear the group interaction but also to converse together privately.
e. Locate the meetings based on convenience and suitability of meeting facilities, near the dam or elsewhere if travel costs are prohibitive. Dam operators may be more comfortable with meeting locations close to the project location.

6. Consider productivity when setting up in person and remote meetings.
    a. Most teams are only able to work efficiently for forty hours in person, with added travel on each end. However, one or two ten-hour days may be acceptably effective and allow the team to wrap up the risk meetings by noon on Friday. Per the FERC's March 2024 presentation, very few dams will have PFMAs and risk meetings that are shorter than a full week. In advance, the Licensee and consultant should schedule virtual workshops to finish what could not be completed in-person.
    b. A general rule of thumb is that a virtual meeting becomes unproductive after about four hours per day, and remote participants are likely to be more distracted (emails, interruptions) than if they were in-person. However, virtual meetings are more easily accommodated by busy schedules and the breaks between virtual meetings allow time to ponder

failure modes. For specialized SMEs like a corrosion expert or seismic specialist or consequence modeler, experience suggests that remote participation and virtual meetings are a much more efficient use of their labor than requiring these specialists to travel to in-person meetings.

c. The majority of CAs have a week of in-person PFMA meetings and then transition to virtual or mostly-virtual meetings for all future PFMA and L2RA discussions. Schedule plenty of "contingency" time to make sure that if extra days are needed, then the team already has available schedule.

7. Take staff less experienced with risk analysis to your meetings. Running the risk engine is a great entry-level role, and staff with great writing skills and patience will be good candidates for note taker.
    a. Even if they are not paid from the project funds, this on-the-job training time is valuable to build the Licensee's and consultant's future risk teams.
    b. For the Licensee, consider inviting regional operations managers and upper management to the PFMA or risk meetings. For consultants, consider inviting consequence modelers, mid-level dam inspectors, and those showing an early career interest in risk-based decision making.

8. Have a time gap between PFMA and L2RA sessions.
    a. After the PFMA, assign homework again if homework can be completed without full group participation. Generally, only one or two SMEs are the key participants for each PFM, so have them read the worksheets and consider what other information they would need to estimate risk. Often a structural engineer may need to take something learned from the PFMA (for example, a range of expected friction angles) and run a quick sensitivity analysis on global stability. Similarly, a geotechnical engineer may look more closely at the available construction documents after the PFMA team proposes circuitous routes for internal erosion between structures and embankments.
    b. The gap in time between PFMA and risk session allows the hydrology and hydraulics team to confirm final rating curves, estimated reservoir surcharge and drawdown times, and develop a good range of consequences representing appropriate failure modes.
    c. If the PFMA identified any data gaps, a few weeks' time prior to the risk session allows the Licensee to counter with more research and minimize the failure modes that fall into the "Insufficient Information" disposition. Note that for all potential failure modes assigned as Insufficient Information, the team must develop written recommendations on how to get enough information to better classify the failure mode. Also, if the Licensee disagrees with a "Credible" disposition, the gap period allows

the Licensee to search for more photos, records, or information to support a reconsideration of the disposition at the risk session.

d. Somewhere between four and eight weeks is recommended as a gap between PFMA and session.

9. The final report flows from the PIPR, so a well-written PIPR will reduce the amount of effort needed to write the final report. In general, consider the following allocation of responsibility:
    a. The independent consultant(s) should take the lead on report text and figure preparation.
    b. The note taker and recorder take responsibility for completing the PFM worksheets and disposition tables.
    c. The remaining team members review the draft report and complete their sections of the report as appropriate.
    d. The Licensee should budget at least three weeks between draft and final reports for review time.

CONCLUSION

Early experience suggests that the comprehensive assessment has significantly increased the amount of effort and cost for FERC inspections. Based on bid results alone, it appears that the new comprehensive assessment costs for just the independent consultant and subject matter experts is between ten and twelve times the cost of the pre-2020 Part 12D inspections – and this excludes costs associated with the note taker, recorder, and facilitator roles plus all the internal preparation costs that the Licensee bears. In fact, when considering all costs (consultants, Licensee team, facilities, travel), the costs associated with the new comprehensive assessments in these first two years of bidding CAs seem to range between $300,000 and $900,000. While it seems improbable that future costs will halve, the author is certain that an equal number of consultant bids are inflated due to inefficiencies as there are bids that underestimate the effort needed to meet FERC guidelines. Given the large cost of CAs (and for some Licensees this financial burden cannot be offset by generation), the recommendations above are offered in the interest of keeping CAs as affordable as possible for Licensees and consultants alike – bearing in mind that if costs balloon as a CA progresses, the negative financial impact is likely to be shared by both. And by coming together to develop common approaches and training, the industry can properly staff all the comprehensive assessments expected in the coming years.

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these organizations recognize that reducing CA uncertainty will require a three-party discussion between FERC, Licensees, and consultants.

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