Quest Integrity™

CHALLENGE CONVENTION

WHITE PAPER

DO YOU KNOW THE USEFUL REMAINING LIFE OF YOUR CRITICAL WATERWAY AND GENERATOR COMPONENTS?

ON AVERAGE, U.S. HYDROPOWER PLANTS ARE 64 YEARS OLD[1]. HAVE YOU CONSIDERED THE CONDITION OF YOUR FIXED AND ROTATING STEEL COMPONENTS?

FACT: According to the EIA [1], the average hydro-electric facility has been in operation for more than 64 years. These statistics, coupled with load following operational demands of 21st century power-grid balancing indicate an emerging challenge for the hydropower industry. How do we maintain critical plant components that have long exceeded their design life and operate in ways not originally envisioned in order to ensure effective and continue production?

By utilizing an effective long-term integrity management strategy, hydropower plant operators gain a unique understanding of the condition of critical hydropower plant components. Both fixed and rotating equipment within a facility is susceptible to crippling damage over time. By implementing a long-term asset integrity management program, facilities are able to identify, predict, and manage damage and stress on components, allowing for the effective extension of component life.

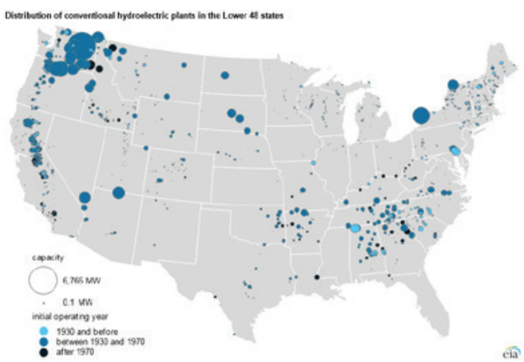

Figure 1. Locations and operating age of hydroelectric plants located in the United States [1]

MAKING A PLAN – MANAGING THE INTEGRITY OF CRITICAL HYDROPOWER COMPONENTS

Asset integrity management (AIM) programs can be a vital tool for hydropower plants operating assets with unknown conditions. While a component failure may not produce catastrophic results, the monetary implications of plant downtime can be significant. By developing a comprehensive asset integrity management program, facilities are able to monitor the long-term condition of assets, predicting and mitigating issues before they arise.

Fitness-for-Service

Fitness-for-Service (FFS) engineering assessments are a useful strategic tool in an asset integrity management program. Fitness-for-Service assessments are a multi-disciplinary approach to evaluate structural components to determine if they are fit for continued service. The typical outcome of an FFS assessment is a "go/no-go" decision on continued operation. An evaluation of remaining life or inspection intervals may also be part of such an assessment, along with remediation of the degradation mechanism.

Calculating Remaining Life

Another important feature of an asset integrity management strategy is the ability to calculate the useful remaining life of plant equipment. Calculating remaining life is particularly important when managing assets that have been in-service for a number of years, and can be a largely useful tool in avoiding unexpected downtime and planning for strategic maintenance and inspection. Operating conditions and equipment history are factored into the assessment to calculate remaining life and determine appropriate operating parameters for extending component life.

ENSURING THE INTEGRITY OF CRITICAL COMPONENTS

There are a number of integral hydropower plant components that largely benefit from predictive engineering assessments. Both fixed and rotating equipment run the risk of long-term damage, and can benefit significantly from undergoing such engineering assessments.

Rotating Equipment

Generator rotors, shafts and turbine runners typically come to mind when considering critical rotating equipment in a hydropower station. Damage mechanisms such as fatigue driven crack-like flaws could lead to sudden and potential catastrophic unit failure.

Case Study – Rotor Spider Cracking

Chelan County Public Utility District (CPUD) of Chelan County, Washington owns and operates 19 generators at the Rock Island Powerhouse on the Columbia River. Inspections conducted in 2014 and 2015 indicated cracking in welds within the generator rotor spiders of 5 units (see Figure 2). The majority of these indications were found within the hub region of the rotor spiders.

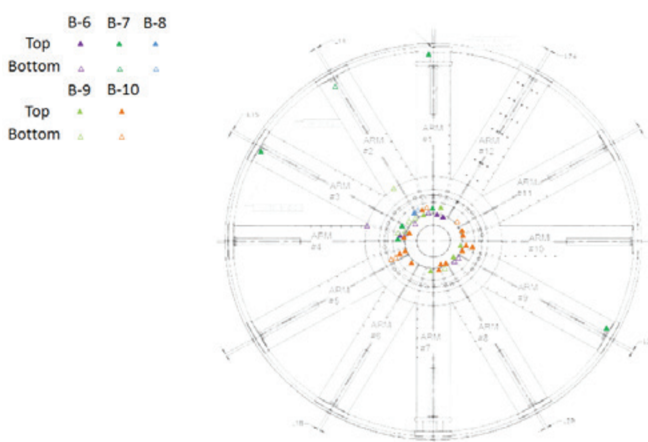

Figure 2. Example of rotor spider that was experiencing cracking in welds.

CPUD pursued an investigation to determine the root cause of the cracks and the susceptibility of the generator rotor spiders to fatigue induced crack growth and failure [2]. The investigation developed into a coordinated effort between CPUD, the structural testing and monitoring company BDI, and Quest Integrity. BDI, Quest Integrity, and CPUD developed a test program involving installation of strain gages, accelerometers, thermistors, and a custom data acquisition system to measure the structural response of the rotor spider through both cold and hot unit test programs.

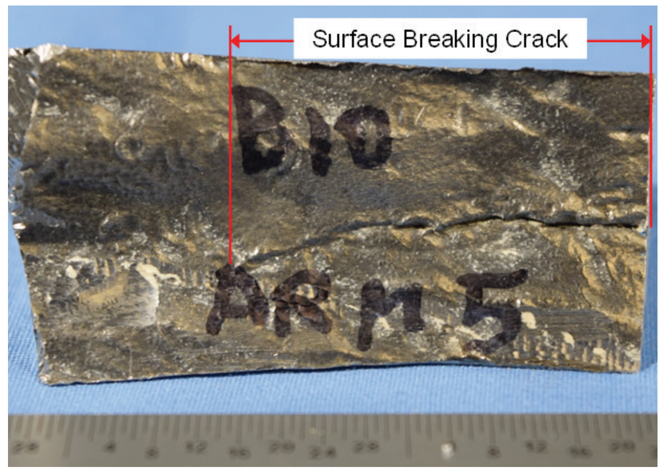

Figure 3. Crack located in the weld face metallurgical sample.

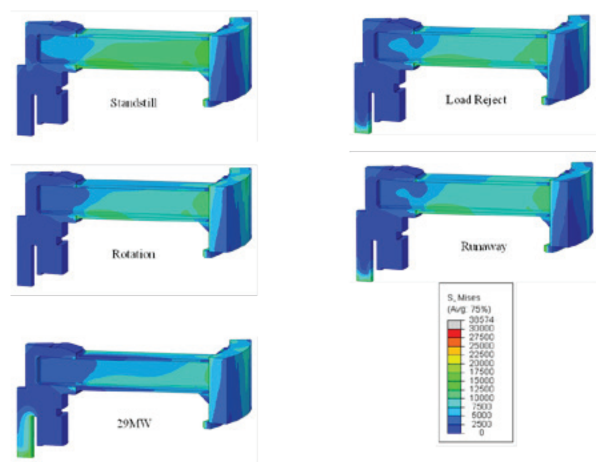

Figure 4. Finite element analysis (FEA) results that were used as the basis to determine the rotor spider's fitness-for-service.

The results of the investigation provided a quantitative approach towards rotor spider integrity management and enabled CPUD to move from a "fixed-time" inspection schedule to one that is based on condition assessment and remaining life. This ultimately allowed CPUD to continue to use units B9 and B10 rotor spiders, reduce the frequency of inspections and "generation-lost" due to those outages. The resulting return on project investment was approximately $3 million US dollars [2].

Fixed Equipment

Critical waterway and pressure boundary components, such as spiral case, penstocks, associated manways, headcover and stay vanes can suffer from metal loss and pitting due to years of operation, and crack-like defects due to poor welds and original manufacturing defects. Over time these defects could lead to sudden failure.

Case Study – Penstock Integrity Study

Snowy Hydro and Quest Integrity carried out a study to address the Fitness-for-Service and integrity management of penstocks at Murray 1 Power station [3]. Murray 1 Power station is located near the town of Khancoban in the Snowy Mountains NSW, and has a generating capacity of 950MW, through ten 95MW vertical-shaft Francis type turbines. The three penstocks are circular steel conduits approximately 1,585m (5,200ft) long, with a vertical fall of approximately 427m (1,400ft). Two of the penstocks each supplied water to four turbines while the smaller third penstock supplied water to only two turbines.

The penstocks were originally coated internally with coal tar enamel coating and externally with inorganic zinc silicate coating. The coatings were considered to be at end-of-life and areas of corrosion existed. Some penstocks had the internal and/or external coatings replaced, while others maintained the original coatings.

The objectives of this project were to develop a reliable condition assessment method that provided:

- Methods for ultrasonic non-destructive testing to determine the amount of metal loss due to corrosion of in-service penstocks;
- a tool for assessing the present and ongoing Fitness-for-Service and integrity of the penstocks;
- a sound technical justification for not recoating (internal or external) penstocks.

It was also important to develop an ongoing condition assessment process and means of managing the integrity of the penstocks and shafts, without the need to drain the penstock or confined space access.

Design Review and Stress Analysis

A finite element analysis (FEA) and design review was conducted on the three penstocks. Each penstock was modelled using Abaqus FEA software (see Figure 5). The design review assessment considered both normal and emergency load conditions. The von Mises stress (see Figure 6) in each of the penstocks was compared with their maximum allowable stress for each operating condition (normal and emergency).

The results of the design review and stress analysis found that all penstocks satisfied the design acceptance criteria.

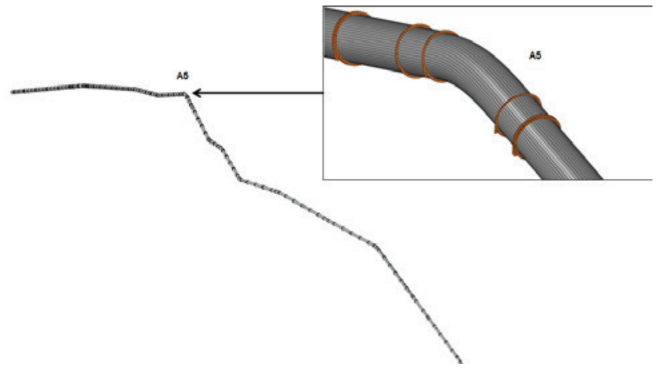

Figure 5. Example of structured finite element mesh used for all three penstocks.

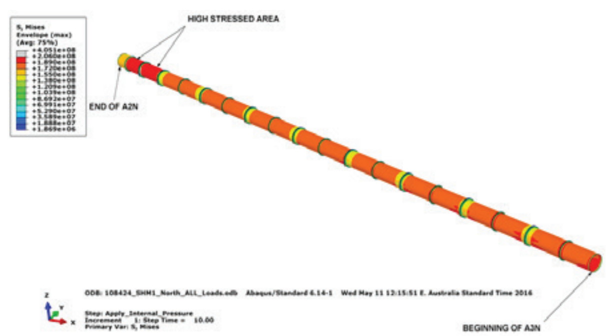

Figure 6: Example of stress results in penstock section A2N to A3N.

Inspection

As part of this project, an on-site advanced ultrasonic inspection of the three penstocks was performed at predetermined locations of peak stress. Time of flight diffraction (ToFD), which uses the time for which an ultrasonic (UT) pulse takes from transmitter to receiver probe to determine position and size of a reflector (i.e. defect), was employed.

In order to ensure that the results were accurate and repeatable, a test calibration was conducted on a section of penstock that had been previously removed from service (see Figure 7).

The results of the inspection found that at the tested locations, the wall thickness was consistently greater than the design thickness.

Figure7: Removed section of penstock used for ToFD calibration.

Fitness-for-Service
Stresses identified during the finite element analysis of the penstocks were considered in order to determine the fitness-for-service of the inspected elements. Through comparison of these stresses to the ASME FFS-1 fitness-for-service failure criteria, the current risk profile of the penstocks was evaluated along with the maximum allowable wall loss defects. The failure criteria utilised in this assessment were the conditions for the protection against plastic collapse and local failure, based on linear elastic analysis. The fitness-for-service assessment was carried out considering generalized corrosion, localized corrosion, and cracking. The Fitness-for-Service assessment ultimately determined that all three penstocks were fit for continued operation.

Remaining Life Assessment
In order to determine remaining life, a corrosion rate was required. Based on discussion between Snowy Hydro and Quest Integrity, a corrosion rate was calculated based on the maximum depth of corrosion found during the previous inspection and an assumed time in service (since 1970). This resulted in a corrosion growth rate of 0.024mm/year, which in turn allowed the owner to accurately plan for upcoming maintenance operations.

By utilizing a multi-faceted engineering solution, the Snowy Hydro was able to remove non-essential and non-critical maintenance tasks, move from a "fixed-time" schedule to one that is based on condition assessment, and provided a more comprehensive approach towards penstock maintenance and integrity management.

THE BIGGER PICTURE

While it is important to maintain optimal power generation and output, it is equally important to consider each component of the hydropower plant, and how these components fit together as a cohesive whole. By utilizing an asset integrity management program, facilities are able to significantly extend the life of their equipment, while obtaining a clear and accurate picture of current and long-term asset conditions. Ensuring component life with engineering assessments and actionable data not only ensures assets are fit for continued operation, but also paves the road for safe operations well into the future.

REFERENCES

[1] U.S Energy Information Administration, "Hydroelectric generators are among the United States' oldest power plants," 13 March 2017. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=30312 .

[2] E. Scheibler, J. Sipple and B. Bickford, "Life Management of Generator Rotor Spiders through Structural Testing and Fitness-for-Service," in CEATI International Hydropower Workshop, Tucson, 2018.

[3] E. Scheibler and J. De Groote, "Penstock Fitness-for-Service Study," in HPEE, Queenstown, 2016.