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NEWS & VIEWS

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Plant Materials Aging and Degradation

NUCLEAR IGSCC MITIGATION OPTIMIZATION AND EQUIPMENT ADVANCES 24

CEO Message

Leading Through a Pandemic

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> Finding the balance between getting the job done and ensuring everyone's safety is paramount to SI, and we'll continue to work in this direction, even when this pandemic is firmly in the rearview mirror.

Reflecting back over my first six months with SI, I would say it was not exactly what I would have imagined. This time has been a challenge for all of us as we navigate both our personal and professional lives through the coronavirus pandemic. While it is certainly not over, I wanted to highlight some of the changes we instituted at SI to get us – both you, our clients, and our employees – through this pandemic.

- At the end of February, we restricted travel to several international destinations already impacted by the virus
- By the first week of March, we halted all domestic non-essential travel and closed offices to non-employees
- By mid-March, we encouraged all employees to work from home. We did not officially close our offices as we knew several tasks could only be performed in an office such as shipping and receiving of NDE equipment and running applications requiring high computing power.

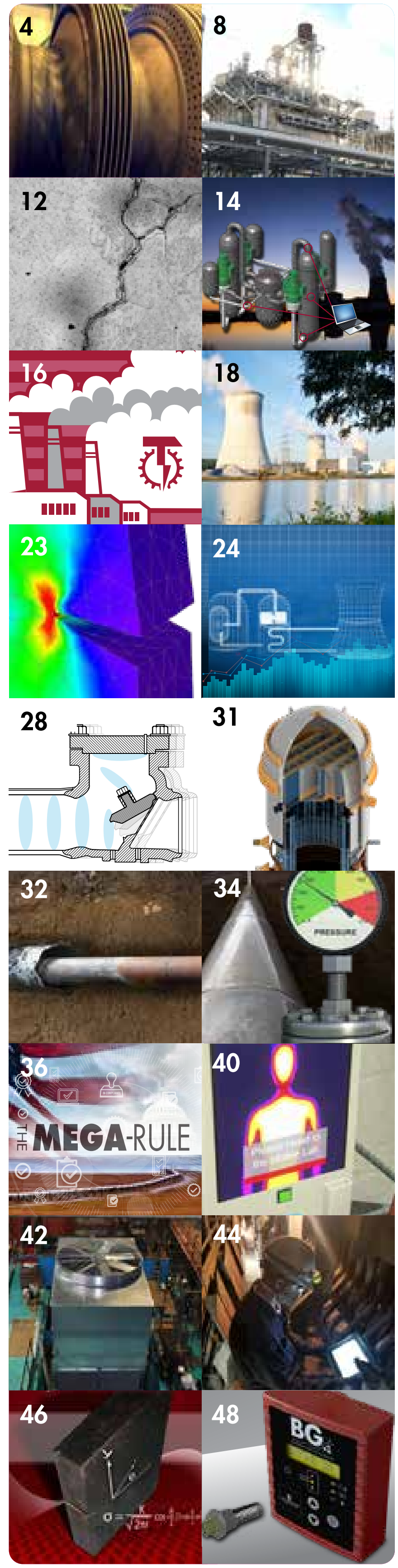
I commend all of our employees for remaining productive as their work environments and communication options became limited. With service to our clients as a top priority, I hope all of you continued to receive the high level of service, in all respects, that you've come to expect from SI. At some point, we'll be back in our offices on a regular basis, but until then, we'll continue to deliver for you remotely.

As challenging as working from home has been, a large portion of our business requires us to be on-site with clients. Faced with state travel restrictions, quarantine requirements and additional client protocols, it required an extra level of attention and planning, as well as client understanding, to get the right people in place at just the right time.

SI is about more than simply project work though. During this time, we've not slowed down in finding ways to improve our business, both in our processes as well as innovations for the future. We've redesigned how our sales and marketing team is organized to refocus internal communications and drive more informed conversations with our clients. As a smaller company, we have weathered the pandemic as well as I could have hoped and are positioned as a company to be around for another 35 years. We have re-organized internally to have clear leadership in each business unit – Oil & Gas, Nuclear, Fossil and Critical Structures & Facilities. We've also continued to push forward on new services and technologies, including Material Verification Intelligence for pipelines, the Pegasus fuel performance code and BG4, our latest biofilm sensor. We have made an effort to better organize technical expertise by our business unit served. Hopefully, you will find this a bit easier to understand our companies span of technical prowess. All of these developments have been recently highlighted on our LinkedIn page, so I welcome you to connect with us for more developments in the future.

I know all of our clients were faced with similar challenges during this time. It is this shared experience that enables us to understand each other and recognize the great effort on everyone's part to ensure we get the job done. Finding the balance between getting the job done and ensuring everyone's safety is paramount to SI, and we'll continue to work in this direction, even when this pandemic is firmly in the rearview mirror. Overall, during these challenging times, I am appreciative of our clients for continuing to trust SI to always deliver.

In this Issue



Considerations of Pin Cracking in Finger Pin Turbine Blade Attachments

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FIGURE 1. ABOVE L-1 and L-0 Disk Side Finger Pin Attachments

OEMs recommend periodic inspection of pinned finger turbine blade attachments for detection of service-induced damage as part of ongoing rotor maintenance activity.

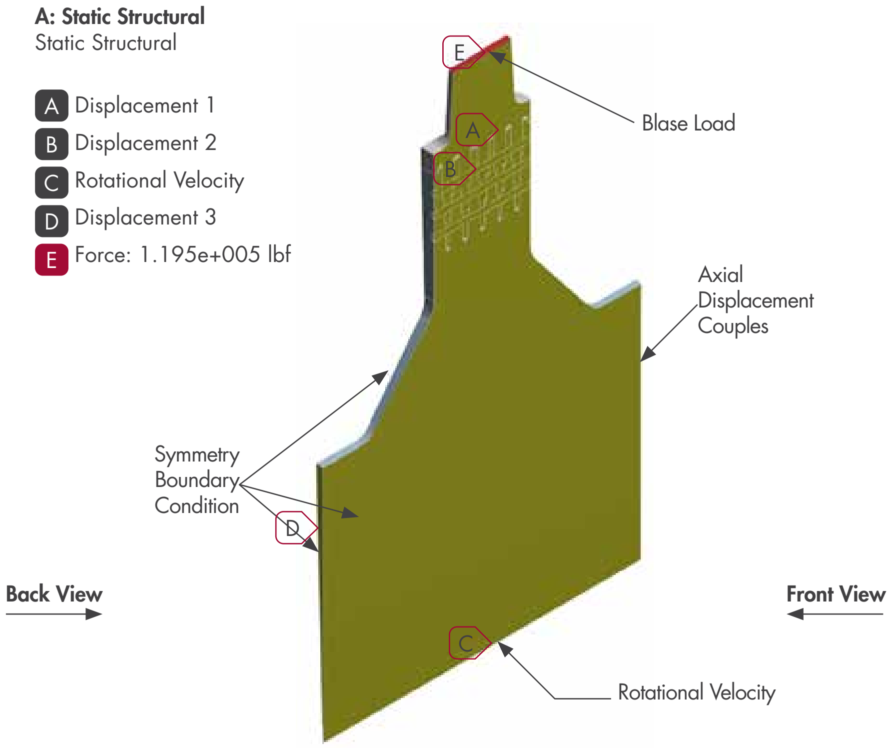

FIGURE 2. 3D FE Modeling of a Finger Pin Attachment Geometry

This article provides an example where ultrasonic inspection detected cracking in several pins of finger attachments and outlines an engineering assessment to support continued operation and identify a re-inspection interval. This approach can be applied to other pinned finger blade attachments to determine suitability for service.

Finger pin attachment designs are most common in the L-1 and L-0 stages of LP rotors where the largest blades are located. The finger pin design is capable of supporting long blades (> 40") with weights in excess of 100 lbs. Figure 1 is a photo showing the disk side component of finger pin connections at L-1 and L-0 stages. The blade side components of the connection have a mating set of fingers that are secured to the wheel with 3 pins per blade at the inner, middle and outer radial locations.

Finger pin inspections are performed using ultrasonic (UT) transducers from the admission and discharge ends of the pins. UT pin inspection is often part of a scheduled magnetic particle inspection of the LP rotor periphery and is part of ongoing maintenance activity. Inspections of disk and blade side fingers on the other hand are usually performed to address known issues (OEM TIL) or as a follow up to evidence of stress corrosion cracking (SCC) in the attachment. Finger inspections are more involved requiring blade removal and therefore are more resource intensive to perform.

The evaluation of finger pin inspection data is discussed. Pin data is reviewed to identify the affected pin shear planes and unable to transmit shear loading. Supporting finite element (FE) analysis is described that focuses on evaluating the redistribution of finger stresses to determine potential stress overload failures in the fingers (both disk and blade sides) as well as the pins. Disk and blade side finger inspection data, used to evaluate cracking in the attachment fingers, is discussed in a News and View article published by Structural Integrity (SI) in 2015 [1].

Stresses in the pins and fingers are obtained from a 3D FE analysis of a fully bladed finger pin attachment. As shown in Figure 2, symmetry boundary conditions are used with a one-half blade arc disk segment to effectively simulate the full disk geometry. Note that one plane of the model cuts through the center of the pins and blade (front surface) with the opposing boundary located at the blade outer surfaces (back surface). A pie shaped wedge of the stage disk defined by these bounding surfaces is included in the model. Contact elements are used at the pin/disk, pin/blade and disk/blade finger interfaces.

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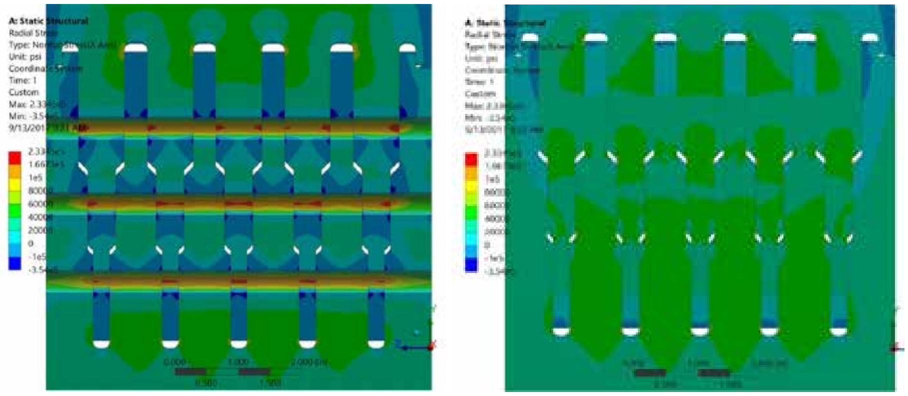


FIGURE 3. FRONT VIEW SHOWN ON THE LEFT BACK VIEW SHOWN ON THE RIGHT
Contour plots of radial stress distributions in the finger pin attachment

Stage Design Finger Stresses (ksi)		
Path ID	Disk σ_y > 75 ksi	Blade σ_y > 113 ksi
1	38.9	38.9
2	42.5	44.6
3	46.1	36.1
4	29.6	35.3
5	37.7	36.3
6	48.1	23.1

TABLE 1. Back Side Surface Radial Stress Summary

Contour plots of radial stress distributions across the front and back surfaces of the FE Model are shown in Figure 3. Note that blade and disk finger stresses are uniform across all fingers. Figure 4 shows a plot of the through thickness (from back to front surfaces) distribution of radial stress at a typical disk side finger location. The stresses at the back-surface are of primary interest as these stress levels determine when attachment failure will occur. Corresponding plots for blade side finger radial stresses are similar to the disk side plots. Table 1 is a comparison of the disk side and blade side finger stresses on the back side of the model for the as-designed condition.

Cracked pin inspection data is recorded for each blade and pin location. UT measured distances from the end of the pin to defect locations from both the admission and discharge ends of the pin are recorded. A sample of data collected is shown in Table 2. Note that when the sum of the admission and discharge side UT measured distances equals the disk thickness (6.09"), a single defect is identified. When that sum is less than the disk thickness then two or more defects may be present. The data is tabulated to determine how many defects are collectively present at each shear plane for all blade locations. Figure 5 is the schematic drawing of the finger pin attachment showing the locations of shear planes that have 1 or more recorded defects.

Total = 6.09" Single Defect

Total = 5.48" 2 defects + "potential defects"

Bucket No.	Outer		Middle	
	Adm.	Dis.	Adm.	Dis.
1	5.32	0.77	5.16	0.92
2	removed	removed	ok	ok
3	4.66	0.84	5.22	0.92
4	ok	ok	ok	ok
5	removed	removed	ok	ok
6	ok	ok	ok	ok
7	ok	ok	ok	ok
8	4.65	0.83	ok	ok
9	5.32	0.7	5.5	0.4
10	4.67	1.2	ok	ok

TABLE 2. Pin defect sample data (disk thickness = 6.09 inches)

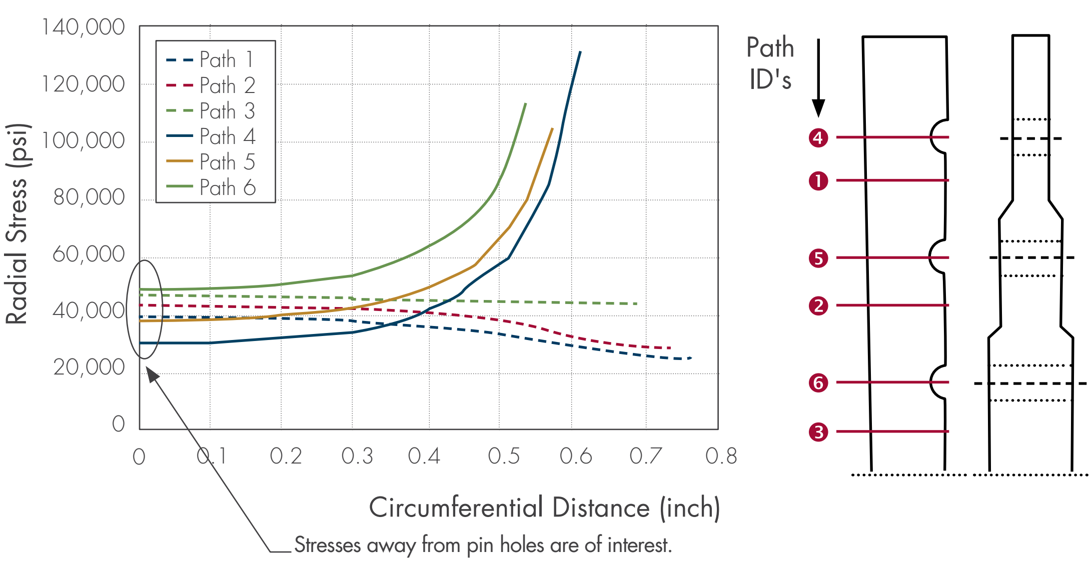


FIGURE 4. Through thickness (from back to front surfaces) distribution of radial stress at a typical disk side finger location.

To evaluate the effect of pin defects on finger pin attachment stresses, two bounding assumptions are made. First the locations of pin defects plotted in Figure 5 are assumed to prevent any transfer of shear loading, effectively modeling broken pins at those locations. Second, the defect locations shown in Figures 5 are assumed broken at all blade locations. Both assumptions are most limiting adding considerable conservatism to the analysis results.

The model discussed earlier is modified to include the broken shear planes identified in Figure 5. A contour plot of the resulting radial stress distribution on the back surface of the model is shown in Figure 6. Broken shear pin locations and maximum radial stress locations are identified in the plot. Note that when viewing the back-side surface of the model the broken shear pin locations are on the left side of the model. The locations of maximum radial stress are observed to be in the blade and disk fingers adjacent to the broken shear pin locations. This trend is also evident on the front-surface blade side radial stresses (not shown).

Table 3 is a summary of the maximum radial stresses in the finger pin attachment with broken pins. Table 3 includes maximum stresses for the five-disk side and six blade side fingers. Stresses from the as-designed attachment FE analysis are included to serve as a reference for comparison of the redistributed stresses from broken pins. Inspection of Table 3 shows that the highest radial stresses are in the blade and disk fingers adjacent to the broken shear pin locations (fingers B4 and D4 in Figure 6) with stress levels attenuating to lower values in fingers further removed from B4 and D4 locations. Radial stress levels in all blade side and disk side fingers, are well below yield levels indicating that the effects of pin defects are not compromising rotor integrity or preventing continued rotor operation.

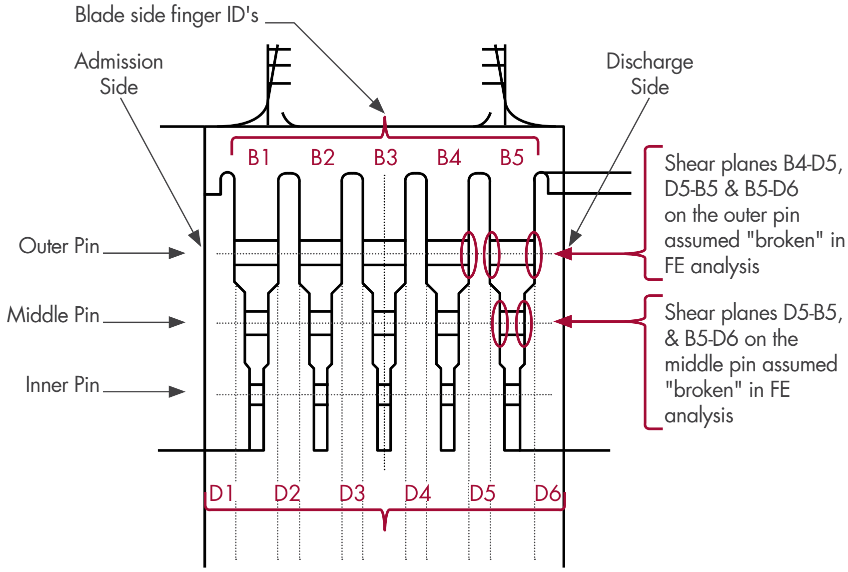


FIGURE 5. Shear plane locations having one or more UT recorded defects

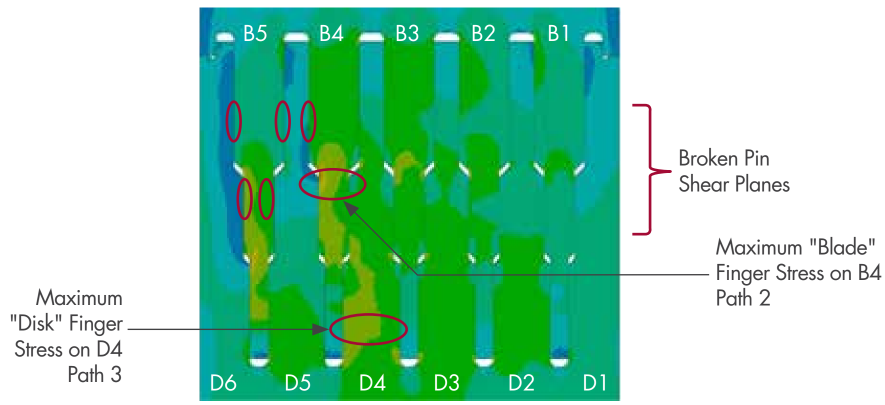


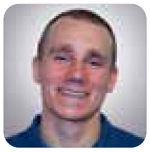
FIGURE 6. Contour plots of radial stress with broken shear pins – back surface

Finger "Broken Pin" Stress (ksi)					
Disk $\sigma_y > 75$ ksi			Blade $\sigma_y > 113$ ksi		
Finger ID	Path 3	Path 6	Finger ID	Path 2	Path 5
Design	46.1	44.6	Design	44.6	36.3
D1	27.7	29.2	B1	38.4	31.0
D2	43.9	45.8	B2	47.3	38.9
D3	51.4	53.4	B3	55.5	45.3
D4	58.5	61.1	B4	68.0	59.3
D5	44.9	41.9	B5	56.6	54.9
D6	24.2	22.7			

TABLE 3. Summary of maximum radial stresses

References / Footnotes

[1] Lange, C. and Jackson, H.; "Cracked Pin Finger Turbine Blade Attachment Assessment for Continued Operation;" News & Views 2015 Volume 39.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To provide operating flexibility, combined cycle plants are typically equipped with bypass systems (high pressure routing steam to cold reheat and hot reheat routing steam to the condenser). These bypass systems include conditioning valves designed to reduce steam pressures followed by outlet desuperheaters which inject water to reduce steam temperatures.

This service environment exposes the downstream piping to a high frequency of temperature transients making these areas one of the most prominent 'industry issues'. Some example problems that can arise from either improper operating logic or poor design include:

1. inadequate distance downstream of spraywater injection resulting in insufficient time for spraywater to evaporate,
2. leak-through of spraywater due to worn block and/or flow control valves in the spraywater supply line,
3. excessive spraywater injection (overspray) in which excessive water is introduced or water is introduced when insufficient steam flow or temperature head exists to evaporate the water, and
4. worn or faulty spray nozzles that have incorrect spray patterns or ineffective atomization.

These issues can result in thermal shock (quenching) of the downstream piping due to direct water impingement and/or significant thermal differentials from the top-to-bottom of the pipe because of unevaporated water pooling in the piping. The primary damage mechanism, as a result, is thermal fatigue cracking which typically initiates at ID stress concentrations (weld counterbores) and propagates from the ID towards the OD (Figure 1). Depending on the flexibility of the bypass line, this can also result in OD cracking from significant bending loads in conjunction with the primary ID thermal fatigue cracking (Figure 2).

Bypass Line Spray Issues

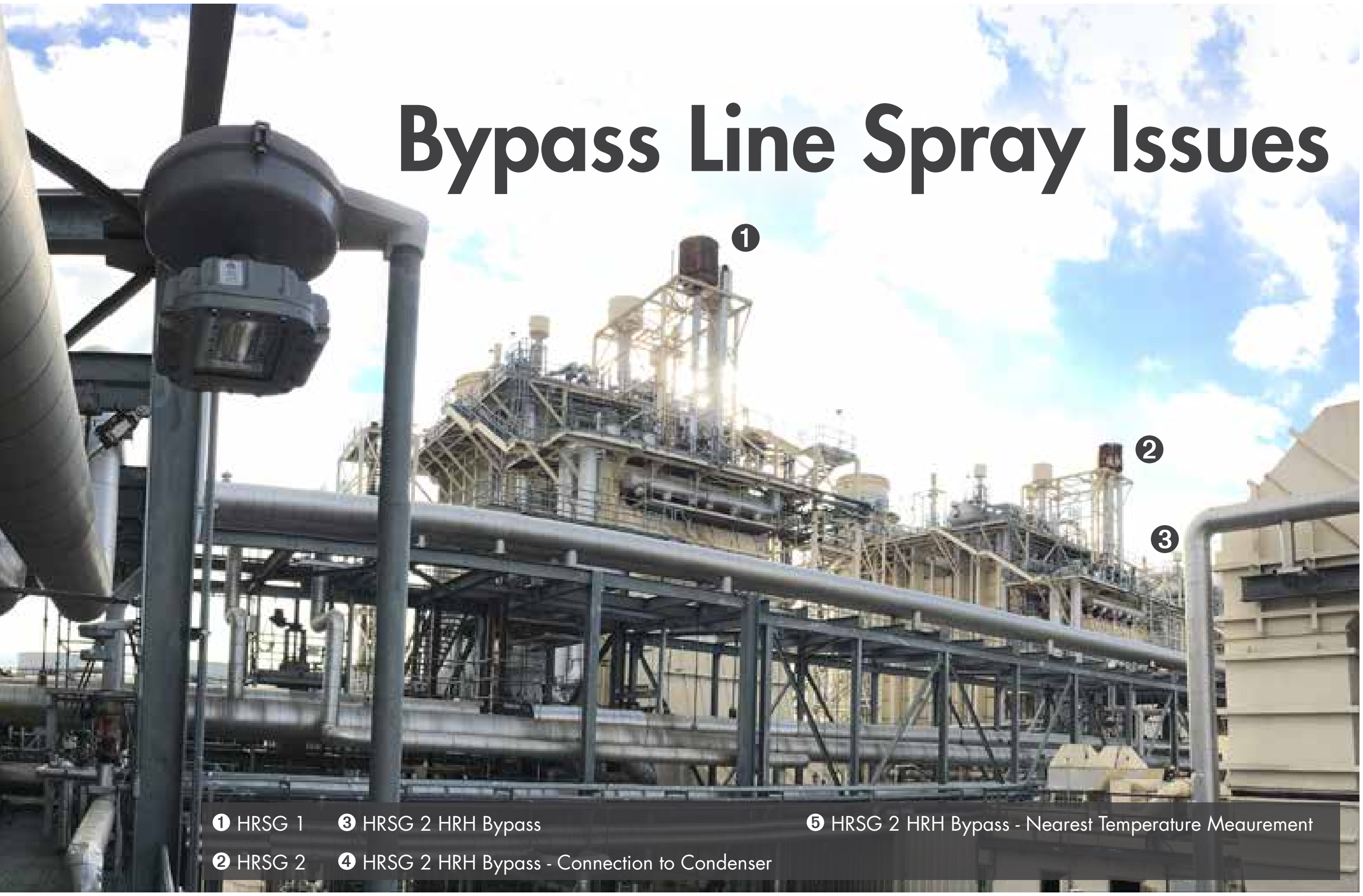

FIGURE 3. ABOVE Example of the nearest temperature measurement on a hot reheat bypass line.

FIGURE 1. Example of a major through-wall crack (~70% of the circumference) at a shop weld. This cracking was located within the spool supplied by the valve manufacturer.

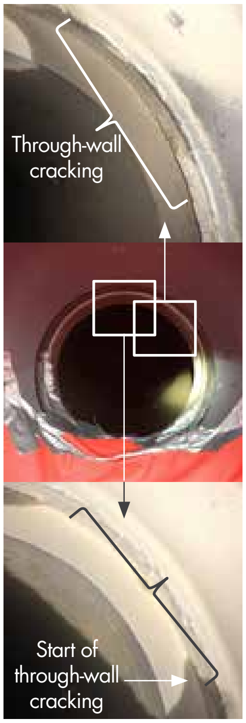

FIGURE 2. LEFT Example of a major through-wall crack (~70% of the circumference) examined from the ID surface where cracking is occurring at the counterbore-to-land transition (stress concentration site). This particular girth weld had both ID and OD cracking at the remaining intact wall.

The crucial aspect in assessing the performance of these bypass system is being able to determine the magnitude and frequency of thermal transients. However, the nearest temperature transmitters (thermoelements) are typically located far downstream, such that local thermal transients at the conditioning valve and desuperheater are often not detected (Figure 3).

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FIGURE 4. Attemperator Damage Tracking App showing the count of pooling and impingement events from local thermocouple measurements.

To expedite analysis of thermocouple data and provide plant staff with the most up-to-date tracking, SI has also developed an online damage tracking application which has algorithms configured to automatically count the number and severity of impingement and flooding events, thereby providing plant engineers with real-time trends in damage accumulation rates. The software can even be configured to provide email alerts when certain magnitude events occur or based on trends in damage accumulation (Figure 4). This allows early detection of potentially damaging events so that appropriate mitigations (maintenance, logic updates, etc.) can be performed before costly repairs are required.

While reviewing data far downstream may still identify issues, Structural Integrity (SI) typically recommends the installing local surface mounted thermocouples (TCs) to evaluate temperature differentials around the pipe circumference and on downstream elbows for impingement. Type K thermocouples with 20 Ga. solid wire with glass/glass insulation and stainless steel over-braid are recommended. Ideally, these surface mounted thermocouples would be routed to the digital control system (DCS) for view in the data historian (PI) or placed in a temporary enclosure with a data logger such that bulk data can be extracted for review by engineers.

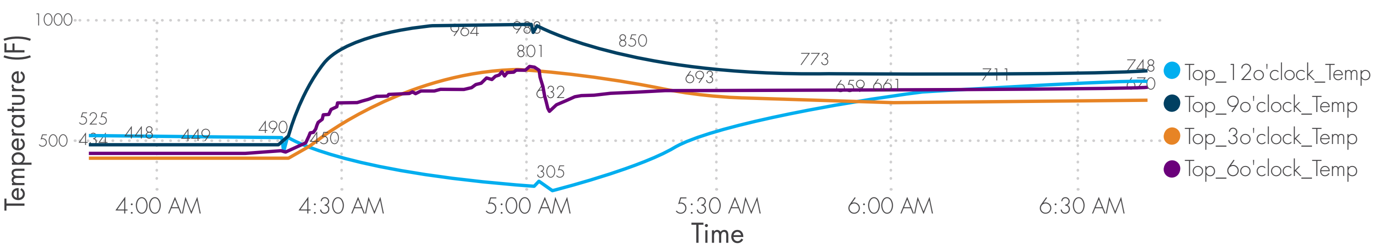

FIGURE 5. Example of a startup transient from the temporary data logger used at a select combined cycle plant.

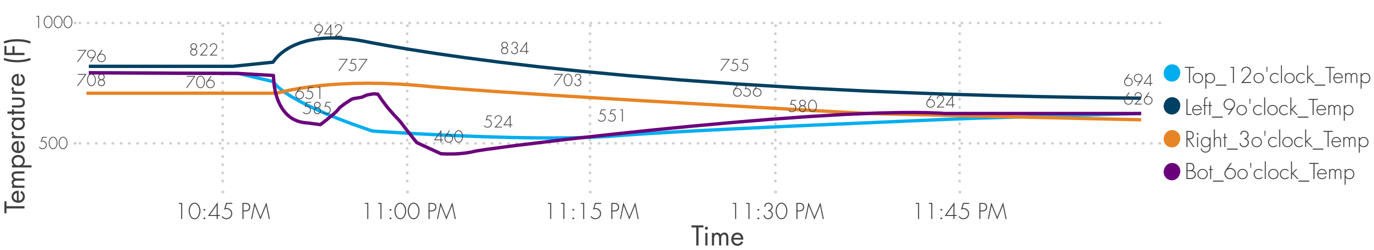

FIGURE 6. Example of a shutdown transient from the temporary data logger used at a select combined cycle plant.

Case Study

To provide some context, a select combined cycle plant (2x1) recently experienced a through-wall leak at a girth weld on one of the HRSG's hot reheat to condenser bypass line. A ring section containing the failed girth weld was removed and submitted to SI's Materials Lab in Austin, Texas for review. The examination indicated that the crack was consistent with typical thermal fatigue damage. As previously mentioned, this is the expected damage mechanism for the area considering the proximity of a spray water station. SI recommended that the plant install local thermocouples (TCs) around the failed area to assess the magnitude of transients experienced during load change events and normal operation. The plant installed 4 local TC's on the top, bottom and sides of the pipe along with a local data logger.

Review of the data revealed significant temperature variations (up to 700°F) around the pipe circumference during load change events. These differences occurred up to 4 times per day: typically early in the morning between when the unit was started and later in the evening between 9-10pm when the unit was shutdown. Figure 5 and Figure 6 show representative startups and shutdowns from the newly installed TCs.

Recommendations

Based on the significant temperature variations observed, it is extremely likely that the identified thermal fatigue damage which caused the initial failure would initiate damage again. It was recommended the plant:

1. Perform a more in-depth review of the hot reheat bypass and the overall control logic to determine if the transients can be mitigated.
2. Install pertinent surface-mounted TCs on the other HRSG hot reheat bypass line as well as their high pressure bypass lines.
   - Continue to collect data from the currently installed remote data logger to further assess the transient information.
3. If operational changes cannot be implemented to control the magnitude of events, the next step would be to evaluate a design change to eliminate the thermal events.
   - The current attemperator design is a single nozzle style however an alteration to a ring manifold style attemperator may provide better distribution of spray and reduce temperature differentials.
   - Also, it may be even be beneficial to consider adding a liner to the bypass piping (which is typically done on interstage attermperators).
4. At the next available outage, perform a localized inspection of the hot reheat bypass girth welds downstream of the pressure-reducing valve and the attemperator nozzles. The spray nozzles should also be checked to see:
   - Whether the spray nozzles are oriented correctly spraying downstream in the pipe and not skewed so that water is not spraying directly at the pipe wall,
   - Whether the spray nozzles have any cracks which may be causing poor distribution of the spray water.

Instrumenting all 4 areas (2 hot reheat bypass – 1 already instrumented, 2 high pressure bypass) will provide valuable information between the two HRSGs/two systems. Understanding the transients is the necessary first step, then evaluating/changing the logic, and follow-up with pertinent NDE inspections to ensure there is an understanding of the potential geometric factors here that could exacerbate any issue. If follow-on inspections find damage then the plant may also consider FEA/fracture mechanics to assess the timing of when to take further action.

Metallurgical Lab Case Study

Grade 91 Elbows Cracked Before Installation

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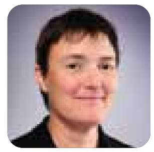

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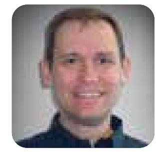
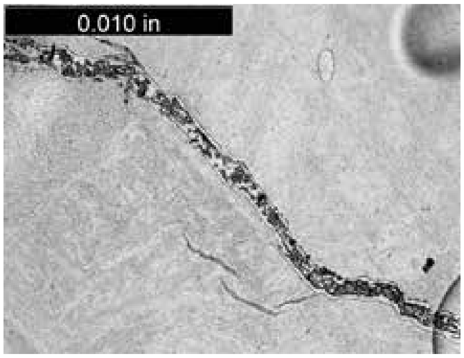


Structural Integrity (SI) personnel visited a power plant construction site to examine four Grade 91 elbows (ASTM A234-WP91 20-inch OD Sch. 60) that were found to contain axially oriented surface indications. The elbows had not yet been installed. The indications were initially noticed during magnetic particle testing (MT) after one end of an elbow was field welded to a straight section and post weld heat treated (PWHT). Subsequently, three additional similarly welded elbows were inspected and indications were found at both the welded (inlet) and open (outlet) ends of three elbows.

The elbow with the most significant indications was selected for SI's on-site examinations. Figure 1 shows the inlet and outlet ends of the selected elbow.

Locations on the extrados of the selected elbow at both the welded (inlet) and open (outlet) ends had been ground and inspected by MT and linear phased array ultrasonic testing (LPA) prior to SI's visit. Indications were noted in all areas examined. Hardness testing and ultrasonic wall thickness measurements had also been performed prior to SI's visit. The hardness values in the weld heat-affected zone (HAZ) and base metal on the elbow ranged from 209 to 239 HB at quadrants around the circumference; these hardness values are within the normal range for Grade 91 material. An area on the extrados of the elbow near the weld also underwent an exploratory grinding/excavation exercise to determine how deep the indications were. Approximately 0.5 inches of material was removed, and the indications were still evident. The final wall thickness in the area was reported to be 0.799 inch, with initial wall thickness ranging from 1.200 – 1.300 inch.

FIGURE 1. The inlet LEFT and outlet RIGHT ends of the elbow selected for examination. The grinding on the outlet end had been done prior to SI's examination.



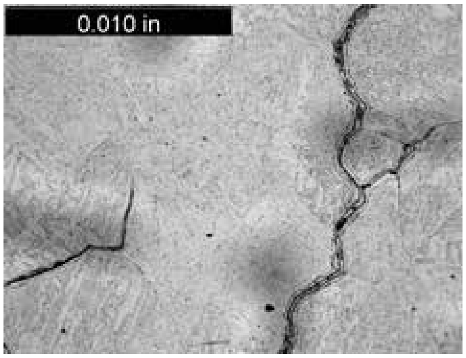


FIGURE 2. The typical appearance of the cracking at the inlet UPPER and outlet LOWER ends of the elbow.

As part of SI's examination, in-place metallography/replication was performed on the selected elbow at the welded (inlet) and open (outlet) ends in areas that were known to contain indications. Hardness testing was performed in each of the areas replicated. The cracking in the replicated areas was intergranular, exhibited relatively significant branching, and was oxide lined or filled; examples of the cracking present at each end are shown in Figure 2. The hardness values were in the 220 – 240 HB range, which is within the normal range for Grade 91 material (ASTM SA 335 Grade 91 requires hardness values in the range of 190 – 250 HB for new material).

Even though the hardness values were normal, the cracking present in the elbow is characteristic of stress corrosion cracking (SCC), which is usually associated with Grade 91 with high hardness (greater than ~350 HB). The presence of oxide within the cracks indicates the cracking was present when the material was heated to a high enough temperature to form the oxide, such as during tempering or PWHT. Since cracks were present at both the welded and unwelded ends of the elbow, the cracking most likely formed prior to the field welding. The oxide-filled cracking at both ends of the elbow and the hardness values within the normal range indicate that the components were heat treated after the cracks formed. SI recommended that the manufacturing history and fabrication records for the elbows be reviewed to determine if they were left in a moist environment in a hardened condition. Such a condition would have existed after a normalizing heat treatment but prior to tempering, or possibly after a hot working operation, if the working occurred above ~1600°F and the components were air cooled.

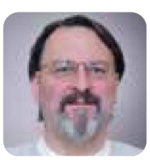
SI recommended that the elbows not be placed into service with the type of indications/cracks documented during the evaluation and that any indications identified should, at the very least, be removed by grinding. The depth and extent of the cracking could necessitate repair or replacement of the components.

Stress Corrosion Cracking in CSEF Steels

When higher-chromium creep-strength enhanced ferritic steels, including Grade 91, are left in the untempered or under-tempered condition they are susceptible to stress-corrosion cracking (SCC) in what would otherwise be considered "benign" environments. A comparison of cases of unexpected cracking in Grade 91 boiler components found no common factors with regard to fabrication or service history, other than the fact that the components had been left in a fully hardened condition for an extended period of time before the final tempering post fabrication heat-treatment was applied. Since SCC can only occur if moisture is present, and since a common source of moisture is condensation due to changes in ambient temperature, all Grade 91 weld joints should be maintained at temperatures above the dew point, or they should be kept in a humidity controlled environment until the required PWHT can be performed.

SI:FatiguePro Version 4.0 Crack Growth Module

Application Case Study Complex Multi-Cycle Nuclear Transients



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As plants enter their initial or subsequent license renewal period one of the requirements is to show that fatigue (including environmental effects) is adequately managed. For some locations in pressurized water reactors (PWRs), it can be difficult to demonstrate an environmental fatigue usage factor less than the code allowable value of 1.0. Therefore, plants are increasingly turning to flaw tolerance evaluations using the rules of the ASME Code, Section XI, Appendix L. Appendix L analytically determines an inspection interval based on the time it takes for a postulated flaw (axial or circumferential) to grow to the allowable flaw size. For surge line locations, this evaluation can be very complex, as the crack growth assessment must consider many loadings, such as: insurge/outsurge effects, thermal stratification in the horizontal section of the line, thermal expansion of the piping (including anchor movements), and internal pressure. Trying to envelope all of these loads using traditional tools can lead to excess conservatism in the evaluation, and short inspection intervals that reduce the value of an Appendix L evaluation.

Figure 1 shows a plot of just the thermal stress from one complex transient that was evaluated recently for a US plant. As shown, there are multiple large peak-and-valley cycles within the transient. To perform a crack growth analysis using this complex loading, the complicated transient stress would have to be combined with other loadings (e.g., pressure, piping, residual stress) and then all the cycles determined from each peak and valley. Using traditional Fatigue Crack Growth (FCG) tools, this work would require extensive manual manipulation of the transient data, or writing scripts to automate the process. Rather than do this, Structural Integrity (SI) chose to use the crack growth module in SI:FatiguePro 4.0 (FP4) to perform this analysis.

The FP4 software is designed to calculate crack growth for one or more specified flaw models, using the actual plant operating history as input. Using specialized algorithms, it does this with a minimum of user input required. First, FP4 processes the plant input data to calculate through-wall stresses, as a function of time, for each analysis location. Next, it calculates the stress intensity factor (K) versus time, based on the current crack size and the calculated stress history. Then a Rainflow cycle counting algorithm is used to determine the number of cycles contained in the K history, and the K_{min}/K_{max} values for each cycle. At the end of each day, the incremental crack growth from the identified K cycles is calculated and added to the evaluation (increasing the current crack size, which is an input to the next day's K calculation). This process is repeated for each day of plant input, until all the data is processed or the crack reaches the allowable flaw size.

To perform the evaluation, a simulated 10-year operating stress history was created by combining and sequencing the stress analysis results. For each design transient, a number of expected cycles was determined that would bound any 10-year interval in the license renewal period. The resulting set of transients was put into a possible sequence and arranged to minimize shocks between the end of one transient and the beginning of the next. This sequence was used as input for the FP4 evaluation.

Two FP4 projects were created with FCG locations to model six potential hypothetical flaws. Then the simulated 10-year operating history was read into the FP4 software. The analysis was started, and the crack growth calculations (for all locations) were executed as described above. After 10 years of growth, none of the flaws exceeded 65% of the allowable flaw size. Figure 2 shows the calculated crack growth over a 10-year period for 3 of the locations evaluated.

Using the FP4 crack growth module for transients with complex loadings provides the most accurate calculation of crack growth available, removing any unnecessary conservatism from the evaluation. This means that achieving a 10-year inspection interval for Appendix L evaluations is more likely.

This option is especially appealing for plants that already have FP4 installed, as it is substantially cheaper to convert existing fatigue locations to a flaw tolerance approach, compared to creating one from scratch.

Beyond Appendix L, FP4 can be used to monitor the potential growth of flaws found during inservice inspection using the actual plant operating history (similar to the way a stress-based fatigue application works). If you would like to know more about this approach or others, please reach out to Tim Gilman (tgilman@structint.com) or Curt Carney (ccarney@structint.com).

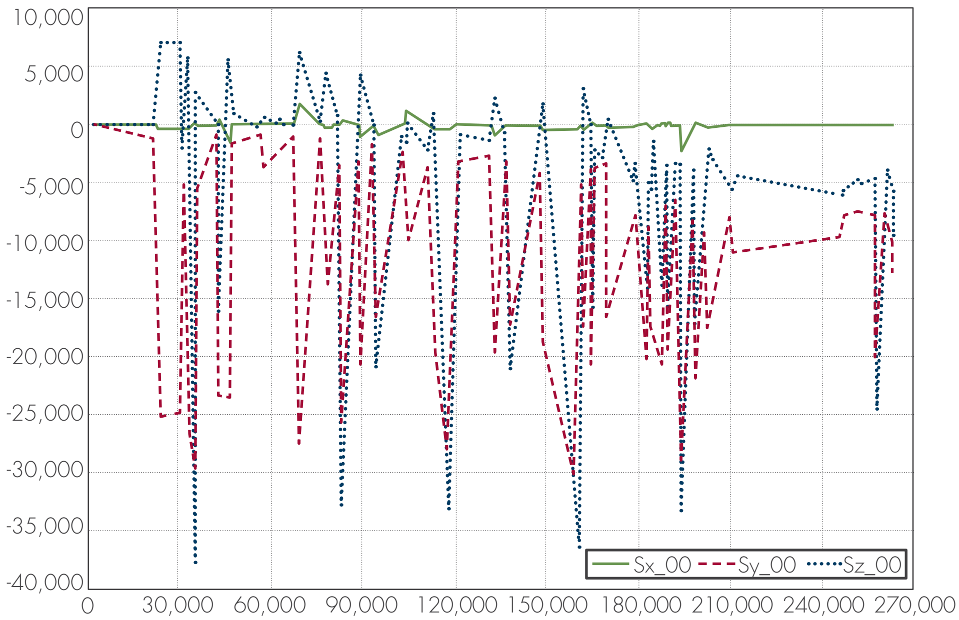

FIGURE 1. Example Insurge/Outsurge Stress Response

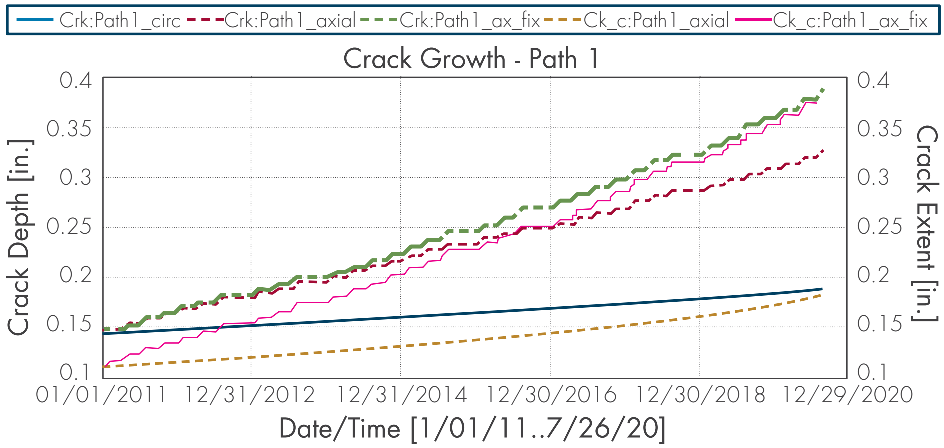

FIGURE 2. Fatigue Crack Growth for 10-Year Period Using SI:FatiguePro 4.0

Environmentally-Assisted Fatigue

Screening and Managing EAF Effects in Class 1 Reactor Coolant Components

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Environmentally-Assisted Fatigue (EAF) screening is used to systematically identify limiting locations for managing EAF effects on Class 1 reactor coolant pressure boundary components wetted by primary coolant. This article provides an overview of the methods developed and used by Structural Integrity (SI) for Class 1 components having explicit fatigue analyses performed using ANSI/ASME B31.7[1] and ASME Section III[2]. A future article will discuss how this is performed for Class 1 piping designed and analyzed to ASME/ANSI B31.1[3].

What needs to be done for License Renewal

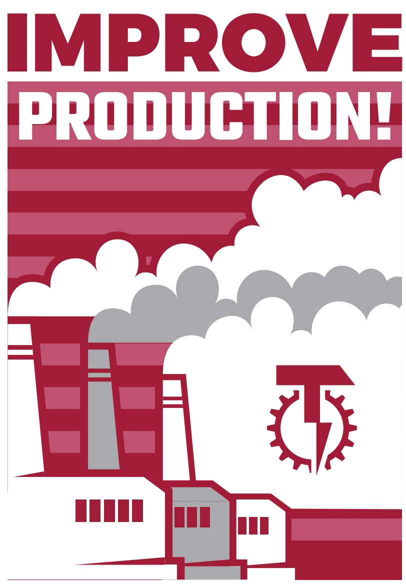
The basic requirements for EAF screening for US plants are established by USNRC Regulatory Guide 1.207[4] and fall into two basic categories:

Category 1 - Early license renewal applications for 60 years (prior to issuance of NUREG-1801, Revision 2[5] in December 2010).

- Identify the NUREG/CR-6260[6] locations for each applicant's NSSS vendor and vintage.
- Evaluate the license period CUF_{en} (EAF cumulative usage factor) values for the 6260 locations.

Category 2 - Later license renewal applications for 60 years and all Subsequent License Renewal (SLR) applications following the guidelines of NUREG-2191[7].

- Identify the NUREG/CR-6260 locations for each applicant's NSSS vendor and vintage.
- Evaluate the license period CUF_{en} values for the 6260 locations.
- Plus determine whether there are more limiting locations than the NUREG/CR- 6260 locations.



EAF screening was developed for the Category 2 plants where it was necessary to determine whether the NUREG/CR-6260 components were the limiting components in the Class 1 systems for the effects of EAF. It has also been applied to Category 1 plants who elected to perform a 'gap analysis' relative to NUREG-1801, Revision 2.

Steps to Determine Component EAF Rankings

<u>**Collect Data**</u>

Obtain design information, such as fatigue analysis, material properties, plant transient characteristics and design cycles.

<u>**Determine Thermal Zones**</u>

Thermal Zones are a collection of piping and other components which undergo essentially the same group of thermal and pressure transients during plant operations.

<u>**Evaluate Locations**</u>

Components in each Thermal Zone are evaluated to establish relative cumulative fatigue usage (CUF) and EAF values. These rankings will account for differences in stress and stress range as well as environmental effects, which are material specific. If the differences are a result of differences in analytical rigor, they must be resolved to a common basis prior to comparison. The purpose of ranking on a common basis is to assure the leading components for fatigue damage are identified in each Thermal Zone. Once these leading components are identified, the CUF values for each leading component may be reduced by reanalysis to determine if the CUF_{en} is conservatively less than or greater than a value of 1.0 or less than the similarly determined value for the NUREG/CR-6260 component in that Thermal Zone.

ASME Class 1 components are segregated into Thermal Zones by material. CUF values of these components may be reduced by:

- Evaluating fatigue load pairings for over-conservatism.
- Using projected cycles vs. design cycles (more common with BWR plants).
- Evaluation using a newer edition of the ASME Code.
- Application of the ASME Code Case N-779[8] alternative rules for calculation of K_e.
- Application of ASME Code Case N-902[9] Thickness Factor and Gradient Factors.

A determination of a F_{en} value for each component is required to compute the comparative CUF_{en} values. The F_{en} evaluation method uses relevant parameters, such as primary coolant dissolved oxygen, maximum transient temperature and estimated tensile strain range of the leading transients. F_{en} values can often be reduced by use of average transient temperatures and/or actual plant transient temperature data, so long as Regulatory Guide 1.207 requirements for use of applicable NUREG guidance documents for calculation of F_{en} values are followed.

Ranking and Identification of Sentinel Locations

A sentinel location is a specific location in a piping system or component that serves as a leading indicator for EAF damage accumulation in a specific Thermal Zone.

CUF_{en} values are determined by the product of the CUF and the F_{en} value.

IMPROVE EFFICIENCY

The components in each Thermal Zone are compared on the basis of the CUF_{en} value produced on a common basis. Sentinel locations are those components with the highest CUF_{en} values.

Management of EAF

Ongoing management of the sentinel locations can be accomplished through several methods:

- Plant transient counting (where CUF_{en} values are low).
- Management with a fatigue monitoring program (where CUF_{en} values may approach 1.0 by the end of the extended period of operation).
- Inclusion in the plant's inservice inspection program (where a CUF_{en} value of less than 1.0 is unable to be achieved and a flaw tolerance evaluation has been performed).

Benefit to Plant Owners

This process will optimize plant owner costs by:

- Minimizing the requirement to perform new detailed stress and fatigue analyses.
- Grouping and ranking allows management of one (or only a few) sentinel locations in each Thermal Zone compared to managing all components individually.
- Meeting the regulatory requirements to manage EAF using a graded approach.

Footnotes

(1) ANSI/ASME B31.7-1969, Nuclear Power Piping, American National Standards Institute.

(2) ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components.

(3) ANSI/ASME B31.1, Power Piping, American National Standards Institute.

(4) Regulatory Guide 1.207, Revision 1, Guidelines for Evaluating the Effects of Light-Water Reactor Water Environments in Fatigue Analyses of Metal Components, U.S. Nuclear Regulatory Commission, Washington, DC, June 2018.

(5) NUREG-1801, Revision 2, Generic Aging Lessons Learned (GALL) Report, U. S. Nuclear Regulatory Commission, Washington, DC, December 2010.

(6) NUREG/CR-6260, Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components, March 1995, ML031480219.

(7) NUREG-2191, Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report, U.S. Nuclear Regulatory Commission, Washington, DC, July 2017.

(8) Case N-779, Alternative Rules for Simplified Elastic-Plastic Analysis, Class 1, Section III, Division 1, ASME, New York, NY, Approved January 26, 2009.

(9) Case N-902, Thickness and Gradient Factors for Section III Piping Fatigue Analyses, Section III, Division 1, ASME, New York, NY, Approved February 20, 2020.

Examination Optimization for PWR and BWR Components

Optimizing the inspection interval for high-reliability components whose examinations have a significant outage impact.

Welds and similar components in nuclear power plants are subject to periodic examination under ASME Code, Section XI. Typically, examinations are performed during every ten-year inspection interval using volumetric examination techniques, or a combination of volumetric and surface examination techniques. Nuclear plants worldwide have performed numerous such inspections over the plant history with few service induced flaws identified. Since personnel health and safety, radiation exposure, and overall outage costs associated with these inspections can be significant, Structural Integrity (SI) was contracted by the Electric Power Research Institute (EPRI) to review the technical bases for the inspection intervals for select components. The goal was to determine whether the frequency of current inspection requirements was justified or could be optimized (i.e., reduced in order to devote more attention to higher-value inspections and thereby maximize overall plant safety). Special priority was given to components demonstrating an exceptional history of reliability and whose examinations have a significant outage impact.

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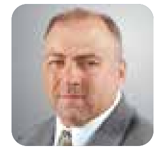

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To identify which components and inspection requirements were most suitable for optimization, EPRI performed a scoping investigation to collect the following information:

- The original bases for the examinations;
- Applicable degradation mechanisms, and the potential to mitigate any potential damage associated with each mechanism;
- Operating experience, examination data, and examination results, e.g., fleet experience;
- Previous relief requests submitted to regulators;
- Industry guidance documents that replace or complement ASME Code requirements;
- Redundancy of inspections caused by other industry materials initiatives and activities (e.g., Boiling Water Reactor Vessel and Internals Project (BWRVIP), Materials Reliability Program (MRP), etc.); and
- Existing Code Cases that provide alternatives to existing ASME Code inspection requirements and their bases.

Continued on next page

After compilation and review of the information collected, EPRI and their members determined that the inspection requirements for the following components were most suitable for optimization:

- Pressurized water reactor (PWR) steam generator shell and nozzle welds and nozzle inside radius sections;
- PWR pressurizer shell and nozzle welds; and
- Boiling water reactor (BWR) heat exchanger[1] shell and nozzle welds and nozzle inside radius sections.

Note 1. ASME Code Case N-706-1 provides alternative inspection requirements for PWR heat exchanger components. Most PWRs now use this Code Case as an alternative.

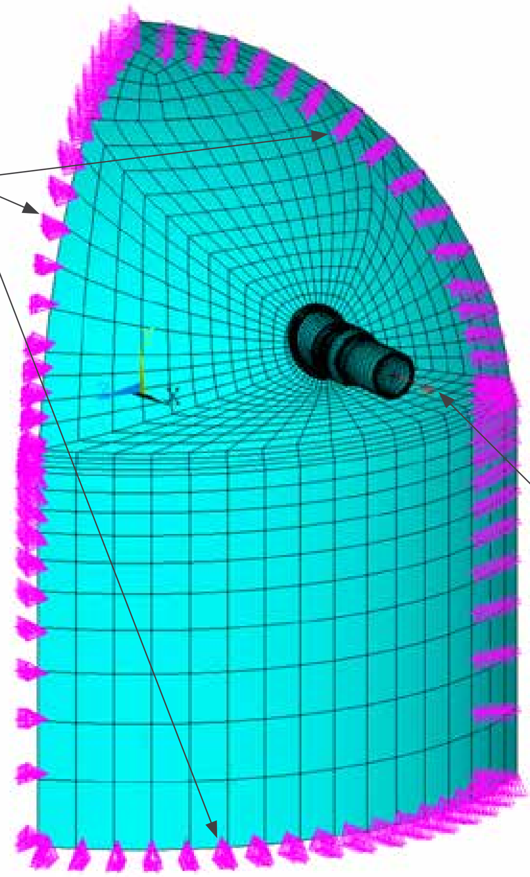

FIGURE 7-14. from EPRI Report 3002015905

For each of the components listed above, the following steps were performed:

Review of Previous Related Projects

A review was performed of all previous industry initiatives that provided optimized or revised examination requirements for related components (e.g., nozzle-to-shell welds, inner radii) in lieu of ASME Code, Section XI inspection requirements. Initiatives were documented in a variety of sources (e.g., BWRVIP reports, MRP reports, EPRI reports, Pressurized Water Reactor Owner's Group (PWROG) reports, plant-specific utility relief requests and associated regulatory safety evaluation reports (SERs), ASME Code Cases, etc.). The relevance of each initiative to the current work was determined, and the resultant relevant optimized requirements were documented.

Review of Inspection History and Examination Effectiveness

EPRI conducted an industry survey to collect the number of examinations performed for each selected component (e.g., pressurizer nozzle-to-shell weld). Responses were obtained from a total of 74 nuclear units worldwide (69 U.S. and 5 international units). The data gathered from this survey covered Babcock & Wilcox (B&W), Combustion Engineering (CE), Westinghouse (W), and General Electric (GE) plant designs. The following information was tabulated for each unit:

- The total number of each component;
- The total number of ISI examinations performed on each component;
- The number of examinations containing flaws exceeding ASME Code, Section XI acceptance standards (i.e., IWB-3500);
- The total number of flaws detected (across all examinations for the component);
- The details on how all detected flaws were dispositioned;
- The estimated personnel dose accumulated per examination (including pre- and post-examination activities such as insulation removal, scaffold erection, etc.);
- Any impacts the examination had on outage activities; and
- Relief Requests submitted and approved by regulators.

Survey of Components and Selection of Representative Components for Analysis

The design and fabrication history of each vessel type (PWR steam generator, PWR pressurizer, and BWR heat exchanger) was investigated. As part of the EPRI survey described above, details of component configurations and vessel operating conditions were collected. This information was reviewed by SI to assess differences and similarities across the different plant designs for each selected component. Industry and plant-specific operating experience (including degradation history) were also reviewed. Based on this information, representative component configurations were selected for further evaluation.

Evaluation of Potential Degradation Mechanisms

The selected components were evaluated for potential susceptibility to typical degradation mechanisms, including those identified in the U.S. Nuclear Regulatory Commission's (NRC's) Generic Aging Lessons Learned (GALL) Report for Subsequent License Renewal (SLR), NUREG-2191. Identified degradation mechanisms included those associated with environmentally assisted cracking, localized corrosion, flow-sensitivity, general corrosion, and fatigue. In most cases, the evaluation determined that only fatigue-related degradation mechanisms were significant enough to merit detailed evaluation; these mechanisms were then considered in the deterministic fracture mechanics (DFM) and probabilistic fracture mechanics (PFM) evaluations discussed below.

Component Stress Analysis

Applicable materials, operating loads, and transients were established for the selected components. Due to the complex geometry and associated stress distributions in the components selected for evaluation, finite element analyses (FEA) were performed for all components. Two-dimensional (2-D) axisymmetric and three-dimensional (3-D) finite element models were used depending on the symmetry of each component, and thermal stress analyses were performed for applicable thermal transients and internal pressure to develop stress distributions for use in the DFM and PFM evaluations.

Deterministic and Probabilistic Fracture Mechanics Evaluations

The DFM and PFM approaches used in this project were based on methods used in previous inspection optimization projects. Those previous projects (many for reactor pressure vessels) involved either a decrease in examination frequency, a reduction in examination scope, or both. The DFM evaluations were performed using bounding inputs to determine the length of acceptable component operability with a postulated flaw. The results of the DFM investigation were also used to determine the critical stress paths for consideration in the PFM analyses. The results of the DFM evaluations concluded that all selected components are very flaw tolerant, with the capability of operating with a postulated flaw for more than 80 years.

PFM evaluations were performed to demonstrate the reliability of each selected component assuming various inspection scenarios (e.g., preservice inspection (PSI) only, PSI followed by 10-year inservice inspections (ISI), etc.). Monte Carlo probabilistic

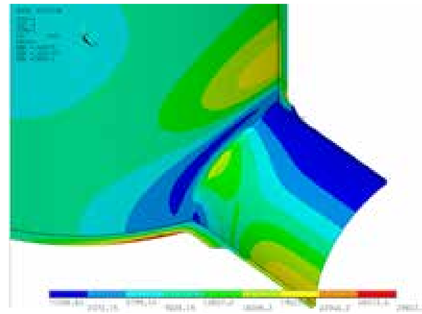

FIGURE 7-16. from EPRI Report 3002018473

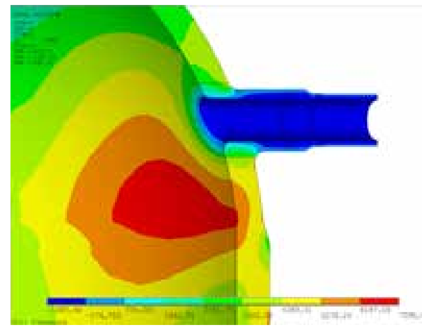

FIGURE 7-17. from EPRI Report 3002015905

analysis techniques were used to determine the effect of randomized inputs and various inspection scenarios on the probabilities of rupture and leakage for the selected components. Sensitivity studies were performed to investigate possible variation in the various input parameters to establish the key parameters that most influence the results.

The PFM evaluations were performed using a new software code, **PROMISE** (**PR**obablistic **O**pti**M**ization of **I**n**S**p**E**ction), Version 2.0, which implemented a probabilistic model of fatigue crack growth using linear elastic fracture mechanics (LEFM) methods, consistent with ASME code, Section XI flaw evaluation procedures. The **PROMISE** software was developed, verified, validated, and tested under the provisions of a 10 CFR 50, Appendix B Nuclear Quality Assurance Program.

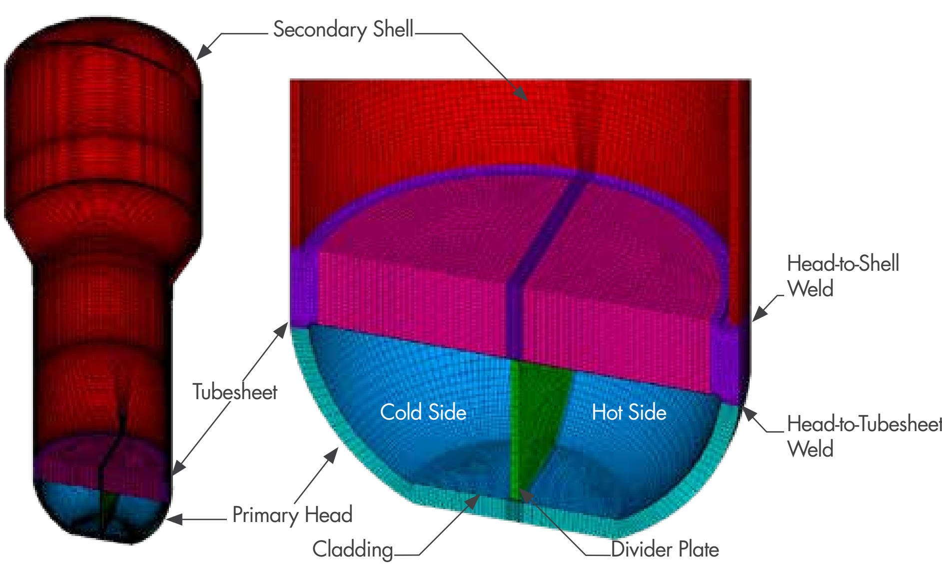

FIGURE 7-19. from EPRI Report 3002015906

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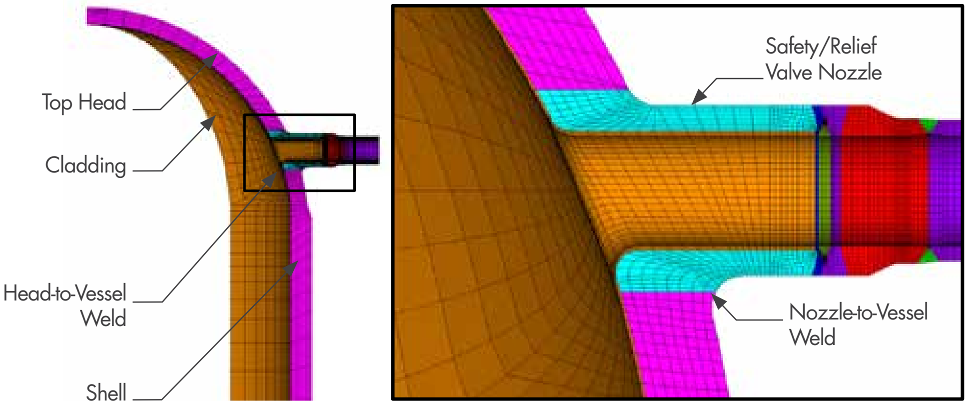


FIGURE 7-12. from EPRI Report 3002015905

Probabilities of rupture and leakage were determined for the limiting stress paths in each selected component for a variety of inspection scenarios. The results of the PFM evaluations demonstrated that the NRC acceptance criteria of 1.0E-6 for probabilities of rupture and leakage could be maintained for all components for inspection intervals longer than the 10-year intervals defined in Section XI of the ASME Code. Therefore, the results demonstrate that examinations for the selected components can be extended beyond the current ASME Code-defined interval; in some cases, they can be extended out to the end of the current licensed operating period (at least 30 years for most plants).

Plant-Specific Applicability

In order for plant owners to use the technical bases established by this work to obtain relief for their plant, they must demonstrate that the representative geometries, materials, and loading conditions used for the selected components bound their plant-specific information. Based on this analysis, criteria are provided for each component regarding the component configuration, component dimensions, component materials, applicable transient loadings, and other relevant parameters that must be satisfied on a plant-specific basis. If all criteria are satisfied for a given component, the results of the investigation can be used for the plant as the technical basis to establish revised inspection schedules for that component.

This work is documented in the following four EPRI reports, all of which are publicly available for download at www.epri.com:

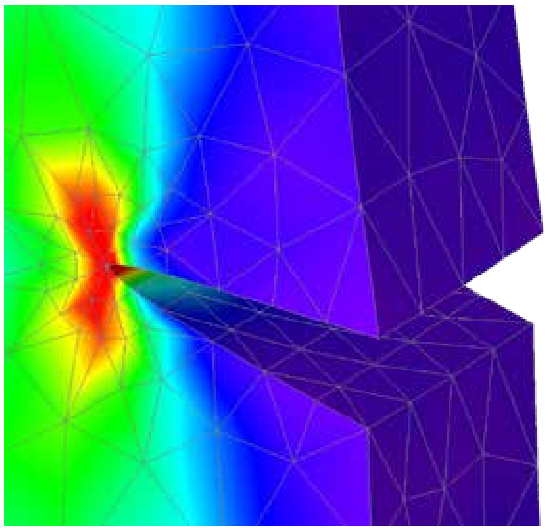
- *Technical Bases for Inspection Requirements for PWR Steam Generator Feedwater and Main Steam Nozzle-to-Shell Welds and Nozzle Inside Radius Sections, EPRI, Palo Alto, CA: 2019. 3002014590.*
- *Technical Bases for Inspection Requirements for PWR Steam Generator Class 1 Nozzle-to-Vessel Welds and Class 2 Vessel Head, Shell, Tubesheet-to-Head, and Tubesheet-to-Shell Welds,* EPRI, Palo Alto, CA: 2019. 3002015906.
- *Technical Bases for Inspection Requirements for PWR Pressurizer Head, Shell-to-Head, and Nozzle-to-Vessel Welds,* EPRI, Palo Alto, CA: 2019. 3002015905.
- *Technical Bases for Examination Requirements for Class 2 BWR Heat Exchanger Nozzle-to-Shell Welds; Nozzle Inside Radius Sections; and Vessel Head, Shell, and Tubesheet-to-Shell Welds,* EPRI, Palo Alto, CA: 2020. 3002018473.

The first plant-specific submittal was made by a U.S. two-unit site in December 2019 based on EPRI Report 3002014590, requesting an inspection alternative to current ASME Code, Section XI examination requirements for steam generator main steam and feedwater nozzle-to-shell weld and inner radii examinations. The alternative requests an increase in the inspection frequency for these items from 10 to 30 years. Additional plant-specific submittals are pending based on the technical bases provided in the other EPRI reports.

This project provided SI with the opportunity to use its experience in structural reliability to develop a customized software tool (**PROMISE**) that can be used to optimize the inspection schedules for various plant components. This tool is based on similar previous software codes, and can be used for similar applications in the nuclear industry where a rigorous technical basis is required to optimize inspection schedules for high-reliability components involving significant outage impact.

SI personnel have experience in all aspects of the evaluation performed above. Please contact Scott Chesworth at SI (schesworth@structint.com or 408.833.7295) or Bob Grizzi at EPRI (rgrizzi@epri.com or 704.595.2511) if you would like to learn more about component examination optimization.

Fatigue Adjustment Factors for Increased Cyclic Life



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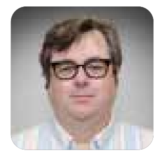

100% of thermal stress was treated as nonlinear gradient stress and linear bending stress was about 12% of the moment stress. Structural Integrity's (SI's) review of the stress terms used in piping analysis show that pressure stress does create bending stress in components...

EPRI Report 3002014121 "Development of Fatigue Usage Life and Gradient Factors" has developed fatigue usage adjustment factors that account for: 1) increased cyclic life associated with the growth of potential engineering size fatigue cracks in thicker components (thickness factor, TF; also called life factor, LF), and 2) the presence of through-thickness stress gradients (gradient factor, GF). (TF is used in the issued Code Case.) These factors are applied to cumulative usage factor, U, in air.

TF is a function of thickness, as well as cyclic strain range for each load set pair. GF depends on these as well as the fraction of stress that is membrane, linear through-wall bending, or nonlinear gradient. Formulas for these factors have been approved by the ASME Board of Nuclear Codes and Standards and will soon be available as Boiler and Pressure Vessel Code Nuclear Code Case N-902. Section 10 of the EPRI report provides a sample problem, including how to categorize stress based on its origin. The stated categorization is as follows:

- Pressure stress was treated as membrane stress.
- Moment stress was also treated as membrane stress.
- Thermal stresses ($\alpha_a Ta - \alpha_b T_b$, ΔT_1, and ΔT_2 terms) were treated as linear and gradient through-thickness stress.

However, a review of the stress categorization performed suggested there may be an opportunity to optimize use of classifications in some cases. 100% of thermal stress was treated as nonlinear gradient stress, and linear bending stress was about 12% of the moment stress.

Structural Integrity's (SI's) review of the stress terms used in piping analysis show that pressure stress does create bending stress in components; one example is the intersection region of a tee, whose saddle-shaped geometry tends to bulge outward, causing bending. This bending is classified as secondary and peak stress in the current ASME Section III rules. Also, much of the thermal stress is actually membrane and linear rather than nonlinear. Recategorizing stress as linear bending should remove excess conservatism and may yield acceptable fatigue usage without more costly analyses.

SI has performed our own stress categorization and has applied this Code Case for one client, and we can do the same for other clients.


1.28
2.57
3.98
3.35
6.17

Plant Materials Aging and Degradation

Nuclear IGSCC Mitigation Optimization and Equipment Advances

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INDUSTRY CHALLENGE

From the US Department of Energy, Office of Nuclear Energy, "*The demanding environments of an operating nuclear reactor may impact the ability of a broad range of materials to perform their intended function over extended service periods. Routine surveillance and repair/replacement activities can mitigate the impact of this degradation; however, failures still occur. With reactors being licensed to operate for periods up to 60 years, with further extensions under consideration, and power uprates being planned, many of the plant systems, structures, and components will be expected to tolerate more demanding environments for longer periods. The longer plant operating lifetimes may increase the susceptibility of different systems, structures, and components to degradation and may introduce new degradation modes.*

While all components potentially can be replaced, decisions to simply replace components may not be practical or the most economically favorable option. Therefore, understanding, controlling, and mitigating materials degradation processes and establishing a sound technical basis for long-range planning of necessary replacements are key priorities for extended nuclear power plant operations and power uprate considerations. https://www.energy.gov/ne/materials-aging-and-degradation".

Collectively this is a strategic pathway for nuclear power sustainability and advancement.

This article summarizes the investment by Structural Integrity (SI) to meet the spirit and intent to mitigate material degradation for existing nuclear reactors, specifically Boiling Water Reactors (BWRs), to support extended plant operations by developing, optimizing and implementing an 'advanced mitigation strategy'.

ADVANCED MITIGATION STRATEGY - OPTIMIZATION

Continuous Noble Metal Injection (CNMI)

The Next Generation of Noble Metal Application for Boiling Water Reactors

U.S. BWRs typically inject a platinum (Pt) catalyst solution approximately once per year (11 – 16 months) over a 10-day period during full power operation. European BWRs split the annual Pt amount into multiple Pt injections per year to maintain catalytic activity on surfaces that are subject to catalyst wear or coverage by crud deposits or oxide growth. This approach has also been shown to maintain lower reactor recirculation system (RRS) ECP throughout the operating cycle as compared to a single annual injection optimizing IGSCC mitigation of reactor vessel internals. One European BWR recently found undetectable crack growth with multiple Pt injections per year versus only reductions in crack growth rates with annual platinum injection. U.S. plants recognize the IGSCC mitigation advantages of multiple injections per year over one annual injection but have not implemented this approach because

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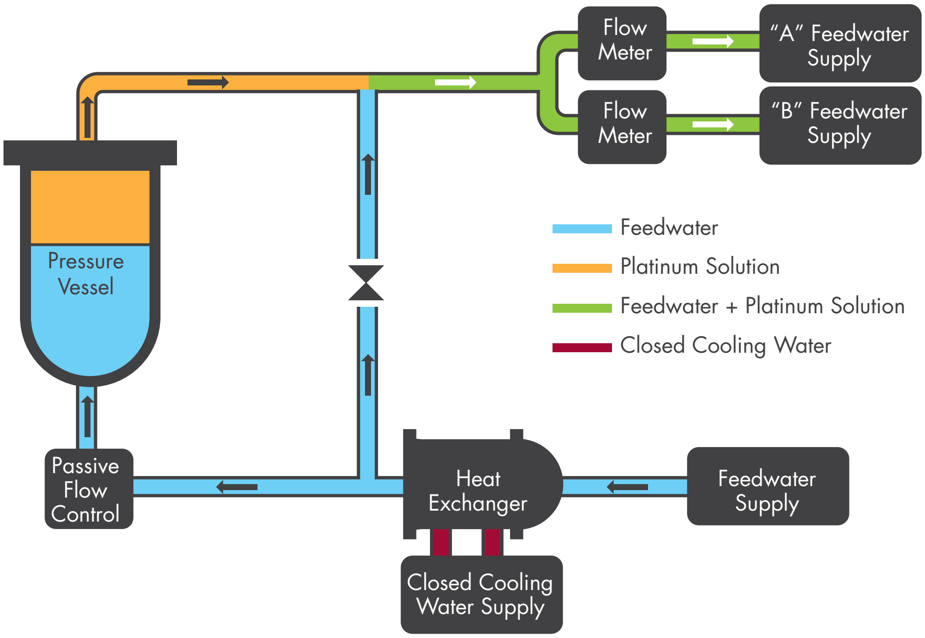

FIGURE 1. CNMI skid simplified schematic

of the added labor burden associated with operation, maintenance, and supervision of the active platinum injection equipment.

Solution

In response to the costly operation and maintenance of the current equipment to inject platinum in addition to its flow rate limitations, Structural Integrity (SI) developed, patented, and demonstrated a passive injection technology called Continuous Noble Metal Injection (CNMI). The CNMI skid utilizes the identical chemical that the current process utilizes, however it is designed with minimal operator invention as it utilizes the differential pressure between two points in the feedwater system as the driving force. The higher dilution flow as compared to the current process provides improved dispersion of the platinum compound into the high temperature feedwater streams and less heating of the injection flow as it approaches the feedwater tap, decreasing the potential for injection tap plugging. The passive process has no automation and provides flow, temperature, pressure, and differential pressure indications for process monitoring. CNMI allows for a wide range of injection flow capability spanning from the typical annual 10-day application to a continuous flow rate. Capillaries on the passive skid can be changed out or swapped while the skid remains in service in a matter of minutes using a simple skid operating procedure. A simplified schematic of the CNMI passive injection system is shown in Figure 1.

FIGURE 2. CNMI skid Installed at NMP2

The CNMI technology was successfully installed and demonstrated at Exelon's Nine Mile Point Unit 2 (NMP2), located in the state of New York on the shore of Lake Ontario, for the duration of cycle 17 spanning March 2018-March 2020 and is currently in service. During the operating cycle at NMP2, the CNMI technology was utilized to inject at the typical 10-day injection, intermediate rates, continuous rate and during power changes. The installed CNMI skid in the turbine building at NMP2 is shown in Figure 2.

Design Benefits

The CNMI technology is passive in that it utilizes no pumps, eliminates the need for frequent maintenance and minimizes the need for personnel oversight reducing O&M and labor costs supporting FTE reductions and offers many advantages over the current process:

- Lower plant labor burden when compared to existing equipment for Operations, Chemistry and Maintenance
- Significant reduction in chemistry staff and technician oversight during application
- Improved equipment reliability (no pumps)
- Direct Replacement and Upgrade of current obsolete OLNC skid
- High dilution flow (lower propensity for injection line plugging) preventing costly delays in platinum injection or inspections of injection lines
- Wide Pt injection rate range, spanning current to continuous, for long-term process and crack mitigation optimization

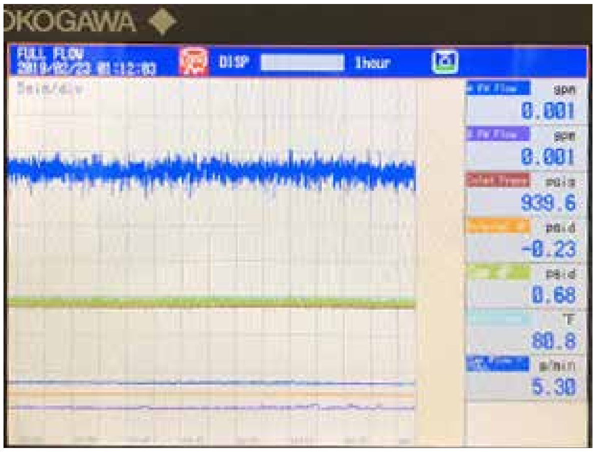

FIGURE 3: CNMI Skid Yokogawa Recorder

Initial Results

Based on several BWRs yearly person-hours and material costs to prepare, operate and maintain the current equipment versus the person-hours and costs to operate the CNMI skid at Nine Mile Point Unit 2, the average single unit site is estimated to save over $1.5M and 4.6 FTE over ten years. The installed Yokogawa recorder on the CNMI skid, as shown in Figure 3, allows chemistry technicians to remotely monitor the platinum injection via the plant camera system or on plant rounds with no required manipulations. Additionally, the applied platinum is totalized for ease of the chemistry department to monitor and track the total amount of platinum added.

CNMI allows for a versatile application strategy where the allotted annual amount of Pt can be injected online in a single application, in multiple applications or continuously throughout the operating cycle as demonstrated at Nine Mile Point Unit 2. Injecting platinum in smaller amounts more frequently or continuously renews platinum particles on surfaces, ensuring surface catalytic activity is maintained throughout the cycle to mitigate cracking. Utilizing the CNMI technology by injecting platinum in smaller batch amounts or continuously allows stations to replenish surface Pt losses or decreases in catalytic activity during plant operation optimizing IGSCC mitigation. The resulting smaller particle size from a lower injection rate allows a more homogenous covering of a surface with the same total amount of platinum with smaller particles more likely to diffuse into existing cracks improving the effectiveness of platinum applications for IGSCC mitigation.

Laboratory data supports radiological benefits from utilizing the CNMI technology by applying platinum more frequently or continuously. In laboratory studies, the lowest Co-60 deposition rates were observed with HWC+Zn and HWC+Zn+NMCA. These experiments utilized ECPs near the redox potential of -500 mV(SHE) to ~-550 mV(SHE) for HWC and HWC+NMCA, respectively. Plants have observed ECP initially after OLNC near the redox potential but increases until next OLNC. CNMI will keep ECP continuously near the redox potential, thus lower Co-60 deposition when used in combination with zinc injection. At Nine Mile Point Unit 2 during cycle 17 when the station utilized the CNMI technology and applied platinum more frequently and for a short duration continuously, they were able to maintain low ECP in RRS piping which lowers the Co-60 incorporation rate into the oxide film and thus lowers drywell shutdown dose rates (as observed with a lower recontamination rate in the 2020 outage vs. 2014 outage both following chemical decontaminations). At a low continuous Pt injection rate, injection can continue right up to the refueling outage without causing increased shutdown Co-60 as demonstrated at NMP2.

As demonstrated at Nine Mile Point Unit 2, the CNMI Skid is a reliable and passive method of injecting platinum chemical into the BWR feedwater system at power operating conditions to mitigate IGSCC with reduced cost, reduced workload and measured lower radiation fields. Structural Integrity developed this patented technology to deliver value to BWR stations while optimizing asset protection through IGSCC mitigation. For more information, please contact Erica Libra-Sharkey (elibra-sharkey@structint.com) or Mike Ford (mford@structint.com).

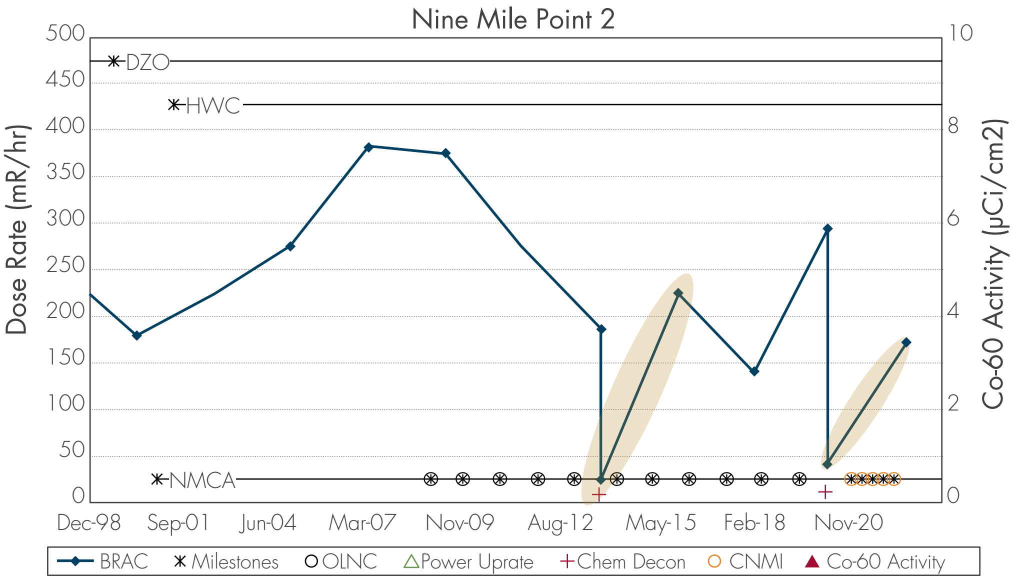

FIGURE 4. Nine Mile Point BRAC History Conclusion

Acoustic Resonance

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Acoustic resonance is a phenomenon in which an acoustic system amplifies sound waves whose frequency matches one of its own natural frequencies of vibration (its resonance frequencies).

Acoustic cavity resonance can be found in everyday life. In the most simple at home example, blowing air over the open end of a bottle. Blow too hard, nothing. Blow too soft, nothing. When done just right, the bottle produces a sound (audible vibration). Just like that, you have acoustic resonance. Every wind instrument in a band uses acoustic cavity resonance to produce music. Take a piece of flexible hose, spin it in the air until it whistles, again, acoustic resonance. When an acoustic cavity resonance happens inside piping systems, especially those with high energy flow, those seemingly harmless vibrations we illustrated above can cause serious damage. This phenomena can occur in nearly any industry, sometimes with benign consequences and other times with catastrophic results.

Structural Integrity (SI) was brought in to assist with persistent issues with the testable check valves that have a history of failing local leak rate testing (LLRT) following each operating cycle, requiring maintenance and rework. The cause of the degradation has been attributed to excessive flow induced vibration, resulting in chattering of the valve disc. The valves are located on a relatively short dead leg off a main flow path. A differential pressure modification was implemented to ensure a positive sealing pressure, maintenance practices were optimized, and operational recommendations were developed/deployed. These actions were partially effective, but LLRT failures for a subset of check valves persisted.

Localized vibration and temperature monitoring of the valves were installed in accordance with recommendations from SI. The monitoring data indicates that an acoustic resonance condition exists where the valve dead-leg cavity frequency aligns with pump vane passing frequency. In particular, pump speeds in a specific rpm range result in significant acoustic response (pressure pulsations) and elevated vibrations on the valves themselves. The operator used the measurements and correlation to inform tighter operational restrictions (minimize time in the rpm range causing elevated vibration) to minimize resonant alignment. These operational restrictions provided the first successful LLRT results in several outages, shortened the outage by several days, and provided necessary insight into the mechanisms influencing this abnormal valve wear.

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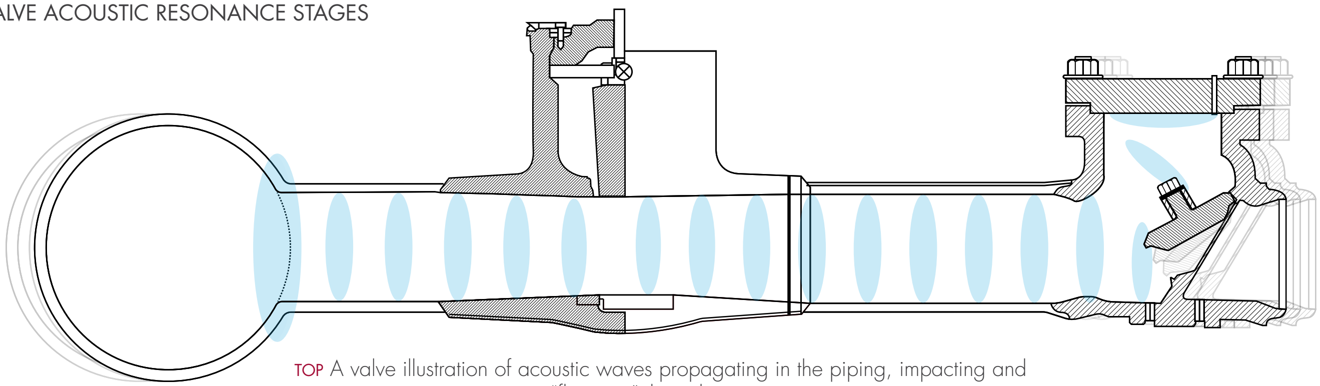
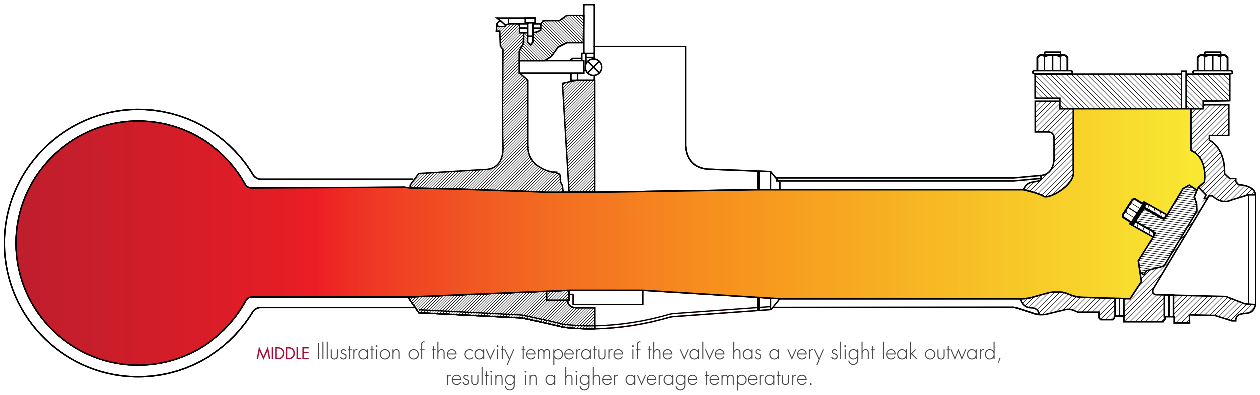
The resonance condition is a function of the acoustic wavelength of the valve cavity, which in turn is governed by the fluid temperature and physical geometry/length. The fluid temperature within the cavities can vary slightly depending on the valve seal-tightness of the valves as well as the length of the cavity (insulation heat losses). However, the primary variable affecting the onset of resonance is the cavity geometry/length. Barring operational changes, the only way to avoid the potential for resonance would be to physically modify the valve cavity geometry such that its acoustic wavelength is either well-above or well-below pump speeds during all

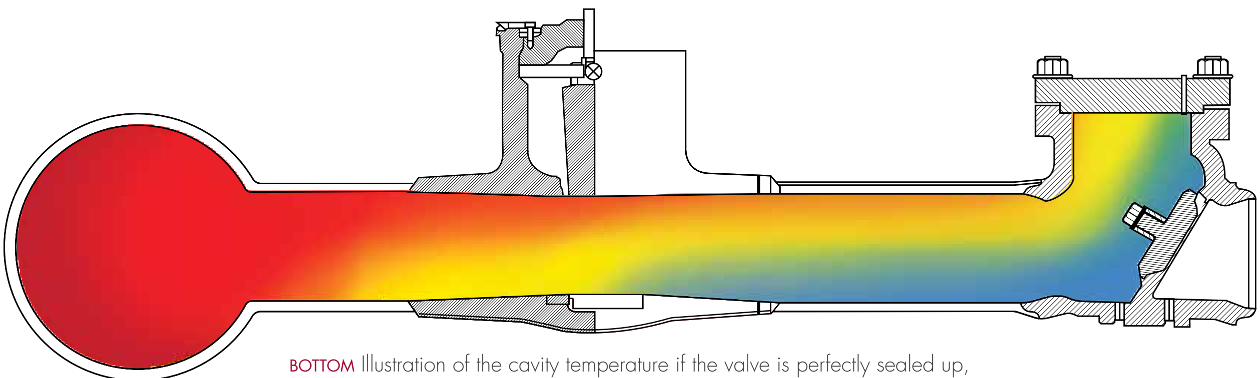
VALVE ACOUSTIC RESONANCE STAGES



TOP A valve illustration of acoustic waves propagating in the piping, impacting and "fluttering" the valve seat.



MIDDLE Illustration of the cavity temperature if the valve has a very slight leak outward, resulting in a higher average temperature.



BOTTOM Illustration of the cavity temperature if the valve is perfectly sealed up, resulting in a slightly colder overall temperature but also slightly stratified.

normal operating conditions. Due to the extremely high cost of frequent valve maintenance (every outage), high cost of cavity length modifications and complications that arise with operational limitations, SI was commissioned to assess the viability and likelihood-of success of three different scenarios:

A. **Moving the valves closer to the main header**, thereby increasing the cavity frequency and (ideally) avoiding an acoustic resonance condition entirely.

B. **Moving the valves further from the main header**, thereby decreasing the cavity frequency. Note: this scenario does not eliminate the potential for acoustic resonance because the pumps are variable speed but may be similarly effective if the resulting cavity wavelength aligns with a region where the pumps have historically not operated.

C. **No physical modifications**; continued/expanded operational restrictions to avoid placing pump speeds or vane passing frequency (VPF) from the pump impeller into alignment with the cavity resonance.

The assessment performed by SI applied statistical methods to governing equations to develop approximate cavity acoustic conditions and benchmarked those results against empirical data measured by the instrumentation. A series of probability distribution functions (PDFs) were assigned to the variables in each equation and Monte-Carlo simulations were performed to predict the likelihood of ensuing outcomes.

Continued on next page

The results were initially used to test/confirm inherent assumptions and unknowns, thereby improving the accuracy/relevance of the applied PDFs. The revised model/PDFs were then used to develop confidence projections for the various scenarios described above.

One of the more-significant uncertainties pertained to the effective acoustic length of the valve cavities. While the valve sizes and physical locations are relatively well-defined by as-built drawings, the cavity internal geometry is complicated by presence of the valve disc and, to a lesser extent, entrance effects at the header. Two different lengths were postulated via PDFs: 1) a "short" case where the acoustic wavelength is equivalent to the straight-line distance from header to valve disc, and 2) a "long" case which includes the valve upper cavity geometry. Based upon approximated fluid temperatures and apparent acoustic onset conditions, this analysis concluded that only the "short" case is applicable/present, using the instrumentation data. The effective acoustic cavity length was benchmarked to a value of approximately 81 inches, which is shorter than the nominal length measured from drawings, and indicates that acoustic wave formation occurs inside the valve cavity (past the header transition sweep-o-let).

Fluid temperature within the valve cavity also has a not-insignificant effect on acoustic conditions and associated modelling results. For example, the difference in fluid sound speed between 500 and 550°F is approximately 15%. Any such difference directly impacts the cavity wavelength; the indicated 15% variance corresponds to a pump speed range of ±225 rpm at nominal operating conditions. Temperature sensors were installed on the valve cavities in order to characterize the actual fluid conditions during operation. The ensuing data effectively demonstrated two different cases, dependent on valve condition and/or maintenance, as follows:

1. "Hot" case, where some amount of valve leak-by is present (e.g. below LLRT-acceptable threshold, or due to seal degradation), resulting in elevated temperature throughout the cavity (average bulk temperature = 525°F).

2. "Stagnant" case, where valve is tightly sealed, resulting in cooler temperatures and some amount of stratification at the end of the cavity (average bulk temperature = 517°F). Note: the cooling effect increases exponentially with cavity length; if the valve were to be moved 60 inches further from the header, the predicted stagnant temperature would be 434°F.

The observed temperature differences introduce a duality of outcomes (frequencies) for any scenario, dependent on the sealing state/effectiveness of the valve. Holding all other parameters equal, the ~8°F observed difference in bulk temperature corresponds to a pump speed range of approximately 22 rpm. Thus, there is a potential for the currently-observed "peak" resonance conditions to shift by ±20 rpm if their sealing state changes. For cavities that are tightly sealed ("Stagnant" case), deterioration or leak-by will shift the frequency lower; for cavities that are leaking-by ("Hot" case), any maintenance activities that restore the original seal integrity will shift the frequency higher.

From the limited data that is available, there is some evidence of hydraulic/acoustic cross-coupling between piping trains. Furthermore, separation of pump speeds appeared to reduce maximum responses, indicating that a "beating" type phenomenon was likely present and contributive to valve degradation during previous "normal" operating regimes where both pumps were operated semi-synchronously. Updating the predictive model to include both bias and uncertainty, the observed results were used to re-evaluate the modification scenarios introduced above, with conclusions as follows:

A. **Move the Valves Closer to the Header**: It is possible to shift the cavity frequency substantially higher with a fairly-small movement. SI found 95% statistical confidence in complete avoidance of resonance by shortening the valve cavity by 7 inches or more.

B. **Move the Valves Father from the Header**: There are additional considerations for this option, due to the additional uncertainties in cavity temperature profile and uncertainties associated with the future pump operating band. Based on the historical data, pump operation between 900 and 1,250 rpm is very limited, and it is possible to obtain high confidence (>90%) in resonance avoidance if this entire range is considered restricted. This option would require a valve movement in the range of 52 ± 5 inches as well as an operational restriction to avoid 900 to 1250rpm, where possible.

C. **Operational Restrictions Only**: The data obtained to-date is insufficient to fully characterize/project the long-term outcome of this approach, wherein no physical modifications are performed. This is a function of the time data that was acquired at presumed worst-case conditions (minimal) as well as the observed potential for variation in local sealing state (i.e. temperature profile). Some risk of resonance and associated degradation will always be present for this scenario.

The utility is using SI's model and probabilistic predictions to evaluate the cost and benefits for each option and employing similar approaches to inform valve strategies at other stations.

Increase in Reinspection Intervals for BWR Reactor Internals

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A U.S. BWR utility contracted with Structural Integrity (SI) to review their current reinspection guidance documents relative to those contained in the BWRVIP inspection guidelines, the purpose of which was two-fold:

- **Are current reinspection guidelines compliant with industry requirements?**
- **Are there components where reinspection intervals could possibly be extended?**

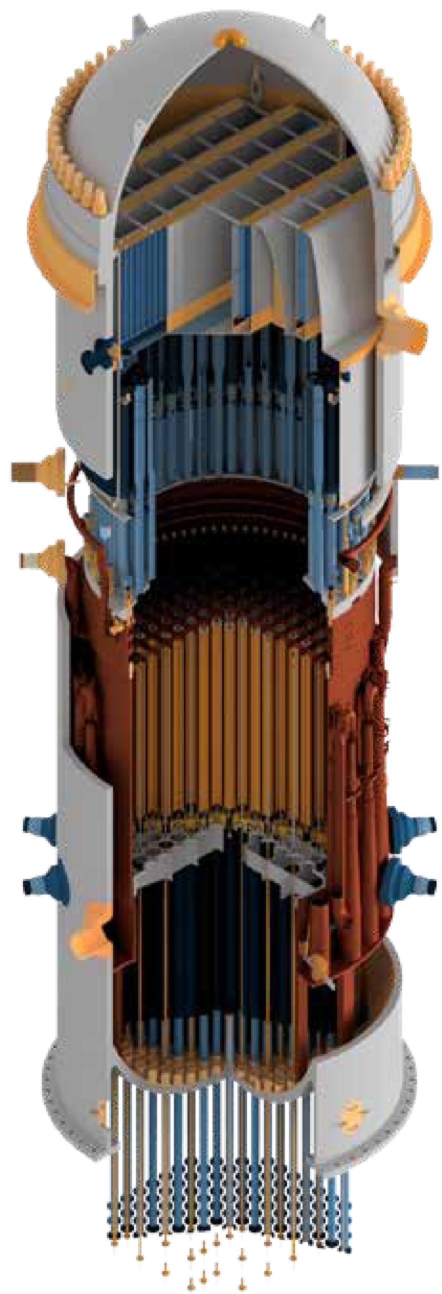
The specific reactor internals addressed in the review included:

- Core spray piping and spargers
- Core shroud and shroud support
- Access hole covers
- Jet pumps
- Top guide
- Lower plenum
- Vessel ID attachments
- RPV instrument penetrations
- Core plate hold-down bolts/ plugs
- Steam dryer
- SLC/core plate ΔP penetration
- Bottom head drain line

The review concluded that the utility's reinspection program was compliant with industry standards. In addition, for flawed components, further investigation could result in the reinspection intervals possibly being extended for the following:

- Core spray piping and spargers
- Jet pumps
- Core plate hold-down bolts

To date, one weld in the core spray piping has been addressed using finite element analysis techniques, with the reinspection interval increased to the maximum allowed by industry guidelines. Increase in the reinspection intervals for specific jet pump welds and core plate hold-down bolts is currently being evaluated.



Optimizing Cathodic Protection Commitments

Aging Management Program (AMP XI.M42)

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License renewal applications (LRAs) often involve commitments to future actions. These can be classified into one of three categories: appropriate, overcommitment, and ambiguous implementation. Appropriate commitments include those actions that are expected by the NRC (such as those explicitly identified in the GALL[1] and GALL-SLR[2]) as well as some less restrictive actions that are technically justified by engineering evaluation. These commitments can generally be implemented within one operating cycle using existing technology, are cost-effective, and are consistent with the GALL and GALL-SLR.

Overcommitments and those commitments with ambiguous implementations can be avoided and cost-effectiveness optimized by obtaining independent third party reviews (ITPR) of the LRA.

Overcommitments

Actions that fall into this category are typically in response to anticipated or perceived NRC requests or requirements. This would include actions such as accelerated implementation schedules, expanded scope, and increased number of inspections from what is needed to ensure required functions are maintained throughout the period of extended operation (PEO). These types of commitments are the easiest to identify and avoid with an ITPR.

Overcommitment Example

Based on NRC challenges and two requests for additional information (RAIs), one utility elected to dramatically accelerate implementation of a new cathodic protection (CP) system and increase the number of required direct examinations. Preventive Action Category C in Table XI.M41-2 of the GALL-SLR requires that the new or refurbished CP system be operational “5 years prior to the end of the inspection period of interest.” In this case, Category C can only be utilized when CP is operational and effective during the 5 years prior to entering the subsequent PEO (SPEO). As a result of the NRC RAIs, the utility committed to implementing a CP system 9 years prior to entering the SPEO. Although a CP system will help mitigate the effects of any externally initiated corrosion, the compressed schedule for implementation will unnecessarily increase the overall cost of implementation.

In another example, a utility was challenged to justify that Preventive Action Category F was appropriate. Note that Category F in Table XI.M41-2 requires the most direct inspections of buried piping. The utility ultimately committed to increasing the number of direct examinations for all categories, including those locations that meet the Category C requirements. Instead of performing up to 7 total inspections during each 10-year interval, the utility may be required to perform up to 20 inspections during each interval. The minimum cost of each additional inspection is estimated to be $200,000.

In both of these examples, an independent third party review by Structural Integrity (SI) could have identified these overcommitments and provided cost effective alternatives prior to submittal to the NRC.

Ambiguous Implementations

This category of commitment is often driven by requirements within the GALL / GALL-SLR, but guidance for implementation does not yet exist. This results in commitments for which the implementation technology does not yet exist and/or cannot be implemented withing one operating cycle. This type of commitment is the most difficult to avoid because the commitments are explicitly identified in the GALL / GALL-SLR and because it impacts all applicants (i.e., there is no operating experience on which to rely). Those sites entering their PEO / SPEO first will bear the brunt of these types of commitments as they will be the first to attempt implementation.

Ambiguous Implementation Example

In order to utilize Preventive Action Category C in Table XI.M41-2 for carbon steel piping, the utility must demonstrate CP effectiveness for 80% of the time. Annual CP surveys are typically utilized to demonstrate effectiveness and trending, but these surveys cover only a small portion of the in-scope systems. It is not clear how, or even if, annual CP surveys can be used to meet the 80% effectiveness for the entire length of the buried line. SI has raised this issue (and others) during the EPRI Buried Pipe Assistance Program (BPIG) and Cathodic Protection Users Group (CPUG) meetings. An SI presentation at the 2017 CPUG meeting detailed the implications of this problem for one plant with 96 existing annual survey test points. The analysis showed that 459 test points would be required to ensure full coverage of all in-scope piping, which is almost a five-fold increase in test points. Although the NRC is typically present at these meetings, the NRC has not offered additional insight or guidance.

For those commitments for which the implementation is ambiguous, SI can assist the utility with stating how the requirement will be met. Regarding the 80% effectiveness criterion, technical justification should be included in the LRA to shield the utility from any changes in NRC philosophy (and eliminate the potential need to add 500% more test points). An ITPR of the LRA will help identify commitments with ambiguous implementations and strategies to both optimize the cost-effectiveness of the commitment and shield the utility from changing regulatory opinions.

Footnote

[1] NUREG-1801, Revision 2, Generic Aging Lessons Learned (GALL) Report, U. S. Nuclear Regulatory Commission, Washington, DC, December 2010.

[2] NUREG-2191, Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR)

Strategic Evaluation of MAOP

Reconfirmation Plans and Options

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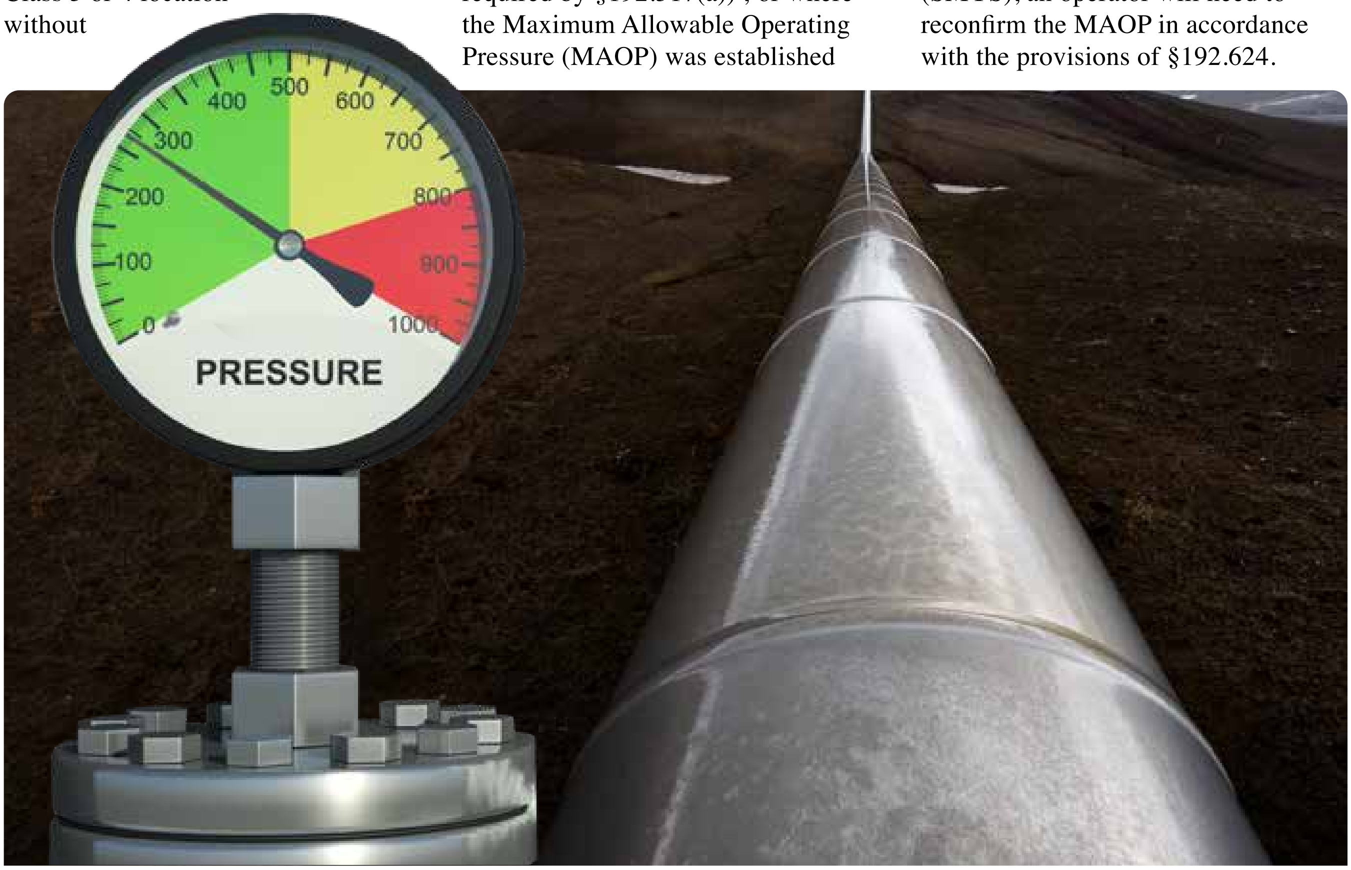
On October 1, 2019, the Pipeline and Hazardous Materials Safety Administration (PHMSA) published amendments to 49 CFR Parts 191 and 192 in the Federal Register issuing the *Pipeline Safety: Safety of Gas Transmission Pipelines: MAOP Reconfirmation, Expansion of Assessment Requirements, and Other Related Amendments Final Rule* (Final Rule).

The Final Rule requires that for on-shore steel transmission pipelines in an High Consequence Area (HCA), Class 3 or 4 location without Traceable, Verifiable and Complete (TV&C) records for §192.619(a)(2) (pressure testing, including records required by §192.517(a)) ; or where the Maximum Allowable Operating Pressure (MAOP) was established based on the Grandfather Clause and the MAOP creates a stress ≥ 30% of the Specified Minimum Yield Strength (SMYS), an operator will need to reconfirm the MAOP in accordance with the provisions of §192.624.



Operators must develop and document procedures to satisfy §192.624 by July 1, 2021, and have until July 3, 2028, to Reconfirm the MAOP for 50% of their subject pipeline mileage and until July 2, 2035, to reconfirm the MAOP for 100% of subject mileage. There are six Methods prescriptively identified to Reconfirm MAOP:

1. A hydrostatic pressure test per Subpart J along with Material Verification per §192.607
2. Pressure Reduction with Material Verification in some cases
3. Engineering Critical Assessment (ECA),
4. Pipe replacement,
5. Pressure reduction for pipeline segments with Small Potential Impact Radius (PIR) (≤ 150 ft.), or
6. Alternative technology submitted to PHMSA with no objection received within 90 days.

Most pipeline operators performed initial MAOP Records Verification projects following the San Bruno incident from 2011-2014 based on NTSB and PHMSA Advisory Bulletins. Based on the new transmission pipeline MAOP Reconfirmation requirements, gas transmission pipeline operators will likely need to revisit their MAOP Records data to ensure alignment with the Final Rule and ensure regulatory compliance in establishing their MAOP Reconfirmation Plans. Careful consideration and prioritization regarding “missing items” within pressure test records can assist in establishing scope inclusion and prioritization within the MAOP Reconfirmation Plan.

In accordance with §192.517, the Records of the pressure test must contain at least all of the following information:

1. The operator's name, the name of the operator's employee responsible for making the test, and the name of any test company used.
2. Test medium used.
3. Test pressure.
4. Test duration.
5. Pressure recording charts, or other record of pressure readings.
6. Elevation variations, whenever significant for the particular test.
7. Leaks and failures noted and their disposition.

Pressure test records missing key information should be considered in scope for MAOP Reconfirmation. Although §192.517 requires a comprehensive range of information, certain items, such as “Elevation variations, whenever significant for the particular test”, can be evaluated on previously tested pipelines based on conservative assumptions applied to the pipeline alignment using digital elevation modeling and analysis.

The pressure reduction options (Method 2 and Method 5) require establishing MAOP using the highest actual operating pressure sustained by the pipeline during the 5 years preceding October 1, 2019, divided by the greater of 1.25 or the applicable class location (1.1 for Small PIR segments).The highest actual sustained pressure must have been reached for a minimum cumulative duration of 8 hours during a continuous 30-day period. In most cases, the pressure reduction options for MAOP Reconfirmation will be untenable to pipeline operators as they will result in significant reductions relative to MAOP.

MAOP Reconfirmation options should be strategically evaluated to develop the optimal plan, and should consider factors such as:

- Age and risk profile of the pipeline segment,
- Defect susceptibility and results of prior inspections, failures, or pressure tests,
- Desired remaining life of the pipeline asset,
- Ability of the pipeline to accommodate instrumented In-Line Inspection (ILI) tools,
- Respective costs of each reconfirmation method,
- The ability to achieve favorable rate recovery of reconfirmation costs.

The following table illustrates a respective cost review for a major pipeline operator for several of the MAOP Reconfirmation Methods. *Assumes the line can accommodate ILI tools and approximately $1M in assessment costs consisting of ILI for corrosion, cracking and deformation, NDE Verification of Findings, and Material Verification.

Reconfirmation Option:	Pipe Replacement	New Pressure Test	ECA*
Estimate $ per mile	$11.5M	$2M	$0.1M
Est. Total Costs	$115M	$20M	$1.1M

TABLE 1. Example MAOP Reconfirmation Costs for a 10 Mile Pipeline Segment

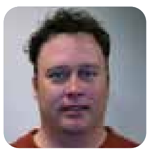
Structural Integrity has been deeply involved in the Final Rule since 2011 and has significant expertise in pipeline safety regulations with dedicated resources to support development of an effective strategic plan for MAOP Reconfirmation and implementation, and has developed innovative tools to ensure regulatory compliance.

References / Footnotes

[1] Section §192.619(c), commonly referred to as the Grandfather Clause, allows for pipelines installed prior to July 1, 1970 to be operated at the highest actual operating pressure to which the pipeline was subjected in the preceding 5 years from this date.

Implementation of Material Verification

In Support of Mega-Rule Part 1 Requirements



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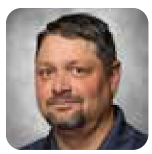

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Operators are now required to define sampling programs and perform destructive (laboratory) or non-destructive testing to capture this information and take additional actions when inconsistent results are identified until a confidence level of 95% is achieved.

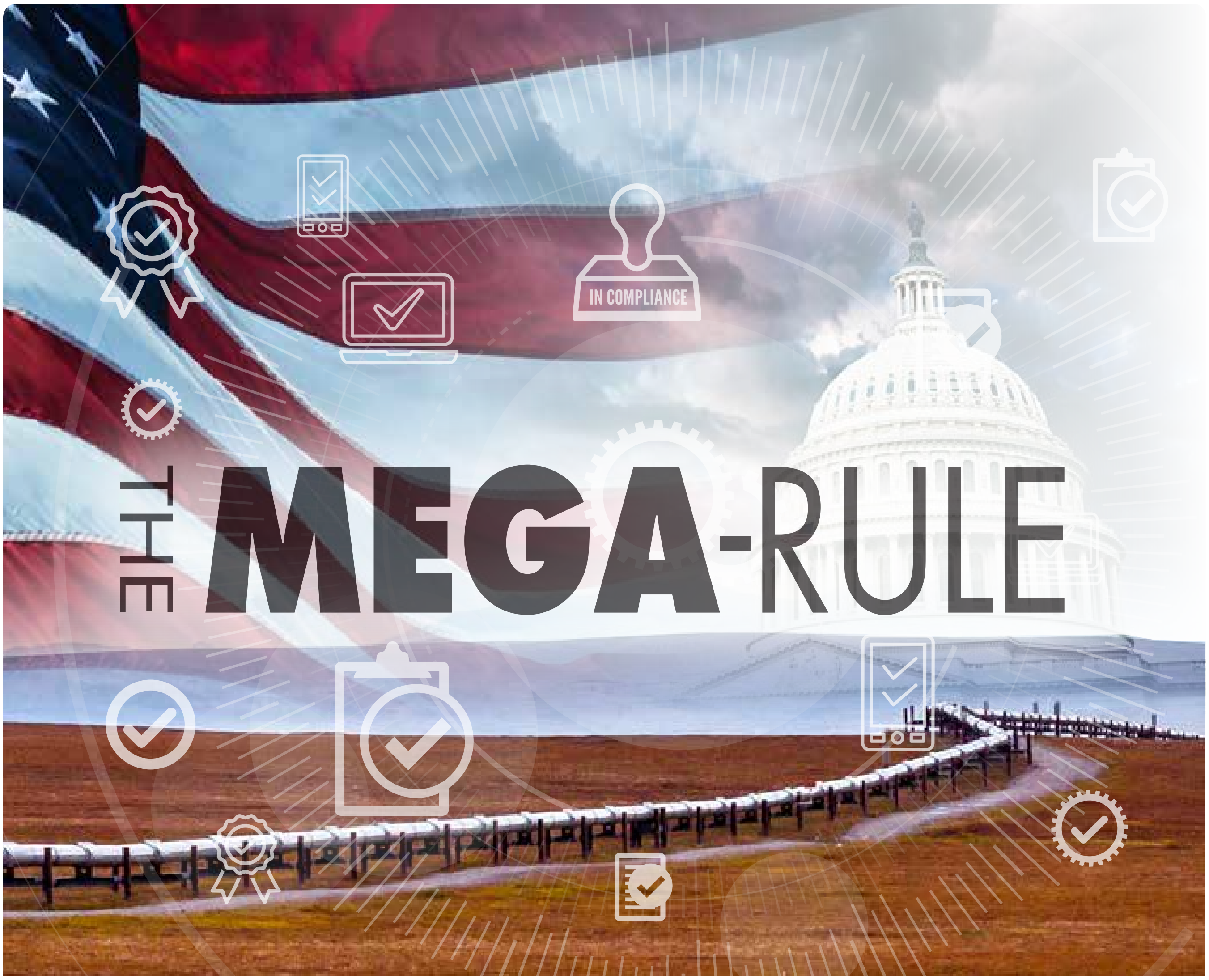
Various sections of Mega-Rule 1 require operators of natural gas transmission pipelines to ensure adequate Traceable, Verifiable, and Complete (TV&C) material records or implement a Material Verification (MV) Program to confirm specific pipeline attributes including diameter, wall thickness, seam type, and grade. Operators are now required to define sampling programs and perform destructive (laboratory) or non-destructive testing to capture this information and take additional actions when inconsistent results are identified until a confidence level of 95% is achieved. Opportunistic sampling per population is required until completion of testing of one excavation per mile (rounded up to the nearest whole number) up to 150 excavations (if the population exceeds 150 miles). Regulators have communicated an expectation that sampling locations or test sites are to be equally spaced throughout the population mileage.

To support implementation of these programs, pipeline operators must develop robust procedures to support implementation of the program including:

- Population identification and grouping,
- Sampling and test feasibility,
- Laboratory test requirements and methods for designated populations,
- In-situ test methods and protocol,
- Inconsistent results and increased sampling protocol, and
- Final verification and test completion.

Prior to and since the release of Mega-Rule 1, Structural Integirt (SI) has been assisting our clients in preparing these procedures and providing turnkey support of the entire process including:

- MV procedure development,
- TV&C records review,
- Population segmentation, grouping and analysis,
- Test site planning,
- Field testing, and
- Implementing data management applications to track verification progress and identify and resolve conflicts identified.



In 2017 and 2018, SI was the lead contributor to a Pipeline Research Council International (PRCI) study to develop field protocol for a non-proprietary algorithm developed by PRCI. This study included the evaluation of several "in-the-ditch" data collection methodologies, including both proprietary and non-proprietary methods. This PRCI project was one of the largest, independent validation efforts for MV to date, and it resulted in validating the performance of multiple techniques (both proprietary and non-proprietary).

Beginning in early 2019, SI internal field specialists with decades of experience conducting similar tests for other industries, began performing in-the-ditch MV data collection using non-proprietary techniques for clients to vet and streamline the MV processes in anticipation of the release of Mega-Rule 1. Since that time, we have completed in-the-ditch MV testing for multiple pipeline operators on more than 50 different test sites. This work has focused on optimizing the field collection process, including revising procedures as needed and streamlining field data collection and analysis.

Field testing should confirm the pipe diameter, nominal wall thickness, long seam weld type, and pipe grade. Applying the non-proprietary algorithm developed from PRCI and other industry research, the following items, in addition to conventional wall thickness and diameter measurements, can be collected and used to infer the material strength properties (and ultimately confirm the pipe grade):

1. Portable Hardness Testing
2. Metallurgical Replications
3. Chemistry Analysis

Portable Hardness Testing

Hardness is the resistance of a material to permanent indentation made by a stronger material. It is important to recognize that hardness is an empirical test and not a material property. SI has multiple methods for measuring

Continued on next page

hardness, with Ultrasonic Contact Impedance (UCI) representing one of the most common and accurate methods for field use. This approach utilizes a Vickers diamond tip/indenter that is attached to the end of a metal rod that is excited into ultrasonic oscillation by piezoelectric transducers. As the oscillating indenter penetrates the test sample, a frequency shift occurs in the indenter, which can be measured and related to the penetration of the indenter into the sample. The deeper the indenter penetrates the material, the larger the indentation area, the larger the frequency shift of the rod/indenter, and the lower the hardness of the material. The measured frequency shift can then be correlated into a hardness value in the Vickers scale using appropriate conversion curves that are specific to the probe being used.

As is the case with all MV field data collection processes, reliable results begin with proper surface preparation of the pipe sample in addition to an experienced specialist capable of assuring the collection of reliable data. In accordance with Mega-Rule 1, SI's procedures specify testing to be conducted at a sufficient number of locations (five different axial locations in two different quadrants) for each sample of piping examined.

Metallurgical Replications

Metallurgical replication is a field-implemented technique that allows for the in-situ NDE of material microstructure and metallurgical condition. The process uses thin films to duplicate the microstructure of the pipe being evaluated. Buffing and polishing are carried out in progressively finer increments to remove scratches and any deformed surface layers that can interfere with detailed microstructural interpretation. It is critical that all scratches and deformities are removed as the surface is polished to a mirror finish. The surface is then etched to reveal the microstructural features of interest, after which, a thin piece of acetate film is moistened in acetone and applied to the prepared surface. The acetate conforms to the surface, "duplicating" the surface features. The acetate is subsequently removed and mounted to a glass slide for microscopic examination at high magnifications. The microstructure is then analyzed from the replications to determine ferrite grain size, pearlite volume, and inclusion volume to be used as inputs into strength predictions.

Chemistry Analysis

Chemistry testing is performed to confirm chemical composition and support the identification of pipe grade. Additionally, chemical composition serves as an additional input into the material strength prediction algorithms. There are multiple ways to determine the chemical composition of steel pipe, including using a burr bit to collect metal shavings with subsequent laboratory analysis of the shavings and/or the use of portable chemistry analyzers. Each method must have a robust procedure with detailed steps for collection and/or testing to ensure accurate and repeatable results.

FIGURE 2. Photograph of polishing step in preparation for metallurgical replications.

Pipe Components

In addition to verifying line pipe properties, for mainline pipeline components other than line pipe (e.g. Valves, Tees, Flanges, etc.), TV&C records must document the applicable standards to which the component was manufactured to ensure the pressure rating capacity. In cases where TV&C records for these components do not exist, SI personnel have experience visually inspecting components and

FIGURE 1. Photograph of hardness test being conducted with a portable UCI system.

FIGURE 3. Photographs of an acetate film LEFT being removed from the component surface and RIGHT mounted to a slide for microscopic examination.

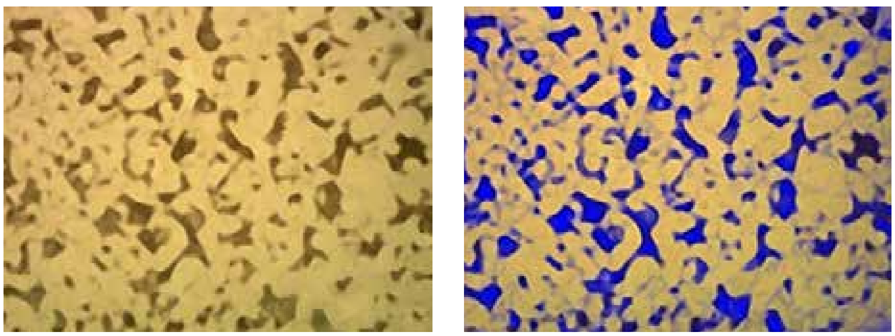


FIGURE 4. LEFT Microstructure micrograph and RIGHT a digitally enhanced image of the micrograph.

documenting key information: such as photo-documentation, GPS location, and the manufacturer's stamped or tagged material pressure rating and/or material type (e.g. ANSI 300).

MV Data Processing

These MV requirements will create data management challenges in terms of different departments, laboratories, and subcontractors requiring different levels of access to information and different needs to update information as results of the material verification process are completed. In addition to data management issues, the ability to ensure compliance and track progress through implementation of the MV process pose additional challenges. To help address these challenges, Structural Integrity has developed a new tool, Material Verification Intelligence (MVI), as a web-based application that can help identify and organize essential data and ensure implementation is aligned with supporting MV procedures and track progress through verifying population groups.

FIGURE 5. Screenshot of MVI Application

Summary

In response to the Mega-Rule 1 requirements, gas transmission pipeline operators must perform MV where required by Part 192 for segments where TV&C material property records do not exist. SI has developed a comprehensive MV offering to assist our clients with meeting these requirements. A key component of this offering is the establishment of detailed field test procedures and expert NDE professionals to perform the collection, analysis, and processing of the appropriate MV data. We look forward to assisting our existing and future clients and continuing to expand our service offerings to support regulatory requirements.

SI Supports Parsons' "DetectWise" Modular COVID Test Facility

The health facility is designed to fully separate patients from medical workers, protecting both parties and minimizing the PPE required to operate the suite.

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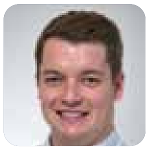

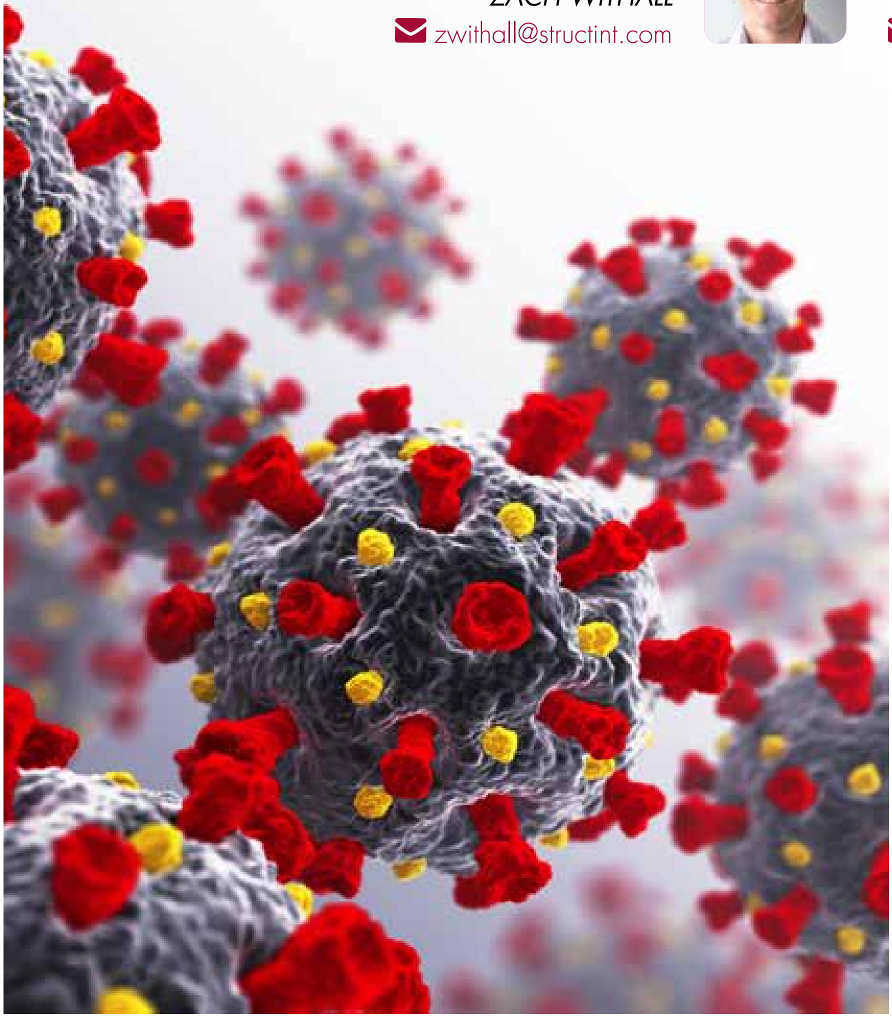

COVID-19 has presented humanity with unprecedented challenges. As economies reopen, solutions are needed that allow businesses to operate while protecting the health, safety, and security of the general public.

In an effort to positively impact that change, Structural Integrity Associates (SI) is working with Parsons Corporation, a global technology leader, to design a self-contained, mobile health screening facility for rapid, efficient and scalable testing.

The mobile facility is part of Parsons' DetectWise™ suite of health solutions meant to combat the COVID-19 pandemic. SI provided structural design services for the facility.

Modular Design

The design goals of the COVID-19 testing facility were simple but critical: the unit must be lightweight, easily deployable in a variety of regions, and structurally resilient under extreme-loading circumstances. Owing to the time-sensitive nature of the pandemic, ease of manufacturing, transportation

FIGURE 1. Test Facility Under Construction

Photos courtesy Parsons Corporation,
www.Parsons.com

FIGURE 2. Parsons Touchless Screening Kiosk

FIGURE 3. Modular Laboratory

FIGURE 4. Patient Examination Booth Equipped with Ultraviolet Flash Disinfection system

and construction were paramount to the success of the project. The testing module's lightweight design reduces fabrication costs, facilitates a shorter fabrication schedule, and reduces inertial design loads, such as seismic and transportation induced shock loads. The reduced seismic loads mean that the testing facility can be deployed in most high seismic regions while still meeting ASCE 7-16 code requirements.

Small pad foundations are located underneath the module to resist gravity, wind, and seismic loading with minimal site preparation. Helical soil anchors are an option for areas with large wind or seismic loading to keep the suites properly anchored during extreme events.

The primary gravity and lateral force resisting systems are wall, floor, and roof membranes constructed of stiffened sheet metal, which minimize cost and weight while providing excellent structural reliability and vibration control during use. Lugs are welded directly to the exterior of the base to easily lock the unit in place during transportation, installation, and as attachment points for soil anchors.

The health facility is designed to fully separate patients from medical workers, protecting both parties and minimizing the PPE required to operate the suite. Each patient booth has a built-in glovebox wall and a "bag out" sealed chamber to allow for testing without direct contact. Patient booths can be chemically disinfected with an Ultraviolet Flash Disinfection system after every use.

SI's expertise with modular structures comes from our extensive history designing modular central plants that house HVAC systems. Creating a modular design that is fabricated off-site at the manufacturer's facility and subsequently shipped to the site for installation reduces the schedule impact on-site and allows for greater quality control, providing a more robust product for the client.

DetectWise Integrated Solution

The modular facility is a critical part of Parsons' integrated, touchless suite of DetectWise solutions that include touchless screening kiosks, drive-up tech booths, health authentication software and diamond-tip rapid testing sensors.

SI is proud to assist Parsons in helping accelerate the transition to a new normal. We are all in this together, and we hope our efforts can save lives and minimize the economic interruption caused by COVID-19.

Post Seismic Certification: What Do Manufacturers Do to Keep Their Products TRU Listed?

TRU COMPLIANCE LISTED

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Certification of products to withstand extreme event loading can open many opportunities for manufacturers to sell high value products when others have a barrier to entry, but certification is not a one-and-done effort. TRU Compliance (TRU) exists to provide certification services and ongoing support to ensure that our manufacturers remain competitive and compliant with demanding code requirements and project specifications.

In the Spring of 2019, TRU Compliance, a division of Structural Integrity Associates, achieved International Accreditation Service (IAS) accreditation to ISO 17065 as a product certification agency for seismic, wind, and physical security. By our certification scheme, approved products are issued a Compliance Report (CR) which details a listing of certified products and levels. Compliance Reports are valid for up to 6 years but require annual maintenance to avoid suspension.

> How does TRU or the public know the manufacturer is continuing to produce a product that complies with the certified construction and configuration without retesting periodically?

The answer is an annual product surveillance. In order for a certification to remain active and TRU Listed, the manufacturer must submit to annual surveillance activities so that TRU may verify that the product that was evaluated as the basis of the certification is still representative of the product being produced. Over the validity period of the certificate, annual surveillance may be conducted remotely, but must be performed at least once in-person either at the manufacturer's facility or at a point of sale in order to be eligible for renewal. Surveillance activities look for *Product*, *Process*, and *Management*.

Product Surveillance examines the newly produced certified product for physical characteristics that are important to its structural performance, such as materials and connections.

Process Surveillance examines how the product is made, including the factory and machinery used and the suppliers contracted for subcomponents.

Management Surveillance examines the quality programs in place and the corporate system that protects a manufacturer from shipping defective product or making undocumented changes.

Certifications issued by TRU Compliance are tracked within the [TRU Compliance Certification Database](), which is visible to the public. Near the anniversary of the certification issue date, a remote surveillance interview is initiated between a TRU Certification Engineer and the manufacturer. A surveillance can also be triggered at any time within the certification cycle if a manufacturer requests a modification to their certification. If any deviation is noted from the original certification, the TRU Engineer documents the finding and presents it to the Certification Decision Maker (CDM) who evaluates the deviations to determine if they fall within the acceptable limits of the certification standard. Based on these finding, the manufacturer's certification either remains active or is suspended until they provide a satisfactory resolution to address the noncompliance. A client can appeal a noncompliance assessment by filing a formal complaint or appeal to SI's QA Department (CorporateServiceQA@structint.com). Structural Integrity Associates, Inc. Director of Quality Management (DQM) determines if the appeal relates to the certification activities. If the DQM decides the appeal has merit, an internal review takes place to facilitate a resolution to the appeal with personnel independent of the certification.

Continued certification takes diligence on the part of the manufacturer and is required by building codes. These requirements allow certifying bodies to ensure the safest possible products are being installed in facilities with a high consequence of failure. TRU's accredited product certification program is designed to do just that.

FIGURE 1. Cooling tower mounted to shake table for seismic testing.

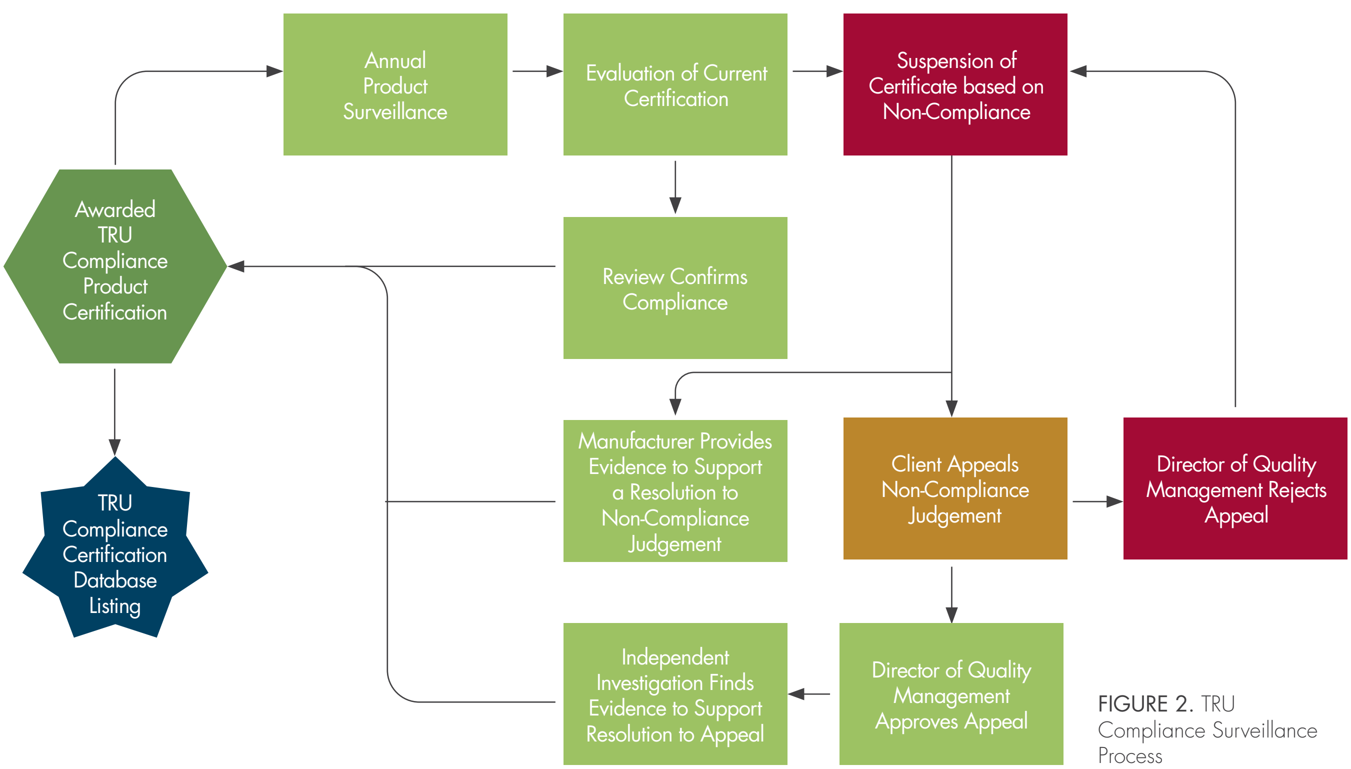

FIGURE 2. TRU Compliance Surveillance Process

SI Field Service Quality and Efficiency Solutions

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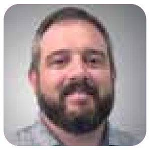

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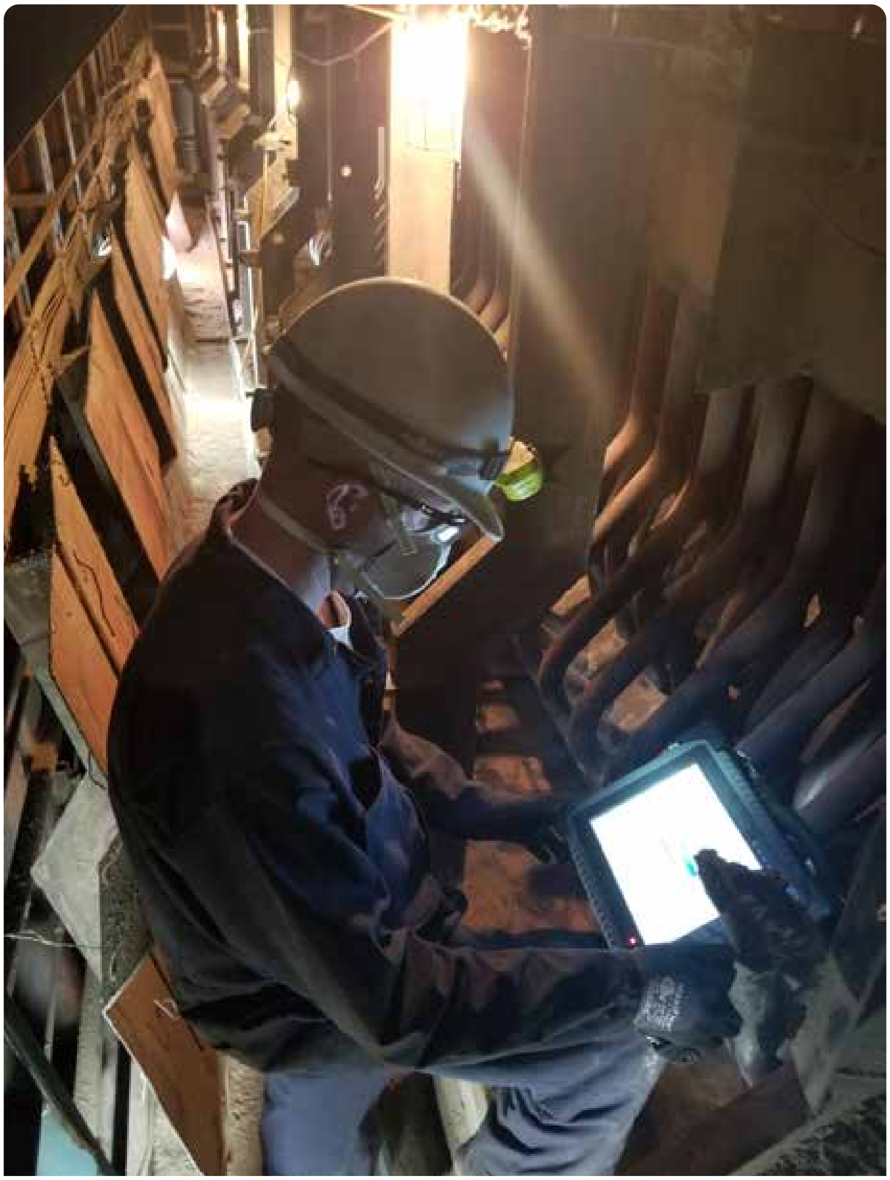


To help meet demanding outage schedules and stay within lean operation and maintenance budgets, Structural Integrity Associates, Inc. (SI) has implemented several new field data collection and analysis tools that enable delivery of a higher-quality final inspection product in a more efficient manner. These include customized software tools for streamlining the NDE data acquisition, analysis, and reporting processes. Moving forward, these tools will reduce time-on-pipe for inspections, as well as the associated analysis and reporting time.

For large inspection scopes, collecting, tagging, managing, transferring, and documenting data can be a very labor-intensive process with opportunities for human performance errors. While inspection instruments and analysis software typically have built-in reporting capabilities, these tend to be very general so they can be applied to a wide variety of applications. This can make it cumbersome to tailor these features to a specific application. By working directly with the inspection instrument OEM and their Software Development Kit (SDK), SI has developed tools that have been integrated directly into the existing acquisition and analysis software, allowing SI's NDE professionals to focus on performing quality inspections and analysis in less time.

These custom software tools include the following capabilities:

Data Acquisition Application (Integrated with Acquisition Hardware)

- Allows the examiner to import a list of welds to be inspected along with any project and component-specific information, which is then used to automatically populate information fields within the tool, eliminating the need for the user to do this manually in the field.
- All inspection related information (e.g., component details, examiner findings, etc.) is saved directly into the data file. This creates a more reliable process for keeping track of critical inspection information and provides the data analyst easy access to the information, allowing them to create analysis records more efficiently.
- Compiles all commonly used controls on the instrument into one location, allowing for inspections to be completed faster and more efficiently.

Analysis Application (Integrated with Desktop Analysis Software)

- Once the analyst opens the data file in the analysis software, the inspection related information is quickly imported into the SI Analysis Application with the click of a button. This allows the analyst to focus their attention on performing quality analysis and create analysis records more efficiently, not having to re-enter component specific information that, historically, was not ported over from the data collection instrument.
- Provides functionality to give an in-depth analysis for each individual scan, take screenshots, enter findings, and then combine all of the inspection and analysis information in an automatically generated report, which significantly reduces the time required to create analysis records.

Data Storage, Management, and Reporting (PlantTrack web application available for use by plant operators)

- Once data is acquired and reviewed, the inspection records are uploaded into the web application (PlantTrack) for maintaining the information. All records can be loaded whether they be volumetric exams, thickness and hardness measurements, Mag particle and replica images, or any other data collected, or results generated during an examination
- Recommendations for both long- and short-term actions are documented and tracked within the software and can be tagged to an inspection record, a location of interest, or an entire system
- Data and recommendations are then displayed as an overlay on interactive drawings of the system, enabling analysts to assess the health of the systems, identify what has already been done, and plan what needs to be done

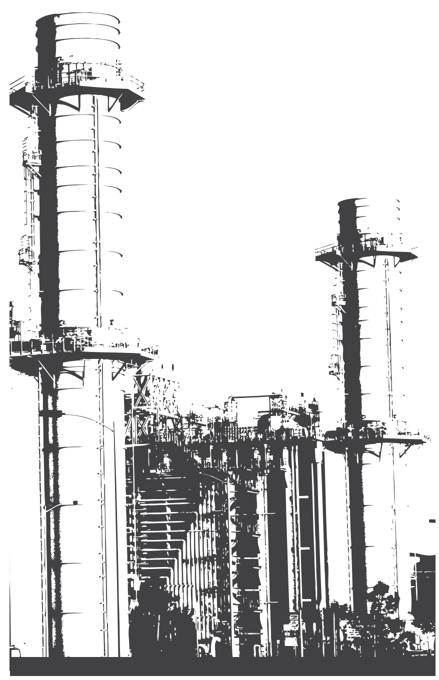
These tools have been applied to field projects across multiple industries and have helped SI achieve our goal of improving quality and efficiency of our services. An approximate 20% decrease in time-on-pipe has been observed, with similar time savings observed when performing analysis and creating records. The streamlined process has also resulted in roughly a 90% reduction in human performance related errors with documentation. Moving forward, SI will continue to pursue approaches to increase quality and efficiency of our field services through the implementation of customized tools and technology solutions.

PlantTrack™
Engineering Insight Through Data

ANDROID APP ON Google play

Available on the iPhone App Store

structint.com/software/planttrackapp



SI Talent

Our Employees Are Our Most Important Assets

We provide an environment where achievement, creativity, and teamwork are rewarded, trust and respect for the individual are paramount. Employees are empowered to make decisions to satisfy client needs and are provided the necessary development opportunities to meet their professional growth needs and be able to execute in their positions.

DO JUN (DJ) SHIM
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ASME FELLOW AWARD

Structural Integrity (SI) would like to congratulate Do Jun (DJ) Shim, Ph.D., on receiving the rank of Fellow of ASME, July 21, 2020. Dr. Shim received his award at the Materials and Fabrication (M&F) Technical Committee meeting during the ASME Pressure Vessels and Piping Division (PVP) Conference. Dr. Shim has been a long-time contributor to both the PVP Division and ASME Codes and Standards in the area of nuclear Codes and Standards. His work has centered around fracture mechanics life assessment. He has worked for many years in advancing the state-of-the-art advancements of fracture mechanics life assessment in the nuclear industry. With only about 3% of ASME members, achieving this award, it is a great honor of distinction attained for his significant engineering achievements.

Please join us in congratulating Dr. Shim in this outstanding recognition of his career achievements.

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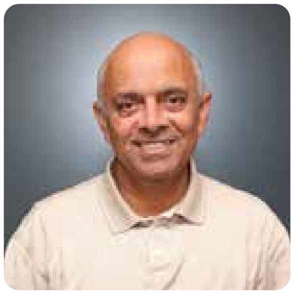

DILIP DEDHIA
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RICCARDELLA INNOVATION AWARD

Innovation is a part of SI's history and core values, and recognizing the contributions of our employees that bring this value to fruition is a priority. The SI Riccardella' Innovation' Award

acknowledges the achievements of Gerry Davina and Dilip Dedhia for their outstanding business development initiatives and strategic science and technology advances that have enhanced SI's reputation as an industry leader. Contributions include areas of probabilistic fracture mechanics, software development, and Programmable Logic Control (PLC) Systems for chemistry process control at nuclear power plants.

Please join us in congratulating Gerry and Dilip.

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YUSEF (JOE) RASHID

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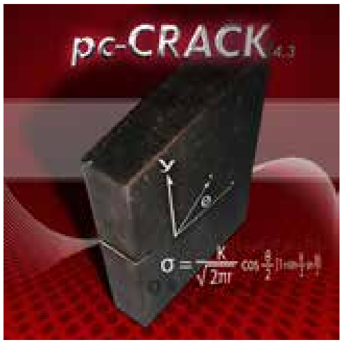
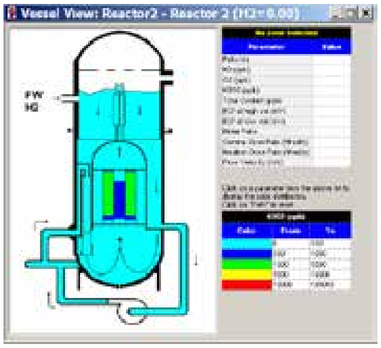
SI LIFETIME ACHIEVEMENT AWARD

SI proudly presents The Lifetime Achievement Award to Stan Tang and Yusef (Joe) Rashid. This SI award recognizes employees that have an outstanding vision in innovation, career-long leadership, commitment, and dedication to the success of our organization. Stan's work in deterministic and probabilistic fracture mechanics and fatigue has supported solving numerous industry issues (e.g., BWRVIP-05) and has led to innovative developments within SI (pc-CRACK and FatiguePro). And Joe has distinguished himself as a pre-eminent authority in nuclear fuel rod behavior in the world. Both have done extraordinary work and have exemplified the ongoing excellence that SI strives to provide the industry. Thank you for being a part of what makes us unique.





Congratulations, Stan and Joe!

LIVIA MELLO

ASCE/SEI AMMANN FELLOWSHIP AWARD

Congratulations to Livia Costa Mello on being one of the 2020 O.H. Ammann Fellowship Recipients!

Livia Mello is currently a graduate research assistant at the University of Houston (UH). She is a Civil Engineering doctoral student working under the supervision of Professors Roberto Ballarini and Jia-Liang Le. Her doctoral research is in developing a novel computational model applicable to the analysis of time-dependent progressive collapse in reinforced concrete buildings. She earned her bachelor's degree in Civil Engineering from the Federal University of Viçosa in Brazil, and her master's degree in Civil Engineering from UH. She is a student member of ASCE/SEI and the Society of Women Engineers (SWE), having held officer positions at the SWEUH Section. Most recently, Ms. Mello is working as a Summer intern at Structural Integrity Associates, in their Critical Infrastructure (CI) business unit. The CI group performs advanced finite element analysis, structural analysis, structural design, and evaluations of critical infrastructure, including nuclear power plants, defense installations, dams, and bridges.

Livia has accepted an offer to join SI full time in 2021 after the completion of her PhD.

"I am honored and beyond thankful for being one of the O.H. Ammann Fellowship recipients. This award already has and will continue to have a major impact on my career as a structural engineer. My leading professional goal is to advocate and be an active participant in building a stronger relationship between industry and academia. Awards and fellowships like this highlight the importance of investing in education and supporting research developments as an effective way to advance the structural engineering profession."

-Livia Costa Mello

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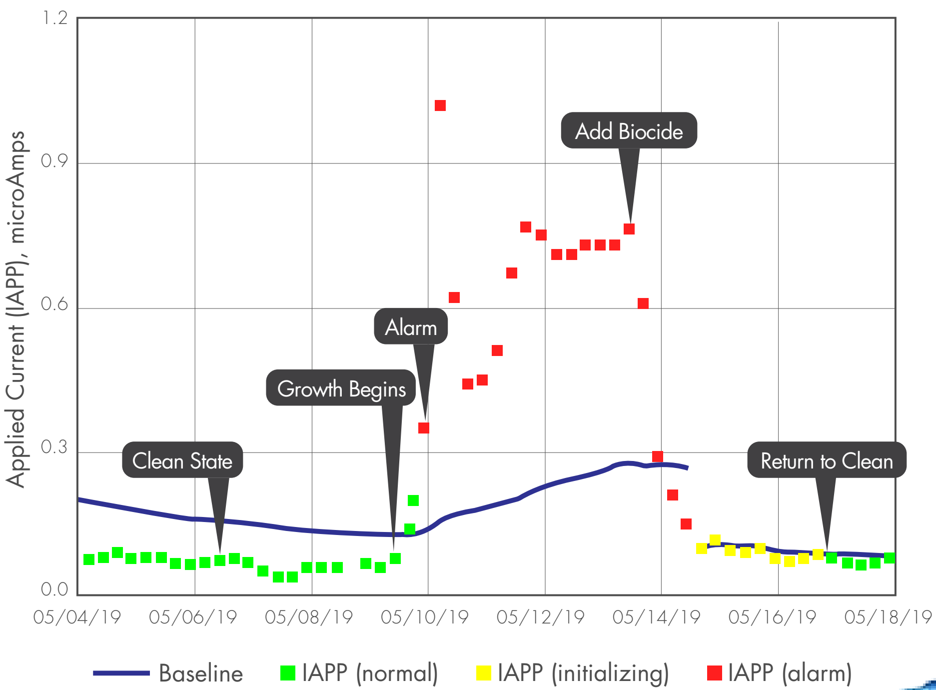
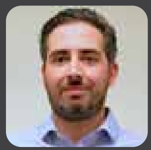
BIoGEORGE™ BG4 – BIOFILM GROWTH DETECTOR WEBINAR

Are biofilms and microbiologically influenced corrosion (MIC) a problem in your water systems? Are the costs of your biocide treatments too high? Learn more from a recording of a recent webinar about The BIoGEORGE™ BG4 Biofilm Growth Detector. Visit si-biofilmgrowth.com and listen to SI's expert, Ed Dougherty, present the BG4 capabilities and benefits of real-time biofilm monitoring.

Inefficiencies and equipment failures are large and expensive problems in any industrial process, but the cause of the problem may be smaller than you think. You might have a biofilm problem. This webinar will explain what biofilms are, how they develop, and how to best monitor the activity of biofilm on wetted surfaces online and in real-time. Exploring how to avoid adding excess biocide that could otherwise significantly increase operational costs, present unnecessary environmental burdens, and result in higher corrosion rates.



SI-biofilmgrowth.com



Presenter
EDWARD DOUGHERTY
edougherty@structint.com

Mr. Dougherty has over a decade of experience in the areas of nuclear water chemistry and systems support. At SI, Mr. Dougherty supports areas of water chemistry assessments, condensate polishing, ion exchange resins, septa, service water treatment, raw water treatment, and biofilm detection. Mr. Dougherty also manages the BIoGEORGE™ Biofilm Growth Detector product line offered by SI.

Working with utility clients, he has performed chemistry and engineering assessments that have helped promote optimization of plant operating practices.

For more information, go to:

www.structint.com/news-and-views-48