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Structural Integrity Associates, Inc.®

NEWS & VIEWS

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RODIS ROBOTIC ILI WITH SIPEC™ TECHNOLOGY PG.3

Structural Integrity Associates, Inc.®

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Building Blocks of Knowledge

Over the holidays, I had the profound pleasure of attending my youngest daughter's graduation from the University of Maryland (different school, but engineering like her dad and older sister). The student speaker was very impressive and if Structural Integrity had an electrical engineering consulting business, she'd definitely be a targeted hire. She spoke of wondering how she, as a new graduate with limited knowledge, could make a contribution to technology, to industry and to the world. She wondered how much knowledge it must take to design, manufacture, program, service and maintain an everyday common device such as a cellphone, car or notebook computer. All of these devices are much too complex for any one engineer to fully comprehend, yet we still enjoy these devices in our lives with more advanced versions created endlessly.

As I listened to the roll call of Doctoral, Masters and Bachelors candidates (and even for a winter graduation, there were plenty of them), I had time to reflect on the knowledge needs of the electric power industry and how each of us, regardless of education, discipline, or experience level, contributes to making it work. And for me, "working" means the lights come on each and every time I flip a light switch in my house.

My first thought during the naming of Doctoral candidates was that I know a LOT more about a nuclear or fossil power plant than I know about my cell phone. But then again, do I? I know about some of the components in the plants and a little about their operating environment, their materials of construction, how they might degrade and age, how to inspect them, and a little about how to put all of that information together to estimate how they will perform in the future. My next thought (this time during the naming of Masters candidates) was the components I know anything about are only a very small subset of all the components and systems in a generating plant, and I know essentially nothing of the fuel handling or transmission and distribution systems outside of the plant.

As they started naming those receiving Bachelor degrees, I realized I couldn't oversee a single power plant component, much less an entire plant. Although I once worked in the maintenance department of a nuclear plant, I could no more change pump seals or do routine maintenance on a valve than I could do the 50,000 mile tune-up on my truck However, I get around on my cellphone pretty good for someone who's college computer classes were taught with punch cards. For example, I can upgrade my phone's operating system, add new apps, operate the e-mail, phone, GPS, camera, change notifications and tones, and even occasionally fix connectivity issues.

So, to return to this insightful speaker's question – after investing a life's career to an industry and discipline, and yet knowing so little of everything that needs to be known to make the industry function, how do we contribute? The speaker said it best – through simple addition. As individuals, we each contribute a small piece to increase the knowledge of the group with which we work or interact. This group then contributes its knowledge to the knowledge of other groups within in our company thus expanding the total knowledge in the company. Next, our company's knowledge is shared and merged with the knowledge of other companies increasing the knowledge of the industry. This process of simple addition continues until the total knowledge of the community is sufficient to design, manufacture, operate and maintain an industry.

At SI, the principle that no one can know everything yet each individual, regardless of position, role or experience level, contributes a small but essential piece of knowledge is evident to me – I see it in our collaborative approach to problem solving and our continuous effort at innovation. Not only are we adept at putting these discrete building blocks of knowledge together but the idea reinforces the essential need to drive learning and the perpetual search for additional staff to join SI to add new pieces of knowledge to our knowledge base – making us stronger and better able to cope with tomorrow's challenges.

Simple addition is a powerful calculus – it works at SI and it works for the electric power industry. Every time the phone rings here, we solve a challenging problem with a multi-disciplinary team approach, and each time I flip a switch in my house, the lights come on.

CORROSION INNOVATION AWARD

Structural Integrity's dynamic pulsed eddy current technology, SIPEC™, took center stage at the 2015 National Association of Corrosion Engineers (NACE) Conference, where it earned an award for innovation from Materials Performance (MP) magazine. On March 16, NACE President Harvey Hack presented the 2015 MP Corrosion Innovation of the Year Award to Structural Integrity and our strategic partner Diakont for the RODIS Robotic in-line inspection (ILI) with SIPEC™.

Annually, the award showcases progressive technological developments in all aspects of corrosion prevention and mitigation. The SIPEC/RODIS technology earned the award by making corrosion detection easier for pipelines and power plants facing situations where conventional ILI tools may not be feasible.

The tool is designed for applications where direct access to the internal surface of the pipe is difficult or impossible, such as internally corroded and lined piping. In these situations, the RODIS Robotic ILI with SIPEC sensor technology can identify internal and external corrosion, while improving data quality and decreasing inspection time and costs.

Structural Integrity's unique pulsed eddy current (SIPEC) sensor offers several advantages over existing sensors, including improved spatial resolution, improved signal-to-noise ratio, and the ability to acquire data while in motion (dynamic data acquisition). The SIPEC sensor integrates with Diakont's RODIS R-ILI crawler, which contains dual-base tracks for navigation on horizontal surfaces and a single top track that can be extended to push against the inside of the pipe wall for stabilization. This provides the necessary traction to hold the crawler in place while inspecting difficult pipe geometries.

This award is a testament to the spirit of innovation that we share with our strategic partners. We congratulate the engineers and other team members at both Structural Integrity and Diakont who developed this industry-leading technology.

FINETECH JOINS STRUCTURAL INTEGRITY

finetech CHEMISTRY & ENGINEERING

To better serve our clients, Structural Integrity routinely joins forces with other leading companies whose unique expertise complements our own. We are excited to announce the latest industry leader to join the Structural Integriy family: Finetech, Inc.

In March, we finalized the acquisition of Finetech, a leading engineering consulting firm for water chemistry and power plant and industrial water processes. Based in Parsippany, New Jersey, Finetech's water chemistry expertise is applied in the power industry to control environmental cracking and corrosion, ensure fuel reliability and minimize radiation fields.

As an experienced engineering consulting firm, Finetech also designs, fabricates and supports the installation and startup of water purification system hardware and instrumentation and control upgrades at nuclear power plants in the U.S. and around the world.

Both SI and Finetech were founded in 1983 to serve the nuclear power industry. The acquisition promises to leverage each company's unique strengths and provide new growth opportunities.

Finetech's advanced solutions for chemical control and water purification will deepen our expertise and ability to provide innovative, integrated solutions. Likewise, as a fully owned subsidiary of Structural Integrity, Finetech will have more opportunities to apply its chemical engineering and chemistry expertise to all the markets we serve.

Working with Finetech and other uniquely qualified colleagues, we will continue to provide the most advanced turnkey solutions to the electric power industry.

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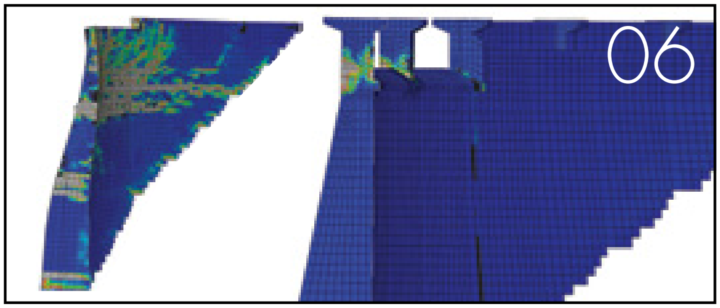

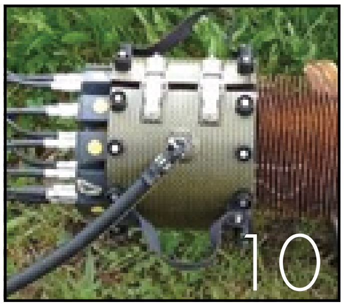

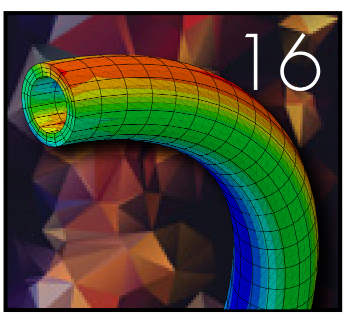

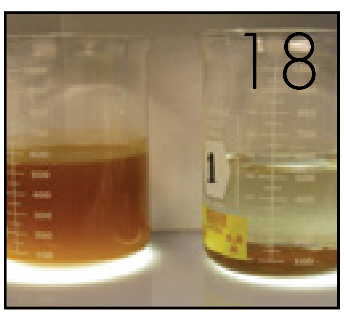

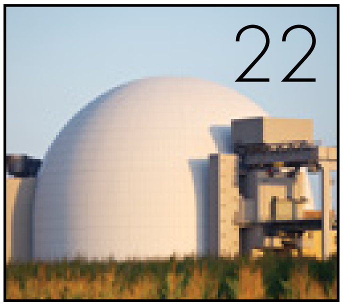
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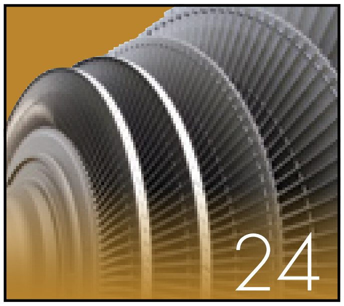
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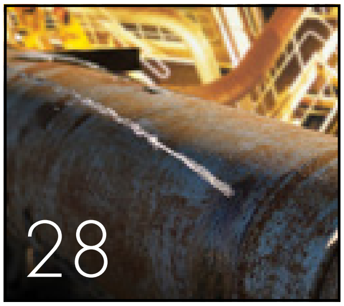
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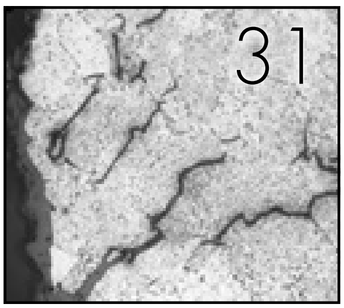
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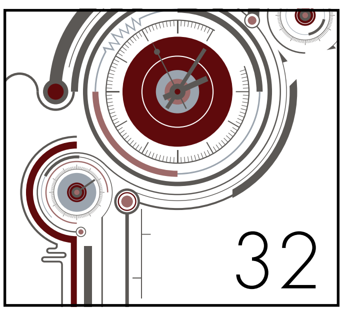
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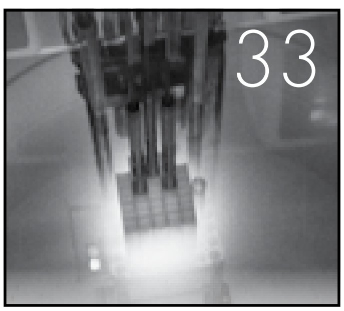
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NACE
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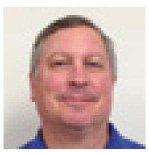
SEISMIC ASSESSMENT AND REMEDIATION OF AGING CONCRETE INFRASTRUCTURE



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A hot topic in the news lately is our country's aging infrastructure and the significant resources required to repair, replace, and modernize it. Due to the high cost of these efforts, owners need to rank critical structures for risk-of-failure consequences versus repair or replacement costs and find the most cost-effective solutions for renovating existing infrastructure.

First, what is aging infrastructure?

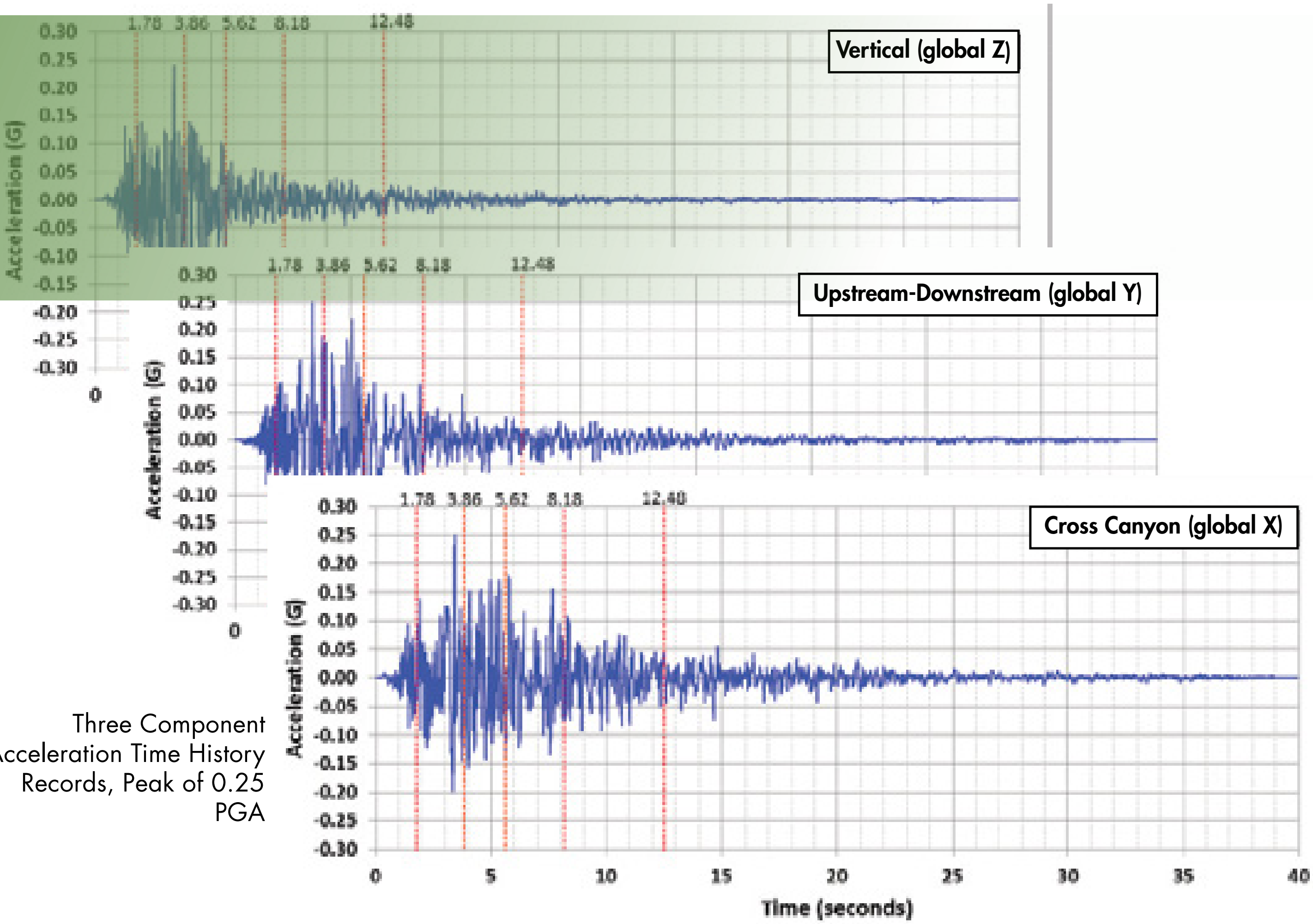
- A structure that is nearing or has exceeded the lifetime expectancy that was used as a basis for the structural design.
- A structure that has degraded over time due to factors such as steel corrosion, freeze-thaw damage, or alkali-aggregate reaction (AAR).
- Known deficiencies in existing structural design due to ever-evolving design code requirements or increases in defined regional seismic hazards.

For large concrete structures, lifetime expectancies established during the design process are based on expected serviceability limits, postulated service requirements needs, building code requirements, and even economic considerations for capital investments. Variables that can effect expected structural lifetime include environmental conditions, consistency and quality of materials and of construction workmanship, and even changes in loading not envisioned at the design stage. Often, these structures must perform well beyond the original design life.

Throughout the country, many large concrete structures, such as bridges and dams remain in active service as they approach and exceed centenarian status. For many dams, replacement is considered prohibitive due to potentially lost hydroelectric generation revenue or water storage logistics. However, failure of these structures, leading to rapid drawdown of impounded reservoirs, could have more costly consequences. Identifying seismic vulnerabilities and designing retrofit modifications is key to safely extending the lifetime of these structures at a fraction of complete replacement costs.

Owners use a variety of techniques, including core sampling and non-destructive examination, to evaluate consistency or distribution of material degradation within the structures. Some also apply structural health monitoring by employing various instrumentation to monitor displacements at key target points and accelerometers to monitor the fundamental dynamic modes of a structure. These efforts are a step in the right direction, but are of little use if data is not carefully processed and considered. Such was the case within the collapse of several wind turbine towers in Pennsylvania and the near loss of an upper spill crest and tainter gate at a large dam on the Columbia River in Washington State.

Identifying seismic vulnerabilities and efficacy of retrofit modifications typically relies on some form of computer calculated structural analysis, most commonly response spectrum analysis (RSA). In short, RSA entails developing a linear elastic finite element model and calculating the primary modes of vibration. Depending on the size and configuration of the structure, most of the required modes and mass participation can be captured within the first 5 to 20 modes. Higher frequency/short period response is typically not as critical for larger structures during seismic events. The individual modal



Three Component Acceleration Time History Records, Peak of 0.25 PGA

responses are applied to the defined spectral acceleration to calculate the force response for design purposes. The limitation of this methodology is that the material response is linear and does not account for or track damage to the structure during the seismic event. Typically, the assumptions used combine the magnitudes of different modes of response in the most conservative manner. Thus, the RSA methodology has the tendency to provide an overly conservative bounding response, which can lead to exaggerated damage assessments and retrofit solutions. These excessive remediation solutions result in unnecessarily high retrofit construction costs, or worse, lead to a modified structure that is overly stiff or massive, which may create new seismic vulnerabilities.

A linear time-history analysis offers a more accurate analysis in which a representative site-specific earthquake record time-history is applied to the structure to evaluate the response. This methodology is a more realistic evaluation for a particular postulated seismic event in which multiple frequency responses

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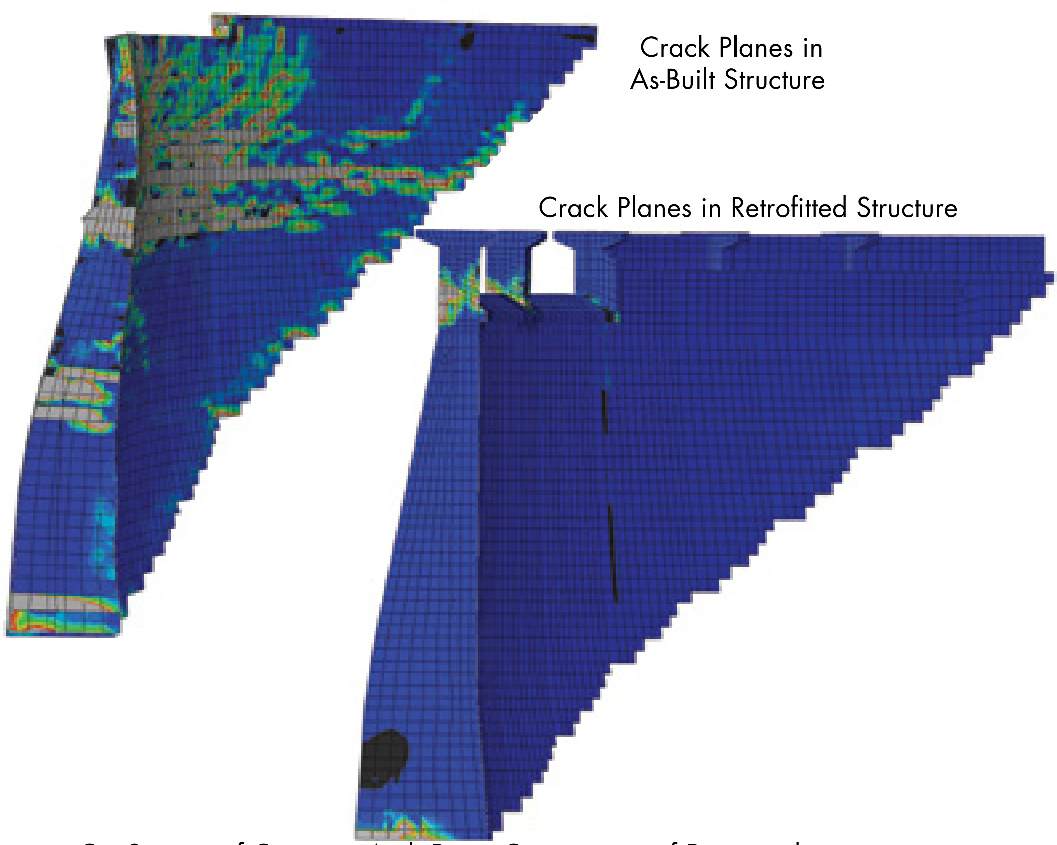


Cut Section of Concrete Arch Dam, Comparison of Damage between As-Built and Retrofit Conditions

SEISMIC ASSESSMENT AND REMEDIATION OF AGING CONCRETE INFRASTRUCTURE

CONTINUED

will be excited. In addition, nonlinear material response should be included to avoid overly conservative results that do not accurately portray the true performance of a structure.

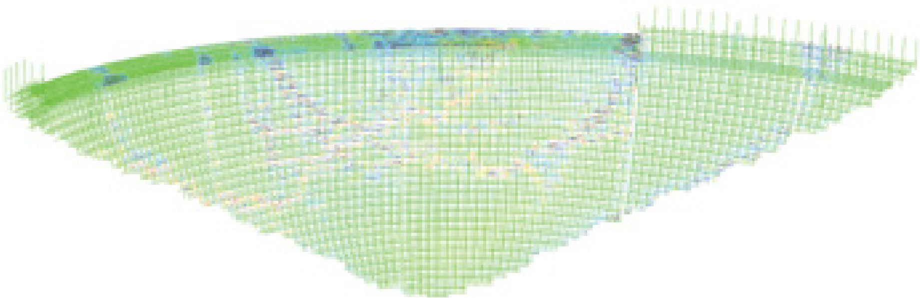
Subject to currently defined maximum credible seismic events, damage will occur within most existing concrete or masonry structures. Accumulated damage will change the structural stiffness and dynamic characteristics, which will change the structural response during the seismic event. This effect cannot be captured with a linear model. Capturing the nonlinear material response allows evaluation of the true performance of a structure during and after the postulated earthquake. This approach is referred to as performance-based analyses, as opposed to linear design-based analyses.

Several general purpose finite element codes offer concrete constitutive material models that are reasonably effective in representing either compressive crushing or tensile cracking. Because concrete is inherently asymmetrical in tension and compression, a robust performance-based seismic analysis must capture both the compression and tension interaction in the concrete to accurately determine the cyclic response of a structure during a seismic event. An equally important aspect in evaluating a response is to capture the shear resistance and capacity of a structure, particularly across cracked planes. The shear resistance can reduce significantly as cracks open, and can increase significantly across closed crack planes. Our concrete material model can accurately capture the coupled compressive, tensile, and shear response required to accurately represent the seismic response of concrete structures.

Lake Almanor Intake Tower

Our proprietary concrete model has been developed and refined over the past several decades. ANATECH was heavily involved in the California Seismic Bridge Retrofit effort following the 1989 Loma Prieta earthquake, including numerous proof test validations at the University of California Structural Systems Labs at the San Diego and Berkeley campuses and at the University of Nevada at Reno.

Recently, ANATECH has been involved in seismic vulnerability studies for large unreinforced concrete dams and intake towers. These projects involved performance-based nonlinear, material time-history analyses on 3-D finite element models representing the in-situ structures. These analyses successfully identified seismic vulnerabilities and allowed for the design of targeted retrofit measures. Follow-up nonlinear time history analyses are then performed on modified models to either validate the efficacy of the retrofit measures or to guide the designer to come up with more robust retrofit solutions. This process of providing expert nonlinear analysis side-by-side with the retrofit design process can lead to efficient, innovative, and cost-effective solutions for aging concrete infrastructure. Future earthquakes are inevitable, so it is important to realistically assess and remediate deficient seismic conditions of existing aging structures.



Axial Strain in Reinforcement Layer Added As Part of Retrofit Design

NEW TRAINING PROGRAM TARGETS TURNOVER ISSUE

Linking Theory and Practice

With nearly 40 percent of the current workforce eligible to retire in the next three to five years, the power industry faces a huge loss of knowledge. As a trusted partner to the energy industry, Structural Integrity is working to make sure that knowledge gap is quickly backfilled.

To help clients navigate the coming changes and prepare the next generation of workers, in 2014, Structural Integrity formalized and expanded our training program for power plant and engineering professionals. New training on critical topics -- from fracture mechanics to fatigue -- will preserve industry knowledge so plants can continue to operate safely, efficiently and reliably.

Our training program offers a broad spectrum of courses to meet the needs of the novice, as well as the seasoned professional. All of our courses are designed to link theory and practice for a deeper understanding of highly technical topics.

Our instructors are at the forefront of their fields; many hold leadership roles and are active members on Code and Standards Committees. These industry experts use real-world examples to illustrate practical solutions to challenging technical issues.

All of our training shares one goal: to build in-house expertise so our clients can solve problems in the earliest stages. More informed employees are better prepared to help power plants resolve issues, mitigate risks, assist with vendor oversight, and save money by minimizing downtime.

Training can be conducted at your company's location or at one of our many offices – whichever is most convenient and cost-effective for you. Participants will receive credit toward Professional Development Hours.

The science and technology of structural integrity are always evolving. We work hard to stay on the leading edge and to prepare our clients for the challenges ahead. With the debut of this new training, there have never been more opportunities to learn from the experts at Structural Integrity.

To learn more or schedule a training session, email us at info@structint.com. We also welcome your requests for new training topics.

COURSE OFFERINGS

- ASME Code Section III
- ASME Code Section XI
- Flaw Evaluations – ASME Code Case N-513)
- Corrosion Control in Light Water Reactors
- Corrosion Control - Microbiologically Influenced & Other Raw Water Corrosion
- Fracture Mechanics
- Metal Fatigue
- NDE for Engineers and Managers
- Fuel Manufacturing Issues Affecting Performance
- Pellet-Clad Interaction
- Fuel Rod Performance Modeling
- Spent Fuel Integrity Analysis in Transportation Casks
- Plant Vibration Damage and Effective Solutions
- Welding & Materials

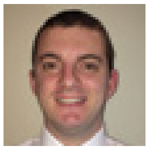
HERE'S WHAT OUR CLIENTS HAVE TO SAY ABOUT STRUCTURAL INTEGRITY TRAINING:

"Structural Integrity's technical capabilities and expertise are well-known in the industry. In comparison to other vendors, they have an edge on technical issues and solutions."

"Thank you to everyone at Structural Integrity for putting together such an engaging training workshop— the visual aids and post-workshop demos were particularly helpful..."

"All the presentations were clearly organized and informative, but also presented simply so someone like myself could easily understand even the complicated topics."

RAPID, NON-INVASIVE SCREENING OF FINNED TUBES WITH GUIDED WAVE TESTING



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BACKGROUND

Finned tubes are widely used in tightly-packed bundles in heat exchangers and chemical processing facilities. They are preferable to bare tubes because of their enhanced heat transfer characteristics. Heat transfer can be adjusted by altering the fin height, thickness, density, and/or material. The fins are spiral wound on to the tube, either by brazing or welding, and may be solid or serrated.

Current NDE technologies for finned tube are limited to time-consuming, invasive methods which require direct access to the internal or external surface of the tube. For example, visual inspection, remote field eddy current, and ultrasonic internal rotating inspection systems (IRIS).

INTRODUCTION

Guided Wave Testing (GWT) is a low-frequency ultrasonic technique that has been utilized extensively for screening above ground and buried pipe. GWT facilitates inspection of tens to hundreds of feet of pipe from a single location, thereby enabling inspection of pipe with limited access. For example, inspecting buried segments of pipe from within an excavation, inspecting insulated segments of pipe by removing a few feet of insulation, or inspecting buried segments of pipe through a wall penetration.

It is important to note that GWT is a qualitative screening tool and that GWT inspection results provide an axial location, approximate circumferential location, and relative severity of any wall loss indications that are identified. The relative severity is typically referenced to the magnitude of one or more girth weld indications. The sensitivity of GWT can vary, but is typically around five percent cross-sectional area change for most applications. In most GWT applications, the torsional wave mode, which is characterized by material displacements in the circumferential direction of the pipe, is used at frequencies ranging from approximately 20 kHz to 80 kHz.

GWT OF FINNED TUBES

Finned tubes add an additional layer of complexity to GWT due to the presence of periodically spaced fins along the tube axis. Most GWT field experts and engineers would likely conclude that the presence of mechanically-coupled structures on the OD surface would successively reflect a portion of the incident energy, leading to rapid attenuation and practically no penetration. This conclusion is not unfounded, as GWT training courses typically teach inspectors that anything attached to the OD surface of a pipe will produce attenuation and indications in the data. However, such courses overlook a class of solutions to the guided wave problem known as Bloch wave functions. Bloch wave functions account for structural periodicity in the problem (i.e. they assume the presence of the periodically-spaced fins on the external surface of the tube). Physically, this results in frequency pass bands and frequency stop bands which depend on dimensions and material properties of the tube and the fins.

To validate these theoretical conclusions, finite element models of guided wave propagation in a finned tube were generated. Figure 1 shows an image of the model geometry of the finned tube. The modeled structure was 10' long with 6" of bare tube on either side to simulate the bare area that would be needed for transducer placement. Figure 2 shows a zoomed image of the finite element mesh that was generated. Incident guided waves were generated over the range of frequencies typical of GWT inspections, using both torsional and longitudinal mode excitation.

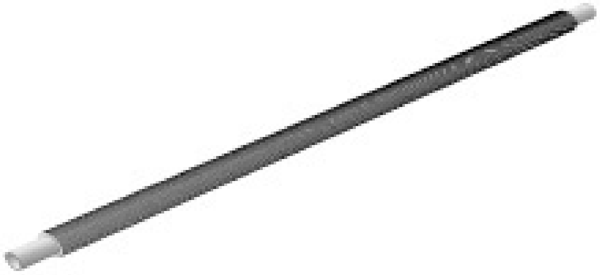

Figure 1. Finite element model geometry.

Figure 2. Zoomed image of the finite element mesh.

As a baseline for comparison, the same frequencies were tested on a bare tube having the same dimensions and material properties. Figure 3 shows the results of the frequency sweep on the bare tube. The vertical strip of black/red pixels near the center of the image are indications from the tube end across the frequency range. One can see that the indication from the tube end is consistent across the entire frequency range.

Figure 4 shows the frequency sweep results on the finned tube. Notice that, in contrast to the bare tube, there are specific frequency ranges at which there are indications from the tube end and specific frequency ranges where there is no indication from the tube end. The regions where there are reflections from the tube end are the frequency pass bands. Conversely, were there are no indications from the tube ends, there are frequency stop bands.

The finite element results corroborate the theoretical hypothesis and provide a method for determining the frequency pass bands associated with the specific dimensions and material properties of the finned tube. This implies that, utilizing finite element models, the frequency pass bands of any finned tube configuration can be predicted; thereby facilitating the design of ultrasonic transducers that can operate within the frequency pass band ranges. Utilizing this process, GWT can effectively be used to rapidly screen finned tubes for damage in the tube wall.

Finally, experimental testing was carried out to corroborate the finite element models. Experimental testing was carried out on a section of finned tube that had been removed from service. Figure 5 shows the results of the frequency sweep conducted on the experimental testing component. Similar to the finite element models, the experimental results show frequency pass bands and stop bands. Within the frequency pass bands, there is a discernable indication from the cut end of the finned tube.

FLAW DETECTION POTENTIAL

Figure 6 shows a schematic, including photographs, of the experimental flaw detection test setup. Fins have been removed from three sections of the finned tube to create access points for transducer placement. The access points were selected such that a saw cut flaw was located 10', 15' and 25' from the transducer. The depth of the saw cut flaw was varied incrementally to represent 7.5%, 10%, 12.5%, and 13.3% cross-sectional area changes.

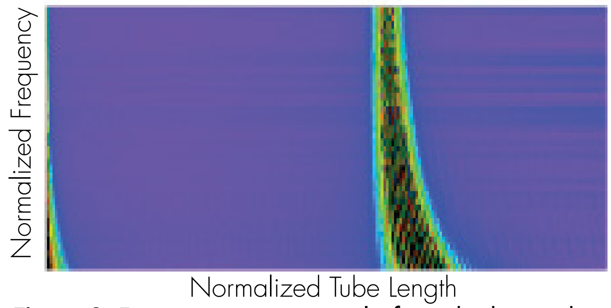

Figure 3. Frequency sweep results from the bare tube.

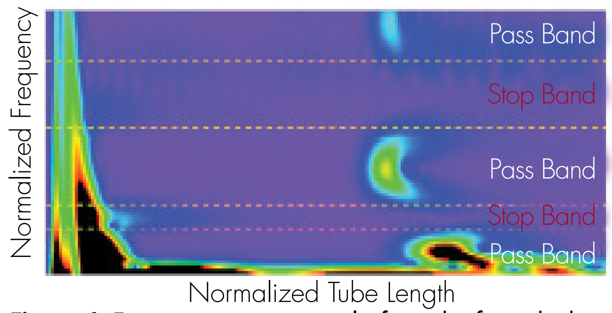

Figure 4. Frequency sweep results from the finned tube.

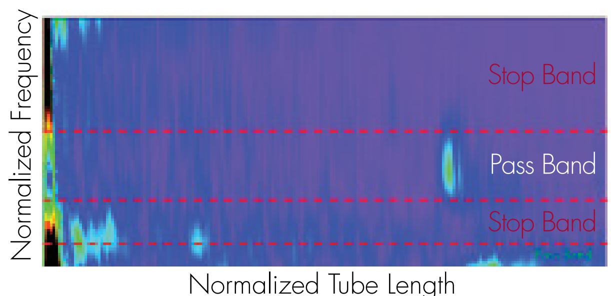

Figure 5. Experimental results from the finned tube.

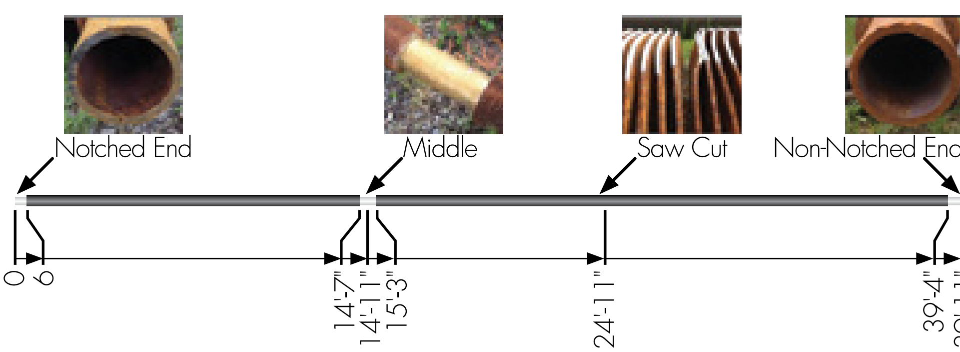

Figure 6. Schematic of the experimental flaw detection test setup.

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RAPID, NON-INVASIVE SCREENING...

CONTINUED

Figure 7 show A-scan waveforms acquired on the test finned tube. Each graph includes the waveform from the pristine finned tube (black trace) for comparison with the waveform from the flawed finned tube (red trace). Moving from top to bottom, the red trace represents increasingly severe cross-sectional area loss, from 7.5% to 13.3%, respectively. The annotations in each graph indicate the echo from the defect, as well as the echo from the cut end of the tube in the data.

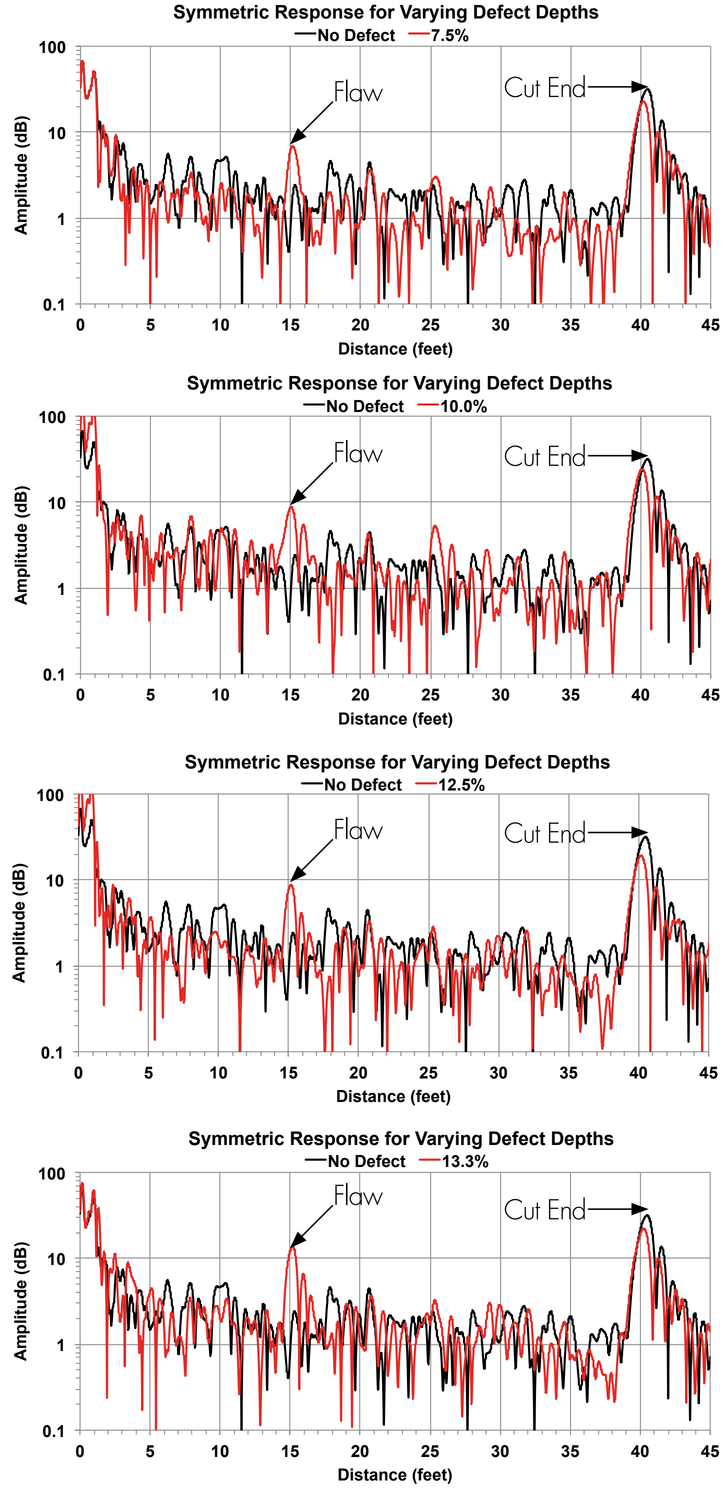


Figure 7. Experimental results from the finned tube.

Figure 7 demonstrates that GWT has excellent sensitivity to the sawcut flaw. It is important to consider the flaw geometry in assessing the capabilities of GWT in screening finned tubes as the technique is, in general, more sensitive to sharp changes in cross-sectional area (e.g. a sawcut flaw, localized wall thinning) than to gradual changes in cross-sectional area (e.g. gradual wall thinning from erosion). Additional testing is required to validate the detection capabilities of GWT in finned tubes with other flaw geometries.

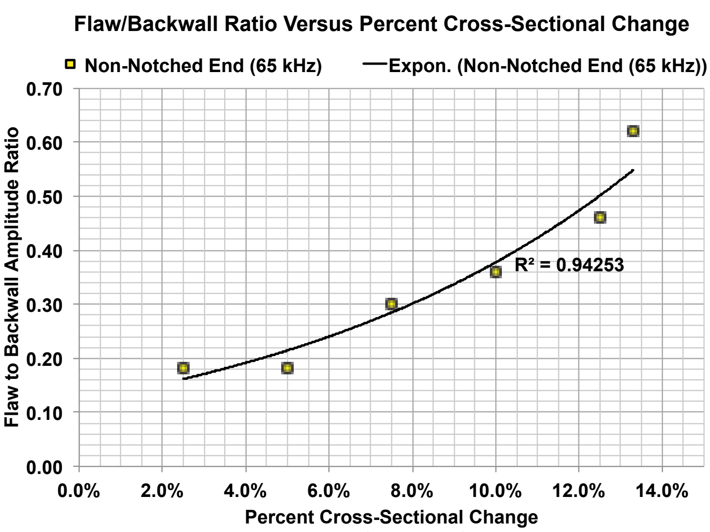


Figure 8. Experimental results from the flaw sensitivity study showing the amplitude ratio of the flaw/cut-end echo as a function of percent cross-sectional area of the flaw.

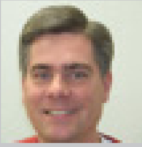
As shown in the waveform graphs, the amplitude of the response from the flaw grows in proportional to the flaw cross-sectional area. Figure 8 shows the correlation between cross-sectional area loss and amplitude.

CONCLUSIONS

The results of this theoretical, numerical, and experimental investigation demonstrate that GWT clearly has potential to be used in a screening capacity for identifying flaws in finned tubes. The pass band frequencies for any combination of material properties, tube dimensions, and fin dimensions can be determined numerically via finite element analysis. Flaw sensitivity study results show that GWT is sensitive to the sharp change in cross-sectional area of the sawcut flaw geometry. Additional tests are necessary to establish the sensitivity of GWT to flaw geometries characterized by gradual wall thinning.

This work has shown that GWT has the potential to be applied as a rapid and non-intrusive screening method for these previously difficult to inspect components which have otherwise required direct and intrusive access for inspections.

UPTURN IN THERMAL FATIGUE OPERATING EXPERIENCE



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In 2014, there was a significant upturn in thermal fatigue related events at several U.S. nuclear power plants. In April, McGuire Unit 2 discovered a part-wall crack in a cold leg safety injection line during a scheduled MRP-146 inspection. [Note: MRP-146 is an Electric Power Research Institute (EPRI) program document that provides industry guidance for the management of swirl penetration cyclic stratification that can result in thermal fatigue damage of reactor coolant system (RCS) branch piping.] Extent of condition examinations took place in September at McGuire Unit 1 during a refueling outage where two more safety injections lines were found with part-wall cracking. In addition, McGuire Unit 1 discovered mixing tee thermal fatigue cracking (part-wall) in a residual heat removal (RHR) system branch tee during a scheduled MRP-192 inspection. [Note: MRP-192 is an EPRI program document that provides industry guidance for the management of thermal mixing that can result in fatigue damage in RHR mixing tees.]

McGuire was not the only site affected. In October, a U.S. BWR experienced a through-wall leak in a bypass mixing tee in their reactor water clean-up system. In November, Oconee Unit 1 discovered part-wall cracking in a RCS drain line during a scheduled MRP-146 inspection. Finally in December, North Anna Unit 1 experienced a through-wall leak in a cold leg drain elbow.

While the root cause determinations are not completed for many of these events, thermal fatigue is strongly believed to be a contributing factor if not the direct cause. Although there were two through-wall leaks, the proactive inspections driven by the MRP-146 and MRP-192 guidance documents are being successful in finding cracking before cracking reveals itself. An industry wide team that includes Structural Integrity is evaluating these events to assess causes and then provide modified guidance to avoid future plant disruptions.

Update Improves High Energy piping Data Management

By: NAIL OZBOYA
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It's no secret that power plants today are forced to operate with a much smaller staff than they did in the past. In addition, today's workforce is more mobile than it was in the past. Retirements and higher turnover of employees mean that much of the tribal knowledge that used to exist at a plant is walking out the door.

To help address this issue, in 2013, Structural Integrity introduced PlantTrack, a software tool to manage the information, data, and knowledge around plant equipment. This article focuses on recent updates to the interface for high-energy piping, and why information management has become critical for piping systems.

The importance of systematic high-energy piping inspections and effective management of the findings is getting more attention every day. Several catastrophic pipe failures have occurred in the past several decades, caused by various failure mechanisms, including creep, fatigue, thermal fatigue, creep-fatigue, microstructural instability, and flow-accelerated corrosion. Most of the conventional plants are aging and some are put in cycling-load conditions they were not designed for. Similar issues also exist in combined cycle plants as more of them are put into continuous service that pushes design limits.

The extended use of the Creep Strength- Enhanced Ferritic (CSEF) steels (such as grades 91 and 92) in the manufacture of piping and components requires more sophisticated and complex inspection programs and analysis efforts. While these steels have superior strength over the traditional alloys, their strength characteristics at high temperature could be substantially deteriorated due to improper processing.

Structural Integrity's PlantTrack program allows owners to manage all activities and records associated with inspections. The PlantTrack dashboard has been updated to improve access and highlight inspection-related efforts. The user can easily access the graphical display of inspection activities and results, without first starting the interactive graphics module.

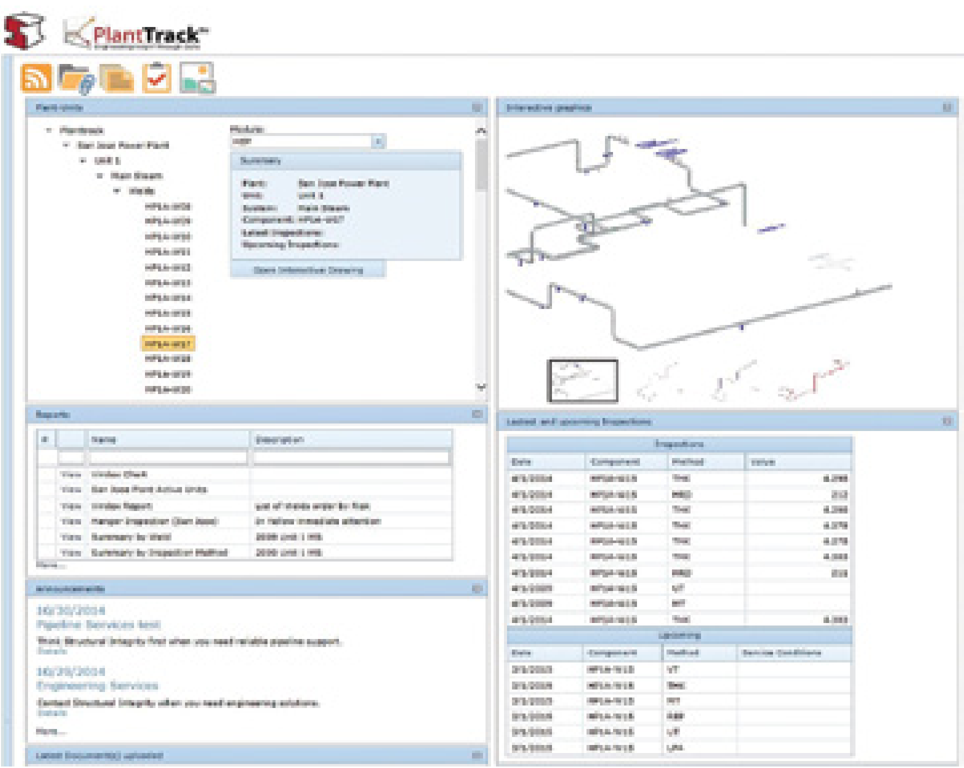


Figure 1. Sample PlantTrack Dashboard
The inspection and analysis history of piping systems and components can easily be accessed by simply selecting the system or particular component. The techniques used during the inspection can be displayed by using the pre-developed filters on the main interface.

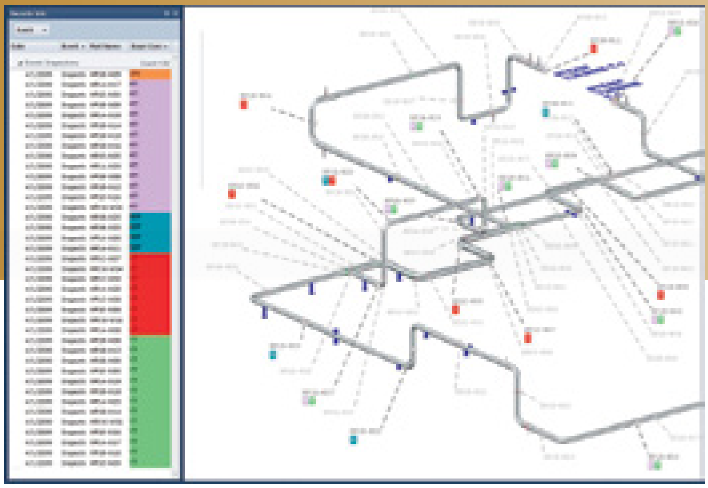


Figure 2. Graphical Display of Inspection Methods Used

PlantTrack also allows planning of inspection activities for the upcoming outage, as listed in Figure 3 and graphically displayed in Figure 4.

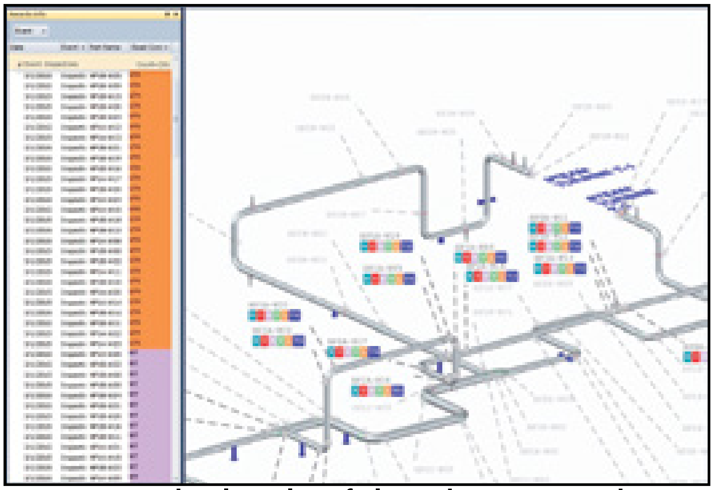


Figure 4. Graphical Display of Planned Inspection Techniques

Several failures of critical piping can be traced back to issues with pipe supports. Thorough inspections of pipe support systems are required to detect issues with improper design or installation, aging, or poor maintenance techniques. PlantTrack provides proper tools to document the pipe support findings, as well as calculated loads, movements, and stresses.

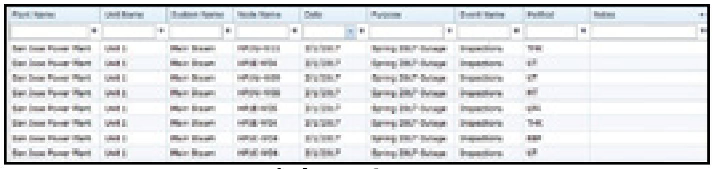


Figure 3. List of Planned Inspection Activities

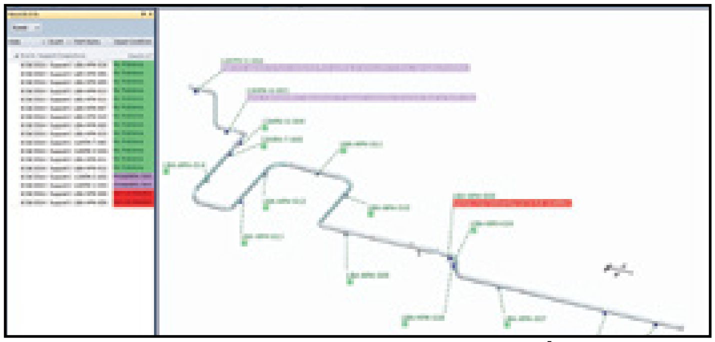
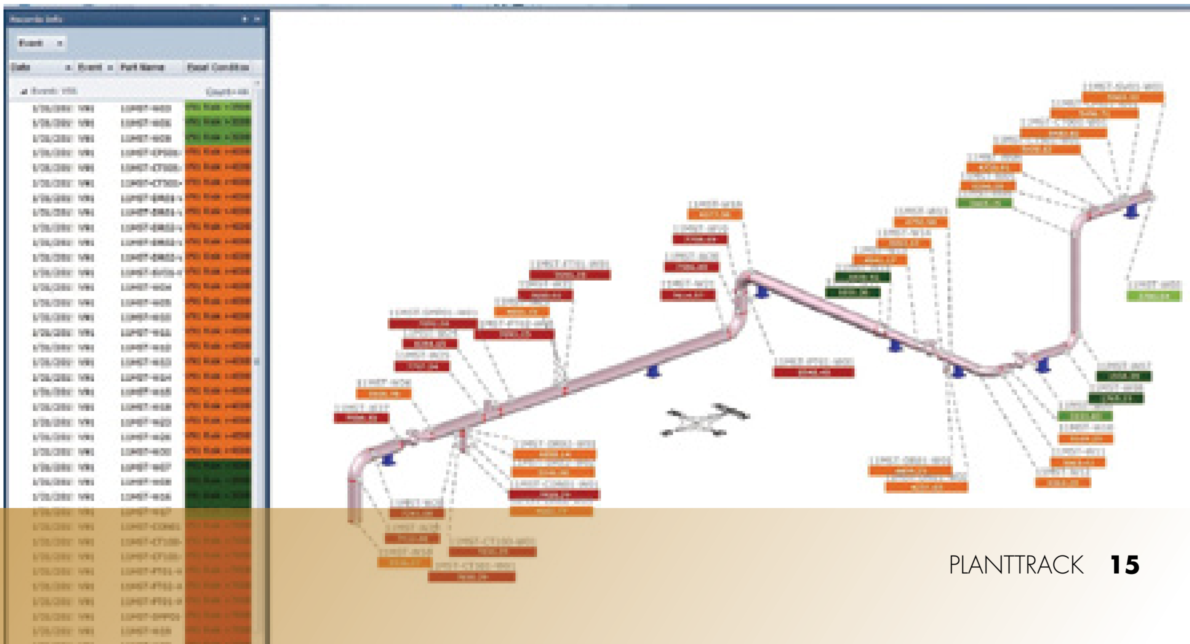


Figure 5. Pipe Support Inspection Findings

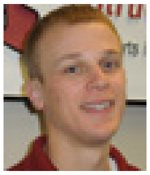
While the inspections are useful in identifying problem areas, in most cases additional analytical and metallurgical studies are needed to refine the inspection findings. These could include stress analyses, remaining useful life calculations, and further metallographic examinations. To help power plants make decisions regarding their maintenance planning, Structural Integrity has developed Vindex and Vindex_91 programs to rank risks associated with piping system welds, so the maintenance budget can be allocated efficiently. These programs take into account stress analyses, inspection results, consequences of a possible failure, piping and weld materials and configurations. Figure 6 displays the ranking of Vindex risk values for a sample system.

Figure 6. Graphical representation of Risk Values

PlantTrack can color code locations based on 'Risk', whether that risk comes from SI's Vindex results, an Risk Based Inspection (RBI) study, or other methods.



APPLYING PIPING ANALYSIS METHODS TO CATHODIC PROTECTION SYSTEMS



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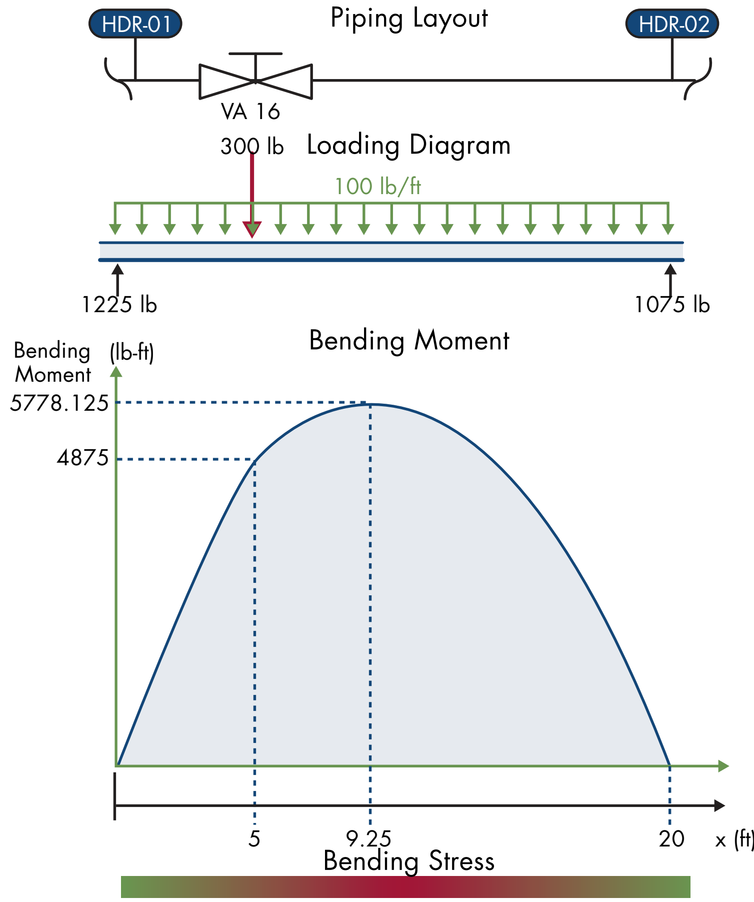
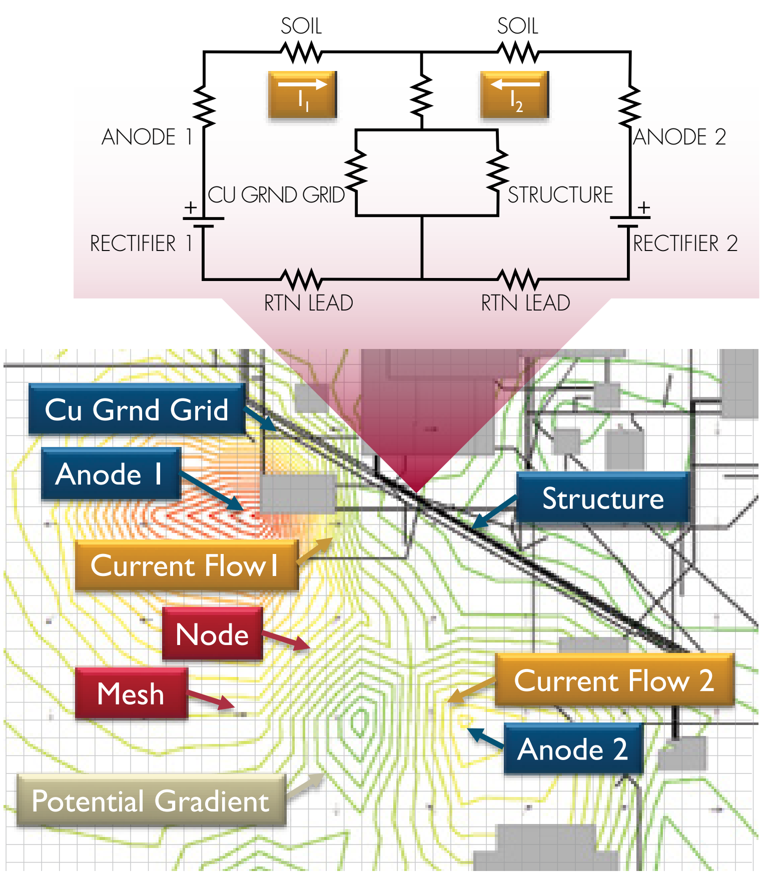
The design of piping components is traditionally accomplished through the application of stress criteria, such as those presented in ASME Section III. Understanding the distribution of stress in a single span of piping, as shown to the right, can easily be achieved using basic formulas and hand calculations by designers. Unfortunately, the complex configuration of piping networks to support operation of nuclear power plants quickly makes performing these hand calculations infeasible.

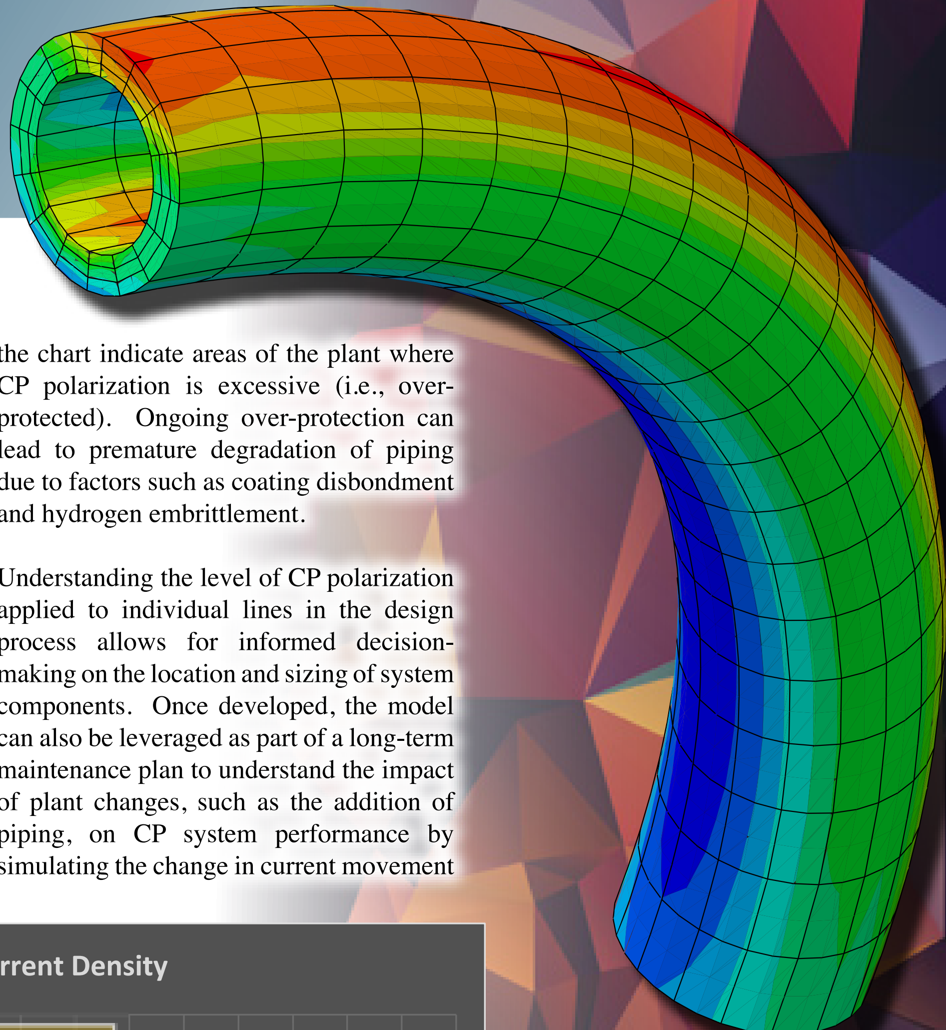


For years, designers have used finite element (FE) methods to overcome the computational challenges associated with these complex systems. FE methods divide complex piping networks into a series of non-overlapping elements with varying degrees of freedom. The response of the individual elements is then determined using computer simulations that connect all of the individual elements to develop a stress distribution throughout the system. The distribution is then compared to the applicable ASME stress criteria to determine acceptance.



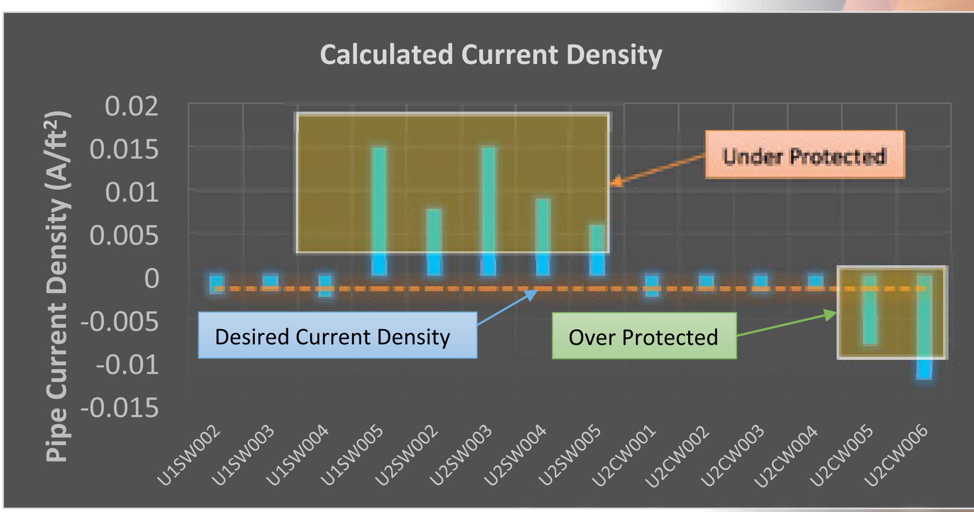
Stresses developed through FE methods are used throughout the design and operation of individual piping systems to ensure they operate in a safe and reliable manner. This includes assessing wall thickness requirements during original design and conducting fitness-for-service evaluations when wall thinning is observed during normal operations.

Much like piping systems, the analytical methods used in cathodic protection (CP) system design are simplistic hand calculations, until the complexities associated with nuclear power plant construction are introduced. These complexities have traditionally been addressed through the application of engineering judgment rather than analytical models. As such, CP system design has commonly been referred to as “more of an art than a science”. This approach often leads to over-designing the system or an iterative installation process to ensure effective CP is provided to all critical assets.

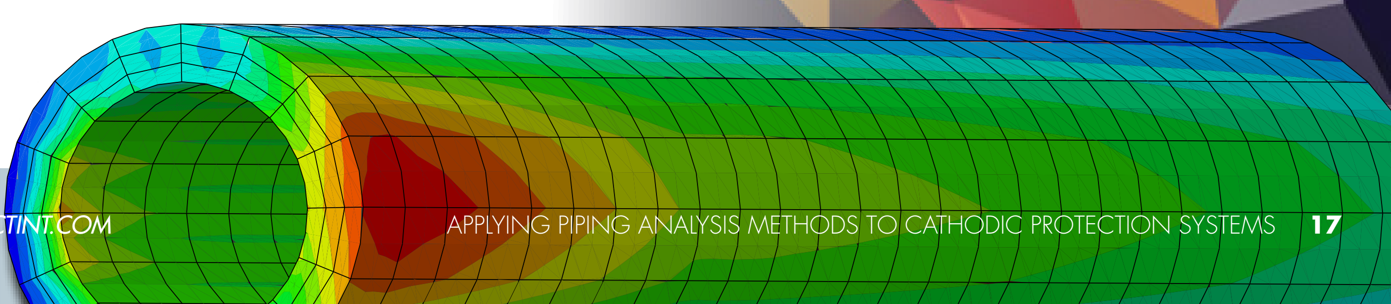


Similar to piping design, FE methods are now available to bridge the gap between hand calculations for CP system design and the complexities associated with a nuclear power plant. These FE methods generate a series of circuits to simulate the flow of current and potential gradients between CP system anode(s) and plant structure(s), as shown to the left. The model then considers coating efficiency and polarization curves to simulate whether CP polarization on individual structures, such as buried piping, is sufficient to mitigate the treat of external corrosion.

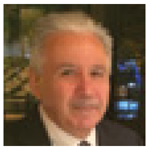
We show example of the benefit of this evaluation method for buried piping is shown in the figure below. The bars highlighted in the upper half of the chart represent individual piping segments with insufficient CP polarization (i.e. under-protected). These segments require additional anodes, rearrangement of proposed ground beds, or increased output from existing ground beds to mitigate the threat of external corrosion. Similarly, The bars highlighted in the lower half of the chart indicate areas of the plant where CP polarization is excessive (i.e., over-protected). Ongoing over-protection can lead to premature degradation of piping due to factors such as coating disbondment and hydrogen embrittlement.



Understanding the level of CP polarization applied to individual lines in the design process allows for informed decision-making on the location and sizing of system components. Once developed, the model can also be leveraged as part of a long-term maintenance plan to understand the impact of plant changes, such as the addition of piping, on CP system performance by simulating the change in current movement and resultant change in polarization. The information gained from the simulation can then be used for informed allocation of funds to improve overall CP system performance.



A COST EFFECTIVE SOLUTION FOR IMPROVING BWR LIQUID RADWASTE WATER PROCESSING FROM FINETECH



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In an effort to reduce crud transport from the feedwater system to the reactor vessel and increase BWR Fuel Reliability while reducing Collective Radiation Exposure, BWRs have upgraded their condensate treatment systems to improve the removal efficiency of particulate iron. BWRs with condensate filter/demineralizers (CF/Ds) have installed filter septa with smaller particle retention ratings while BWRs originally designed with only deep bed condensate polishers have installed full-flow filtration systems upstream of the deep beds. As a result of these changes, many plants have successfully reduced feedwater iron to very low levels, ≤ 0.1 ppb.

CF/Ds and full-flow condensate filters must be periodically cleaned by backwashing. The cleaning process generates a large volume (5,000 -10,000 gallons) of liquid waste that contains highly concentrated particulate iron oxides. This waste stream is transferred from a backwash receiver tank (BWRT) to phase separation tanks, where the iron particles are allowed to settle and the clearer water (called supernatant) is decanted to the liquid radwaste processing system for filtration and demineralization. With improvements made in iron removal using condensate high iron removal efficiency filtration, many plants have experienced difficulties in processing phase separator decants due to carryover of fine iron particles that no longer are free settling. Iron oxide particle sizes typically range from 1 to 100 μm, and particles smaller than about 20 μm settle very slowly. This has resulted in short run times (low processing throughputs) of liquid radwaste filtration equipment, leading to the generation of high volumes of waste filter media that are subject to high disposal costs as low-level radioactive waste. In extreme cases, the inability to process decant solutions in a timely manner can impact condensate treatment system operation, which can ultimately impact reactor power generation.

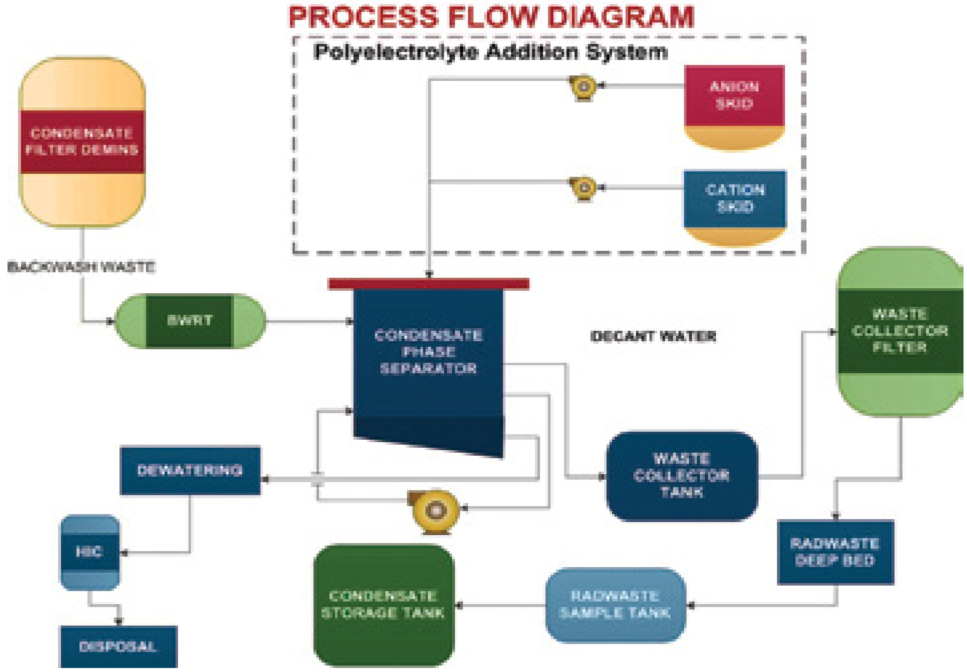

Figure 1. Condensate Filter Backwash Process Flow Diagram

Finetech, a Structural Integrity Associates company, has developed an innovative, cost effective solution that uses polyelectrolytes to enhance the settling of the iron particles in the backwash waste stream. Polyelectrolytes are long chain high molecular weight organic compounds with repeating (monomer) units that have a positive, negative or neutral surface charge. They are added to the backwash water in the phase separator tanks to agglomerate the fine iron particles into larger particles that settle more easily. Polyelectrolytes have an extremely high affinity to adsorb to the particle surfaces, so there is no measureable residual in the water. The keys to success of this process are selection of the optimal polyelectrolyte or polyelectrolyte combination (molecular weight and charge density are key attributes), determination of the optimum dosages, achieving the proper mixing in the phase separator and introducing the polyelectrolyte to uniformly contact all particles. Proper mixing provides the required particle collisions to allow particles to coagulate, agglomerate and densify so that settling is rapid and fine particles are incorporated into the agglomerated particle masses. A typical simplified flow diagram showing polyelectrolyte addition is provided in Figure 1.

On-site laboratory jar testing of representative backwash samples by an experienced Finetech chemist is first performed to determine the types and quantities of polyelectrolytes required (see Figure 2). The test protocol has been developed to simulate the actual plant process. Next, we perform a detailed engineering evaluation to determine the best method of full-scale polyelectrolyte addition to the phase separator tanks, including an evaluation of the tank mixing capabilities. In many applications, a polyelectrolyte addition

Figure 2. Jar Test Results: Left (before) and Right (after) polyelectrolyte addition.

Figure 3. Phase Separator Tank Modification (BWR 4)

skid is specified and a new large diameter jet mixing nozzle is installed in the phase separator tanks (Figure 3) to replace existing mixing eductors that are prone to plugging. Typically, the use of two oppositely charged polyelectrolytes provides the best results. For a 10,000 gallon batch of condensate filter backwash liquid waste, the quantity of each polyelectrolyte required is equivalent to about a teaspoon, for a total raw chemical usage cost of less than $1.00.

Numerous cases can be cited where Finetech's polyelectrolyte treatment has been applied with great success. At a BWR-4, the station increased the volume of water processed through the liquid waste filter by a factor of 33 or more, translating to an equivalent radwaste volume reduction. At a BWR 3, spent radwaste filter media (precoat material) volume generation was reduced by a factor of about 73. Presently, polyelectrolyte addition is performed at 11 BWR sites, and Finetech is working on a conceptual design for a BWR-6. The overall goal of this innovative polyelectrolyte addition approach is to enable today's condensate filter backwash waste to be processed efficiently with a significant reduction in O&M costs and improved reliability of the liquid radwaste processing system.

STRUCTURAL INTEGRITY'S NEW OIL AND GAS BUSINESS UNIT

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Several years after initial passing of the initial pipeline safety regulation, and after a multitude of integrity assessments, replacements, surveys, and mountains of data files analyzed and reviewed, the industry is poised for a new set of rules that will have an even greater impact. A Noticed of Proposed Rulemaking (NPRM) is currently anticipated that will drive a rigorous verification process, the Integrity Verification Process (IVP), which will impact nearly all Hazardous Liquid and Gas Pipeline operators. The new regulation is being coined "TIMP 2.0" or the "Mega-Rule"due to the significant nature of work expected from all those involved in the pipeline industry.

SOME OF THE ANTICIPATED CHANGES INCLUDE:

- Elimination of the grandfather clause for pre-1970 natural gas pipelines
- Identification and new requirements for moderate consequence areas,
- Requirements to replace or de-rate pipe without verifiable records,
- Further and more stringent requirements for Hydrostatic Pressure Testing,
- More stringent assessment requirements and requirements for greater In-Line Inspection,
- Further requirements for identifying threats and mitigating risk,
- Engineering Critical Analysis,
- New modeling with fracture mechanics for failure stress and cyclic fatigue growth

The exact timing of the new regulation remains uncertain, but based on latest sources, the following provides an anticipated timeline for the new regulation:

Rulemaking	DOT Estimated Date to OMB*	DOT Estimated Publication Date
Safety of Gas Transmission Pipeline	April 13, 2015	July 31, 2015
Safety of Hazardous Liquid Pipeline	May 1, 2014 (actual)	June 30, 2015

*OMB: Office of Management and Budget
These times estimates according to DOT, and are subject to significant revision.

Although Structural Integrity has provided services to support the pipeline integrity market for over a decade, SI has formed the Oil & Gas Business Unit in anticipation of these new regulations to increase our growth potential in support of this market the unit will have focus on developing expertise and new capabilities to support of our clients.

VOLUMETRIC ULTRASONIC EXAMINATIONS: ASME CODE COMPLIANT VS. IN-SERVICE EVALUATIONS – Which is Right for You?

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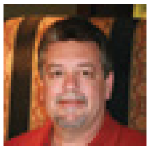

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As a means to promote and regulate welding quality and workmanship, Section V Article 4 of the ASME code provides requirements for performing ultrasonic examinations for weld acceptance. As part of managing aging assets, and without any other guidelines, many times these requirements are referenced for examining welds that have been in service for many years. Additionally, and aside from ASME Section XI, no other code sections actually require or detail examinations during the service life of the component; this includes Section I, Section VIII and B31.1. It's important to understand the difference between ASME code compliant UT exams and the Structural Integrity examination approach as it relates to component serviceability.

CODE COMPLIANT EXAMINATION

As it matters to the fabrication of pressure vessels, the ASME code is the governing body and the applicable ASME code section is dependent on the particular component to be fabricated. For example, B31.1 of the code addresses the fabrication, examination and acceptance standards for power piping and Table 136.4 of B31.1 details what components must be examined and how they are to be examined. Typically these examinations are required on welds joining two components where either a surface examination or a volumetric examination is performed. The acceptance criteria are based on workmanship and the examinations are conducted with the intention of providing assurance that the component will be serviceable.

Purpose

Until recently, the required method for performing a volumetric examination was radiography; however, recent editions of the code now only stipulate that a volumetric examination shall be conducted which can be either radiography or ultrasonic examination. Regardless of which method is chosen, ASME Section V is the governing code section detailing how the examinations are to be conducted. The techniques and methods established in Section V are designed to address the fabrication of the components. Specifically, the acceptance criteria found in Section I, VIII and B31.1 address new construction / fabrication related flaws such as incomplete penetration, slag, porosity, etc.

Examination

Article 4 of Section V contains the specific calibration requirements for the ultrasonic system to perform a code required examination. Additionally, the calibration blocks to be used are specified to contain either side drilled holes and/or notches, of specific sizes based on component thickness.

Once the calibration is established the code gives details on how the weld is to be examined. For welds, scans must be performed to detect indications parallel to the weld and perpendicular to the weld (e.g., transverse cracking). To achieve this, the weld must be inspected from four directions which occasionally require that the component surfaces be contoured to support the probe orientations. Any indications found are evaluated based on permissible lengths and the amplitude of the UT signal as compared to the calibration holes or notches.

IN-SERVICE EVALUATIONS

As mentioned previously, the codes do not address performing any NDE examinations after the component is placed in service. Recent editions of B31.1 now require that a program for monitoring the piping system during service is in place, but it is not specific on monitoring practices. As a result, many equipment owners defer to and rely on criteria established in the code rather than implementing examination practices specifically for the detection of service-induced damage.

Purpose

In general, there are several failure modes that can occur to welds and components during their service life. The type of failure will primarily depend on the service pattern(s) that the component is exposed to during its life. For instance, high temperature components are subject to creep damage and/or creep fatigue while components operating below the creep temperature range may be subject to thermal fatigue damage.

With the lack of any guidance and the failures that began to appear in the early 1980's, the need for some guidelines and applied practices for detecting damage mechanisms became apparent. Through

work with EPRI and the MPC (Materials Property Council), we developed best practice techniques for the detection of service damage specific to component types and failure modes.

While the basis of our UT procedures is derived from ASME Section V, we deviate substantially from the recommended calibration practices. By utilizing instrument focusing capabilities and creating calibration standards to increase sensitivity and resolution, our service procedures greatly increase the likelihood of detecting damage in its earliest stages. In addition to higher calibration sensitivities, we have incorporated the latest technologies available for time of flight diffraction (TOFD) and linear phased array (LPA) ultrasonic techniques to provide even greater accuracy and confidence in our ability to detect and characterize damage.

Examination

It is the intent of Structural Integrity's examination process to provide a full interrogation of the weld volume when looking for service-related damage. As part of the inspection protocol, the volumetric examinations are complemented with wet fluorescent magnetic particle (WFMT) surface inspection and metallographic replication. Generally speaking, service damage associated with girth welds tends to initiate in the primary (circumferential) weld axis either on the ID/OD surfaces or subsurface and extends radially around the weld volume such that the primary scan axis is perpendicular to the weld. Conversely, longitudinally welded seams tend to show damage in the same volumetric planes but are oriented parallel to the pipe axis and extend axially down the component length. At the sensitivities used for these examinations, it is commonplace to see small original manufacturing flaws which may or may not have been reported in the original weld acceptance examination- most likely radiography. These fabrication flaws are usually not significant enough to be a concern to continued operation and will not propagate to failure under normal service conditions.

There are some fabrication related flaws, such as lack of fusion or cracking from the welding process, which could propagate to failure. These are routinely detected and documented as part of our in-service inspection practice. Once documented, the inspection data can then be further analyzed to enable a decision on whether to repair the flaw or re-inspect the weld at a later date.

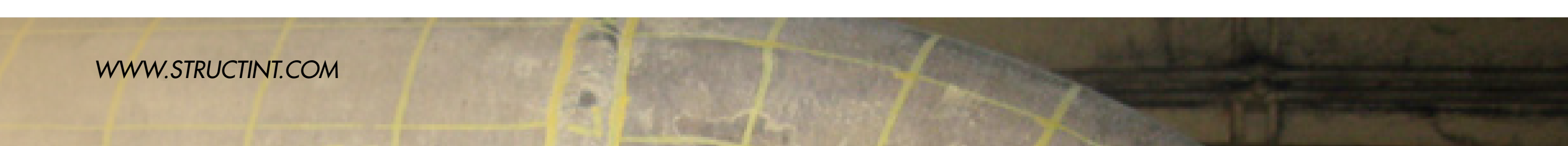
Recently, there have been a number of transverse cracks (perpendicular to the weld axis) found in welds. Based on our experiences, these cracks are fabrication related (with a greater propensity to be found in submerged arc type welds) and do not normally propagate to failure. In many cases, these indications can be found at the OD surface and properly conducted surface examinations will detect them. At which point, all appropriate measures would be taken to ultrasonically evaluate the flaw and determine depth values, if significant.

At their greatest extent, transverse cracks pose a potential leak risk so they should be repaired if found; however, they do not pose a threat to the serviceability of the weld itself or create conditions associated with catastrophic failures. Due to the fact that most weld caps are left in the as-welded condition, which is permissible by code, it is very difficult to perform a meaningful examination looking for transverse cracks without conditioning the weld cap (flat-topping) and modifying the probe/wedge assembly to secure contact with the part. As previously mentioned, the ASME and B31.1 codes require this type of examination as part of the weld acceptance practices for new construction. Since transverse cracks are considered to be fabrication related, and significant depths occur infrequently, it is not part of our normal UT serviceability examination practice to look for this form of cracking.

CONCLUSION

While it is good practice to use the code requirements as a foundation for developing procedures, it has been proven that the calibration requirements of the code are not sufficient to detect service-related damage at the earliest stages possible. Structural Integrity, on the other hand, has compiled numerous examples and experiences confirming the effectiveness of its service inspection strategies through decades of continued implementation and development. Put simply, as it relates to the continued operation of these aging components and the safety of employees working near them, any examination being conducted to detect service-related damage should be performed utilizing the best techniques and practices available.

Therefore, when seeking inspection support to perform service evaluations, requiring that the examinations and acceptance criteria be in accordance with the applicable code section is not recommended. Alternatively, consider requesting that the examinations be conducted in accordance with EPRI standards and/or MPC recommendations. Coupling these expectations with the utilization of qualified technicians will provide the best possible inspection scenario for evaluating your high energy piping.



APPLYING SHORT-RANGE GUIDED WAVE TESTING TO INSPECT NUCLEAR CONTAINMENT STRUCTURES

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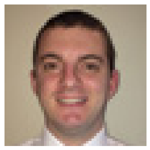

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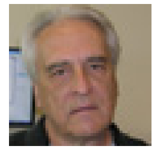

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Short-Range Guided Wave Testing (SR-GWT) is a relatively new NDE technique that is complementary to traditional GWT in that it excels in areas where traditional GWT has limitations. The technology uses high(er) frequency guided waves to provide high-sensitivity and high-resolution assessments of inaccessible areas. Structural Integrity has successfully applied the SR-GWT electromagnetic acoustic transducers (EMAT) technique for many pipe and plate applications and the technology has demonstrated the ability to detect corrosion and stress corrosion cracking (SCC) to a high degree of sensitivity in inaccessible areas such as in pipe penetrations and under pipe supports. The SR-GWT technique we employed uses EMATs to generate guided waves and the combined SR-GWT EMAT technique has the following benefits:

- Optimal for testing short lengths of pipe with relatively high sensitivity
  - Shorter wavelength provides better resolution
  - Up to 5ft of coverage on either side of the sensors
- Works in the dead-zone and near-field of traditional GWT tools
  - Typically ranges from 3ft - 5ft
  - Minimizes indications from contact points
- Minimizes indication from changes in stiffness
  - Useful for wall penetrations and ground penetrations and at supports
- Capable of detecting corrosion and SCC
- EMATs are electromagnetically coupled
  - Non-contact and do not require liquid coupling
  - Are conducive to encoded scanning
  - Work on any conductive metal
  - Can operate through coatings (< 3mm) and on rough/corroded surfaces

In the conceptual illustration in Figure 1, The SR-GWT EMAT technique is being used to generate guided waves in a steel containment structure, which subsequently propagate along the structure and into the inaccessible area beneath the concrete floor. When disrupted by a patch of corrosion in the steel, the guided wave reflects back toward the EMATs, where it is received. The total time that it takes the wave to travel to the corroded region, reflect, and travel back is used to calculate the precise location of the flaw. To screen large areas, the EMATs would be encoded along the axis perpendicular to the direction of wave propagation and rolled along the surface of the structure.

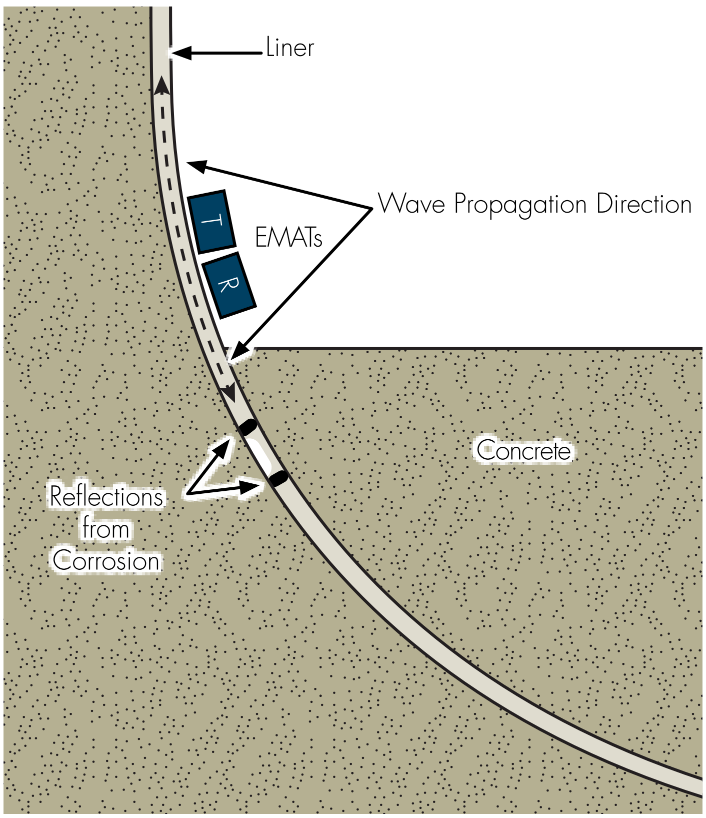

Figure 1: Conceptual illustration of EMAT guided wave inspection concept for containment vessels and liners.

Figure 2 shows a schematic of a containment liner mock-up that was constructed for preliminary testing of the SR-GWT EMAT technique. The details of the mock-up were as follows:

- Constructed of carbon steel with 1.25 inch wall thickness
- Defects are 1 inch diameter flat-bottom holes
- Concrete poured over 3ft by 4ft area covering defects
- Data collected before and after pouring of concrete

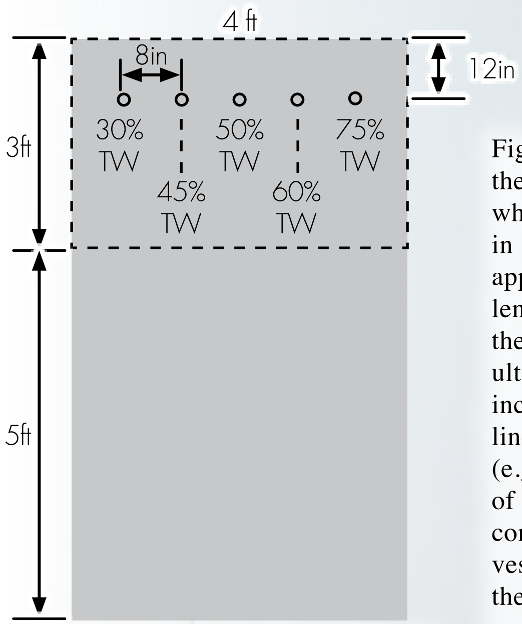

Figure 2: Illustration of containment liner mock-up used for testing SR-GWT EMAT technique.

Figure 3 shows an encoded scan from the containment structure mock-up in which detection of all fabricated flaws in the mock-up from a distance of approximately 3ft away. The diagnostic length or area that can be assessed with the SR-GWT EMAT approach, will ultimately depend on several factors, including the thickness of the vessel or liner, attachments to the vessel or liner (e.g., nelson studs), the general condition of the vessel or liner, and the bonding condition of the concrete to the steel vessel or liner. The EMAT approach for the containment structure inspection application will have a 5ft acquisition limitation in either direction, for a total of 10ft of potential inspection length, centered at the sensor location.

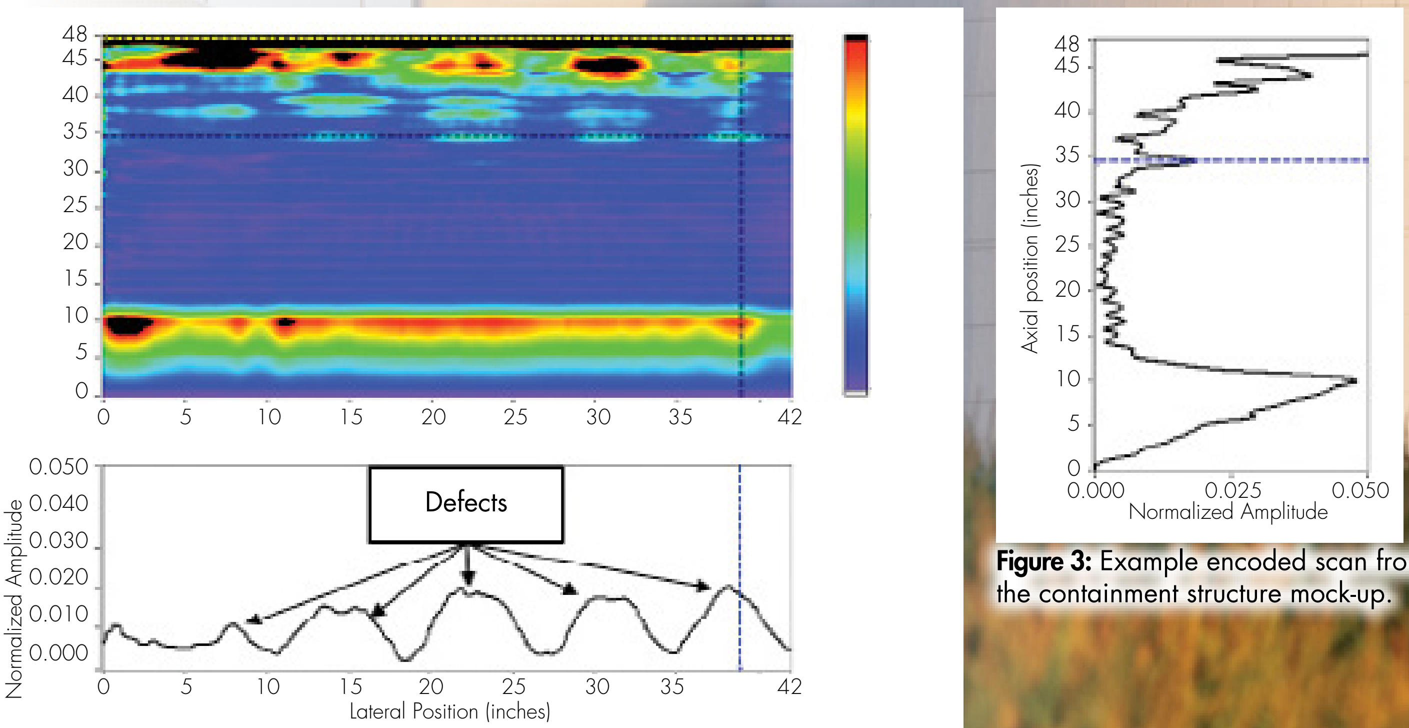

Figure 3: Example encoded scan from the containment structure mock-up.

MISSILE ANALYSIS METHODOLOGY FOR SHRUNK-ON-DISK TURBINE ROTORS

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Structural Integrity Associates (SI) has developed a missile analysis methodology that applies to built-up turbine rotors with shrunk-on disks in both nuclear and fossil applications. Turbine missile analysis of nuclear units is necessitated by NRC requirements. Turbine missile analysis of fossil units is usually performed to assess risk associated with catastrophic failure of suspect rotors relating to material issues, existing flaws, or extraordinary operational circumstances.

In a previous News & Views article published in Spring 2014 [1], we described the analytical and material evaluation protocols to assess the probability of LP turbine disk failures. This article provides an overview of analytical methods we developed to estimate probabilities of missile generation and of missile ejection from the turbine casing given that a turbine disk has failed. Our missile analysis methodology builds on previous work done by EPRI [2] related to turbine missile probabilities.

OVERVIEW OF MISSILE PROBABILITY EVALUATIONS

An assessment of the technical and regulatory issues for the calculation of turbine missile probabilities is addressed in a study completed by EPRI in 2000 [2]. Although that study focused on turbines operating at nuclear facilities, it offers significant insight into the fundamental methodologies that can be generally applied to determine the potential and effects of disk failures. For risk assessment of turbine generator missiles, the EPRI report considers the following three components of analysis:

1. Probability of a missile penetrating (i.e., being ejected from) the turbine casing (P_1);
2. Conditional probability of a missile striking a safety-related system given casing penetration (P_2); and
3. Conditional probability that the safety-related system malfunctions given it is struck (P_3).

The calculated risk, in terms of probability of safety-related system failure (P_4), is determined as the product of the three component probabilities, i.e.:

$$P_4 = P_1 \times P_2 \times P_3 \qquad (1)$$

The present article focuses on methodology for estimating the probability of a missile penetrating the turbine casing, P_1. Reference [2] estimates upper limits of this missile ejection probability in the range of 10^{-5} to 10^{-4} per year of turbine operation. The calculation of probability P_1 is governed by the following equation:

$$P_1 = P_f \times P_e \qquad (2)$$

where; P_f = Probability of disk failure (rupture event); and
P_e = Conditional probability of disk fragment ejection (penetrating the turbine casing), given a disk rupture event.

The calculation of disk failure probability, P_f, is addressed in our previous News & Views article [1]. It is important to note that, because this probability is time dependent (i.e., owing to age-related damage mechanisms, the probability of a disk failure event increases with time), in general, the probability P_1 and the dependent probabilistic result of Eq. (1) will be time dependent, although a time-averaged result can be developed.

The probability of a disk fragment exiting the turbine casing is related to the size and orientation of disk fragments, their respective velocities at impact on the casing, and the relative strength of the casing design and penetration resistance of other interfering structures. As continuation of the preceding calculation, we propose the following equation be used to calculate the conditional probability of disk fragment ejection, P_e:

$$P_e = \sum_{i=2}^{n} S_i \cdot E_i \qquad (3)$$

where; S_i = Probability of a disk-fracture scenario producing disk fragments of size (M/i)
M = Total mass of disk
n = number of disk fragments (minimum of two) considered in a given scenario
E_i = Conditional probability that a disk fragment, given fragment size of scenario S_i, ejects the turbine casing (i.e., size-condition missile eject probability)

The distribution and associated likelihoods of disk fragment sizes (e.g., M/2, M/3, etc.), which define the S_i values, can be based on empirical observations of disk fragments from previous failures, or can be predicted from a probabilistic failure-physics analysis (e.g., probabilistic fracture mechanics, considering various representative flaw configurations).

The summation, Eq. (3), over all possible (i.e., over the meaningful scenario variations of) fragment sizes, given a disk failure event, yields the conditional probability that a disk fragment penetrates the turbine casing, otherwise termed the "conditional missile eject" probability (P_e). Whereas many different scenarios as to combinations of fragment sizes can be considered, we recommend the following four fragment sizes as generally sufficient for the analysis of P_e: M/2, M/3, M/4 and M/5. Additionally, we recommend that the disk stage with the greatest potential for missile ejection be evaluated. In the absence of observational data to suggest otherwise, this critical disk stage is likely to be the L-0 stage having large disk mass, large blades and lack of diaphragm webs on each side (admission and discharge) of the disk. The disk failure probabilities, such as determined from the analysis described in Reference [1], are required inputs to the determination of P_1, and it should be ensured that the characteristics of the applicable governing failure event are consistent also with the critical disk stage being analyzed.

ILLUSTRATION OF ANALYSIS OF SIZE-CONDITIONED MISSILE EJECT PROBABILITIES, E_i

Introduction to general approach

Our general approach for determining values E_i is based on probabilistic analysis of the physics of energy conversion. Prior to disk failure, a rotor disk has both kinetic energy due to its rotary motion and potential energy due to its position with respect to earth's gravitational field. For high initial rotational velocity, it can be assumed that changes in potential energy occurring within the disk casing (i.e., prior to a missile ejection) are comparatively small. Thus, during the process of rupture (i.e., "disk burst") of a rotor disk into fragments of size (M/i), the total energy (in the form of kinetic energy [KE]) of the disk transduces from purely rotational to both rotational and translational:

$$KE = KE_{ROTATIONAL} + KE_{TRANSLATIONAL} \qquad (4a)$$

$$\mathrm{KE} = \frac{I\omega^2}{2} + \frac{\mathrm{mv}^2}{2} \qquad (4b)$$

where I denotes rotary mass moment of inertia, ω is angular velocity, v is translational velocity, and m denotes the mass of the disk element.

Once a fragment is propelled toward targets (which are approximately axisymmetric about the rotor axis) with given translational and rotational velocities, resistance to turbine casing penetration is offered through the energy required to perforate all targets (i.e., the "perforation energy"). Perforation energy (a random variable) depends on the orientation (e.g., sharp-edge or blunt-edge impact) of the colliding fragment and the ratio of rotational to translational energy upon impact. Various configurations of the impactor and targets can be analyzed for determination of values E_i. For purposes of illustration here, the case of fragment mass size (M/4), having translational velocity only and striking as a blunt edge impact, is used as basis for obtaining an estimate of E_4 using a simple probabilistic approach combined with the finite-element analysis (FEA) software LS-DYNA [3] for solution failure physics. This configuration is similar to disk burst scenarios that have been realized in model test results (EPRI, [4]) and have been considered in various studies.

Geometry of impact configuration for the illustrative case

The representative geometry of the impact configuration we consider for illustrative analysis of conditional probability E_4 is shown in the perspective view of Figure 1. The corresponding finite-element mesh, for input to LS-DYNA, is shown in Figure 2.

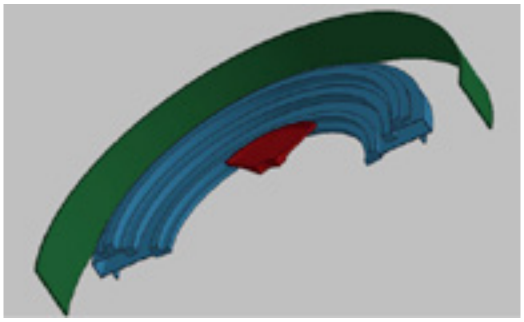

Figure 1. Perspective view of illustrative impact configuration, showing impactor and the various stationary targets

Continued on next page

MISSILE ANALYSIS METHODOLOGY FOR BUILT-UP TURBINE ROTORS

CONTINUED

Figure 2. Finite element mesh showing mesh resolution and geometric detail of the stationary targets.

Material model and boundary conditions for the illustrative case

Representative material properties for the impactor and targets, typical for rotor shrunk-on disks and casing elements, are used. In addition, we applied a representative strain-rate model provided in LS-DYNA.

Sensitivity to various boundary conditions of the targets was studied, and found to have a non-primary, yet non-negligible impact on results. The case of fixed constraint at one end and z-only constraint at the other support (and no constraints out of plane) was taken as a best-estimate (median) configuration.

Simplified probabilistic model

A simple analytical approach for derived distribution development – that is, determination of probability distribution of resulting energy capacity (fragility) from the probability distribution of basic input random variables (material properties, geometries, etc.) – was employed for estimation of the conditional probability E_4.

The approach assumes a double lognormal form of probability distribution for input random variables, modeled after the EPRI methodology for development of seismic fragilities (capacity distributions) [5], and has the following characteristics:

- Total safety margin (with respect to penetration energy capacity) is a product of various margin factors.
- Capacity is approximated by the combined plastic strain energy capability of the targets and impactor in resisting ejection (for the given impact and impactor configuration)

LS-DYNA analyses for bounding cases

In order to estimate the probability distribution of energy capacity, two cases of LS-DYNA analysis were developed to bracket a best-estimate model:

Case 1: Inner target and casing are assigned the typical reference failure strain of 0.22, with conservative strain-rate modification to failure strain using a standard form of the Cowper-Symonds model. No additional crediting of modification to the ultimate stress limits is made;

Case 2: Same case as (1), except the reference failure strain is increased to 0.80.

Results for **Case 1**: An illustration of the results from LS-DYNA analysis for Case 1 is provided in Figure 3. For this case, both the inner target and outer casing perforate (as seen in Figure 2), and the disk fragment ejects with significant residual kinetic energy. Consistent with time-dependent energy results from LS-DYNA (including capability to erode impactor and contain energy of eroded product that is total reduced KE of impactor), the estimated total inner target and outer casing energy resistance for this bounding case is 5.7×10^8 in-lb.

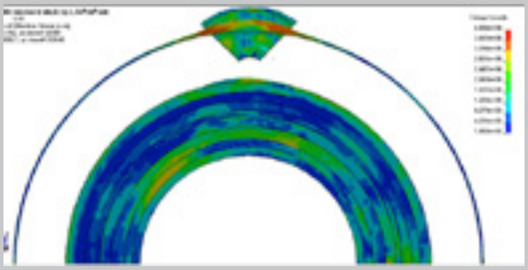

Figure 3. Ejection of disk fragment as realized from LS-DYNA analysis for bounding case 1.

Results for **Case 2**: Illustration of the results from LS-DYNA analysis for Case 2 is provided in Figure 4. For this case, it is seen that the inner target is clearly perforated but the outer casing does not perforate, and hence, contains the impactor. Based on sensitivity analyses, whereas no ejection is observed in this case, it was determined that this case closely approached a case of incipient perforation and consequential ejection. From this bounding case, an estimate of the inner target and outer casing energy resistance is 9.5×10^8 in-lb.

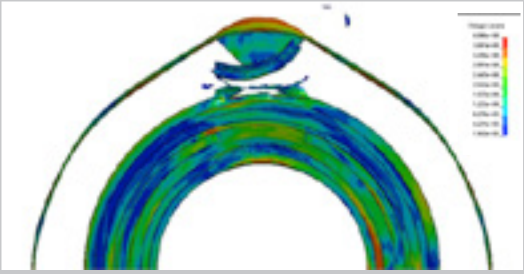

Figure 4. Containment of disk fragment as realized from LS-DYNA analysis for bounding case 2.

ESTIMATION OF CONDITIONAL PROBABILITY, E_4, FOR THIS ILLUSTRATIVE CASE

As noted, the two bounding cases were selected not to be individually representative of a most-suitable or best-estimate assessment, but rather, as reasonably bounding of the overall plastic strain energy (i.e., total area under stress-strain curve at failure). From these cases, plastic strain energy from the total area under the stress-strain curve at ultimate strength (versus a specific shape of the curve) was taken as first-order important.

Based on judgment and simplicity of this approximate analysis, Case 1 was taken as a minus one-sigma (i.e., best estimate minus one logarithmic standard deviation) $-1.0\sigma_{Ln}$ conservative reference (i.e., ultimate stress is not fully credited; and conservative failure strain modification is applied), whereas Case 2 is taken as a $+1.25\sigma_{Ln}$ (optimistic) reference (i.e., ultimate stress is not fully credited, but a very high degree of ultimate strain modification is allowed/credited). Based on these reference points, together with the double lognormal distribution assumption, the best-estimate of the total energy resistance of the targets is determined as 7.2×10^8 in-lb.

Applying this best-estimate value with the probability distribution of the various margin factors (for the primary input random variables), the probability distribution of energy capacity (i.e., size-conditioned missile ejection fragility curve with input energy as capacity/fragility parameter) is determined as shown in Figure 5.

From this fragility curve, the value of E4 for this illustrative case can be described and estimated according to the following summary:

- Initial (pre-burst) energy of shrunk-on disk transduces to translational velocity of an impactor consisting of a ¼-disk fragment
- A median value of 70% of the energy of the ¼-disc fragment, compared to its initially rotating state at 1,800 rpm, corresponds to a translational velocity of 7,000 in/s (e.g., a portion of the 30% energy reduction can be attributed implicitly to blade crumpling)
- $KE = 0.5 * m * v^2 = 8 \times 10^8$ in-lb
- The mean fragment-size-conditional ejection probability, E_4, can be read from the graph of Figure 5, as $E_4=0.33$.
- The 90% confidence range on this size-conditional conditional eject probability for this illustrative case is 0.2% (about 1 in 550) to 92.5% (i.e., nearly 1 in 1 [100 in 108]), as can be read from Figure 5.

ESTIMATION OF TIME-DEPENDENT TURBINE CASING EJECTION PROBABILITY

As previously discussed, through use of Equations (2) and (3), one can determine, respectively, the conditional probability of turbine missile ejection (given a disk rupture event), and the unconditional probability of turbine missile ejection. For illustrative purposes of simplicity only, we assume here that the E_4 case can be taken as representative (i.e., an average case), such that the value of P_e [according to Eq. (3)] can correspondingly be taken as equivalent to E_4.

As already noted, in a Spring 2014 News & View article [1], we described the process for developing time-dependent unconditional probabilities of a disk rupture event (i.e., P_f values). Applying such

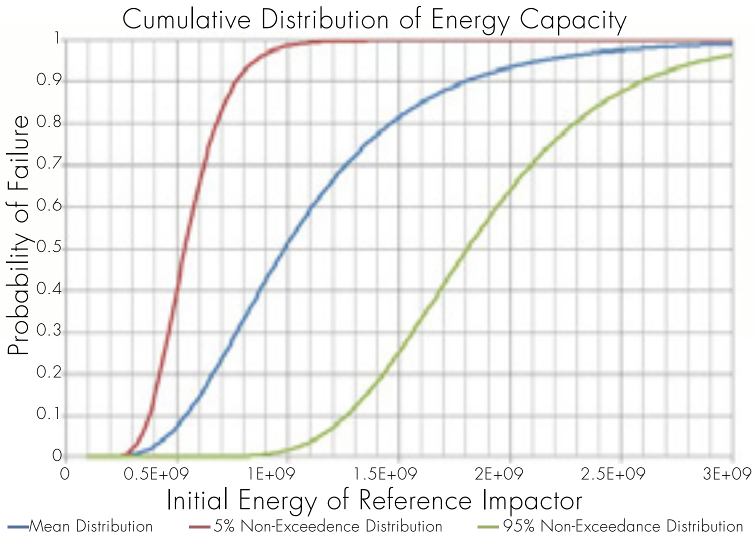

Figure 5. Resulting estimated probability distribution of energy capacity (ejection fragility curve) for the illustrative case.

result, together with the estimate of P_e as just described, a time-dependent result for the unconditional turbine missile ejection probability, P_1, can be obtained [according to Eq. (2)], with a representative result being shown in Figure 6.

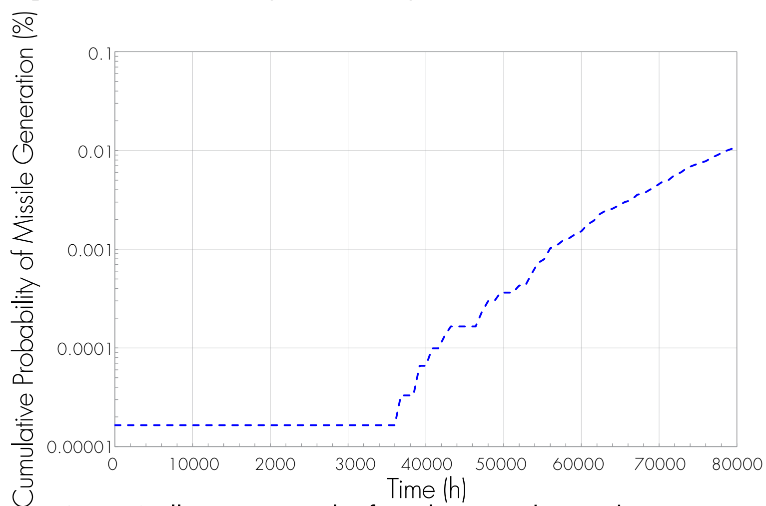

Figure 6. Illustrative result of analysis producing the time-dependent turbine missile generation probability, P_1.

SUMMARY

As plants proceed with plans for continued long-term operation, the importance of estimating the potential and effects of turbine rotor failure becomes increasingly critical to cost-effective operation and development of programs for optimum and safe turbine maintenance. SI is an industry leader in this area and is performing a number of related projects to help clients save money and keep their plants safely operating.

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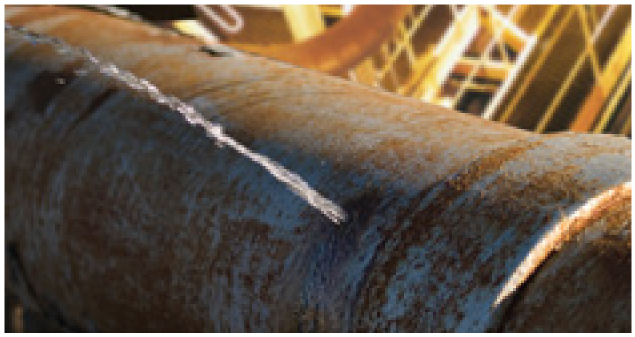
CODE CASE N-513 EVALUATIONS MADE EASY



By: ERIC HOUSTON
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The new version of Structural Integrity Pipe Evaluation (SIPE) software is now available. SIPE 3.1 performs Code Case N-513-3 evaluations from any web enabled device so you can quickly evaluate thinned or leaking pipe to determine if it meets the ASME and NRC requirements for structural stability. If so, repair or replacement may be deferred until the next scheduled refueling outage provided other N 513-3 requirements are met related to subsequent examination and extent of condition.

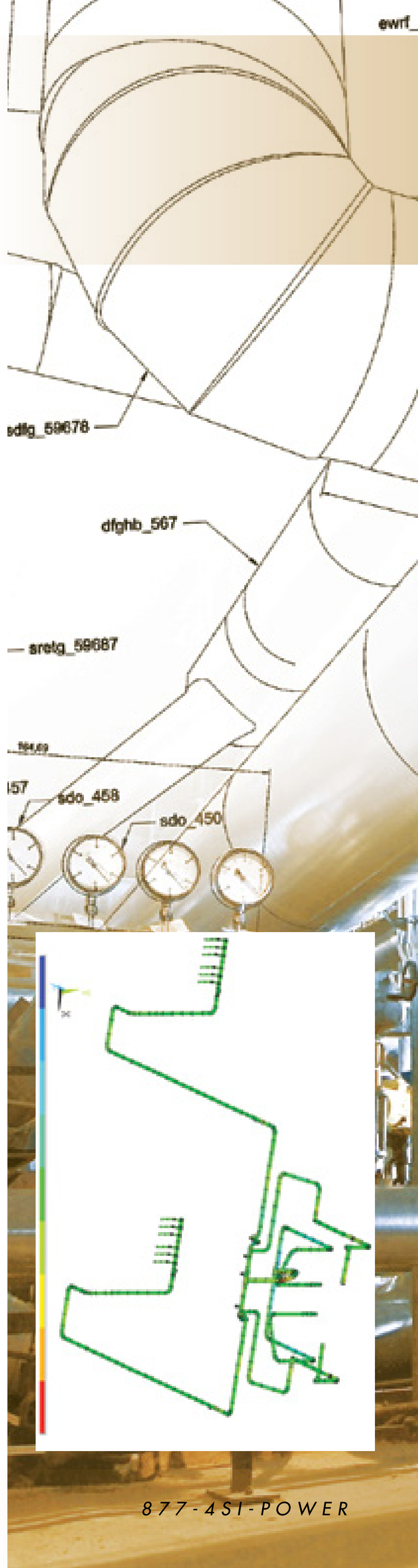
ASME Code Case N-513 provides evaluation rules and criteria for temporary acceptance of flaws, including through-wall flaws, in moderate energy Class 2 and 3 systems. It is one of the most widely used Code Cases in the Nuclear Industry. SIPE 3.1 implements the structural evaluation of Code Case N 513-3 and can be used to support continued operation without repair or replacement.

ADVANTAGES OF SIPE 3.1:

- SIPE 3.1 is developed and maintained under Structural Integrity's Nuclear Quality Assurance program, so independent review of the results is not required
- Web based software – all you need is an internet browser on any computer or smart device, no machine specific QA required
- Simple to use, dynamic fields that update based on the type of evaluation required
- Input and output files are downloadable in plain text format
- SIPE 3.1 is accessed on a secured website (https) and no plant information is saved or stored on any server
- Access via annual subscription
  - Ensures that your evaluation is current with the most up-to-date Code Case N-513 revision
  - Software improvements and fixes are implemented immediately with user notification – no need to update software on every local machine, ensures consistent use of most current software for all users

Familiarity with Code Case N-513-3 and Section XI, Appendix C flaw evaluation methods are required for the use of SIPE 3.1. We have developed a flaw evaluation course and our available to provide this training on-site or at our facilities. For more information on training, see the article on page 9.

For more details, or for access to a free trial of SIPE 3.1, email us at SIPE@structint.com



USING PIPING STRESS ANALYSIS TO SUPPORT INSPECTION PLANNING PRIORITIZATION

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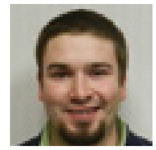

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In recent years, combined cycle and other plants have had high-energy piping systems manufactured from Grade 91 (9 Cr–1 Mo–V) or other Creep Strength Enhanced Ferritic (CSEF) material. The Code-allowable values for these materials allow OEMs to design to temperatures typically in excess of 1050°F, with substantial weight savings. However, industry experience has identified a number of unique issues and complexities that are not present with conventional low-alloy systems:

- CSEF steels are particularly sensitive to heat treatment during the fabrication and erection processes of the piping systems. If done improperly, the material creep strength (and subsequent life) may be drastically reduced.
- HEP systems of combined cycle units– especially those with multiple HRSGs– may have hundreds more girth welds than conventional systems.
- Recent research has shown that initiation of subsurface damage in CSEF girth welds that is detectable with advanced techniques, such as phased array ultrasonics, occurs later in life than low-alloy steel.

High-energy piping (HEP) systems, especially those operating at elevated temperatures that make them susceptible to creep damage (Main Steam and Hot Reheat), are a significant risk for power plants. Under normal operating conditions, these systems accrue creep damage over time, and components have finite lives before failure will occur. The allowable stress values for these piping systems account for creep, but this does not imply that creep damage cannot occur at allowable stress levels and, moreover, does not directly quantify total service life for piping components. Structural Integrity advocates a risk-based prioritization approach that accounts for known industry issues, design limitations, material knowledge, and applied stress.

High energy piping systems at coal- or oil-fired conventional plants are typically constructed from Grade 22 (2¼ Cr–1 Mo) or Grade 11 (1¼ Cr–½ Mo–Si) material and designed to operate between 1000°F and 1050°F. Accurately accounting for stresses that can limit the lifetime of seam-welded components before high consequence rupture is vitally important. Creep damage also manifests itself at girth welds and branch connection welds, primarily due to axial stress resulting from bending caused by thermal expansion loading. While these systems typically have only 25 to 50 girth welds, it is not reasonable to inspect each weld regularly due to outage timing and budgetary constraints. Accurately calculating and understanding the stress that drives failure is a key component of prioritizing welds for inspection.

Due to the issues noted above, detailed stress analysis is vital to managing CSEF HEP systems. These stress results, in conjunction with known industry issues and advanced knowledge of material concerns, can be used to give piping system components a relative ranking to prioritize for inspection.

In addition to prioritization, stress results can be used to perform life calculations that help quantify the urgency of inspecting the highest ranked components. With that in mind, not all stress analyses are created equal. The accuracy of the prioritization and life calculations relies heavily upon accurate stress calculation, which must account for redistribution of stress throughout the system due to creep relaxation over time. With exposure to high temperature, higher stresses will tend to decrease and lower stresses will tend to increase to a steady state level over time. Without accounting for this stress redistribution, life calculations will not accurately reflect the actual life of a given component.

While stress analysis of piping systems in their as-designed conditions is typically used for prioritization and lifing, stress analysis is also recommended for systems that are found to have significant support deficiencies. Issues such as bottomed or locked spring hangers, interference between piping and structural steel or frozen snubbers may limit or constrain thermal expansion, causing large bending stress increases in the piping near the deficiency. Stress analysis can identify these locations and quantify the increase in stress to provide additional assistance in prioritizing locations for inspection.

Without a comprehensive technically-based program, high energy piping systems' life cycles cannot be properly managed. Understanding industry experience, common design issues, material concerns, and the stress that leads to failure is the best way to proactively approach these systems and minimize risk of component failure.

Featured Damage Mechanism - Short-Term Overheating (STO) in Steam-Cooled Boiler Tubes

By: WENDY WEISS
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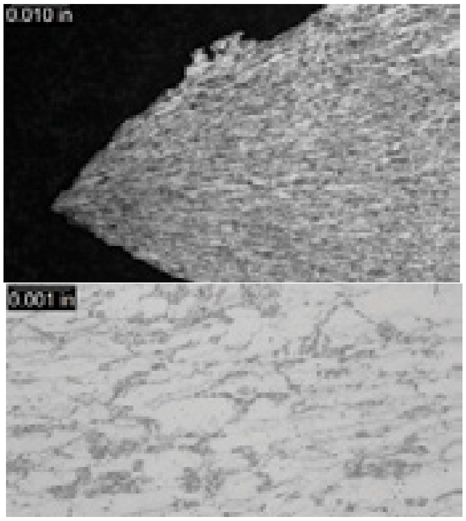
Failure of a superheater or reheater tube due to short-term overheating occurs when the flow of steam that cools the tube is partially or completely interrupted, usually due to some type of blockage in the circuit.

MECHANISM

The mechanism of failure for short-term overheating involves a relatively rapid increase in metal temperature due to the partial or complete interruption of flow through the tube of the cooling fluid. In response to the temperature increase, the strength of the material drops, and under the influence of the internal pressure, the tube begins to swell. Depending on the maximum temperature reached during the overheating incident, failure can occur in a matter of minutes and will appear as a fish-mouth type rupture oriented parallel to the axis of the tube.



Cross-section from the T91 tube rupture, showing significant grain elongation and microstructural degradation (top image)

Typically, the material ductility will increase with the temperature, causing the final rupture to be thin-lipped, with substantial swelling evident in the overheated area. However, where the maximum temperature of exposure exceeds the upper transformation temperature, some heats of material will experience a drop in ductility, in which case the rupture edges may show only a moderate degree of thinning and swelling may be more limited. In these cases, the metallurgical examination of the failure will confirm that the temperature exceeded the upper critical transformation temperature immediately prior to the failure.

TYPICAL LOCATIONS

Because the blockage that causes short-term overheating failures often occurs in the lower bends in superheater or reheater circuits, a common failure location is near (just downstream from) these lower bends. However, the design of the circuits, particularly the distribution of materials and wall thicknesses through the circuit, can cause failure to occur on the outlet leg at a location remote from the blockage -- for example, near a material change in the lower creep strength material.

Exfoliated oxide in a finishing superheater tube

A thin-lipped, fish-mouth rupture in a T91 final superheater tube

FEATURES

- Tube swelling
- Fish-mouth type rupture
- Thin-lipped rupture

Misinterpretation of Shock Wave Damage

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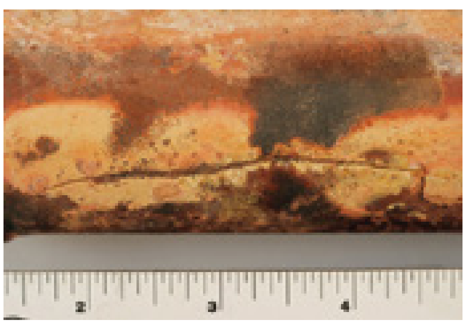
Slag consists of molten, partially fused or re-solidified deposits on furnace walls and other surfaces exposed to radiant heat in coal and other solid fuel fired boilers. Explosive deslagging is one method of dealing with slag buildup; however, if it is not performed correctly it can lead to damage in the boiler, including boiler tube failures.

Shock Wave Damage



Stress Corrosion Cracking

Creep Damage

Figure 1. These images show superheater tubes with relatively straight, thick edged cracks that were caused by different mechanisms.

Shock loading of boiler tubes during the detonation of explosives typically occurs because 1) the charge size is excessive; and/or 2) the charge is not positioned properly relative to a tube in a given area of the furnace. In these cases, the shock wave produced by the detonation is intense enough to instigate brittle fracture in the tube wall. This type of damage can occur either internally within the tube wall or link to the ID or OD surface of the tubing, depending on the location of the shock wave. Secondary cracking that is not connected to the primary crack may also be present. These features are characteristic of shock wave damage; however, they are also associated with other damage mechanisms in steam side tubing, including creep and stress corrosion cracking (SCC). Results from various analyses of tubes with shock wave damage and other damage show how shock wave damage might be misinterpreted as another mechanism.

Shock wave damage, stress corrosion cracking damage, and creep damage can look remarkably similar, as shown in Figure 1. All three of the superheater tubes shown have a relatively straight, thick-edged crack. Therefore, visual examination alone is not enough to determine the damage mechanism for each of these tubes.

Metallographic examination of the damage will reveal creep damage, which consists of voids, aligned voids, and micro-cracks, if it is present. However, shock wave damage and SCC can have similar appearances, even when prepared metallographic samples are examined using a metallurgical microscope, as shown in Figures 2 and 3. Both shock wave damage and SCC can exhibit secondary branched cracking that may be difficult to

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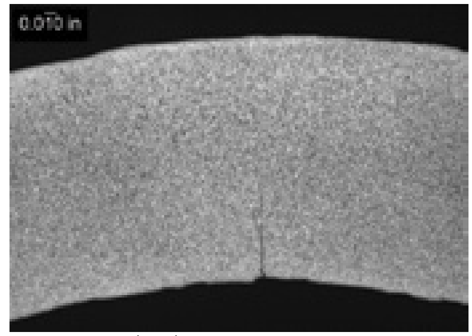
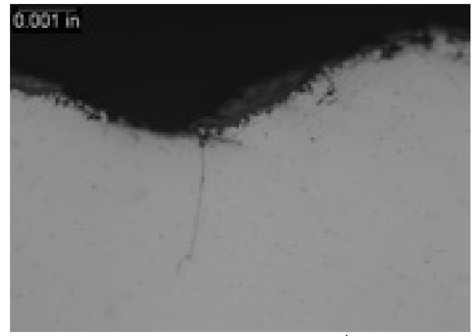
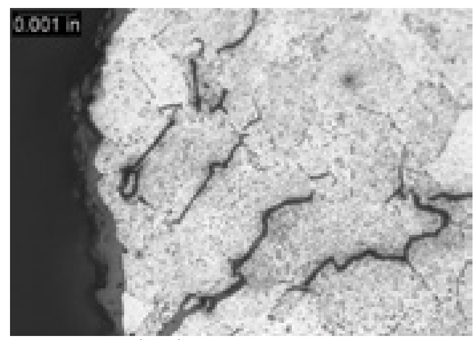


Shock Wave Damage

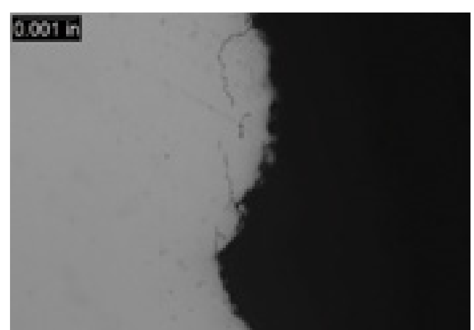


Stress Corrosion Crack

Figure 2. These images show cross-sectional views of a shock wave crack and a stress corrosion crack. While these images were taken at different magnifications, their appearances are similar.



Shock Wave Damage



Stress Corrosion Crack

Figure 3. These images show secondary cracks emanating from a primary fracture surface. Again, the magnifications are different but the branched cracks emanating from the primarily shock wave damage fracture surface could be mistaken for the branched cracking that is often associated with SCC.

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CONTINUED

differentiate. However, higher magnification examination of samples with shock wave damage generally reveals step-wise, secondary cleavage cracks (Figure 4). These small, step-wise cracks, which are relatively straight and at angles to each other, are generally only associated with shock wave damage.

Understanding the history associated with the tube samples is also important. If no explosive cleaning has been used in the boiler, then shock wave damage is not possible. However, shock wave damage does not always present itself immediately following explosive cleaning. Primary shock wave damage may not cause through-wall damage, and may leak after some time in service due to a different mechanism. If the shock wave damage created midwall separation, the stress level in the intact wall would be greatly increased. The increased stresses could lead to the formation of creep damage across the intact wall and eventually to failure. The combination of failure mechanisms could lead to misinterpreting shock wave damage as a creep failure.

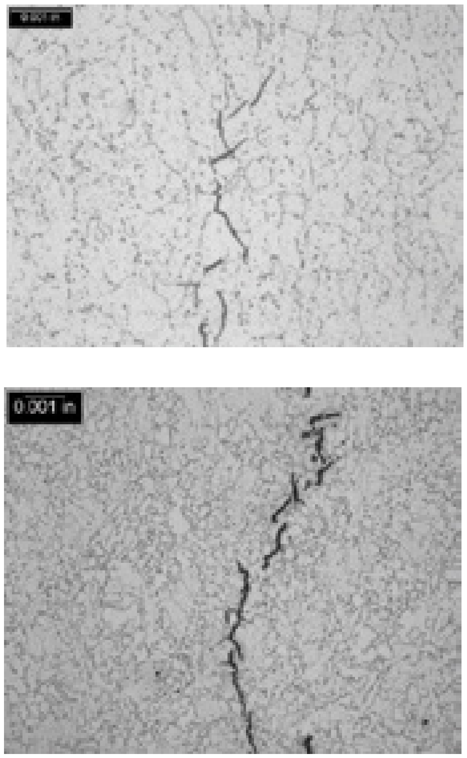


Figure 4. Higher magnification views of shock wave damage cracks reveal the step-wise secondary cleavage cracks that are indicative of shock wave cracking.

Since shock wave damage can occur within multiple tubes located near any of the explosive denotation locations, ensuring reliable operation for units where damaged tubes have been identified requires removal of all damaged tubes that might remain in the boiler. Radiography is a reliable nondestructive method for finding damaged tubes (Figure 5). In addition, extreme care should be taken in the sizing and positioning of the charge to minimize the risk of the same type of damage during the future cleaning.

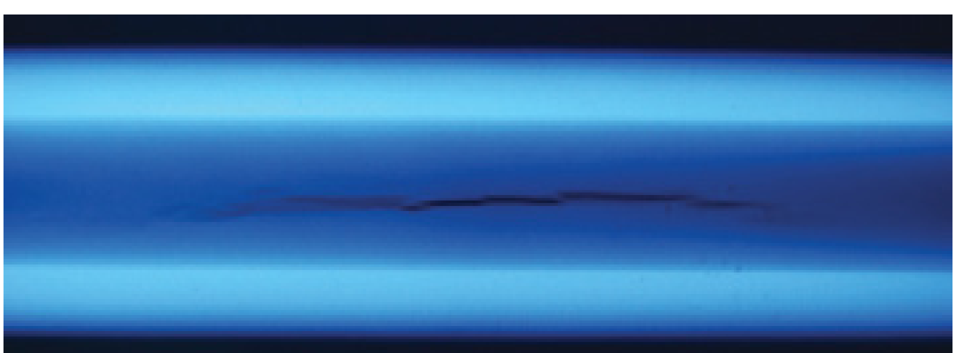
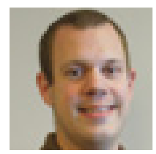


Figure 5. Radiographic image of shock wave damage in a superheater tube.

What Will You Do With Your Leap Second?



By: MATTHEW WALTER
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Due to the natural and very gradual slowing of the earth's rotational speed, the number of seconds in a day shrinks over time. To account for this, every so often the International Earth Rotation and Reference Systems Service adds a second (known as a "leap second") to the atomic clock so that our time-keeping devices are consistent with actual solar time. This has happened several times since 1972, when the leap second was first implemented.

This year, an additional second will be added to cell phones, computers and all other network-controlled clocks on June 30, 2015, at 23:59:60. While software engineers and scientists are trying to figure out if that extra second will disrupt things like GPS systems, websites and flight trackers (in 2012 more than 400 flights in Australia were delayed due to clocks not being in sync), you and I can sit back and wonder: what will we do with an extra second this summer? Personally, I plan to use it to get some extra shuteye that I have been meaning to catch up on.

Here are some other things you can do with your additional second:

- Watch a bee flap it's wings 200 times
- Sprint 12 meters (if you are fast)
- Fly 800 feet in a commercial aircraft
- Free fall 16 feet
- Blink seven times
- Read this sentence

Regardless of what you decide to do with your extra second in 2015, I hope you save a few for the next edition of Cool Facts.

REFERENCES:
http://en.wikipedia.org/wiki/Leap_second
http://www.brainpickings.org/2011/12/23/just-a-second-steve-jenkins/

REACTOR VESSEL MATERIALS TOUGHNESS ESTIMATION METHODS

By: CHRIS LOHSE
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Reactor pressure vessel materials for nuclear power plants are qualified per Section III of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (Code) and Appendix G of Title 10 (Energy) Code of Federal Regulation Part 50 (10 CFR 50). Prior to the Summer 1972 Addenda of the ASME Code, the materials were qualified based on Charpy V-notch tests from specimens oriented in the longitudinal direction (parallel to the principal working direction). The Summer 1972 Addenda to the Code modified the requirements for qualifying a material to include Charpy V-notch tests from specimens oriented in the transverse direction (normal to the principal working direction) and the reference nil-ductility transition temperature (RT_{NDT}), an index that relates to the temperature at which vessel materials begin to change from ductile to brittle behavior. Thus, nuclear power plants whose reactor vessel order dates fell prior to July 1, 1974 have materials that were not ordered to the new specifications.

According to Appendix G of 10 CFR 50, these material requirements were been changed also applied to older plants. Therefore, it became necessary to develop correlations between longitudinally-oriented Charpy V-notch specimen data and data from the newly required tests in order to estimate these data for the older plants. The Materials Engineering Branch of the Division of Engineering for the U.S. Nuclear Regulatory Commission prepared Branch Technical Position 5-3 which provided criteria and guidelines to evaluate the older plant test data and index temperatures with respect to the new requirements. As part of each plant's licensing basis, all reactor vessel beltline materials initial RT_{NDT} values were determined using one of the estimation approaches, or an alternative endorsed by NRC. Recently, it has come to the attention of the NRC staff that several of the Branch Technical Position methods for plates and forgings may give unconservative results for initial RT_{NDT} values. EPRI recently sent a survey to utilities and the NRC is looking more closely at the potential impact on plant P-T limit curves and pressurized thermal shock (RT_{PTS}) evaluations. Understanding the basis for the licensing values for initial RT_{NDT} will help to resolve questions that may arise about use of the estimation methods in the Branch Technical Position.

Structural Integrity has experience in this area and we are prepared to assist utilities in resolving issues or concerns related to reactor vessel material properties.

INSPECTION UNDER PIPE SUPPORTS USING SHORT-RANGE GUIDED WAVE TECHNOLOGY

By: MATT LINDSEY
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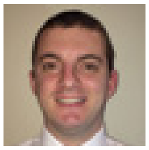

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There are multiple technologies available for the rapid screening of pipelines for corrosion, including conventional guided wave ultrasonics and in-line inspection techniques that utilize magnetic flux leakage or ultrasound. However, these inspection methods may not be applicable or effective in complex pipeline segments, such as those found in pump stations, metering stations, and tank farms. Furthermore, there are often access limitations for inspecting obstructed portions of pipelines. Some obstructed portions of pipelines, such as areas under supports, are also the most likely location of crevice corrosion.

To address this inspection problem, Structural Integrity has developed a Short-Range Guided Wave Testing (SR-GWT) technique that utilizes Electromagnetic Acoustic Transducers (EMATs) to inspect for Corrosion Under Pipe Supports (CUPS). This type of sensor has several advantages, such as being non-contact and having the ability to be used on painted and rough surfaces with minimal surface preparation. This technology operates at higher frequencies than traditional long-range guided wave technology. Higher frequency ultrasound enhances resolution and allows for the interrogation of multiple styles of pipe supports without a disturbance in the data due to contact points with the support. This high frequency technique allows for inspection coverage of the pipe body in the support area.

An example of a complex piping configuration can be seen in Figure 1. The facility operator's goal was to nondestructively assess the integrity in the area under the clamped supports without removing the supports.

With a pipe configuration such as that shown in Figure 1, ultrasonic testing (UT) can be used to inspect 100% of the accessible pipe body. In addition, conventional Guided Wave Testing (GWT) can be used to screen the line for anomalies up to the flanges. Conventional GWT results will show an indication from the clamped support, as seen in Figure 2. This reflection is caused by the contact forces between the pipe and clamp and can be problematic in analyzing the clamped region of the pipeline as the clamp reflection could potentially mask a reflection from crevice corrosion. Due to the possibility

Figure 1. A photo showing clamped supports that were successfully inspected using the SR-GWT technique.

Figure 3. Inspection results using our SR-GWT technique on the clamped support in the positive direction located adjacent to a flanged end and a vent.

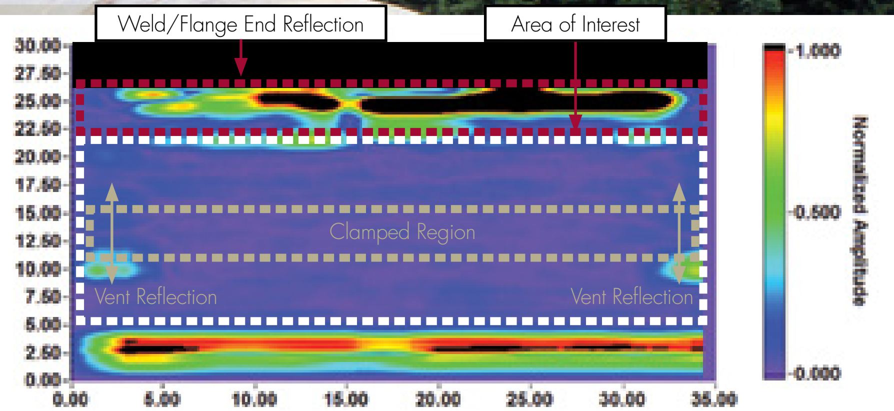
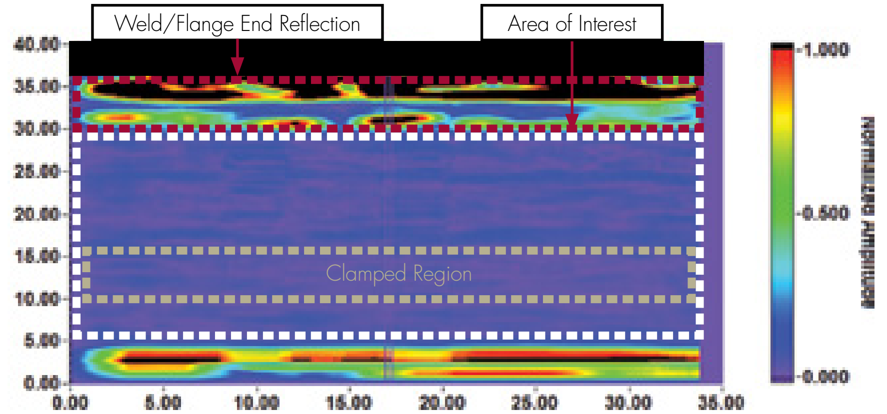


Figure 4. Inspection results using our SR-GWT technique on the clamped support in the negative direction located adjacent to a flanged end



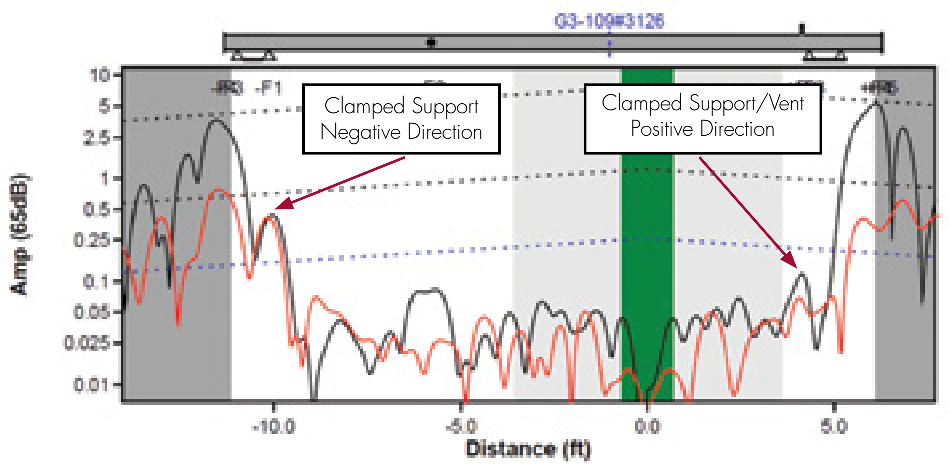


Figure 2. Conventional guided wave inspection results of a clamped support pipeline section.

of a masked indication beneath the support, a GWT inspector can only rely on observation and comparison of the indication from the support with "characteristic" indications from other clamped supports. An indication that would flag a clamped support for further interrogation can include high flexural content, an abnormal response such as amplitude inconsistencies, or a different indication signature than expected. High flexural content indicates a non-symmetric response from the clamp, further indicating a localized cross sectional change in a more concentrated area that may be a sign of corrosion.

It can be noted in the conventional GWT inspection results, shown in Figure 2, that the clamped support in the negative direction produced a high-amplitude reflection. This reflections amplitude is on the order of that expected from a weld. However, the clamped support in the positive direction produced no reflection that is distinguishable from a 2" diameter vent reflection that is located on top of the pipe or the adjacent flanged end. No information can be extracted about the condition of the pipeline under the clamped support from this data alone. In this situation, our SR-GWT technique can be used to remove the ambiguity of the long-range guided wave data, as shown in Figure 3 and Figure 4.

The SR-GWT data is collected and viewed on a handheld inspection system. The data is then uploaded to an in-house post-processing and display software also developed by Structural Integrity, so that data can be viewed on a laptop to facilitate data analysis. The results are shown in a similar format to a conventional C-Scan image with circumferential position shown along the x-axis and axial position along the y-axis.

The SR-GWT data collected from this inspection illustrates the ability of the technique to penetrate beyond the clamped support and not produce any indications from the support itself. The penetration power is evident by the detection of a welded flanged end fitting beyond the clamped support. A 2" diameter vent is also clearly detected in the results of the clamped support in the positive direction in Figure 3. The vent is located at the top of the pipe directly adjacent to the clamp on the near side of the clamp. It can also be noted that in the conventional guided wave data the negative direction support produced a high amplitude reflection,

Continued on next page

INSPECTION UNDER PIPE SUPPORTS USING SHORT RANGE GUIDED WAVE TECHNOLOGY CONTINUED

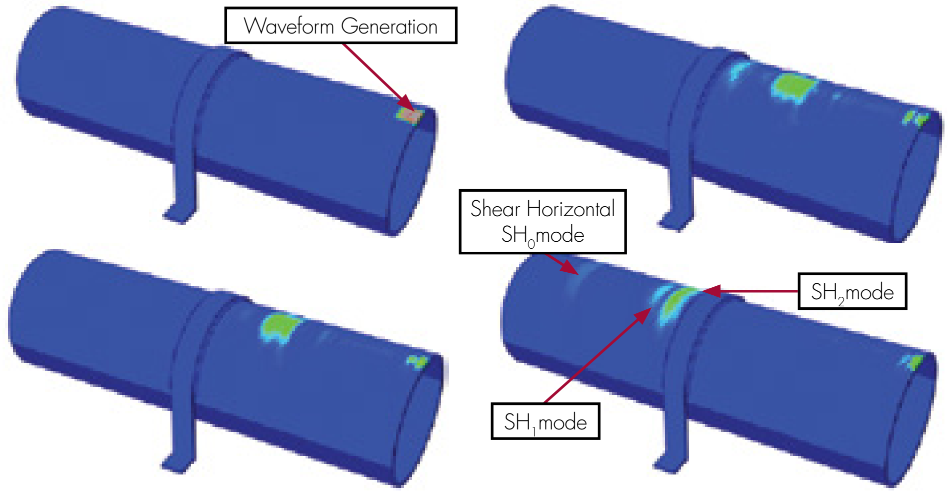


Figure 5. In the top left still image, the shear horizontal guided wave is being generated at the pipe body surface. The next still image is the top right that shows the waveform propagation right before the clamp interface. The next image in the bottom left displays the waveform directly under the clamp traveling along the pipe body. The bottom right image illustrates all waveform energy completely beyond the clamp with no clear reverse direction reflections shown from the clamp.

and the presence of a reflection from the support in the positive direction is questionable, the SR-GWT data is consistent. The SR-GWT data consistently produced no reflection from the clamps and is thus not convoluting any potential corrosion indications.

Finally, a numerical modeling study was performed that accurately represents a clamped support on a 10” diameter pipeline. Several techniques were utilized to verify and illustrate that high-frequency SR-GWT is not affected by a clamped support. Finite element model (FEM) results in Figure 5 show still images of the guided wave propagation along a pipe section. Moving through the images from left to right and top to bottom, the shear horizontal waves are generated at the right end of the pipe and then travel along the top of a pipe segment. A representative Teflon insert has been placed in between the clamp and the pipe OD surface in the model. At this intersection the images show that the guided wave travels under the clamp and energy is retained in the pipe segment, as there are no stresses shown in the clamp. Once all of the energy passes beyond the clamp there is no indication from the clamp traveling back to the sensor where the guided wave was generated.

A waveform was also generated from the model to simulate a pulse-echo A-scan. This is an A-scan signal one would expect to be displayed on ultrasonic data collection equipment. The simulated waveform can be seen in Figure 6. In this waveform the energy has traveled through the clamp and is 100% reflected from the pipe end back to the sensor location. This Finite Element Analysis (FEA) can be completed before ever placing a sensor on the part. Using this modeling capability, a range of support configurations can be analyzed and results verified or predicted using FEA.

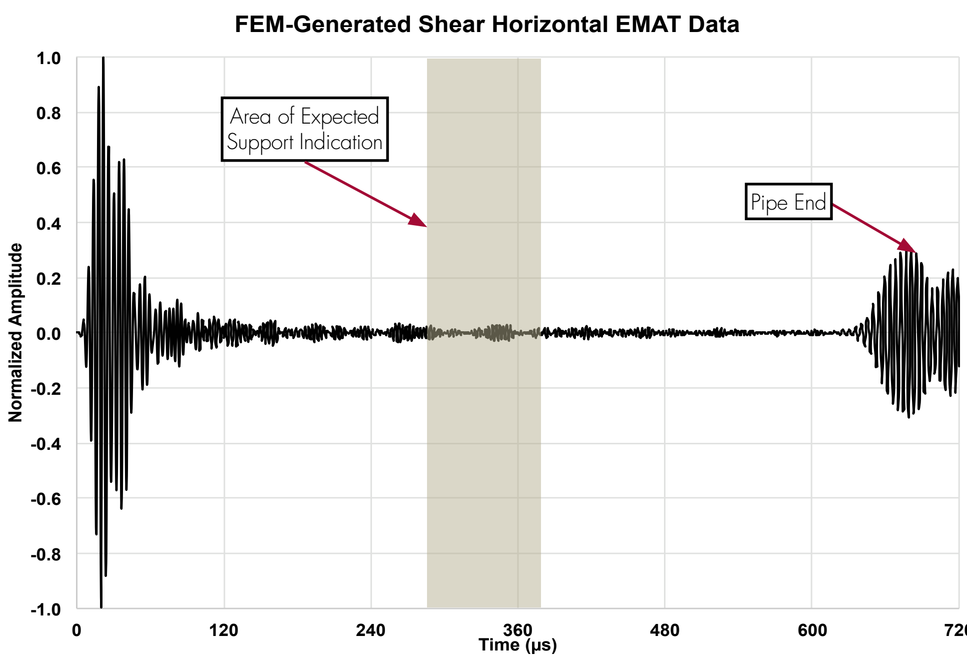


Figure 6. FEM generated waveform showing a pulse-echo shear horizontal guided wave.

In summary, a short range guided wave technique can be used to interrogate support regions where current long-range guided wave techniques can be unreliable and produce inconclusive results. It has been shown through direct field data comparison and numerical modeling that such a technique is valid, reliable, and indications are not present from supports alone when utilizing higher frequency guided waves.

UPDATE ON CASS FLAW TOLERANCE EVALUATION CODE CASE N-838

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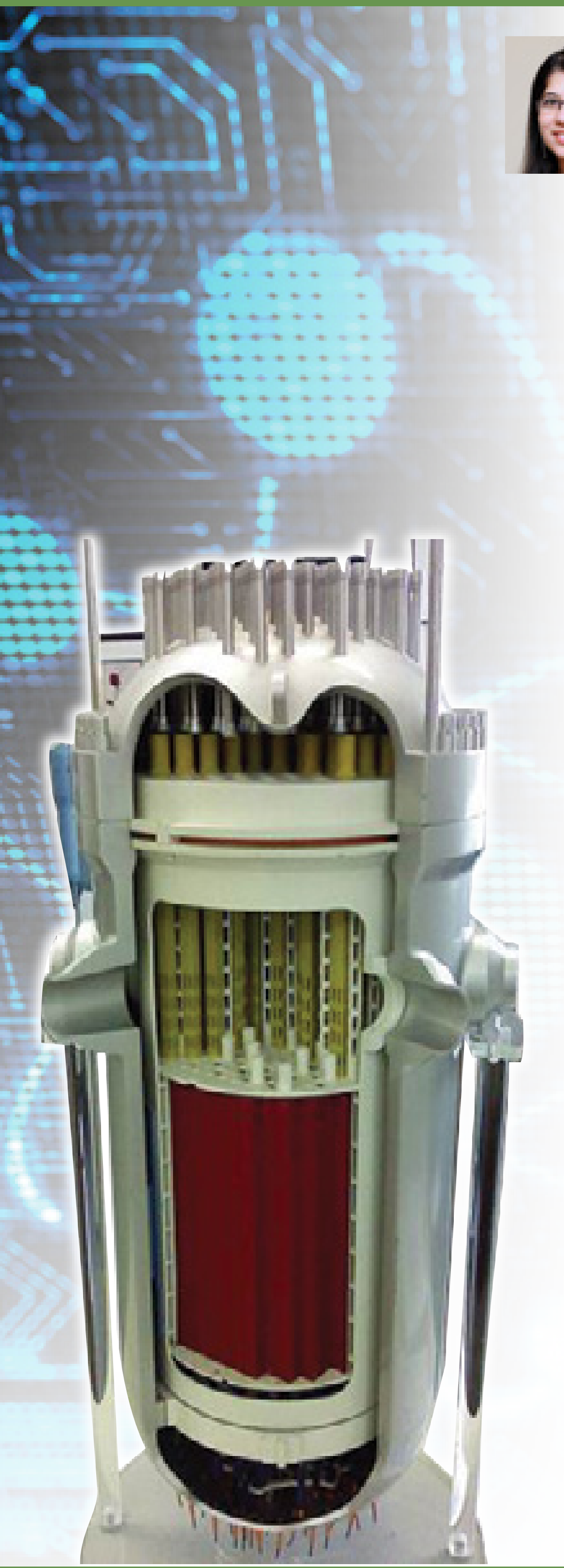
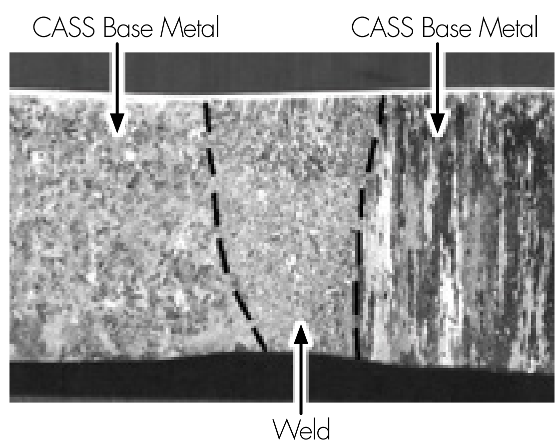


Cast Austenitic Stainless Steel (CASS) materials are used in many PWR Reactor Coolant System (RCS) piping systems. Thermal aging effects are known to occur as the high delta ferrite materials exhibit greater degree of aging and this leads to a reduction in toughness and an increase in strength. Per the Generic Aging Lessons Learned (GALL) Report, Rev. 2 (XI.M12), all CASS piping components must be screened and the aging effects of susceptible components must be managed either by enhanced volumetric examination, or a plant-specific flaw tolerance evaluation. Currently a qualified CASS volumetric examination method is not available. Hence a flaw tolerance evaluation approach is needed for those plants with related license renewal commitments.

FLAW TOLERANCE EVALUATION

Traditional conservative deterministic fracture mechanics analyses lead to tolerable crack sizes well below the sizes that are readily detectable in these large-grained materials. This is largely due to the conservative treatment of the scatter in material properties and the imposition of multipliers (structural factors) on the applied loads. In order to account for the scatter in the tensile and fracture toughness properties that enter into the analysis, a probabilistic approach is taken.



CASS CODE CASE N-838

A probabilistic fracture mechanics alternative approach has been developed as an ASME Section XI Code Case N-838. Structural Integrity has been working closely with EPRI and the ASME Code committees to develop this Code Case. It was approved by the ASME Code Section XI Working Group on Pipe Flaw Evaluation (WGPFE) and Subgroup on Evaluation Standards (SGES). It is now heading to ASME Standards Committee for review and approval in April 2015.

HOW STRUCTURAL INTEGRITY CAN HELP

Structural Integrity can assist utilities in the screening process and developing aging management programs for CASS piping. In developing these programs, plant-specific aspects of managing thermal aging effects in CASS will be evaluated (e.g., delta ferrite > 20% materials for screening purposes) and a flaw tolerance evaluation will be performed for susceptible piping components. Inspections may be needed to validate the absence of significant size flaws in CASS piping, and we can also assist utilities with planning and qualification of improved UT inspection methods.

Technology Brings Structural Integrity Closer to Clients

By: KEVIN LEYPOLDT
■ kleypoldti@structint.com

Now you can communicate with Structural Integrity online using Microsoft Lync or Skype!

This powerful collaboration and meeting platform provides a superior solution for Structural Integrity clients and partners who want to save time, increase productivity, and make meetings even more effective.

With Lync, you can easily connect with us for everything from real-time chats, team meetings and presentations to training seminars, sales events, and product launches. The recent Lync-Skype integration consolidates and streamlines various communication tools into one and simplifies meeting organization and execution. Now you can add Skype contacts to Lync or Lync contacts to Skype and communicate via one-on-one Instant Messaging and audio calling.

Lync's streamlined solution allows users to:

- Quickly check availability of colleagues via presence indicators
- Instant message (IM) between two or more colleagues
- Participate in Lync meetings from your mobile device
- See participants via photos or HD video
- Collaborate and share content, white boards, polls and videos
- Start conversations directly from Office programs

Together, Lync and Skype bring a new level of efficiency and collaboration to the table and makes electronic communication effortless. We look forward to connecting with you soon!

DENVER OFFICE HELPS HABITAT BUILD A HOUSE

By: HAL GUSTIN
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On a cold Saturday morning in December, Structural Integrity's Denver office volunteered as a group with Habitat for Humanity. The non-profit organization relies on volunteer work and donations to provide housing solutions for underprivileged families. Twelve of our employees and several family members lent a hand with tasks ranging from setting up scaffolding to framing internal walls, general maintenance, and housekeeping. With hard work and high spirits, the Denver team helped build a home for a family in need – and enjoyed some team-building along the way.

DID YOU KNOW?

Families who qualify for a Habitat for Humanity house are not given a free house; they purchase the house at cost, with the help of low-interest loans. The families are also required to invest hundreds of hours of their own time towards the completion of the house.

"Over the past couple years I've gotten to know my co-workers fairly well, but now that I've seen them swing a hammer, I have an even better idea of what they can do."

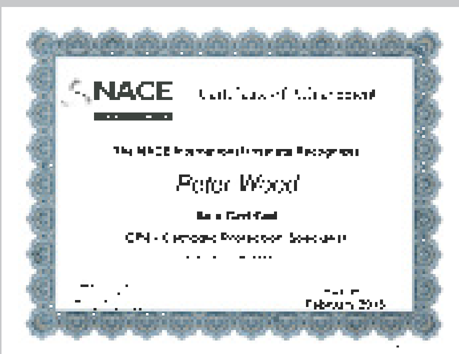
- Hal Gustin, Senior Associate and Habitat for Humanity volunteer

STRUCTURAL INTEGRITY NACE NEWS

PETE WOOD EARNS CP CERTIFICATION

PETE WOOD
■ pwood@structint.com

Congratulations to Senior Specialist Pete Wood for earning his certification as a NACE CP4 Cathodic Protection Specialist in February.

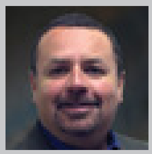


NACE's Cathodic Protection (CP) Program is the most widely recognized and accepted CP training and certification in the world. The program provides students with the theoretical and practical fundamentals for testing, evaluating, and designing both galvanic and impressed current CP systems.

Pete has worked in the corrosion/CP field for seven years. As part of our team of industry-leading professionals, he is responsible for corrosion/CPon surveys, CP system troubleshooting, and new CP system design. He also played a key role in developing the CP monitoring and maintenance modules for EPRI's BPWorks and Structural Integrity's MAPPro software.

Congratulations Pete!

STEVE BIAGIOTTI ASSUMES LEADERSHIP ROLE ON NACE PLANNING COMMITTEE



STEVE BIAGIOTTI
■ sbiagiotti@structint.com

Structural Integrity is pleased to announce that Senior Associate Steve Biagiotti, P.E., has been appointed to the office of vice chair of the TCC Planning Committee, an administrative committee of the NACE International Technical Coordination Committee (TCC).

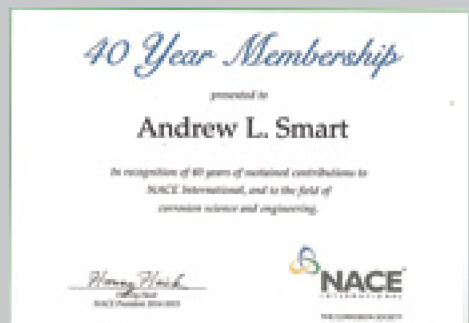
The Planning Committee is of vital importance to the success of the TCC. In his new role, Steve will help lead long-term strategic planning and annual tactical planning that reflects the Association's strategy. The Planning Committee is also responsible for technology forecasting on a five-year cycle.

For nearly 30 years, Steve has played an active leadership role in NACE International, which aims to protect people, assets and the environment from corrosion. His current appointment will continue through the end of CORROSION 2016, at which time he will advance into the position of chair of the TCC Planning Committee for a two-year term. Congratulations Steve!

NACE LIFETIME MEMBER

ANDY SMART
■ asmart@structint.com

NACE International, the worldwide corrosion authority, recently named Andy Smart a Life Member, recognizing him for "...40 years of sustained contributions to NACE International and to the field of corrosion science and engineering."



Andy has been a supporting member of NACE since he joined in 1974. He is also certified by NACE as a Corrosion Specialist and Cathodic Protection Specialist. Today, as a Senior Consultant at Structural Integrity, Andy brings clients a wealth of experience solving corrosion control problems in the oil, gas, pipeline, electric power, concrete, industrial, and commercial sectors, including design and installation of cathodic protection systems. Andy also developed the Structural Integrity's Area Potential-Earth Current (APEC) survey methodology for assessing coating condition and cathodic protection effectiveness.

We applaud our dedicated colleague for his long-time support of NACE's mission to protect people, assets and the environment from corrosion. Congratulations Andy!

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TRADE SHOWS

ANS International High-Level Radioactive Waste Management
Charleston, SC *April 12-16*, Present

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Richmond, VA *April 13-14*,
Exhibit, Present and Sponsor

UC Berkeley Engineering Career Fair
Berkeley, CA *April 15*, Exhibit

EPRI Generation European Workshop and Vendor Exhibit
Madrid, *Spain April 21-23*,
Keynote – Laney Bisbee, CEO

NEI Used Fuel Management
Orlando, FL *May 5-7*, Exhibit
Clarion Unpiggable Pipeline Solutions Forum
Houston, TX *May 12-13*, Present

NEI Nuclear Energy Assembly (NEA)
Washington, DC *May 12-14*, Exhibit

UDH LDPE Plant Improvement Conference
Hamburg, Germany *May 18-20*,
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NAES Operations and Maintenance Managers Conference
Grapevine, TX *May 19-21*, Exhibit

AGA Operations Conference
Grapevine, TX *May 19-21*, Exhibit and Sponsor

11th International Conference on NDE
Jeju Island, Korea *May 19-21*, Exhibit, Present and Sponsor

EPRI Nondestructive Evaluation Technology Week
Hilton Head, SC *June 22-26*, Exhibit and Sponsor

WEBINARS

Building Blocks of Cathodic Protection: Long Term Maintenance
Presenter: Shawn McFarland
Tuesday, April 21, 2015 at 2 pm ET

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