2014 VOLUME 36

Structural Integrity Associates, Inc.®

NEWS & VIEWS

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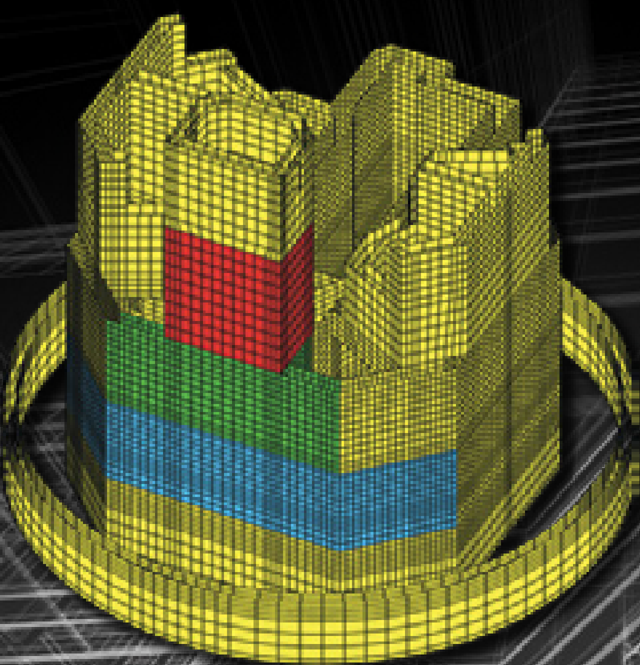
WHAT'S SHAKING IN SEISMIC



Steel Plate Elements

LP Steam Turbine Evaluation Protocol (TIL) 1904 pg.20

Shrunk-On Wheels of Unknown Material Toughness

Structural Integrity Associates, Inc.®

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A Look Ahead

Later this year, we'll start on our next Long Range Plan, one aimed at 2015 – 2018. Our plan starts with a look at current and future market trends and then we consider the solutions needed to support those trends. Next, we assess the technologies and competencies we have or will need to develop/acquire to deliver those solutions in a manner consistent with Structural Integrity's brand. Lastly, we develop strategies supported by action plans to develop, market, resource and deliver the solutions. All of this is founded on a classic, tried-and-true strategic planning process, one that has existed for decades in industry and for years at Structural Integrity. It's also one that has worked pretty well in our relatively slow-paced world of electric utilities and oil and gas pipelines.

Occasionally, a significant industry failure or event will occur that requires a fast-paced solution (typically one required to be developed over the weekend!) and we've always been and will continue to be uniquely positioned to respond to those emergent needs. As I've reported before, we have a very wide range of competencies so that we can form multi-disciplinary SWAT teams. We are employee-owned which means we don't work by a corporate time clock, so we really are responsive at any time of day or day of the week. We are geographically diverse in our office locations so that we can have someone on a site on very short notice... but for now I'll get off my responsiveness soapbox and get back to long range strategic planning.

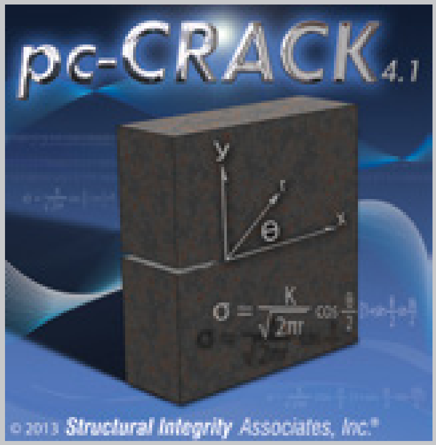
I started this article by noting that our market is relatively slow-paced – it takes many years, if not decades, to design and build plants, and it can be years after an industry-changing event (e.g., seismic reevaluation in the aftermath of Fukushima) for regulatory deadlines to be met. Also, it is often decades before aging issues (buried piping leaks in a nuclear plant, type IV cracking in fossil plant main steam piping, or turbine blade attachment cracking) become industry-wide business drivers. Therefore, long range planning at Structural Integrity should be relatively easy and without much uncertainty. Not so.

There is a newer strategic planning approach that has not yet taken full effect in the utility industry, but still it keeps me up at night (well, just some nights): Big Bang Disruption. Big Bang Disruptors are products and services that enter the market better, cheaper and faster than those they replace. They can appear at any time and come from any source – not just your usual competitors. So what does that really mean? Here are some examples I think we can all relate to: mobile devices serve as virtual incubators for Big Bang Disruption strategies and products, displacing mature products such as video cameras, wristwatches, alarm clocks, day planners, calculators, books, newspapers and magazines. My mobile devices have really cut down on the stuff I lug around on business trips, so thankfully I no longer have to check bags to get all of my support gear to the next town. Smart phone navigation apps replaced paper maps, printed directions and dedicated GPS devices. I can't remember the last time I used my $400 GPS (yes I can, it was the week before I got my new smart phone.) Give me a call if you want a good deal on a used GPS…

You may not see this type of disruption coming for utilities, but neither did the makers of GPS units, video cameras, and day planners. A recent interview with David Crane, the chief executive officer of NRG Energy, identifies a new and disruptive vision for the utility industry. It starts with a growing percentage of the electricity we all use coming from wind, solar and other renewable sources, combined with continued technology development (battery capacity, miniaturization, smart grid). But the real disruption comes from a future where we all increasingly generate our own electricity from rooftop solar, fuel cells, backyard wind farms and other self-contained power systems within our homes and, of course, all managed through your mobile device or smart phone. The rapid expansion of these distributed generation sources eliminates or significantly reduces the need for utilities to generate and distribute electricity, radically altering the need for big power plants and a national grid. Compare this to mobile phones and internet-based telephony services that reduce or eliminate another type of utility – large phone companies providing land line communications systems.

As a fossil guy that worked on high energy piping and headers most of his professional career, I wonder how many 60 ft long, 28" diameter and 4" thick superheater outlet headers will fit in a typical home attic or basement. At least there won't be a fly ash problem.

PC-CRACK 4.1 THE WORLD OF FRACTURE MECHANICS



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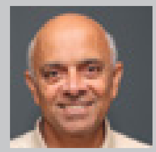

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We are excited to announce the release of a new version of our flagship fracture mechanics analysis software, pc-CRACK 4.1. The software expands the engineering capability by providing an easy-to-use tool that allows users to rapidly perform sophisticated fracture mechanics analyses. pc-CRACK can help inform decisions regarding the effects of structural flaws in a wide variety of materials and components.

pc-CRACK is a Windows-based software for the analysis of cracks and supports both English and SI units. Analysis procedures are based on linear elastic fracture mechanics (LEFM) or elastic-plastic fracture mechanics (EPFM). The software analyzes and predicts flaw behavior, including calculation of crack growth and critical crack sizes for pressure vessels, piping, steam turbines, and structures, with immediate display of analysis results.

As an upgrade to version 3.1, pc-CRACK 4.1 expands the built-in crack geometry library as well as supporting user-defined one- or two-dimensional stress intensity factor inputs to perform custom crack growth calculations. With the 15 added new crack models, a total of 35 LEFM and 15 EPFM crack configurations are included, many with influence functions that allow consideration of arbitrary stresses. pc-CRACK can compute the life of a component subjected to sub-critical crack growth such as fatigue, stress corrosion cracking (SCC), or primary water stress corrosion cracking (PWSCC). It can also compute the critical crack size based on LEFM or EPFM principles.

With the available ASME Codes and Standards (CS) module, pc-CRACK 4.1 CS can compute the allowable crack size based on ASME Section XI IWB-3640 (1998 or 2004). The CS module can also be used for computing the design weld overlay thickness.

pc-CRACK 4.1 CS is validated in accordance with Structural Integrity's Quality Assurance Program which is in compliance with the requirements of 10CFR50 Appendix B, 10CFR21, ANSI/ASME NQA-1-1989 and 1994, and meets the intent of applicable portions of ANSI N45.2.

Email pccrack@structint.com or visit www.structint.com/pc-crack for more information and to obtain a **FREE** demo version.

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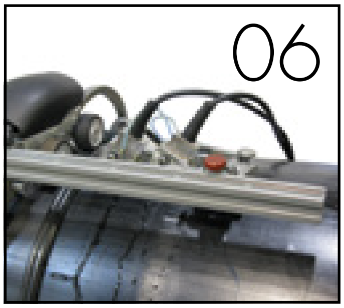

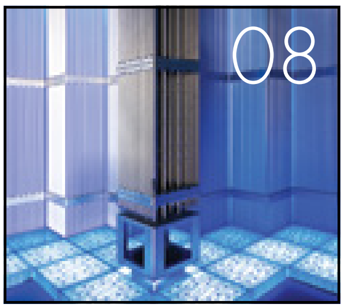

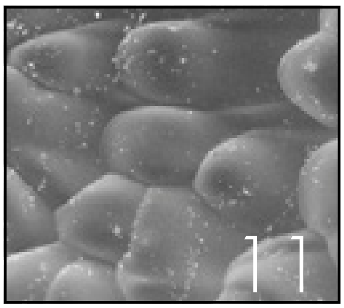

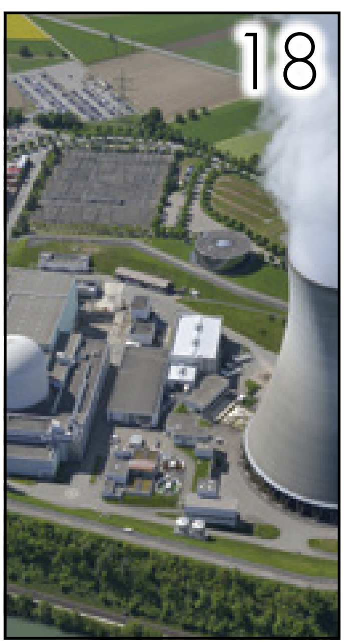

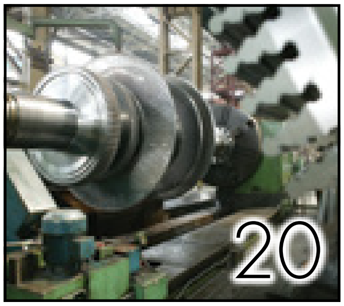
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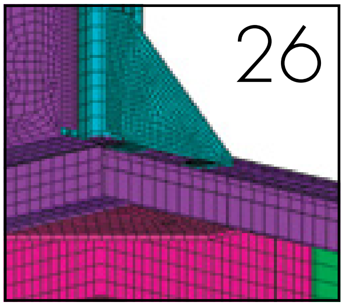
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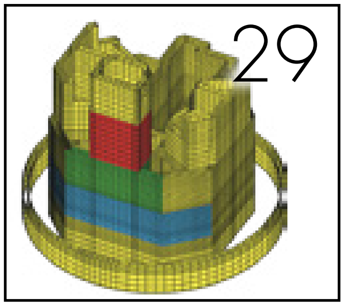
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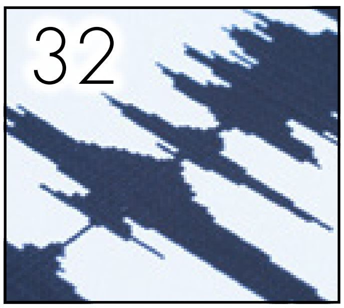
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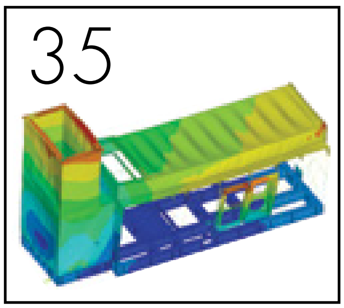
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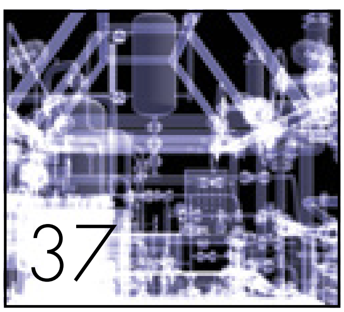
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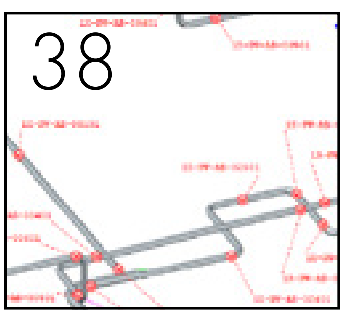
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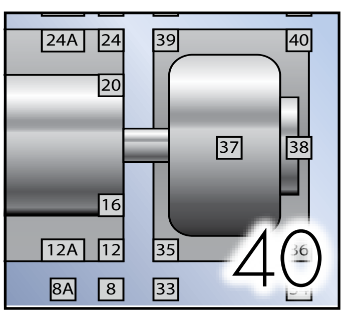
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FERMI REMEDIATION STUDY

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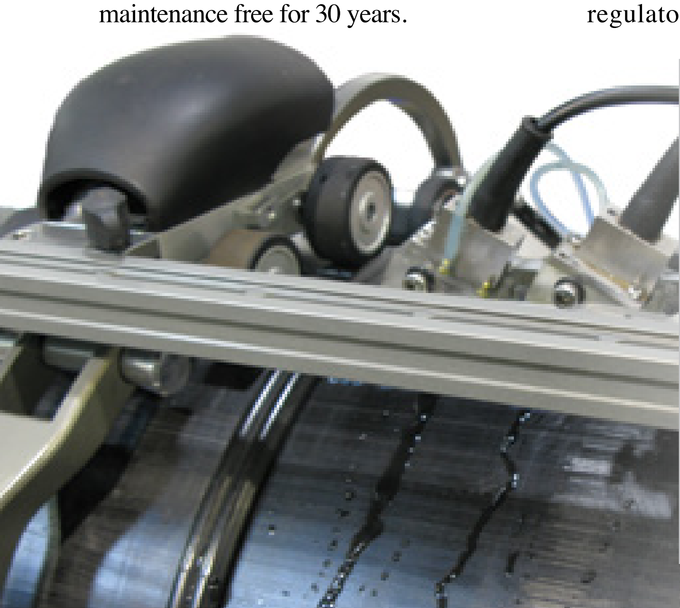
For safety related Service Water (SW) systems in commercial nuclear generating stations, operating experience has shown that life spans of 25 years or more can be achieved without significant or concerted attention to mitigate corrosion. However, as the age of piping systems increases so does the level of effort and cost to manage their aging. Increasingly, system owners are being challenged by both regulators and plant management to not only determine the current state of these systems but to also control further degradation. Many of these systems only see flow during monthly testing, which creates ideal conditions for fouling and corrosion. Despite this, the piping in three safety related SW systems (EESW, RHRSW, and EDGSW) at the Enrico Fermi 2 Nuclear Power Plant (Fermi) have operated relatively maintenance free for 30 years.

Prior to pursuing pipe remediation, Fermi contracted Structural Integrity (SI) to prepare a probabilistic leak prediction model for the in-scope SW systems. The results of the model were compiled in a Life Cycle Management (LCM) plan which has been presented several times to the Plant Health Committee. In addition, the wall loss and leak predictions were verified by performing NDE inspections using advance techniques such as Phased Array UT corrosion mapping. The LCM predicted that leaks would begin to become a problem well before the end of the PEO. Although the in-scope systems had yet to develop a through-wall leak, the Plant Health Committee determined that chasing nuisance leaks was not cost effective and had a potential negative regulatory impact on the site. Instead, the decision was made to pursue pipe remediation.

Remediation options are numerous with no single solution being ideal for all systems or all piping in the same system, even those systems at a single site with similar age and operating conditions. In addition, it is likely that many of the stakeholders involved have already decided what the best remediation is, without the benefit of a thorough review of all the available options. The key to resolving these preconceived notions is to provide a forum in which the opinions of key stakeholders can be aired. For the Fermi safety related SW remediation study, this took the form of a one day on-site meeting.



Prior to the on-site meeting, Structural Integrity compiled system background information from various sources including BPWorks™, MAPProView™ , inspection reports, and a previously developed and validated probabilistic leak model we prepared. We also assembled un-biased meeting content from industry publications (EPRI, ASME, NRC, DOT, etc.), vendors, manufactures, various plant remediation OE, and in-house technical expertise to facilitate pointed discussion for the following topics:

- Establishing current system condition and defining system end of life
- Remediation approach and installation logistics
- Options for continued operation "As-Is" such as inspect and repair, clean, and/or chemically treat
- Isolation from corrosive environment
- Material replacements
- Risk based / relative cost comparison of various options.

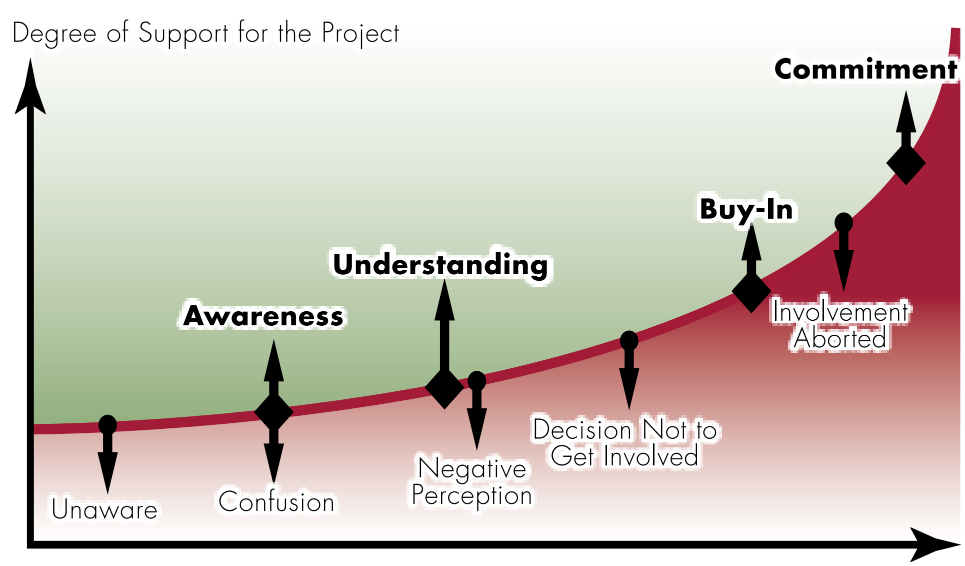
The real purpose of the on-site meeting is to integrate stakeholders early into the process to increase awareness, avoid confusion or negative perceptions, and facilitate buy-in for remediation options with preliminary commitment to the processes selected for more detailed analysis. This approach minimizes the inevitable challenges that occur when a small group hands off their findings to a larger audience. Such challenges typically result in rework (especially when the challenges have already been considered by the smaller group), negative impacts to budget and schedule, and potentially overly conservative assumptions. Of these, overly conservative assumptions have the most significant impact to project success. Avoiding this trap resulted in useful information about the current and projected state of the piping systems.

With a clear picture of the current state of the piping and an understanding of the degradation mechanisms, the relatively large and diverse group was able to discuss the individual factors that affect the system end of life and how best to define it. In this case, the increasing threat of leakage was determined to be the driver and a date was selected based on the probabilistic leak model. Options with long lead times are then eliminated if they cannot be implemented prior to system end of life. Options with a relatively short design life are also eliminated if they do not meet the plant end of life requirements.

A variety of remediation options were reviewed during the site meetings. Discussions as to the viability of an individual option focused on risk (with special consideration as Fermi is the single nuclear unit within DTE), design limitations, and implementation challenges including impact to the site as a whole. After reviewing many options at a high level the on-site meeting resulted in 5 remediation options being selected for additional evaluation, which were ultimately presented in a report to the site:

- Cured-in-place pipe (CIPP)
- Internal epoxy coating
- Replacement with HDPE
- Replacement with AL-6XN®
- Replacement with heavy wall carbon steel.

The continued safe operation of these systems through the PEO and into decommissioning is the ultimate goal of the remediation project. Having a facilitated discussion with all stakeholders ensures that a diverse set of opinions are captured early in the process and each is engaged appropriately throughout the process. This should be viewed as a small investment toward the overall project success of typically very large ($150k+) projects. The information presented in the final report allows site management to determine a cost effective remediation approach that considers all challenges and risks specific to Fermi and ensure the continued safe operation of these important systems.



ASSESSING AND MITIGATING PELLET-CLADDING INTERACTION TYPE FUEL FAILURES

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An important performance issue for nuclear fuel is power operation without incurring fuel failures stemming from a behavioral phenomenon known as pellet-cladding interaction (PCI). PCI failures, while not a safety issue, are nevertheless of concern to nuclear power utilities because they become a factor in operating power reactors at the desired efficiency or could even impede load-follow operation. The technical aspects of the PCI failure mechanism are highly complex, and require a fuel performance computer code with advanced capabilities to enable high-fidelity simulation of the mechanism. ANATECH staff have, for several decades, been in the forefront of this development. Working as contractor to EPRI, ANATECH developed EPRI's fuel performance code Falcon, which is regarded in the industry as the most advanced tool for the modeling and simulation of the PCI mechanism.

Using Falcon, we developed expert systems in the form of operational guidelines to avoid PCI failures and have provided extensive expertise to the nuclear industry in evaluating operational occurrences leading to PCI conditions by aiding utilities to properly apply the operational guidelines to eliminate or mitigate fuel failures. We have not only been intimately involved with the development of industry guidelines related to PCI-type failures, but have worked closely with a number of individual utilities to: 1) assess margin-to-failure under their particular operating strategies and provide guidance on ways to ensure adequate margin to PCI-type failures, and 2) provide a complete understanding of the PCI failure mechanism, contributing factors, remedies and means of assessing margin to PCI-types of failure through training of utility staff.

PELLET-CLAD MECHANICAL INTERACTION (PCMI) AND PCMI-INDUCED FAILURES

PCMI is the loading condition that creates a stress state in the cladding, which, in the presence of pellet cracks incident to the cladding, causes stress concentrations. The chemical environment created by fission products release could cause the cladding to fail by intergranular stress corrosion cracking (SCC) at the point of stress concentration at a pellet crack. The term 'classical PCI' refers to this particular condition of failure by SCC. The two terms PCMI and PCI are often confused, and one simple way to distinguish between them is to refer to PCMI as the cause and PCI as the effect. However, without the SCC chemistry, a cladding failure is purely mechanical, driven by high intensity PCMI. Quite often the two types of failure are combined, with failure initiated as a PCI incipient crack and then completed as a mechanical rupture. Figure 1 below is a micrograph of a high-burnup fuel rod showing all the features that potentially could lead to cladding failure: closed pellet-clad gap, radial pellet cracks, and pellet defect known as missing pellet surface (MPS).

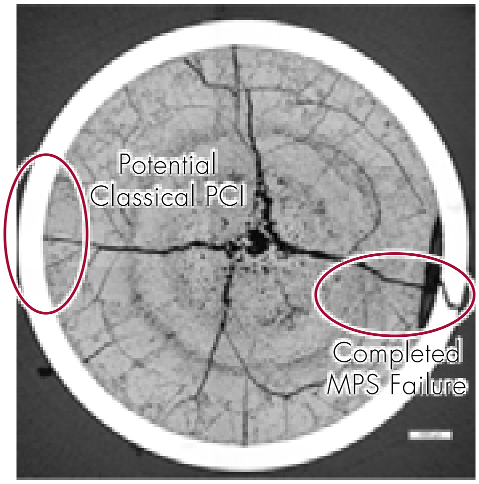

Figure 1: Micrograph Showing Pellet Cracks, MPS Defect and Through-wall Crack [Based on Ref.1]

Conditions for classical PCI are potentially created when the fuel-cladding gap is closed. Prior to gap closure, as the fuel pellet thermally expands outward, cracks are formed due to the substantial thermal gradient across the pellet radius and the resulting differential thermal expansion. The increased temperature, in concert with pellet cracking, enhances fission product release from the pellet matrix and transport to the cladding inner surface. High cladding stresses are generated when the pellet is in contact with the cladding due to the radial expansion of the pellet and the opening of radial cracks that tend to stretch the cladding in the hoop direction. Under this condition of pellet-cladding mechanical interaction (PCMI), in concert with the presence of aggressive fission product species (e.g., iodine), cracks may be generated in the cladding at the inner surface, and potentially propagate through-wall as intergranular SCC. PCMI in the presence of aggressive fission product attack of the cladding inner surface constitutes the classical PCI failure mechanism. Phenomena contributing to the classical PCI failure mechanism are depicted in Figure 2A. Figure 2B illustrates the forces acting on the cladding in the presence of an MPS defect.

INDUSTRY EXPERIENCE

Failures by the classical PCI mechanism were not that unusual in both BWRs and PWRs through the 1980s. Industry responses included improved fuel design and power ramping guidelines for plant startups and restarts. Although there have been several relatively recent cases suggesting classical PCI failures in-reactor, for all practical purposes the remedies implemented have been effective.

However, in the 2003 to 2006 time period, the industry was surprised by the occurrence of multiple failures in several fairly aggressively operated US PWRs owned by the same utility during reactor startups/restarts. Hot cell examination of several failed rods confirmed PCMI failure in the presence of large pellet surface defects as seen in Figure 1. While the affected fuel supplier upgraded inspection and manufacturing processes to mitigate the occurrence of significant MPS defects in pellets, the affected plants/utility implemented a number of operational remedies to further reduce the likelihood of such failures if large MPS defects were present in the fuel including:

- reduced power ramping rate on startups,
- addition of constant power holds to allow relaxation of cladding stress during the return-to-power evolution,
- core design changes to minimize the power change experienced during startup, and
- minimization of the extent/duration of coastdowns.

ANATECH EVALUATION OF MPS DEFECTS AND MARGIN TO FAILURE

Since 2005, we have worked with utilities experiencing MPS failures to evaluate startups in PWRs that were considered susceptible to MPS and with other utilities to assess margin to MPS-related PCI failure, considering: 1) their particular startup strategies, 2) alternate fuel designs, 3) manufacturing upsets, and 4) equipment outages.

In a typical startup PCI risk assessment, we receive data from core simulation calculations from which we identify the limiting fuel assemblies with respect to PCI risk. The vendor or utility then develops the full fuel rod power histories. Using vendor-supplied fuel design information and utility-supplied core operational data (e.g., coolant pressure, temperature and flow rate), we then develop Falcon models, both global (full-length rod) and local (plane cross section), and perform time history analyses to determine the fuel rod response. Using a cladding failure criterion in terms of a stress threshold to

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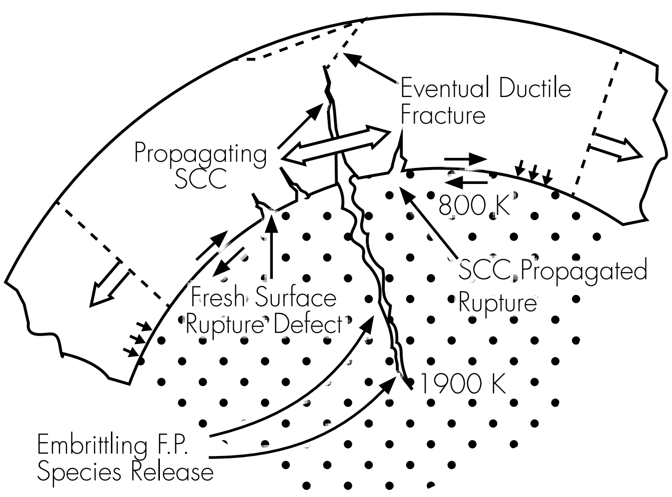

Figure 2A. Classical PCI

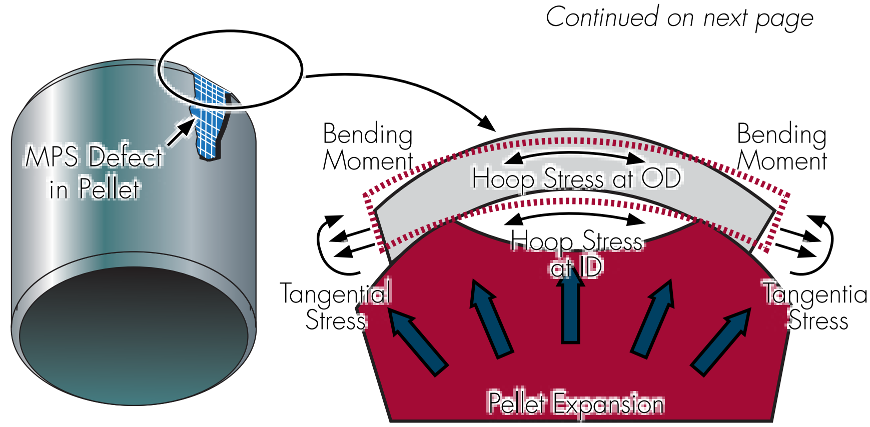

Figure 2B. MPS Defect

Schematic of Pellet/Cladding Interface Showing Critical Phenomena and Forces Contributing to Classical PCI (Figure 2A, Ref.2), and MPS Defect (Figure 2B)

ASSESSING AND MITIGATING PELLET-CLADDING INTERACTION TYPE FUEL FAILURES

CONTINUED

preclude PCI, we determine the power histories that avoid the threat of PCI failures and then develop operational strategies that can increase margin, such as:

- adding constant power holds,
- reducing the rate at which core power is increased,
- reducing the extent of the coastdown (i.e., duration, power level), and/or
- reducing the change in power experienced upon achieving full power conditions.

Once the limiting case has been determined, sensitivity cases can be executed to evaluate 'what ifs', i.e. a change to an alternate fuel design that implements higher uranium loading, inoperability of feedwater heaters, larger MPS defects to bound manufacturing upsets, etc.

ENHANCING UTILITY STAFF AWARENESS OF PCI-TYPE FAILURES AND MITIGATION STRATEGIES

Based on our experience in evaluating PCI-type failures and providing guidance to utilities regarding their particular startup/restart strategies, we have developed and delivered one- and two-day training seminars to help utility staff enhance their awareness and understanding of PCI-type failures. We work closely with the utility's Training and Engineering staff to develop a tailored seminar where topics include:

- PCI-type failure mechanism (including contributory local fuel and cladding phenomena, impacts of core/fuel management, impacts of local effects such as control blade withdrawal),
- classical and MPS-induced PCI failures,
- industry experience, understanding and responses,
- ramp testing programs (BWR and PWR) and guidelines,
- recent PWR experience with PCI-type failures (ramp rate studies, discussion of cases and remedies),
- recent BWR experience with PCI-type failures (discussion of cases and remedies), and
- modeling and analysis of PCI-type failures.

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ANATECH CORP.

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FEATURED DAMAGE MECHANISM: FLOW-ACCELERATED CORROSION (FAC) IN HRSGS

Material Science Center Lab Corner

Take a Virtual Tour at: http://structint.com/metallurigicallab

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For more than 10 years, the leading cause of heat recovery steam generator (HRSG) tube failure has been flow-accelerated corrosion (FAC). Fortunately, the mechanism of FAC, as well as the possible root causes of both single- and two-phase FAC, are well understood.

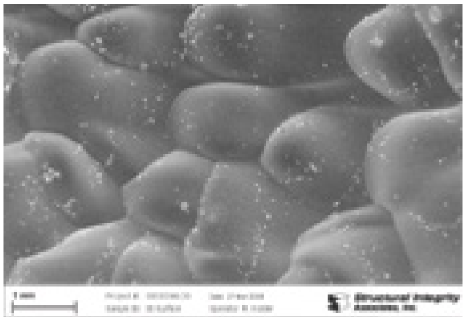
TYPICAL LOCATIONS OF FAC IN HRSGS

FAC involves the single- and two-phase variants predominantly in low pressure (LP) economizers/preheaters and LP evaporators (tubes, headers and risers), with an increasing number of incidents in intermediate pressure (IP) circuits (tubes and risers). All the HRSG components within the temperature range 100-250°C (212-482°F) are susceptible. FAC also occurs in air-cooled condensers if fitted to the combined cycle plant.

MECHANISM OF FAC

FAC is a very complex mechanism which is directly controlled by the cycle chemistry applied to the combined cycle/HRSG and located by turbulent flow conditions. Normally magnetite grows on internal surfaces of the HRSG LP and IP circuits. This oxide is semi-protective because of its high solubility in water across the temperature range mentioned above when local electrochemically reducing environments exist. In combined cycle/HRSG plants such environments are increased by using a reducing agent such as hydrazine (or an equivalent) in the condensate and feedwater. Wherever there are turbulent conditions this will increase the removal of magnetite, resulting in the loss of tube/header wall thickness. By contrast, the use of an oxidizing treatment encourages hematite to form on the magnetite, and this has a much lower solubility in the water and hence is not removed by turbulent conditions in exactly the same locations. In single-phase fluids it is thus most important not to use reducing agents in HRSGs. In two-phase flow regions, the local chemistry cannot be made oxidized to produce the same reduction in FAC; in these regions it is necessary to increase the pH of the damaging droplets, which lowers the solubility of magnetite. Of course if the manufacturer “armors” the location with a chromium, containing material (less than 10% of HRSGs tubing worldwide), the mechanism of FAC will also not occur.

FAC damage in an LP Evaporator Elbow



High magnification scanning electron microscope (SEM) image of FAC damage in LP Evaporator Elbow.

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CAN YOU GUESS WHAT THIS IS?

Take a look at this SEM image and see if you can guess what it is.

Hints: This item is commonly used as a finish for drywall, sheetrock, and plasterboard. In addition, it is a common ingredient in making mead.

Answer: Gypsum – obtained as a by-product from a sulfur dioxide scrubber system

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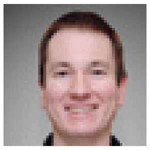

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Encoded Dissimilar Metal Weld Examinations

Structural Integrity continues to be a leader in the advancement of encoded, phased array ultrasonic examinations for the nuclear industry. We offer comprehensive DM weld assessment services through a dedicated, interdisciplinary team of experienced and talented professionals. Our team was formed to provide the critical, expert input needed to prepare for DM weld examinations, including contingency repair solutions. The team includes experts in ASME Code, materials, NDE specialists, stress analysis, fracture mechanics, and Welding to effectively plan and implement the required solution for your outage. We assisted in the preparation by developing component specific minimum thicknesses and detailed examination coverage assessments as well as flaw handbooks to efficiently disposition NDE results.

We partner with AZZ Welding Services Inc. to provide additional surface preparation and repair solutions.

We maintainan inventory of transducers, wedges, and inspection tooling to examine the various DM weld sizes throughout the industry, including complex geometries. In addition, we have fabricated full scale mockups to replicate field conditions to allow just-in-time crew training to maximize proficiency and to practice ALARA principles. Our in-house tooling design and manufacturing capabilities allows us to engineer solutions for challenging weld configurations and areas that have limited access and/or interferences. This allows our clients to conduct encoded examinations

at locations that were previously thought to be unable to inspect using encoded examination systems.

We perform DM weld examinations utilizing the *Procedure for Encoded, Phased Array Ultrasonic Examination of Dissimilar Metal Piping Welds* (Zetec OMNISCAN Raster 03), which was developed by the Electric Power Research Institute (EPRI) NDE Center and qualified through the Performance Demonstration Initiative (PDI) to provide a raster scan technique for the acquisition of circumferential flaw data instead of the electronic line scan technique previously used in the procedure. The raster scanning technique allows for the use of a smaller search unit footprint and may potentially provide improved examination coverage for configurations with limited access or components containing tapered surface geometries.

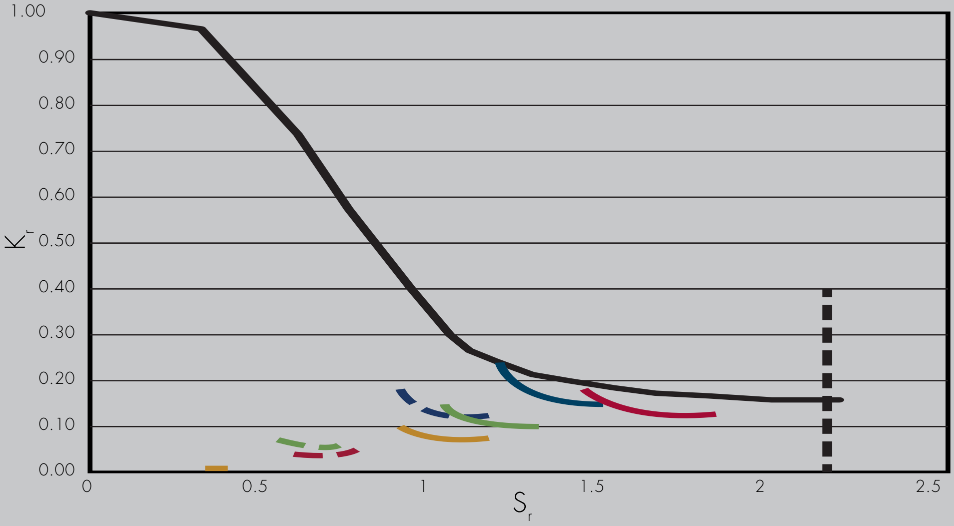
We were awarded contracts to examine Reactor Coolant Pump (RCP) suction and discharge DM welds, Safety Injection DM welds, and Reactor Coolant System (RCS) Cold Leg Drain, Spray and Charging systems for CE designed plants and Pressurizer DM welds for a Westinghouse designed plant.

Evaluation of a Weld Overlay Design Using A Failure Assessment Diagram

During routine inspection of an N5 feedwater nozzle dissimilar metal weld (DMW) of a BWR, an axial flaw was detected in the weld. The flaw was mitigated by applying a full structural weld overlay (WOL) repair consisting of Alloy 52M weld metal and using the gas tungsten arc welding process (GTAW). Because of the ductile nature and very high toughness of the Alloy 52M material, the limit load approach of ASME Code, Section XI, Appendix C was used for the sizing of the overlay. The use of limit load for the design of weld overlays for Alloy 52M material is supported by several industry studies.

In order to address other fracture failure modes such as failure by ductile tearing and brittle fracture, a failure assessment diagram (FAD) approach (see graph below) was used to evaluate the acceptability of the weld overlay design. For the FAD evaluation, the rules of the ASME Code, Section XI, Appendix H, which includes consideration of brittle fracture, elastic-plastic fracture mechanics (ductile tearing) and limit load failure mechanisms were used. The applicable stress combinations were used in combination with the materials J_R resistance curve to determine flaw acceptability at the end of the evaluation period.

The evaluation considered the presence of both a circumferential flaw (360° through the original pipe wall; the design basis for the full structural weld overlay) and an axial flaw. For both circumferential and axial flaws, several assessment points corresponding to the J_R resistance curve were determined and plotted on the FAD curve for austenitic steels in ASME Section XI, Appendix H. The use of the FAD curve in Appendix H, which was derived based on strength properties of stainless steel, is considered conservative in application to Alloy 52M since Alloy 52M has higher strength. All the assessment points were found to be below the FAD curve thus indicating the acceptability of a weld overlay with consideration to all the three possible fracture regimes.



FAD Plot for Circumferential Flaw

Oconee HPI Pipe-to-Safe End Butt Weld Leak

On November 11, 2013, Oconee Nuclear Station (ONS) identified a small Reactor Coolant System (RCS) pressure boundary leak on Unit 1, and initiated a Unit 1 shutdown. Visual inspection confirmed the leak was located on the 1B2 loop High Pressure Injection (HPI) line. ONS Unit 1 was operating at full power when the leak was identified, and a down power to 20% was commenced in order to characterize the leak and leak location. The measured RCS leak rate was 0.13 gpm at the time of beginning the down power.

NONDESTRUCTIVE EXAMINATIONS

In the immediate aftermath of the discovery of the leaking weld in the ONS Unit 1 HPI piping system, Duke Energy requested Structural Integrity to perform encoded, phased array ultrasonic (PAUT) examinations of similar locations on the remaining HPI lines at ONS Units 1 and 2. The welds were initially examined manually by Duke Energy site personnel utilizing an ASME Code, Section XI, Appendix VIII qualified procedure.

As there was no ASME Code, Section XI, Appendix VIII qualified procedures for the encoded PAUT examination of stainless steel piping welds of this diameter and thickness at that time, ONS and SI determined that performing a best-effort examination utilizing a system qualified for use to examine dissimilar metal (DM) piping welds was appropriate, due primarily to the difficulty associated with ultrasonically examining DM welds. We performed these examinations using PAUT technology as implemented by SI Procedure SI-UT-175.

Duke Energy contracted with Structural Integrity (SI) to perform several technical evaluations of the HPI line. These included:

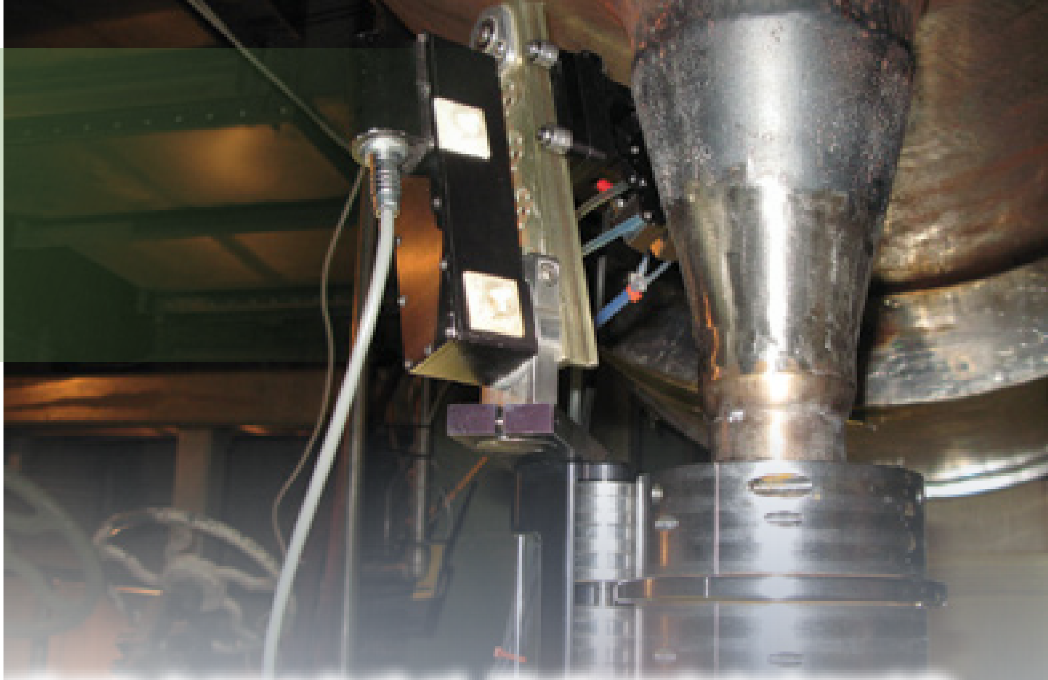
- conducting nondestructive examinations, supporting for the root cause analysis,
- addressing fatigue usage for the leaking weld, and
- performing vibration measurements and analyses.

The thickness and OD of the stainless steel similar metal (SM) HPI welds were within the qualified range of the DM weld procedure. By applying examination techniques which were specifically qualified for use on more challenging DM welds for the examination of austenitic stainless steel piping welds, we reasonably concluded that the examinations of the ONS HPI stainless steel welds were conducted using techniques that are considered more than adequate for the purpose.

Both the manual examination of record and the best-effort encoded examination detected no rejectable indications in any of the seven welds examined at ONS Unit 1 (3 welds) and Unit 2 (4 welds). However, all seven welds examined were found to contain small fabrication-related indications, all of which were found to be acceptable in accordance with the acceptance standards of ASME Code, Section XI, Table IWB-3514-3.

ROOT CAUSE ANALYSIS

The metallurgical analyses were performed by Duke Energy. The crack at the top of the pipe was measured to be 1-5/8 inches long on the inside diameter (ID) and 1/8



inch long on the OD. The crack path was planar, non-branched, and microstructure-independent, indicating that crack growth was driven primarily by mechanical loading high-cycle fatigue rather than thermally-induced stresses. Evidence for environmentally-induced crack initiation, e.g. due to intergranular attack or stress corrosion cracking, was not apparent. The observation of beach marks and fine striations on the fracture surface and the flatness of the crack through the thickness provided evidence that the cracking was due to high-cycle fatigue.

The circumferential crack orientation and location at the top of the pipe were consistent with loading caused by a flow-induced bending moment in the vertical direction. Three or four distinct sets of beach marks observed on the fracture surface are evidence of several periods of stable crack growth, which may correlate with periodic flow testing of the HPI lines.

When piping exhibits fatigue cracking with a completely circumferential orientation, cracking typically initiates on the OD where bending stresses are greatest, with propagation through the thickness to the ID. However, the observed crack initiated from the ID, an unusual but not unique situation, given the presence of a geometric discontinuity coinciding with the site of crack initiation. The geometric discontinuity and misalignment of the pipe and safe end are attributed by Duke Energy to progressive consumption of safe end material during multiple weld repairs. Geometric factors that intensify the stress on the ID can produce ID crack initiation from relatively small notches.

FATIGUE ANALYSES

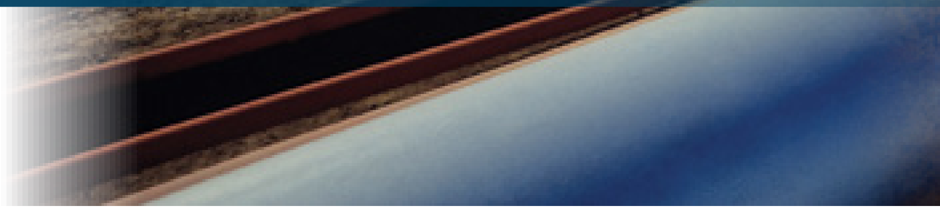
Duke Energy also asked us to update the fatigue usage analyses of this pipe-to-safe end weld, including environmentally assisted fatigue (EAF), to account for the as-found geometry. Because of earlier weld repairs, the taper on the safe end varied in length around the circumference, and the HPI piping was angled with respect to the nozzle. Since the repair would not fully restore the as-designed geometry, the as-found geometry was analyzed as a bounding configuration. Because of prior experience with this location, we were able to quickly model the as-found geometry, and perform finite element analyses to yield stress results. It was shown that fatigue usage was acceptable for the as-found geometry, even with EAF.

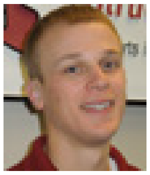
VIBRATION MONITORING AND EVALUATION

All four HPI lines were instrumented (the 1B2 line after repair) using a combination of accelerometers and strain gages. One tri-axial accelerometer measuring vertical and horizontal vibration was placed as close to the HPI pipe-to-safe end weld as was possible, given the presence of cold leg insulation. In addition, two strain gage channels were recorded for lines 1A1 and 1B2, with gages placed on the top and side of the piping (90° apart circumferentially), again as close as possible to the pipe-to-safe end weld. Figure 1 below illustrates this configuration on line 1B2. The strain gages were installed at Duke Energy's suggestion, and were used as an alternate means to evaluate the piping vibration, when the accelerometer data could not be used due to invalid signals. Acceleration and strain data were collected during full and split flow tests, as well as during the period from the start of the first reactor coolant pump through Mode 3. Seven representative recordings were examined, and their results compared to the acceptance criteria. In general, vibration levels were found to be below the criteria and, therefore, acceptable for long term plant operation. Strain data was found to be valid and pointing towards low stress levels in the newly reconfigured pipe-to-safe end weld. This lead to the conclusion that all vibration levels are safe for long-term plant operation.

Figure 1. Line 1B2 Vibration Monitoring Setup

DEMONSTRATING EFFECTIVE EXTERNAL CORROSION CONTROL





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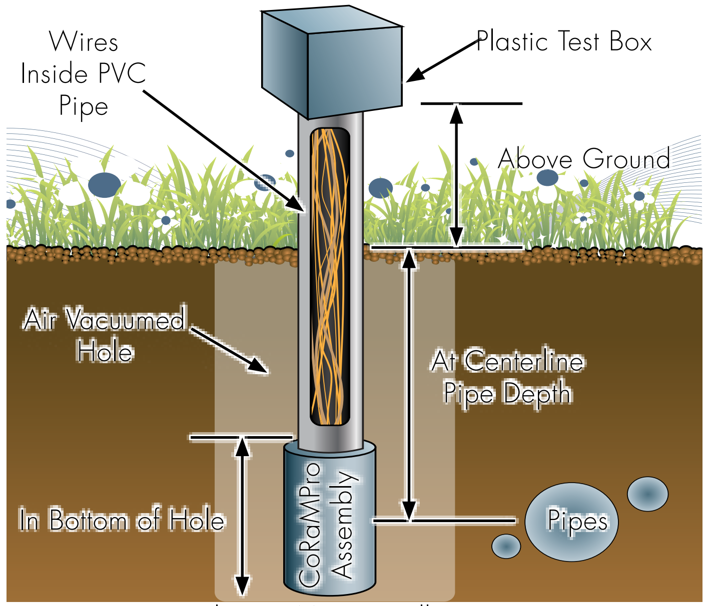
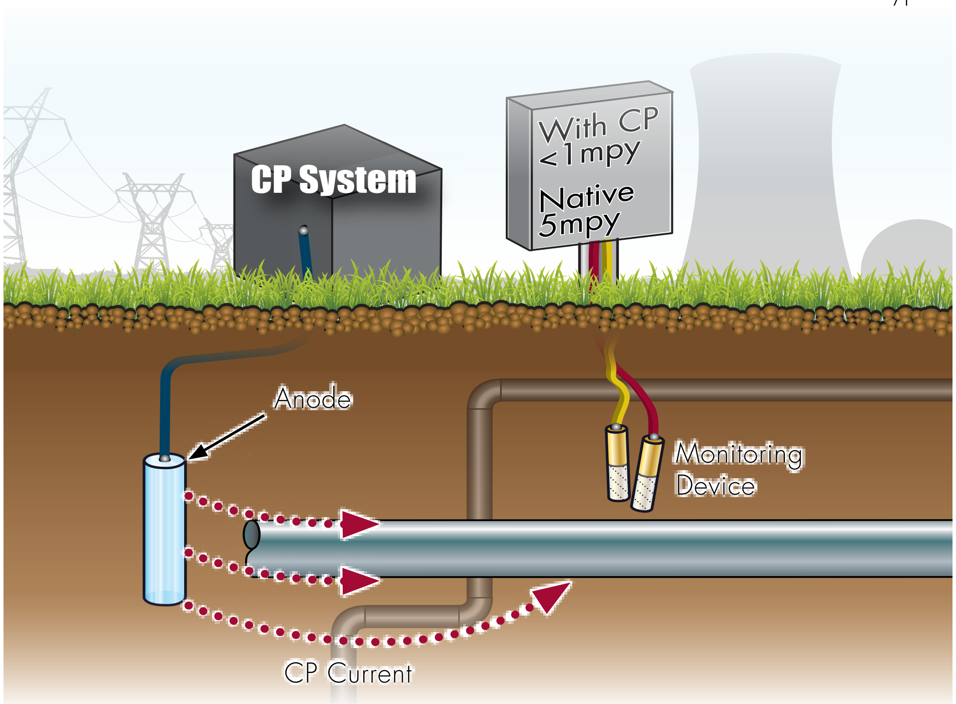
Power plants contain numerous assets that are both generation critical and important to safety. Degradation of these assets can result in expensive, disruptive, and potentially unacceptable consequences. As a result, utilities often establish a variety of aging management programs to maintain the integrity of plant assets.

Corrosion is a degradation mechanism that commonly threatens the integrity of plant assets. Corrosion is a naturally occurring phenomenon that involves the deterioration of a substance (usually a metal) or its properties because of a reaction with its environment. Therefore, in order for corrosion to threaten the integrity of plant assets, a susceptible material (e.g., steels) must be in contact with a corrosive environment (e.g., raw water).

Generally, corrosion monitoring at power plants is associated with the threat of internal corrosion due to process fluids. The results of monitoring for internal corrosion threats can often be extrapolated to other assets with similar operating conditions, fluid properties, and materials. Extrapolation of internal corrosion rates can be a very valuable decision making tool in long-term asset management plan development.



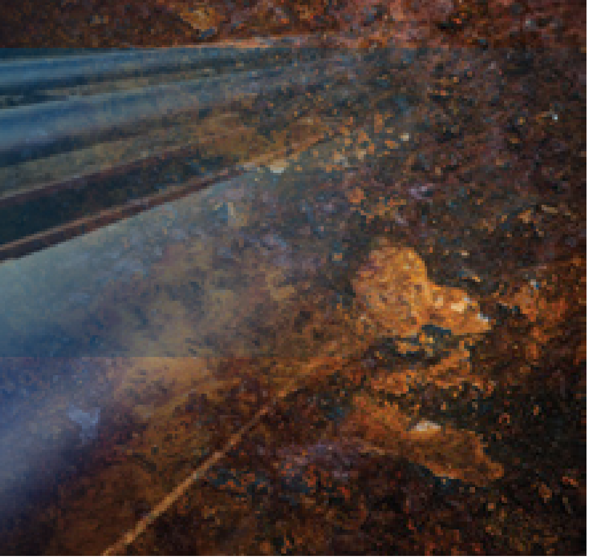
Typical CoRaMPro Installation Layout



Typical Monitor Configuration

Unfortunately, understanding the threat of internal corrosion is only one half of the challenge when developing long-term asset management plans for buried assets. The threat of external corrosion of buried assets is often mitigated through the application of coatings to isolate susceptible materials (e.g., steels) from a corrosive environment (e.g., soil).

Coating holidays (voids, discontinuities) commonly occur over the service life of various coated components. The threat of external corrosion becomes a concern when coating holidays expose assets to potentially corrosive soils. External corrosion rate monitoring is a valuable tool for assessing the corrosivity of soil at a site. Results of monitoring can then be used to evaluate whether or not additional



corrosion controls should be considered. Commonly, determining whether or not to install additional corrosion controls is done based on the metric of observed corrosion rates of 1 mil per year or less.

Cathodic Protection (CP) is commonly applied as an additional corrosion control measure in corrosive environments (>1 mils per year). Effective external corrosion control can be achieved at various levels of CP polarization depending on the environmental conditions. NACE SP0169 contains multiple criteria (e.g.; 850 mV instant off, 100 mV polarization) used to evaluate the adequacy of CP corrosion control. The criteria are intended for use in the absence of environment-specific data demonstrating the effects of CP polarization on corrosion rates.

Often achieving the NACE criteria for effective CP-proves difficult, if not unrealistic, due to the complexity of buried assets. In such situations, corrosion rate monitoring can be employed to demonstrate effective mitigation of external corrosion rates at various levels of polarization. Demonstrating effective corrosion control with CP applied is accomplished by electrically connecting the monitoring device to the CP system.

The concept and benefits of corrosion rate monitoring for sites with and without CP are rather straightforward. However, design of a corrosion rate monitoring solution for a specific situation requires many items to be considered such as monitoring program goal(s), type of material(s) to be assessed, changes in soil strata, and location of buried assets.

Of Mice and Memories

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A recent article in the journal "Nature" provides evidence that memories can be passed down to future generations. Well, that may be overstating it a bit.

Researchers shocked mice while exposing them to a specific odor until the mice associated the odor with pain. The descendants, who were not previously exposed to the odor or even exposed to the parent mice, displayed an obvious fear reaction when exposed to the odor. The exact mechanism for how this transfer of memories occurs is up for debate, but the researchers showed that the descendant mice were more sensitive to the odor by way of increased neurons known to detect the odor. There was no postulated theory on the link between the increased sensitivity to the odor and the fear reaction.

The study of mice presents no direct evidence to support or disprove the possibility of inherited behaviors in humans, but the authors cite anecdotal evidence that this may be the case.

For me, this seemingly small discovery raises more questions than answers. Could this help explain instincts? If this is really possible in humans, does that mean we are predisposed to certain behaviors? Can inherited behaviors influence more complex, abstract concepts such as money? Are environment and experience subordinate or controlling relative to inherited behaviors? Is it only fear that can be passed down, or do positive memories have the same effect? Could that explain why some people like dark chocolate? Could inherited behaviors help explain why, after generations of being relatively isolated from the rest of the world, two New Zealanders would jump off a bridge 150 feet above the Kawarau River attached to a bungee cord?

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FLEXIBLE PLANT OPERATIONS FOR THE US NUCLEAR FLEET

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For most of the 20th century, the majority of electricity generated across the United States was from fossil fuels and hydro-electric dams. Then in 1960, Dresden Unit 1 started to generate power as the first commercial nuclear power plant in the US. From that time through the 1980's more than 100 nuclear units were built and operated as "base load" units supplying power to the nation's electrical grid. Base load units are units that operate at roughly 100% of their rated power until they need to shut down for refueling or maintenance activities. While most of these plants were designed with the capability to operate over a broader power range, industry efforts have been focused on stable, full power operation.

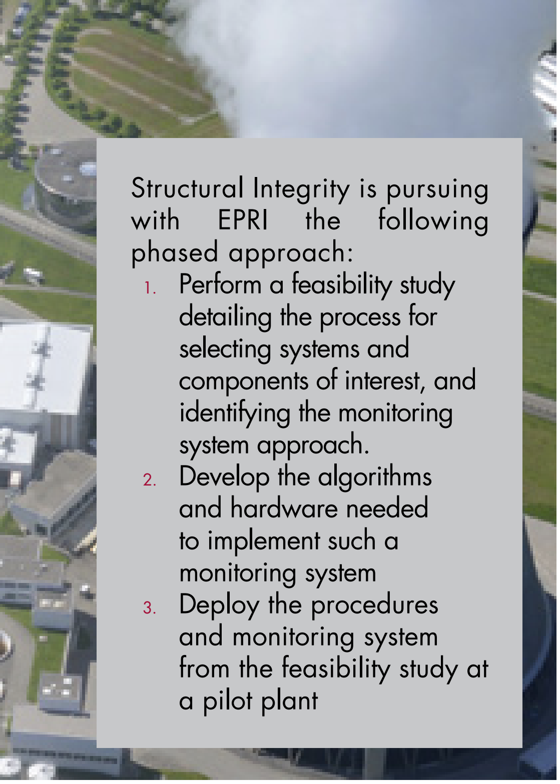
Starting in the early 21st century, there was more of an emphasis in the US to move away from fuel sources with higher carbon content and generate power using natural gas and renewable energy sources like wind and solar. The process of "fracking" or using high pressure water or steam to tap into large shale gas reserves has greatly reduced the price of natural gas, further increasing the amount of electric power generated using this fuel. Approximately 40% of current US electrical generation is from natural gas, wind and solar. What all this means is that the long-held practice of having nuclear plants be almost exclusively base load units is expected to change.

The U.S. nuclear fleet is anticipating the need to adjust plant output to match grid demand, or "load follow" and other activities referred to more generally as 'flexible plant operation.' Under this mode of operation, reactors operate for varying periods of time at intermediate power levels, exposing plant systems to operating conditions that have rarely been encountered for sustained periods of time in the past. Fluctuations in flow rates, pressures, temperatures, and other system parameters may result in additional low-cycle (thermal) fatigue on key components. Changing power levels can also have a number of effects on the fuel which will be discussed in a future article. These variations may also cause increased levels of vibration, resulting in high cycle fatigue. Therefore, prior to implementing load following operations, plants need the ability to identify and monitor conditions that cause fatigue damage or damage due to increased wear and tear in the components used to control plant power. Structural Integrity is currently working on an EPRI sponsored project to help plants identify susceptible components and manage the effects of flexible plant operation.

The impact of flexible plant operation may be likened to the changes that occur during power uprates, implementation of which has resulted in fatigue failures and significant reduction in the wall thickness of pressure boundary components at several U.S. reactor plants. Following a power uprate, plants begin steady-state operation at previously-unobserved levels. Conversely, flexible plant operation will result in much more frequent reductions within the licensed thermal power limit – levels which current plants observe most often during heat-up and cool-down cycles. Regardless, changes in flow rate, pump / turbine running speed, and valve position, among others, increase the likelihood of encountering a vibrational resonance, cavitation or high erosion condition. Many times these effects are the most predominant in secondary plant systems that are not normally monitored as closely as primary systems.

Every U.S. nuclear plant has implemented some method of monitoring low-cycle fatigue to comply with plant Technical Specifications and for license renewal. A majority of these plants utilize Structural Integrity's FatiguePro system, which was developed in cooperation with EPRI. FatiguePro processes relevant information from existing plant instrumentation, to ensure the fatigue usage for select components remain within specified limits. Similarly, many plants also use various forms of vibration monitoring, on a temporary or permanent basis, depending on the information required. These tests range from small-scale periodic surveillance of key components to large-scale, system-wide monitoring programs using tools such as our Versatile Data Acquisition System (VDAS), which is often deployed as part of power uprate implementations.

In order to support reliable plant performance, an evaluation should be performed to identify systems and components that may be vulnerable to operational variations. Using this information, plants could then monitor parameters associated with low- and high-cycle fatigue, as well as other damage mechanisms that may occur as a result of flexible plant operation. Monitoring systems such as FatiguePro and VDAS could be combined and modified to identify operating regimes which are likely to lead to damage, and provide timely guidance to plant personnel so that they can take appropriate action.



Structural Integrity is pursuing with EPRI the following phased approach:

1. Perform a feasibility study detailing the process for selecting systems and components of interest, and identifying the monitoring system approach.
2. Develop the algorithms and hardware needed to implement such a monitoring system
3. Deploy the procedures and monitoring system from the feasibility study at a pilot plant

The general approach to equipment selection is risk-based, with both safety and economic objectives considered.

We believe that any monitoring approach should make use of typical plant monitoring systems to the extent that they provide sufficiently reliable and timely notification to enable plant staff to take action that precludes significant equipment degradation or failure.

The monitoring strategy will consider how safe operating envelopes can be established with triggers providing real-time, or near real-time, feedback with suggested alternatives to plant staff. In the second phase of this effort, the monitoring system may need to be supplemented by additional hardware and/or software.

This is yet another of many challenges for the nuclear industry as plants change their operational modes from base loaded to load following. This will require operating plants to consider and prepare for the effects of load following on everything from the nuclear fuel, which will be covered in a later issue of News & Views, to balance of plant systems. We are working with EPRI to help plants prepare to meet the challenges of flexible plant operation and is available to help utilities efficiently manage the challenges.

FREE WORKSHOP OIL & GAS PIPELINE NDE

SIGN UP NOW SPACE IS LIMITED!

Pipeline operators face increasing challenges to ensure that their aging infrastructures will have the strength and integrity to continue operating safely and reliably. The ability to accurately detect, quantify, and evaluate defects is paramount to ensuring pipeline integrity. Structural Integrity is offering a free one-day workshop covering advanced non-destructive examination (NDE) methodologies to provide a greater understanding and overview of select NDE tools.

WHO SHOULD ATTEND

This workshop is intended for pipeline operator's integrity engineers, project managers, and those overseeing NDE projects.

WHAT YOU WILL LEARN

Our one-day workshop is designed to provide a basic overview and theory of operation as well as a hands-on demonstration about the latest NDE technology used in pipeline assessments.

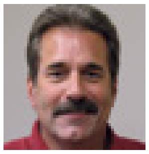
- **Advanced Ultrasonic Methodologies for Crack Sizing**
  Review of advanced ultrasonic NDE methodologies such as Phased Array UT and Time of Flight Diffraction, covering the fundamentals of the technology, operation, capabilities to size crack-like defects, and limitations.
- **Advancements in Guided Wave Technology**
  Learn about breakthroughs in long-range ultrasonic guided wave technology as it relates to pipelines and tanks.
- **Advanced Technologies for Internal and External Corrosion Mapping**
  See an overview of different ultrasonic phased array techniques and automated tools for mapping and quantifying internal corrosion defects as well as new structured light and laser-based technologies for external corrosion mapping.
- **Live Demonstrations & NDE Stations**
  Get a first-hand look at the latest NDE technologies in action. Our engineers and NDE specialists will demonstrate the technology and answer any questions you have about how it can benefit pipeline operators.

Wednesday, April 30, 2014
8:00 am – 3:00 pm (CDT)
Wyndham Houston West – Energy Corridor, Houston, TX

REGISTER NOW www.structint.com/ndeworkshops2014

LP STEAM TURBINE EVALUATION PROTOCOL (TIL) 1904

Shrunk-On Wheels of Unknown Material Toughness



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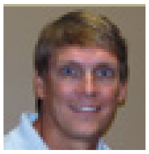

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In response to client requests associated with General Electric Company's recently issued Technical Information Letter (TIL) 1904, which pertains to built-up fossil rotors with early wheel materials, Structural Integrity Associates (SI) has developed analytical and material evaluation protocols to help utility owners assess the need for LP turbine rotor or wheel replacement. TIL 1904, which was distributed to utility owners of subject steam turbine equipment, indicates that some older rotors may have shrunk-on disks with marginal properties, and that such disks could contain or soon develop a critical crack that is below the detection threshold of GE inspection techniques. TIL 1904 further warns that an undetected critical crack could lead to wheel failure and provides several options for mitigating the perceived rotor issues. Those options include including wheel removal with reduced load operation, wheel replacement, or rotor and wheel replacement (using a non-shrunk-on design).

JUSTIFICATION FOR EXAMINATIONS AND ANALYSIS

As a result of the issues raised in GE's TIL 1904, and in response to specific client needs, our efforts have resulted in condition assessments of affected LP rotor wheels, including the development of critical flaw sizes and remaining life estimations, based on currently available information. The overall approach we implemented includes:

- analytical evaluations (including thermal modeling of temperature and stress gradients),
- material evaluations (via removal of small samples of disk material), and deterministic,
- probabilistic fracture mechanics evaluation of disks that are potentially susceptible to stress corrosion cracking (SCC).

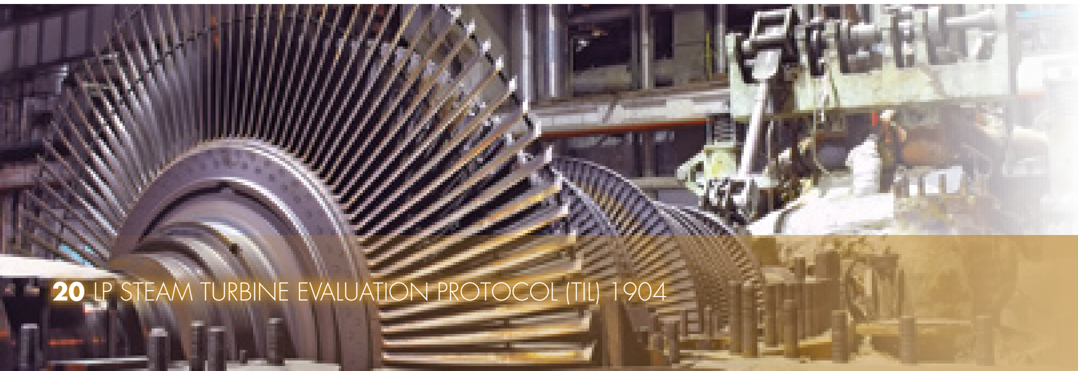
The results of such assessments are potentially helpful when owners must make important decisions regarding repair, replacement, or continued operation with appropriate follow-up inspections of their turbines.

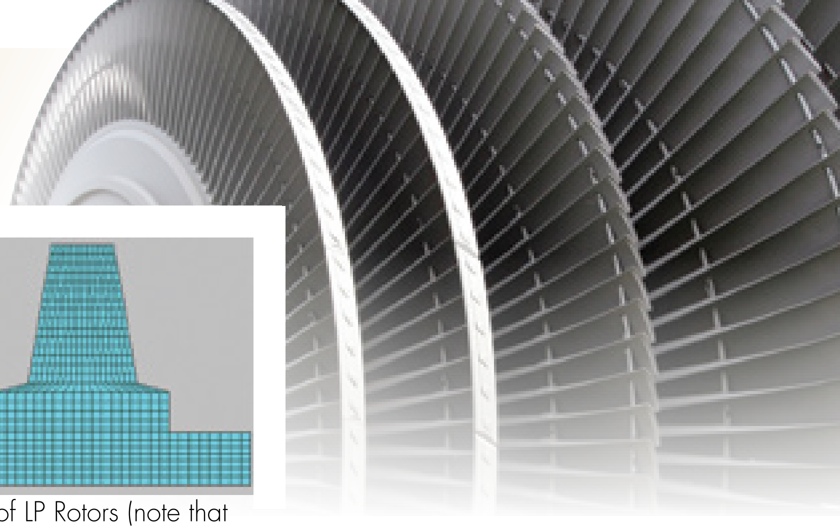
TYPICAL ASSESSMENT STEPS ROTOR/DISK GEOMETRY DEVELOPMENT

The initial steps of the analytical process include obtaining appropriate LP rotor and disk dimensions, and developing a finite element (FE) model, such as that shown in Figure 1. The models are based on tapered disk dimensions, rotor dimensions, and blade weights, which can be obtained through drawings, site measurements, or calculations (in the case of blade weights). The models also include dimensions of axial and radial keyways at the wheel bores of stages containing such geometric features, and are useful for evaluating stresses at these areas of concern. Generation of the model is accomplished through EPRI's SAFER-PC code (Stress and Fracture Evaluation of Rotors).

MODELING/STRESS ANALYSIS

SAFER-PC evaluates LP turbines using transient thermal-elastic finite element stress analysis, incorporating the mechanical and thermal loads experienced by the rotor during





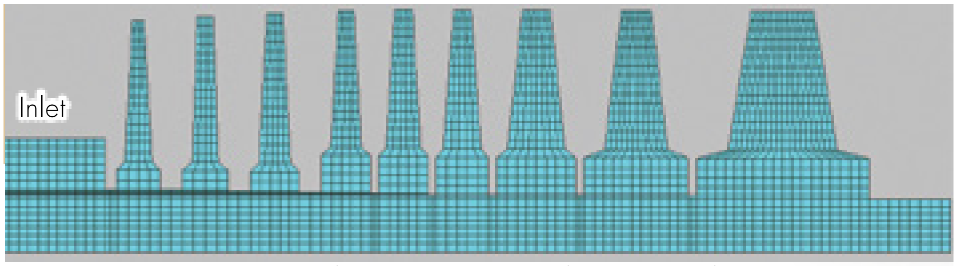
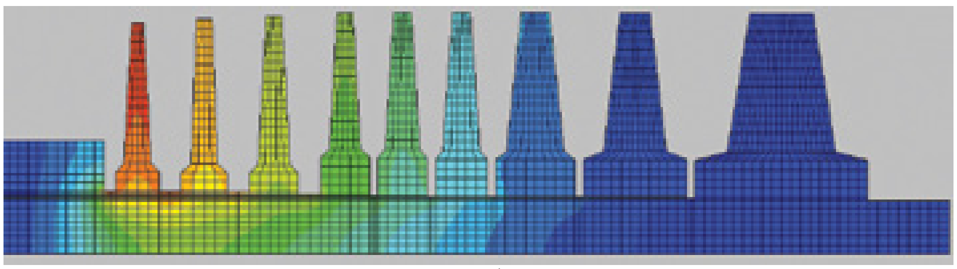
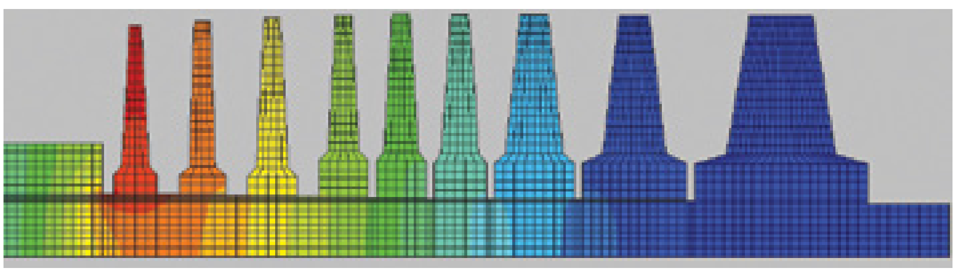


Figure 1. Typical SAFER finite element MESH for analysis of LP Rotors (note that small gaps between adjacent stages are a requirement of the SAFER modeling dueto boundary conditions for thermal transient analyses).

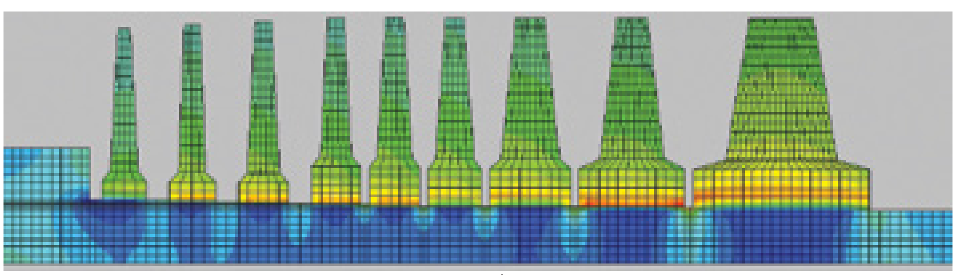


T = 5.0 hours

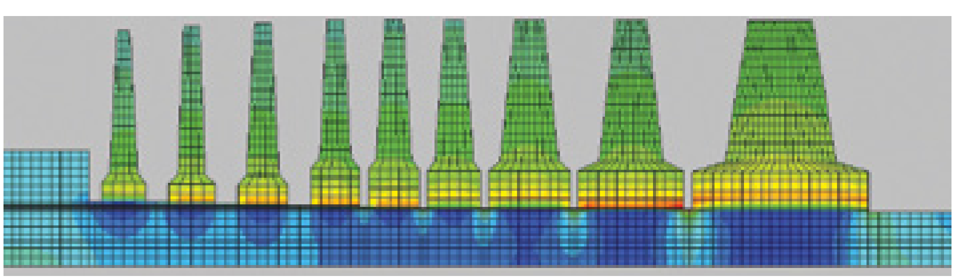


T = 16.4 hours

Figure 2. Typical SAFER Transient Thermal Results (Shown Qualitatively) During Startup.



T = 5.0 hours



T = 16.4 hours

Figure 3. Typical SAFER Stress Analysis Results (Distribution Indicated Qualitatively by Color) Under Various Conditions.

operation. Using operating data provided by the plant, analyses are performed for cold start, steady-state operation, and potential overspeed conditions, with shrink fit (assembly) loads included in the FE model. Evaluation of the cold start conditions are generally the most critical for near-bore defects since thermal stresses are highest while metal temperatures (and associated fracture toughness) are lower. Typical rotor temperature profiles during startup conditions are indicated qualitatively in Figure 2. Once the thermal transients are determined, SAFER stress analysis results are compared under initial startup conditions and during steady-state and overspeed conditions. Examples of start-up conditions are shown in Figure 3.

The most significant stresses in rotor forgings are oriented in the circumferential, or hoop direction, and act perpendicular to axially-oriented defects. Such stresses result from centrifugal loads (from rotor/disk rotation) and radial thermal gradients (through the wheel) that produce tensile hoop stress. With regard to circumferential stresses associated with the shrink-fit of the disks onto the rotor, increasing rotation speed tends to reduce such static installation stresses. As a result, total circumferential stresses at low and high speeds can be more similar than one might expect, although primarily generated from different sources. In any case, stresses from disk installation and turbine rotation are generally more significant than those from thermal transients, and modeling the entire LP turbine under multiple conditions allows for stage-by-stage assessment, which also takes into account disk material and potential for susceptibility to stress corrosion cracking (SCC).

Continued on next page

LP STEAM TURBINE EVALUATION PROTOCOL (TIL) 1904

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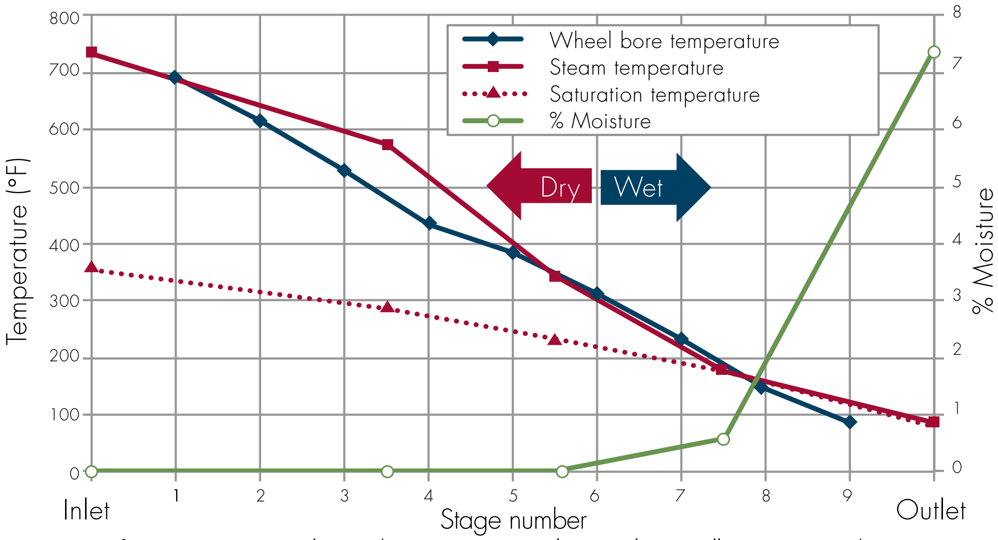

Figure 4. Typical LP Turbine Steam Quality Analysis (Full Power Conditions)

SCC RISK EVALUATION

A review of heat balance data for the generating station can provide LP turbine operational (steady-state) conditions that are useful for assessing SCC risk. For example, a typical evaluation of steam quality under steady-state conditions is shown in Figure 4. SCC requires an appropriate combination of tensile stress, susceptible material, and aggressive (corrosive) environment, and previous industry experience has demonstrated the susceptibility of Cr-Mo-V and Ni-Cr-Mo-V rotor and disk steels to SCC. The aggressive environment occurs in the phase transition zone (PTZ), where expanding superheated steam transitions to saturated steam and condensation can result in thin films on component surfaces. These films can concentrate steam impurities and set up conditions that lead to pitting and stress corrosion cracking.

In general, corrosion damage in an LP turbine is not limited to periods of operation, but can occur during shutdown when surfaces with remnant deposits are left unprotected or when new contaminants are inadvertently introduced to the turbine. Damage such as pitting and SCC can be avoided with good (clean) water chemistry practices and carefully planned maintenance practices, but quantification of the effects of contamination has proven to be difficult and impractical. Nonetheless, evaluation of the steam quality based on design and operating conditions can provide information on stages that are most susceptible to SCC.

Regular inspection intervals are considered good operational practice even in the absence of active degradation mechanisms like SCC. Within an LP turbine, stages that run under "wet" conditions are evaluated using qualitative risk based on known influencing factors along with the operational and maintenance practices of the turbine. Since prediction of crack initiation is not practical, analyses are based on an assumption of existing defects that might propagate via SCC. Further, the possibility of significant shifts of the PTZ within the turbine, such as when operating under non-design conditions, needs to be considered when selecting inspection intervals. In particular, a shift of the PTZ toward the steam inlet can add significant risk due to the dependence of SCC growth rates on temperature.

For steam turbine rotor steels, SCC growth rates are generally considered to be independent of stress intensity above a certain threshold value. For example, at 320 °F (160 °C), the stress intensity threshold is about 20 ksi-in$^{1/2}$ (20 MPa-m$^{1/2}$), with typical SCC crack growth rates of about 1 inch/year (2.54 cm/year) or less. The growth model is therefore based on material yield strength, operating temperature, and a constant that is material dependent. In all cases, however, avoiding poor water chemistry and

using proper turbine protections during layup are encouraged practices for mitigating SCC.

CRITICAL CRACK SIZE EVALUATION

In the case of shrunk-on disks that are the subject of the present analyses, the critical crack size for each disk is estimated by calculating the applied stress intensity, K_1, as a function of crack size (using the SAFER-PC code). Flaws are assumed to be axially oriented and surface-connected, and are either located at the wheel bore (if no keyway is present), or at the bottom notch of the keyway where stress intensity is expected to be highest. Temperature and stress results for each stage are used in combination with the fracture mechanics calculations to determine the critical crack size (corresponding to the assumed crack size that yields a stress intensity that is equal to the fracture toughness of the material, K_{IC}).

DISK MATERIAL PROPERTIES

As General Electric's TIL 1904 pertains to shrunk-on steam turbine disks that may have marginal material properties, evaluating the properties of disks in situ is desirable. Unfortunately, common methods of testing disk materials are destructive and require substantial quantities of metal. In order to obtain data on shrunk-on disks that are intended to remain in service, shallow "scoop" samples are removed from the disk surface regions using specially designed equipment. Analyses of the effects of scoop sample removal on stress within the disks have shown that the material removal has a minimal effect. The scoop samples, which are about one inch in diameter and approximately one-eighth inch in thickness, are then prepared for two types of indention testing, which provide estimates of hardness, yield strength, tensile strength, and fracture toughness.

Since fracture toughness is a material property that represents a material's ability to resist unstable crack propagation, obtaining real data on material toughness is valuable. Figure 5 shows the approximate range of expected fracture toughness for post-service Cr-Mo-V materials (as a function of T-FATT, which is essentially the test temperature minus the Fracture Area Transition Temperature). Note that for materials with unknown properties, the toughness could reside on the lower shelf, which is about 40 ksi-in$^{1/2}$. If data from testing indicates higher toughness values, the calculated critical crack size increases, which provides for justification of continued operation or alternative inspection intervals. Typical results for stress intensity at assumed cracks in different stages in an LP turbine are shown in Figure 6. When the calculated stress intensity for a crack reaches the value of K_{IC}, indicated by the gray dotted line, the critical crack size is identified on the x-axis. This figure shows that having to assume a reduced fracture toughness value for the material (i.e., lowering K_{IC}) reduces the critical crack size for each stage.

INSPECTION OF THE WHEEL BORE/ KEYWAY AREAS

The linear phased array (LPA) ultrasonic inspection approach provides for enhanced

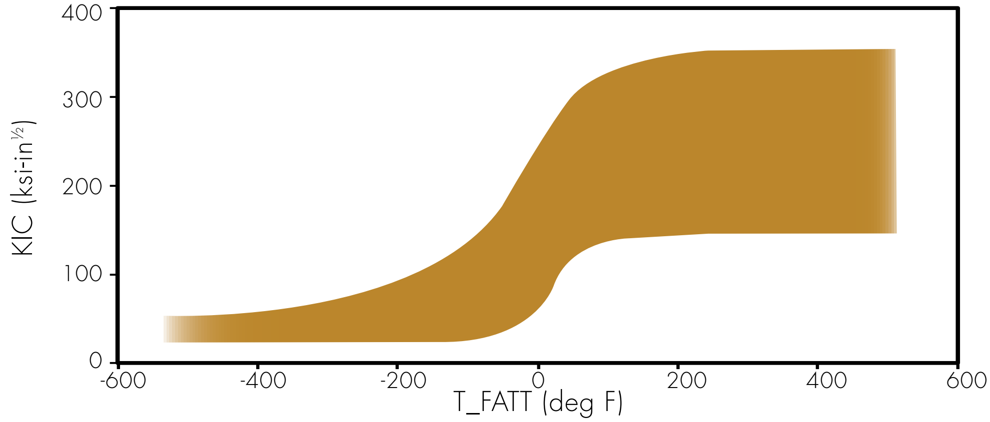

Figure 5. Approximate Range of Expected Fracture Toughness for Post-Service Ni-Cr-Mo-V Disk Materials

LP STEAM TURBINE EVALUATION PROTOCOL (TIL) 1904

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detection and sizing of cracks in the wheel bore and keyway areas. The LPA search unit contains a linear array of multiple independent ultrasonic transducer elements, each supported by its own pulser/receiver. Each array element is sequentially pulsed at very precise intervals, or “phased”, so that the propagating wave from each element arrives simultaneously and in-phase at a given point in the wheel bore.

An automated disk bore examination is performed for the detection of discontinuities propagating from the wheel bore, keyways, and hub face. A multi-element search unit is directed at a normal angle to the bore for the detection of radial-axial oriented cracks at the bore surface and keyways. In addition, the beam is directed toward the bore with the beam aimed tangential to the bore surface in a clockwise and counterclockwise direction. The scanner provides for multiple degrees of freedom that permits the manipulation of the search unit over the disk surface. The scanner end effector assembly, which supports the search unit, is positioned on the wheel to allow full coverage of the wheel bore region. The wheel bore region is scanned by electronically steering the ultrasonic beam through a pre-determined beam angle range in small incremental angles and dynamically focusing the beam at the bore surface. The acquired LPA data is digitized and saved for each encoded position. Analysis of the data identifies relevant flaws which are then sized using tip diffraction and/or sector angle measurements. The resulting data is used as an input for the SAFER-PC analysis.

OVERALL PROGRAM GOALS

With respect to shrunk-on disks in older turbines, the ultimate goals of these analyses are first to evaluate the level of risk associated with continued operation of the turbine, and second to evaluate a reasonable inspection interval if continued operation is warranted. These goals are addressed by running deterministic and probabilistic lifetime evaluations based on the analytical and materials evaluations discussed above and by applying a predictive SCC crack growth analysis with an assumed initial crack size that is equal to the detection limit of non-destructive examination methods. Through the use of appropriate design and operating condition inputs for individual stages, the most critical stages can be evaluated and the life-limiting conditions can be discussed.

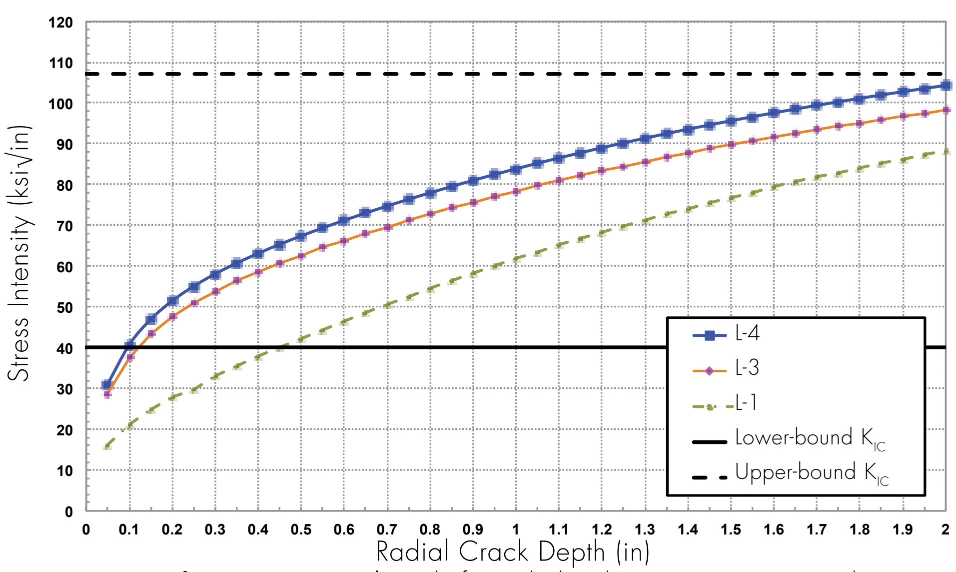
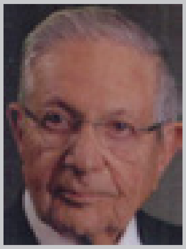


Figure 6. Typical Results for Calculated Stress Intensity vs Crack Size in LP Turbine Disks (Under Overspeed Conditions).

RELEVANCE/APPLICABILITY FOR OTHER TURBINE COMPONENTS

For companies that own or operate steam turbines, it should be noted that many of the methods used for evaluating the LP turbine stages that are the subject of GE TIL 1904 are commonly implemented in evaluations of other turbine components, such as blade attachments, generator dovetails, solid rotor forgings and rotor bores. In particular, analytical software such as SAFER-PC and pc-CRACK, SCC propagation modeling, material sampling and testing, and overall deterministic and probabilistic analyses are applied in various ways to provide key technical information to assist with turbine asset management.

SID BERNSEN WINS ASME AWARD



SID BERNSEN

ASME HONORS SIDNEY BERNSEN FOR STANDARDS LEADERSHIP

Congratulations to Sidney Bernsen, winner of the 2013 Melvin R. Green Codes and Standards Medal from the American Society of Mechanical Engineers.

Dr. Bernsen, an ASME Fellow and Ph.D. consultant to Structural Integrity's ANATECH division, was recognized for outstanding leadership and professionalism in developing and advancing ASME codes and standards. He is considered a pioneer in the development and standardization of quality assurance and nuclear risk management programs for power plants.

Over a 60-year career (and counting), Dr. Bernsen has played an active leadership role in the American Nuclear Society, the International Organization for Standardization, the American National Standards Institute, and ASME.

He is a founding member of the ASME Board on Nuclear Codes and Standards, where he served continuously for more than 38 years. He was the first chair of the ASME Standards Committee on Nuclear Quality Assurance and the Committee on Nuclear Risk Management, where he continues to play a leadership role.

Please join us in congratulating our distinguished colleague!

US WOMEN IN NUCLEAR

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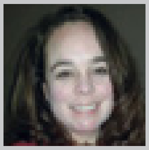

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Structural Integrity was proud to sponsor the US Women In Nuclear (USWIN) Region II conference in February in Wilmington, NC. The conference was hosted by GE Nuclear and drew approximately 200 attendees, including Aparna Alleshwaram and Jennifer Correa, both engineering consultants from SI.

USWIN is an industry-wide organization, established in 1999. It has over 6,000 members in four regions across the US (www.winus.org). Membership includes professionals from across the nuclear industry, and at all levels within the industry. The objectives of the organization are to support an environment in the nuclear industry in which women and men are able to succeed, provide a network through which women and men can further their professional development, and to provide an organized association through which the public is informed about nuclear energy and technologies. The focus of the organization is on women in the nuclear industry, but membership is not restricted to women. The development opportunities are relevant to both genders.

The conference included many relevant topics focusing both on technical and personal career development. Technical development topics of particular interest were the "Panel on New Builds" and the" Lifecycle Management of Aging Plants". The personal development topics which were especially relevant were "Leading Across the Generations" and "Awakening the Leader in You". USWIN encourages its members to take leadership roles in their own organizations and these topics are designed to provide tools for leadership. With attendees from such a wide variety of areas within the nuclear industry, the conference provided excellent networking opportunities for meeting representatives from NSSS vendors, utilities, consulting firms, EPRI, DOE, and the NRC. Attendees were able to interact with people that they may not encounter otherwise and thus, further their understanding of the industry as a whole.

The National Conference will take place from July 27-30 in Boston, MA.

Seismic Qualification of Control Cabinets for New Nuclear Power Plants

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Structural Integrity recently completed the seismic qualification by analysis of cabinet enclosures that house various nuclear power plant control system electrical equipment. The cabinet enclosures contain electrical equipment that is categorized as Seismic Category I; therefore, the structural evaluation of the cabinet enclosures and their anchorage must consider the effect of seismic loads in combination with other normal loads. It is necessary to demonstrate that the cabinet enclosures are structurally sound when subjected to an Operating Basis Earthquake (OBE) and a Safe Shutdown Earthquake (SSE).

BACKGROUND

The seismic qualification by analysis is applied to new cabinets, which have not been qualified by testing or other means, for use in nuclear power plant applications. It is a cost-effective way to assess the performance of the cabinet enclosure due to seismic loads without having to perform testing of the fully integrated cabinet. Design and integration of new cabinets involve multiple disciplines and is repetitive process that can take several design cycles. The analytical approach is an effective tool to evaluate cabinet seismic performance and to test the effectiveness of multiple cycles of proposed design changes without the need to test the integrated cabinet. The cabinets are either floor-mounted or wall-mounted. Floor-mounted cabinets are are anchored to the floor at the base at four corners.

Floor-mounted cabinet enclosure frames are typically bolted structures constructed from pre-fabricated cold-formed steel members. Side panels made of cold-formed sheet metal cover the cabinet frame on the sides, while the front and back of the cabinets are fitted with full-length double-doors that can be opened and closed for service entry. Wall-mounted cabinets are typically constructed from sheet panels, welded at the seams, anchored to the wall at four corners, and are of varying sizes. For wall-mounted cabinets, only the front side is fitted with a single door or double doors. All electrical equipment is mounted inside the cabinet, using mounting rails and reinforced mounting sheet panels. Power is supplied to the equipment through cables and wiring that run along cable wire trays mounted inside the cabinet. Floor-mounted cabinets, including the in-cabinet electrical equipment, weigh between 1150 lbs to 1400 lbs; wall-mounted cabinets range in weight from 120 lbs to 360 lbs.

The structural evaluation by analysis addresses the cabinet frame structural members, panels, and connections, but not the electrical equipment. The functionality of the electrical equipment is demonstrated by shake table testing performed by a testing laboratory and is not part of the qualification by analysis.

APPROACH

The general approach is to use a finite element analysis to obtain member stresses and connection forces for each type of cabinet due to the combined effect of seismic and normal loads. The member stresses and connection forces are then used to perform design checks for comparison with allowable values established in applicable Codes and Standards. The AISI Cold-Formed Steel Manual is used as the basis for the structural evaluation, with additional guidance from the ASCE Steel Design Manual (Allowable Stress Design), and ANSI N-690 Standard.

Seismic loads, Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE), are defined in terms of smoothed, broadened acceleration spectra at different floor levels where the cabinet enclosures are located. A response spectrum analysis is used to determine stresses and forces in the cabinet structural members and connections. A response spectrum analysis takes into account the dynamic characteristics of the cabinet structure and is preferred over an equivalent static analysis approach. To account for the different acceleration spectra at various floor levels, the analysis takes a conservative approach using enveloping spectra from different locations. Floor spectra are typically provided for damping values ranging from 2% through 10%. For bolted cabinet enclosures, appropriate damping values are 2% for OBE and 3% for SSE.

The process is repetitive in that preliminary designs are first evaluated to obtain the initial results and determine whether or not the structural acceptance criteria are met. When the acceptance criteria are not met, mitigations are implemented to improve the performance of the structure, and the mitigated structure is re-evaluated repeatedly until all the critical components are structurally adequate and meet established acceptance criteria. The mitigations that are implemented are also intended to reduce large dynamic responses at equipment attachment points for the purpose of determining required response spectra (RRS) for equipment testing.

FINITE ELEMENT MODEL

For a particular type of cabinet configuration, the cabinet framing is of a common design, and only the mounted equipment pieces inside the cabinets are different in weight and in the mounted locations of the equipment. This characteristic of a common design in the cabinet structural frame in each cabinet type is used as the basis for a cost-effective screening approach by analyzing only one or two bounding cases within the group without the need to analyze each cabinet individually, and applying the bounding case results to all cabinets within the group.

A bill of materials for each cabinet is used to determine the weights of the internals for each cabinet. A comparison is made of the weights of all the individual cabinets, including internal weights, for one cabinet type. Two cabinets, heaviest and lightest, are selected for detailed analysis and evaluation. The two bounding cases represent the complete range of cabinet response frequencies within the group. In cases where there are only small differences in weight between the individual cabinets, only one bounding case is sufficient for analysis and evaluation since the dynamic characteristics of all the individual cabinets would be similar.

The ANSYS software package is used for the finite element analysis. Beam elements are used to model linear frame members, and shell elements are used to model sheet panels and gusset plates. Figures 1, 2, and 3 show a typical floor-mounted cabinet model. Cabinet doors, cable trays, and fireboxes are considered non-structural and do not account for any stiffness contribution; however, their masses are included in the analysis. Weights of external cables entering the cabinet, internal cables and wiring, are included and distributed to the cable tray attachment locations in the cabinet frame. The weight of the cabinet frame is included by defining appropriate mass densities. Equipment pieces are modeled as eccentric lumped masses at their attached locations inside the cabinet.

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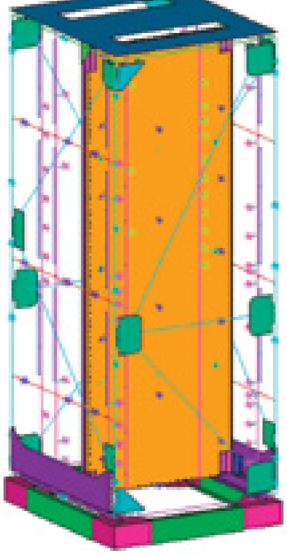

Figure 1. Typical Floor-Mounted Cabinet Finite Element Model

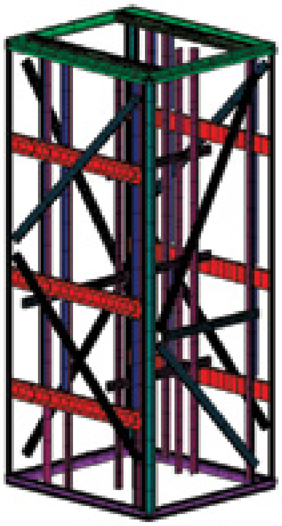

Figure 2. Frame Structure for a Typical Floor-Mounted Cabinet

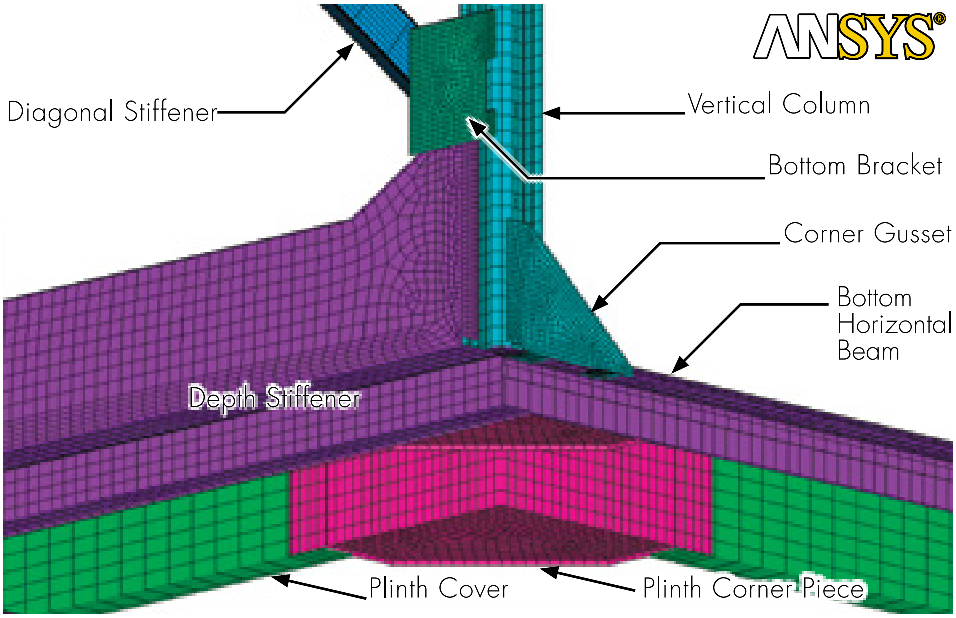

Figure 3. Finite Element Modeling at Corner

ANALYSIS AND STRUCTURAL EVALUATION

A modal frequency analysis using the ANSYS software is performed to determine the structural frequencies and mode shapes (Figures 4, 5, and 6). This is followed up with response spectrum analyses by applying the enveloped acceleration floor spectra for two horizontal directions and one vertical direction, respectively. In the response spectrum analysis, multiple modes are combined by the Complete Quadratic Combination (CQC) method available within the ANSYS software. The directional combination of the three earthquake component directions is by square root of the sum of the squares (SRSS). Modes above 36 Hz are considered rigid based on the shape of the floor acceleration response spectra. Structural mass that is not completely captured (missing mass) is accounted for as static mass subjected to the appropriate spectral acceleration. The response spectrum analysis results are combined with the missing mass effects and with the effects of other normal loads for the worst case impact on the structural forces and stresses.

The results from the finite element analysis are forces and stresses at various cabinet frame members and connections. These are used to perform structural evaluation to determine if the members and connections meet applicable acceptance criteria. Allowable stresses due to tension, compression, shear, bending, pullout, and bearing are established for members and connections using yield stress and ultimate strength for the part being evaluated. Calculated forces and stresses from the analysis are compared to the appropriate allowable values. The design is acceptable if the allowable values are not exceeded. During the evaluation process, if the allowable values are exceeded, mitigations are provided to reduce the calculated stresses. Typically, the mitigations involve stiffening the support base plates, adding bracing, stiffening the mounting panels and mounting rails in such a way that improves the dynamic response of the cabinet.

The analysis steps and structural evaluation, resultsincluding mitigations, are documented in summary reports and in calculation packages that support the conclusions of the summary reports.

CONCLUSION

An analytical method has been effectively used in the seismic design of new cabinets undergoing several cycles of design and integration. The analytical approach is an effective tool to evaluate cabinet seismic performance and the effectiveness of mitigations without the need to test the cabinet.

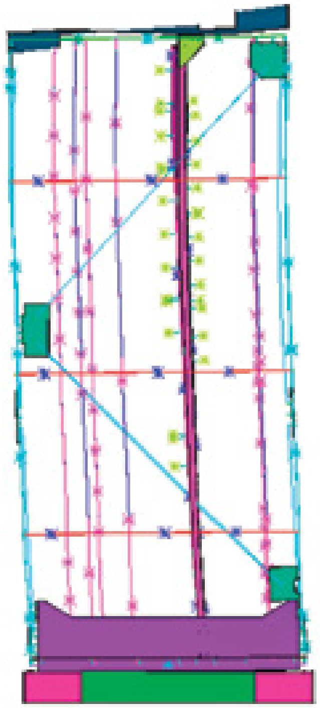

Figure 4. Front-to-Rear Mode, Floor-Mounted Cabinet

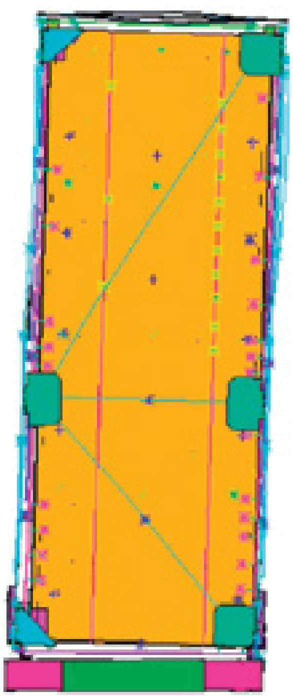

Figure 5. Side-to-Side Mode, Floor-Mounted Cabinet

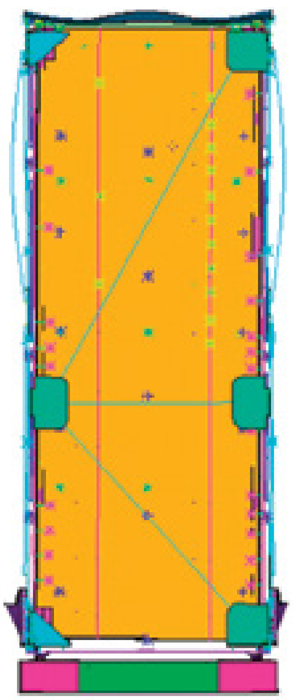

Figure 6. Vertical Mode, Floor-Mounted Cabinet

Strategy, Planning and Implementation of Seismic Margin and Probabilistic Risk Assessments


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Structural Integrity (SI) and SI-ANATECH, together with our partners ENERCON (including Maracor, a Division of ENERCON), SC Solutions, and Fugro Consultants, are assisting clients with strategy, planning and implementation of studies and projects to respond to the Seismic 2.1 information request developed by the NRC's post-Fukushima Near Term Task Force (NTTF). As part of this Seismic 2.1 response team, SI and its partners implement various elements of the NRC and industry approved Screening Prioritization and Implementation Details (SPID) guidance, as well as EPRI's associated Augmented Approach for an Expedited Seismic Evaluation Process (ESEP). We also separately provide related services that encompass all aspects of the NTTF (seismic and flooding), as well as the closely related industry (NEI) FLEX Initiatives and associated NRC mandates (hardened vent provision, and spent fuel pool integrity).

To ensure highest relevance of our services, we closely follow the development and progress of the NTTF and FLEX programs through industry peer calls, NRC information lists, and client visits. Whereas our assistance to clients supports their implementation of available and consistent industry resolution approaches, we also understand that each client has specific preferences and needs that reflect their own particular circumstances in implementing associated procedures and reviews, such as for the SPID screening, and any related studies that may be required.

Regarding the NTTF Seismic 2.1 information request, Structural Integrity and its partners are helping clients achieve significant benefits in the following areas:

GMRS REVIEWS AND SENSITIVITY ANALYSES

The team's GMRS reviews give clients confidence regarding the inputs used to develop their ground-motion response spectra (GMRS), including, in some cases, alternative judgments or adjustments in need of further evaluation. We assess the available geotechnical, geological and geophysical information for each site, and check the development of shear-wave velocity (Vs) profiles, as well as dynamic material properties of the rock and soil materials underlying a site, and we confirm in detail the implementation approach for developing probabilistic site amplification factors. We also develop and implement sensitivity studies to determine the potential impact of variations in model parameters and assumptions; as a result, clients are able to obtain needed insights and to report results confidently to the NRC.

IPEEE ADEQUACY EVALUATIONS AND REVIEWS

SI and its partners have engineers involved in the past development, implementation and review of studies for the earlier IPEEE (individual plant examination of external events) program. In general, IPEEE results serve as an important foundation for resolution of NTTF Seismic 2.1. For clients who can apply their existing IPEEE to screen-out from further evaluation, according to the SPID, a confirmatory evaluation of the continued applicability (and, where necessary, enhancement) of the IPEEE is required. We are supporting clients by performing either the IPEEE adequacy evaluation itself or a third-party review of the client's evaluation.

SEISMIC RISK ESTIMATES (CDF, LERF)

To help clients who want to better understand the general levels of seismic risk at their plant(s), without actually performing a detailed seismic probabilistic risk assessment (SPRA) or seismic margin assessment (SMA), we develop estimates of seismic risk metrics, including core damage frequency (CDF) and large-early release frequency (LERF), using the client's best available seismic hazard and capacity results. For clients having existing IPEEE studies, and new seismic hazard curves, we are

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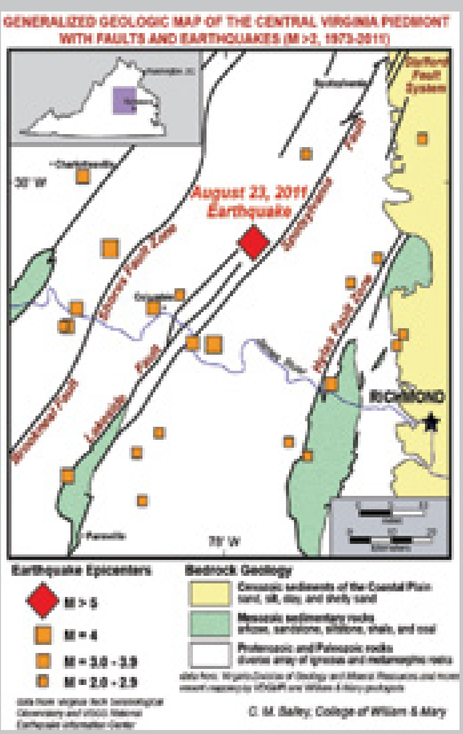
updating component capacity (fragility and/or HCLPF) results, updating and applying existing systems information, developing approximate plant-level fragilities, and quantitatively combining the capacity and hazard information to develop the risk estimates. As this streamlined approach introduces more uncertainty in risk results versus performing a detailed SPRA or SMA, we also develop the entire probability distributions for the risk metrics, which incorporates the additional epistemic uncertainty of applying the approximate approach.

In general, we study the available hazard and capacity information in more depth as compared to the simplified evaluations of risk metrics performed by the industry and NRC (GI-199), and correspondingly, we provide clients with an improved basis for making



decisions concerning subsequent level and detail of analyses. Clients find these results useful, for instance, in planning the most cost-effective detailed SMA or SPRA studies, or for even demonstrating that such detailed studies may not be warranted. Accordingly, the estimates are useful in deciding how to better allocate limited resources, potentially saving the client from major expenditures that are not truly necessary or are not apt to produce meaningful benefit.

TECHNICAL ADVISORY SERVICES

Engineers with SI and its partners include experienced advisers and experts in decision analysis; program development; communication of critical findings, insights and technical guidance to management; and high-level reviews. Clients are leveraging the team's depth of experience, as well as breadth of knowledge and contacts, to make well-informed choices on strategy and resource utilization.

Clients find that they can count not only on the technical robustness and reliability of our advice and insights, but also assurance that we develop feasible and cost-beneficial recommendations.

SITE-SPECIFIC ASSESSMENTS

In contrast to the probabilistic seismic hazard assessment (PSHA) studies developed for plants in the western US, the PSHA studies and related GMRS results developed for the central and eastern US (CEUS) are more limited as their site-specific detail. Although this situation is appropriate considering the generally greater level of seismicity in the western US, for some plants in the CEUS, it is advantageous to undertake an increased level of site-specific detail in their PSHA and GMRS studies. In some cases, it is possible that investing in a suitably designed, site-specific study can eliminate or reduce major expenditures, avoiding work that is not truly needed.

Leveraging our experience and roles in a variety of significant PSHA studies, we advise clients concerning the potential benefits of site-specific PSHA, site field investigations, and other elements of site-specific analysis.

Where an increased level of site-specific analysis is determined to be warranted, We work with Fugro to plan a suitable program for enhancing the site-specific applicability of a client's PSHA and GMRS. Together, we determine the appropriate and justified bases and approaches for improving seismic source modeling, ground-motion models, and site-response amplification models, in order to make them more site-specific, and hence, better justified as the basis for subsequent decision making.

One potential element of improvement for site-response amplification modeling is to conduct suitable field investigations. Fugro has well-established, industry-leading capabilities in performing such investigations, which complements our related expertise and scope of services. Additionally, SI and Fugro perform complementary internal review of project work, or third-party reviews of site-specific assessment work and performed by others.

IMPLEMENTATION OF ESEP, SMA AND SPRA

ENERCON has extensive hands-on knowledge and experience with most nuclear power plants and utilities in the US, and, with SI and other teaming partners, is uniquely positioned to efficiently provide technically complex seismic evaluations (ESEPs, SMAs, SPRAs, and similar) while minimizing the impact on overall plant operation. The team provides services with breadth and depth of seismic expertise, tailored to minimize the burden on utility resources. SI's engineers have previously worked with ENERCON on client needs pertaining to NTTF Seismic 2.3 walkdowns. We are similarly working as a team with ENERCON on ESEP work. Additionally, we are proposing together on subsequent detailed SMA and SPRA studies that are expected to be undertaken by some clients. SI teaming partners are actively engaged in ongoing SPRA activities with multiple clients, and can leverage that experience for improved efficiency and dependable precedence.

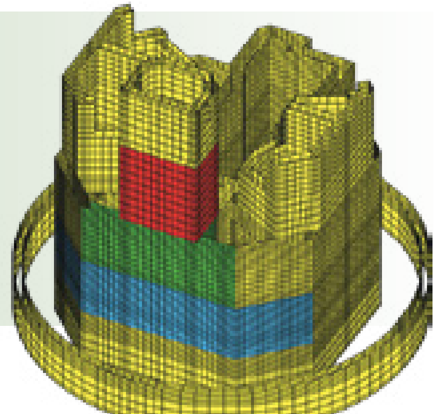
In addition to providing support on seismic screening analysis and associated seismic walkdowns, SI performs the additional walkdowns and information gathering needed as input for performing detailed HCLPF and fragility calculations. As SI, SI-ANATECH and SC Solutions have the reputation for excellence in structural-mechanical modeling, including soil structure interaction (SSI), we add particular value in challenging areas involving complex modeling (e.g., finite element analysis [FEA]), unique failure modes and damage mechanisms, and sophisticated probabilistic techniques in capacity assessment.

Ensuring a consistent, accurate and effective interface between, multiple specialized disciplines (i.e., earth science and seismic hazard, and on the other hand, the response analysis of structures, systems and components (SSCs) and development of fragilities and/or HCLPFs is an especially vital aspect of any successful SMA and SPRA. This is another key area where the team excels and is particularly well experienced.

ADVANCED STUDIES

The team conducts advanced studies that help plant owners solve unique problems, avoid unnecessary expenditures on plant hardware modifications and identify the most effective hardware modifications. In addition to detailed capacity modeling, we undertake the following efforts where beneficial for clients:

- Advising, planning, implementing and/or reviewing approaches for highly accurate margin or risk assessment, such as scenario-based SPRA
- Nonlinear plant response analysis and soil-structure interaction [SSI], including treatment of incoherency in motion
- Probabilistic simulation based on Latin-Hypercube approach, with nonlinear FEA, for fragility or HCLPF assessment of SSCs
- Detailed treatment of failure correlations
- Advanced treatment of recovery actions and associated human reliability analysis.



Steel Plate Elements

Clients of Structural Integrity and SI-ANATECH count on us to provide effective solutions to safety issues and to prevent failures of structures, mechanical components and equipment. Our solutions are not limited to design or operating loads and conditions, but cover all types and levels of potential loadings and damage mechanisms. Clients thus place similar confidence in us to develop effective solutions concerning their earthquake-related issues, including the current NTTF seismic program.

PLANT IMPROVEMENTS

ENERCON is a recognized leader in nuclear plant modification package design and development, field installation engineering support, and project management. Effective work control practices for maintaining project quality, responsiveness, and schedule/budget compliance allows seamless integration with client processes. As such, ENERCON can implement cost-effective plant safety improvements identified by seismic evaluations. This comprehensive capability allows us to provide a holistic approach to seismic evaluation services covering all stages of data gathering, analysis, assessment, and mitigation.

Together with SI and other teaming partners, ENERCON can leverage expert technical analysis and insights to develop and implement plant improvement strategies that provide the most safety-significant enhancements. ENERCON has extensive experience with all forms of plant improvements, including plant hardware replacements and upgrades, design revisions, procedure enhancements and improvements, coping strategy development, instrumentation upgrades, and others.

Probabilistic Risk Assessment and Fragility for External Hazards

By: ROBERT SEWELL, PhD
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STRUCTURAL INTEGRITY EXTERNAL HAZARD PRA SERVICE OFFERING
Structural Integrity (SI) provides clients with a full set of services for fulfilling probabilistic risk assessment (PRA) for all types of external hazards.

Offering a complete service in external events PRA for nuclear facilities poses a challenge for at least the following key reasons:

1. Broad scope of general events (types of hazards) to be listed and considered
2. For any given type of hazard, knowledge of both the hazard and fragility of structures, systems and components (SSCs) is generally required
3. The overall assessment typically requires a detailed plant walkdown and identification of plant/site-unique external hazards
4. Plant systems modeling and response must be generally considered, and any category of external hazard will typically be a common cause (dependent source) of multiple simultaneous failures
5. Rare events (including scenarios that may have never been historically realized) must be generally considered

At Structural Integrity, we address these challenges in a reasoned, managed and systematic fashion that derives from our wealth of experience and relationships acquired in this specific (if not specialty) field of PRA. Our clients thus have, for reasons we highlight below, assurance that we provide them with a spectrum of sound solutions, ranging from industry standard to leading edge, depending on their specific needs.

STRUCTURAL INTEGRITY'S SYSTEMATIC APPROACH

Broad Scope of Events

Any external events PRA starts with the development of a comprehensive set of general events (categories, or types, of hazards). Potentially relevant external hazards encompass literally hundreds of types of events. Extreme winds and floods, aircraft crashes and industrial facility explosions are examples of relatively common types of hazards that come to mind, whereas electromagnetic interference (EMI), cosmic rays and solar storms are perhaps somewhat more exotic. In general, however, all of these must be rationally considered in the PRA.

Whereas early PRAs often involved aggressive screening of most categories of external events based on the qualitative judgments of a particular analyst, advancements in science and the effectiveness in communicating scientific findings have led to an improved information base for formulating screening decisions. It is thus more typical now that screening justifications are based on research that at least cites multiple references that collectively constitute a state of the art and are reasonably representative of the variety of viewpoints of the relevant informed technical community. In some cases, direct input of relevant experts can be applied (or may be needed) in lieu of independent research. A key point, however, is that the external events PRA specialist, no matter how well informed as to the nature, potential and effects of a given hazard, must not simply screen out any event based on personal opinion or experience concerning the hazard. Similarly, the PRA specialist must not rely on just a particular selected expert viewpoint or even a set of viewpoints that may be biased. Accordingly, at SI, our process of identifying and screening external events is performed on the basis of systematic approaches and information that suitably reflect the publications and insights of the relevant informed technical community. We thus maintain broad familiarity with relevant scientific topics and methods, as well as contacts with multiple experts in various disciplines.

Ultimately, the result of our systematic screening of the comprehensive general list of external hazards is that a much smaller set of external hazards – often less than 10 – is found to require some more detailed form of analysis for any particular facility. The more detailed forms of analysis are more quantitative in nature as compared to the first screening, and include conservative hazard-based quantitative screening, conservative fragility-based quantitative screening, or simplified conservative risk assessment.

Following simplified quantitative screening, a typical result is that only one or perhaps a few categories of external hazard may require a more accurate (i.e., not simplified or conservative) assessment of risk.

Owing to the severity of earthquakes, the high degree of uncertainties concerning earthquake hazard and plant capacity, and the facts that earthquakes can occur nearly anywhere and rare events must be considered, some form of detailed analysis of nuclear facilities for the earthquakes hazard will typically be indicated.

HAZARD AND FRAGILITY CONSIDERATIONS

For hazards that are not screened during the initial, research phase, or that cannot be conservatively screened out based solely on arguments of location (i.e., the nuclear facility is too far from the threat) or invulnerability (i.e., capacities, or fragilities, of impacted/exposed SSCs are too high; or, the plant safety systems are not critically affected by loss of the impacted SSCs), some form of more detailed assessment of the hazard will typically be required. In some limited cases, the hazard assessment can be based on a statistical analysis of available data. In most cases, however, physical models and simulations of the hazard phenomena will also be required. For instance, for assessment of tsunami hazard, three types of analyses may generally be performed (or at least considered):

- Statistical analysis of historical tsunami wave data
- Probabilistic simulations of tsunami source generation, wave propagation, and local wave run-up
- Statistical analysis of paleo-tsunami data derived from field studies of ancient tsunami deposits or other tsunami evidence (e.g., death of trees and vegetation accompanying tsunami inundation).

Unique phenomena, and associated science and engineering, are usually involved in assessing each type of hazard. Accordingly, where hazard assessment approaches other than those involving straightforward statistical analysis of available and directly useable (i.e., scrubbed and corrected) data, we typically involves relevant experts to provide needed inputs for performing the hazard assessment. In any case, usually a common framework for computing hazard results, including treatment of aleatory and epistemic variations, can be employed for all categories of hazard.

For hazards that are not screened out during the initial, research phase, or that cannot be conservatively screened out based solely on arguments of low hazard (i.e., the nuclear facility is too far from the hazard source or the effects of the hazard are otherwise not of engineering significance), and for cases where potential damages to impacted/exposed SSCs are detrimental to plant safety systems, some form of more detailed assessment of the fragility of impacted/exposed SSCs and the plant will typically be required.

For nearly any type of external threat and associated loading on SSCs (e.g., impact loads, inertial loads, pressure wave and thermal effects of explosions or aircraft crashes; hydrodynamic loads and flooding impacts from debris-laden tsunami waves, storm surges or moving flood waves; projectiles from wind-induced missiles) We have the experience and capabilities in the relevant engineering methods and probabilistic approaches to develop detailed fragilities. We develop such fragilities based on models ranging from simplified to highly advanced (e.g., nonlinear finite-element modeling [FEA] in combination with Latin Hypercube sampling and simulation for probabilistic analysis), depending on the needs of the client and the relative risk significance of the specific components being analyzed. We are well-known for excellence in the various facets of structural-mechanical modeling, which are also required in preparing robust fragility results. Correspondingly, we are particularly adept at all forms of fragility assessment for external hazards.

EXTERNAL EVENTS PLANT WALKDOWN

Comprehensive procedures for performing an external events walkdown are not yet well documented in the literature. However, our engineers have extensive experience in performing

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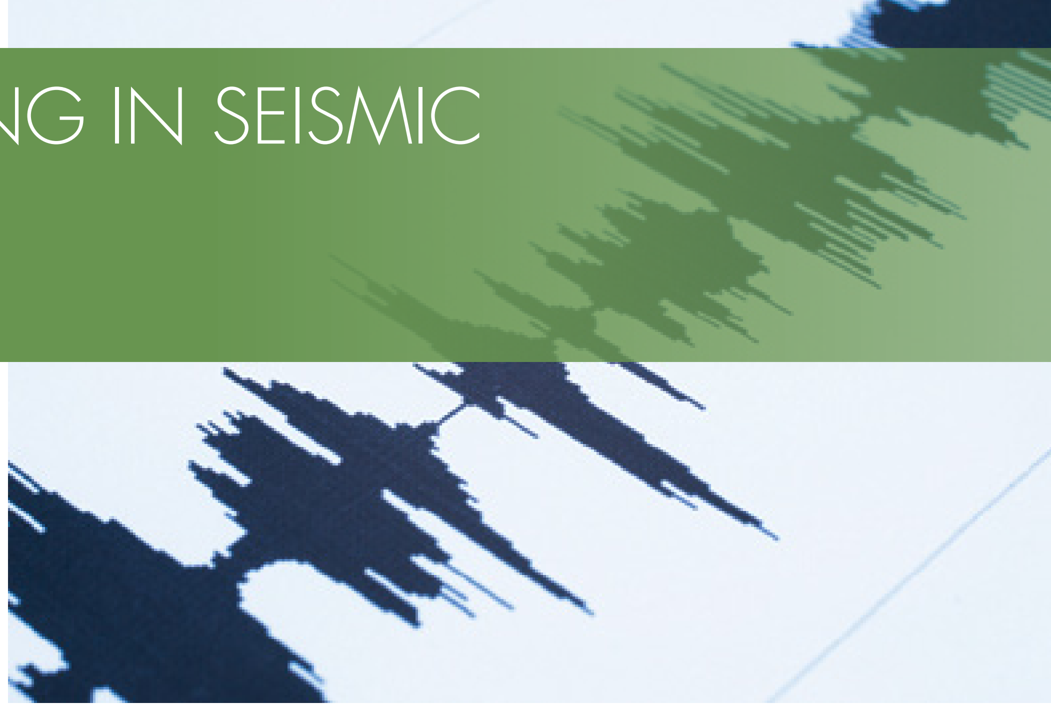


external hazards PRA walkdowns of nuclear facilities, and as a result have developed a comprehensive, leading state-of-the-art process for performing such walkdowns.

A particularly important aspect of the external hazards walkdown is to identify any plant-unique hazards, threats or situations that are not part of the overall general list of hazards, and require further screening and/or detailed analyses.

PLANT SYSTEMS MODELING AND DEPENDENCIES

For hazards that are not screened out during the initial, research phase, or that cannot be conservatively screened out based on hazard and/or on fragility of impacted/exposed SSCs, some form of quantitative plant systems analysis will be required. The systems analysis should be targeted to at least develop the relevant conditional core-damage probabilities (CCDPs) given various combinations of failures (including common-cause and dependent failures) of the impacted SSCs. Alternatively, a complete systems model can be quantified for the relevant initiating events and failures of basic events (including, in general, random failures and human error likelihoods).

Although Structural Integrity is capable of performing systems analyses (event-tree [ET] and fault-tree [FT] development) developing systems models that are applicable for external initiators, in most cases the client will have some form of plant logic model for internal initiators, we either adjust these existing models for external effects, or works with the client to introduce modeling changes or (most typically) to extract the relevant CCDPs for subsequent risk quantification, considering (in addition) the SSC failure rates from the fragility functions and the relevant external event initiating event frequencies from the hazard results.

NEED TO CONSIDER RARE EVENTS

Another important factor in performing an external events PRA for a nuclear facility is that very rare events need to be considered. More specifically, a particular category of hazard cannot generally be eliminated from detailed consideration unless it can be shown that the mean core damage frequency contribution from the event category is less than 10^{-6}/yr (i.e., the repeat time of core damage from the event category exceeds 1,000,000 years).

This requirement presents a particular challenge, for some situations and disciplines. For instance, until recently, tsunami scientists capable of producing hazard results typically focused on predictions for applications (e.g., inundation studies) where hazard levels in the range of 10^{-2}/yr to 10^{-3}/yr (i.e., 100 to 1000 years) were considered sufficient, whereas tsunami hazard models for nuclear applications need to be reliable out to several more orders of magnitude.

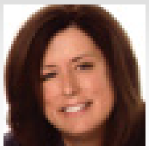
Although rare events must be considered in the external events PRA, for obvious reasons, events with likelihood-consequence profiles similar to so-called "extinction-level events" need not be considered in the PRA. Usually, such events are in any case ~0 (10^{-8}/yr) events. Thus, the scenario of a large asteroid impacting Earth need not be considered in the external events PRA.

STRUCTURAL INTEGRITY 'S PARTICIPATION ON THE ASME JCNRM, EXTERNAL HAZARDS WORKING GROUP

Structural Integrity actively serves on the ASME Joint Committee for Nuclear Risk Management and participates in the Committee's Working Group on External Hazards. Through this participation, we assist in leveraging our considerable experience and related capabilities and contacts to advance the state-of-the-art in External Events PRA. This participation, in turn, is valuable to our clients, as they can be assured of receiving effective and robust solutions in this specialty area of PRA when they choose to work with Structural Integrity.

Clients count on us to provide effective solutions to problems of safety and prevention of failures of structures, mechanical components and equipment. our solutions are not limited to just design or operating loads and conditions, but cover all types and levels of potential loadings and damage mechanisms. Clients thus place similar confidence in us to develop effective solutions concerning the external hazards issues they may encounter.

Seismic Qualification of an Enclosure and Skid for an Emergency Backup Power System



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Nuclear power plant emergency backup power systems must remain fully functional following a major earthquake combined with a loss of offsite power. The system, related components and structure housing the equipment are classified as Seismic Category 1 and are designed to withstand the effects of a safe shutdown earthquake (SSE) without the loss of safety function. Structural Integrity (SI) was engaged by Engine Systems, Inc. (ESI) to perform the seismic qualification of a backup power system for a new plant design. In addition to the components and piping, we qualified the skid, enclosure and exhaust plenum for the system.

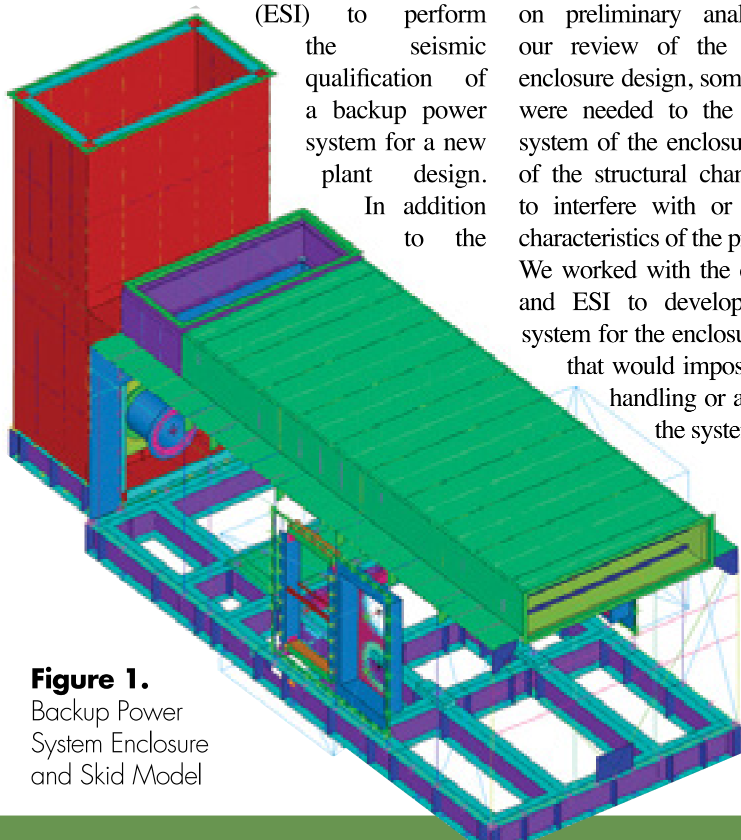

Figure 1. Backup Power System Enclosure and Skid Model

A prototype of the system, including the skid and enclosure, was successfully built and tested in 2010 at ESI prior to final seismic qualification of the enclosure and skid. Based on preliminary analysis and our review of the prototype enclosure design, some changes were needed to the structural system of the enclosure. None of the structural changes were to interfere with or alter the performance characteristics of the previously tested system. We worked with the enclosure manufacturer and ESI to develop an improved lateral system for the enclosure and exhaust plenum that would impose no changes to the air handling or acoustic performance of the system.

Seismic qualification of the enclosure and skid was performed by analysis using ANSYS. The structure and skid were qualified together, using a global model. Load combinations and acceptance criteria were applied in accordance with ANSI/AISC N690-1994(R2004), Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities. Seismic load cases were analyzed by the response spectrum method using mode superposition.

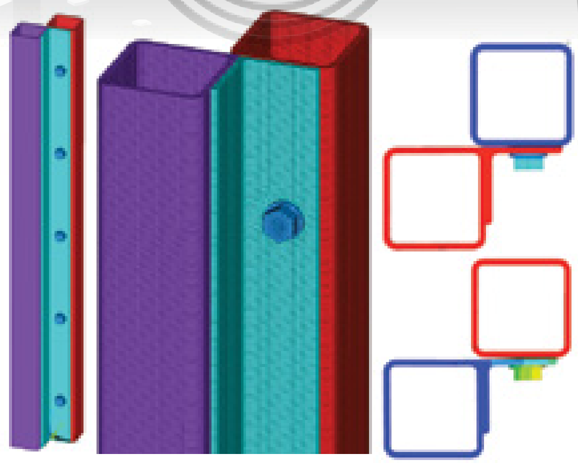

Figure 2. Frame Bolting Flange Model and Unit Load Displacement Results

The finite element model of the enclosure and skid, shown in Figure 1, is composed of 64,800 beam, shell, contact, spring and lumped mass elements. Nodes were located at plate mid-planes and at plate-frame joint locations. Beam sections were offset to maintain accurate position of member centerlines and include any eccentricity in load transfer between members. Large

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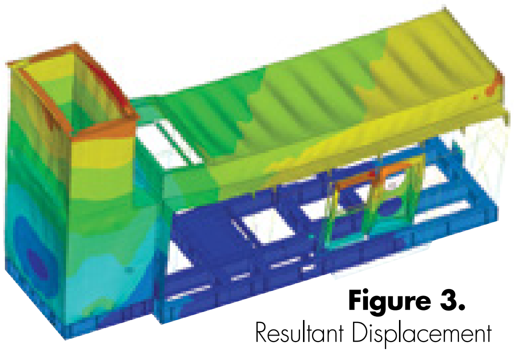


Figure 3. Resultant Displacement Contours Due to Operating and Seismic Loads

web cutouts for piping were modeled at perimeter members of the skid. Pipe supports attached to the skid were modeled with beams and tied to the skid with rigid constraints or discrete elements.

Bolts were modeled with short beams connected to and sharing nodes with main frame members. Bolt stiffness and tying conditions were set based on the results of local connection models, such as those shown in Figure 2. Equipment was modeled as lumped masses with computed inertial properties. Non-structural mass was added through real constants, section properties and increased material densities. The weight of each major assembly was calibrated to match target weights computed in a detailed calculation based on CAD drawings.

The operating temperature distribution for the enclosure and exhaust plenum was obtained from a thermal model of the exhaust plenum wall and heat transfer analysis of the structure. Temperature expansion stresses and connection forces were superimposed with dead, live and seismic loads to obtain the final member and connection forces and moments. The final deformed shape of the structure for one of the load combinations is shown in Figure 3. Final predicted lateral deflection is close to 1/10th that of the preliminary design.

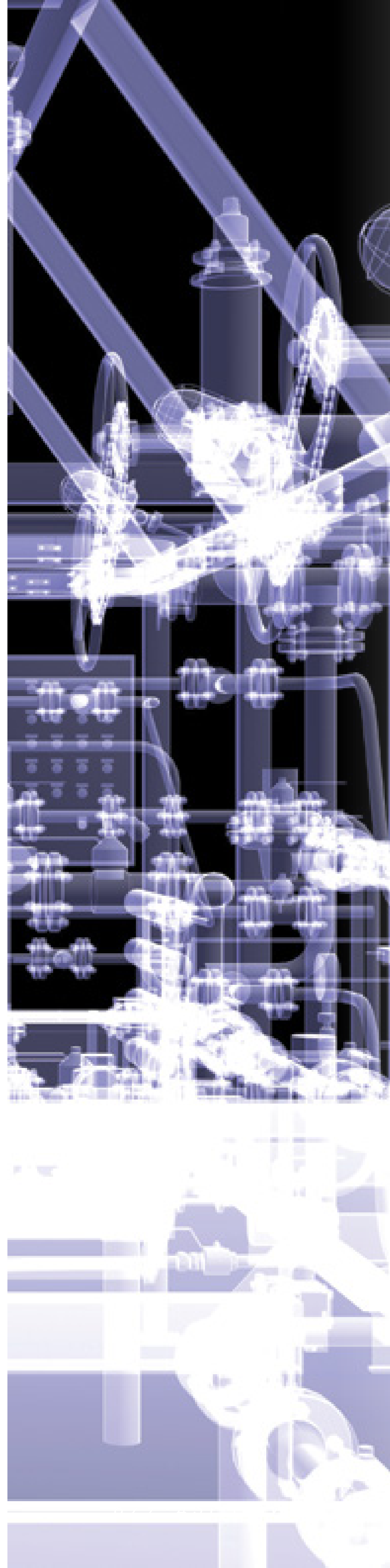
2014 FOSSIL PLANT WORKSHOPS

As part of our continuing effort to increase awareness of emerging issues and technologies that affect the safe and reliable operation of your critical assets, Structural Integrity will be presenting two workshops in 2014. This represents the 6th in this series. This year we will focus on emerging issues with High Energy Piping, Boiler, HRSG and Turbine Generator. The two day workshops will provide technical presentations on a variety of topics by some of the leaders in our industry. We provide plenty of time for Q&A and for our attendees to interact with each other to share their experiences.

We're offering the following workshop locations:
June 18-19 Charlotte NC
July 30-31 Austin TX

This will include the opportunity to tour Structural Integrity facilities in those locations, and to get some "hands on" experience with certain condition assessment technologies

We do have limited space and in the past these have filled up quickly. Go to www.structint.com/fpsworkshops2014 for additional information.



THREE-DIMENSIONAL DEFECT MAPPING

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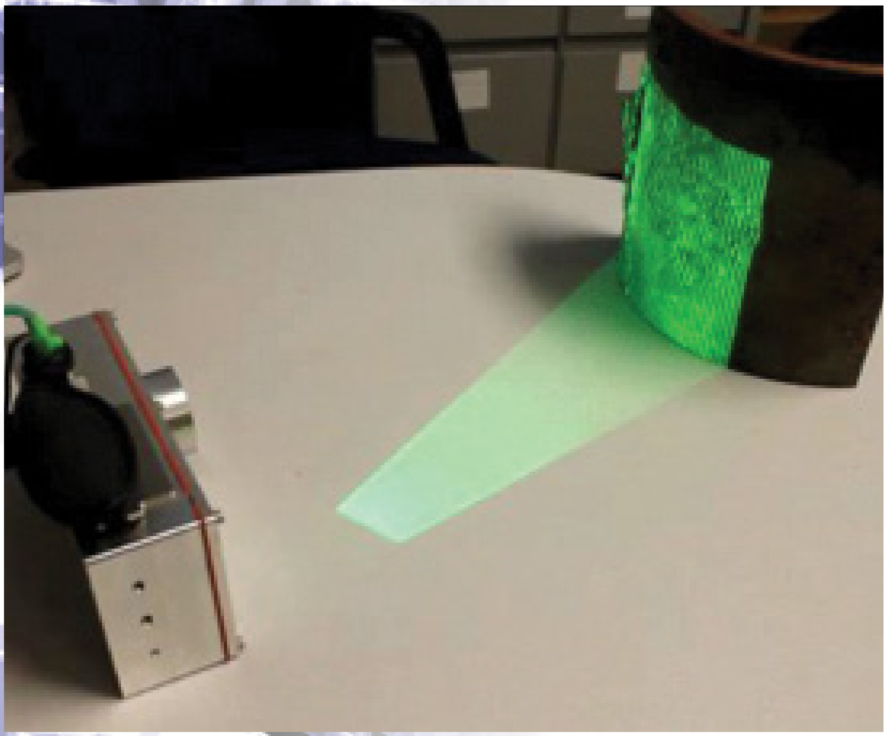
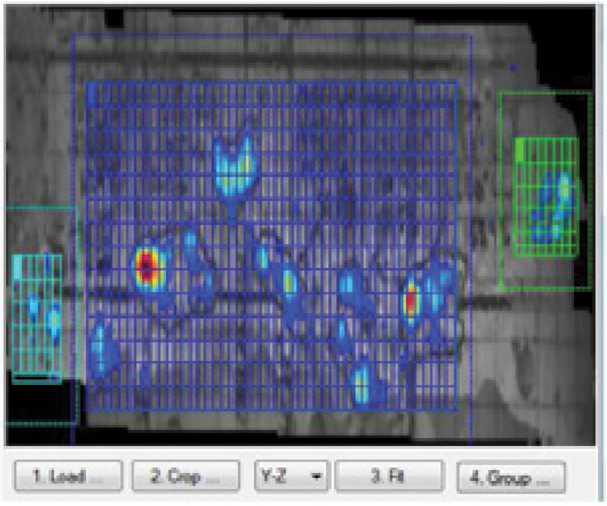
Structural Integrity has recently added the Technical Toolboxes Inc. (TTI) 3D Toolbox to our NDE service offering, which leverages Seikowave's structured light 3-Dimensional scanning tools. The 3D Toolbox is a complete measurement system for inspecting oil and gas pipeline and other facility infrastructure. Included with the 3D Toolbox is the eVox LCG 3D imaging system: a compact 3D measurement system with 40mW optical power, which uses real-time measurements and unique algorithms to process accurate measurements of three-dimensional objects and surfaces. The figures below provide an overview of this system, which can be used for mapping and quantifying external defects such as external corrosion, dents, and gouges.

Similar to laser profilometery, detailed defect information (geometry, depth, etc.) can be captured along with a digital image retained for permanent record. However, the speed and efficiency of data collection, along with the ability to import into advanced analysis tools such as RSTRENG® and Finite Element Analysis (FEA) models is extremely beneficial. Multiple scans can be linked together for analyzing larger areas and/or for capturing greater resolution of defects. Digital records with depth values in high resolution grids, along with river bottom profiles and other data formats, can be viewed and exported for further analysis.





Feature	Volumetric Loss	Max Depth	Aera	Width	Length
01	3494.569	6.3	16450.00	235.0	70.0
02	301.978	3.0	1000.00	40.0	25.0
03	151.777	3.1	750.00	30.0	25.0

HEP Program Tool

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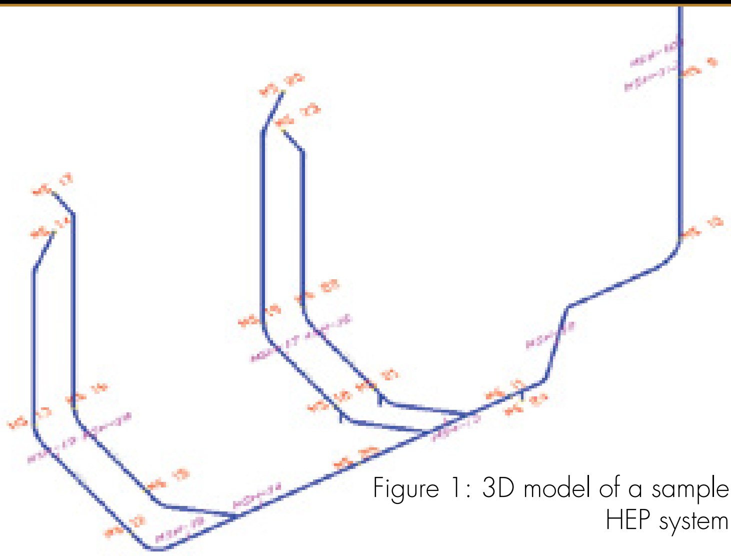


Figure 1: 3D model of a sample HEP system

An integrated and proactive program is required to effectively manage high-energy piping (HEP) systems. Such a program involves several competencies including:

- Data collection and risk ranking
- NDE and sample analysis
- Engineering analysis of data, life fraction and defining inspection intervals
- Data management

Structural Integrity has developed the Vindex© methodology to risk-rank HEP welds for evaluation, taking into account stress, materials, inspection data, consequences and fabrication processes. A similar program called V91 extends the Vindex risk ranking technology to deal with issues related to Grade 91 and other creep strength-enhanced ferritic (CSEF) steels.

The first step is the meticulous data collection effort, including component designs, inspection reports, engineering records, and analysis documentation. Based on the preliminary analysis, cutting-edge nondestructive examination techniques are then deployed to detect HEP damage mechanisms. The CSEF studies include hardness mapping to identify hardness-deficient zones and linear phased-array ultrasonic examinations to locate cracks. These are then followed by advanced analytical tools to predict serviceability and facilitate run/repair/replace decisions, as well as defining inspection intervals.

We developed our PlantTrack™ program as a data management tool for all phases of a successful HEP program. The PlantTrack graphics module includes several options for modeling the HEP system, a true 3D CAD model, a 2D isometric CAD drawing or multi-level scanned images of the system for rapid modeling.

The welds, as well as other piping components, such as hangers, valves, and fittings can be located interactively. PlantTrack provides a centralized location to store and manage all the data required for an effective HEP program. The typical types of records that can be stored in PlantTrack include:

- Plant/unit/system design data and operating conditions
- Piping design information such as diameter, thickness, insulation/coating/lagging, design and operating conditions
- Weld specifications
- Hanger specifications
- Component failure and repair/replacement histories
- Weld, piping and hanger inspection results
- Vindex risk-ranking results
- Stress analysis results
- Inspection and repair recommendations
- Hardness measurements for CSEF studies

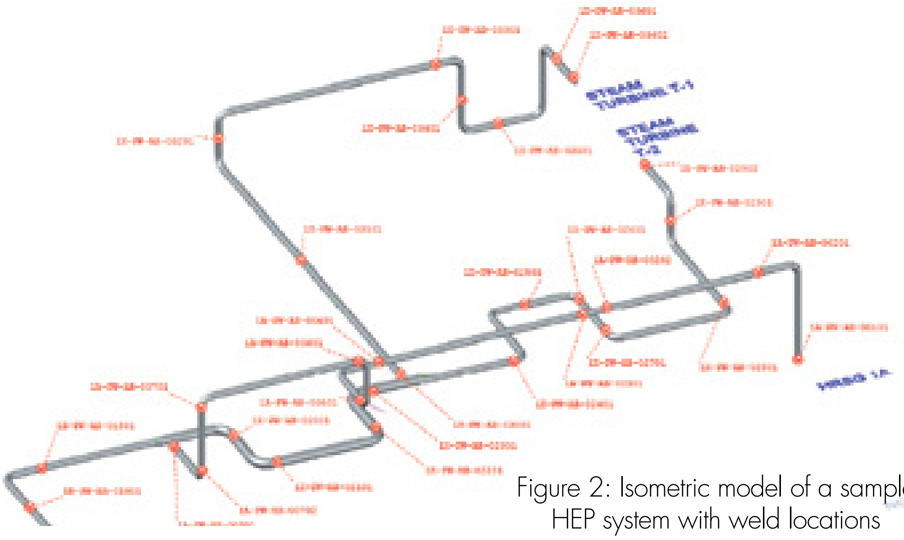


Figure 2: Isometric model of a sample HEP system with weld locations

PlantTrack allows user creation of record types, as well as detailed information to be tracked for each record type. To further assist with data management, all the design and inspection documentation can be linked to components and records, using the document attach feature.

The interactive graphics interface of PlantTrack allows the user to easily list historical data (records/events), as well as color-coding select records in both tabular and graphical displays. The filters could be as simple as identifying inspection locations to more complex queries assigning color codes based on the values of the selected fields associated with the record. PlantTrack allows color coding based on any field. The example below (Figure 3) displays the results of Vindex analysis.

The records can be entered graphically on the interactive drawings, as well as using MS Excel spreadsheets for convenient multiple record entry. Based on the user selection of components and the event type (such as weld/hanger inspection, Vindex analysis) an Excel worksheet is created including all the related data and menus for the fields. After adding data to the worksheet, it is then conveniently imported back in to PlantTrack.

PlantTrack also includes a rich reporting interface. The users can easily create filters to display and print quick lists and trend charts, as well as more complex reports, such as outage and inspection reports, inspection plans, as well as bar and pie charts to trend items like NDE results and failures.

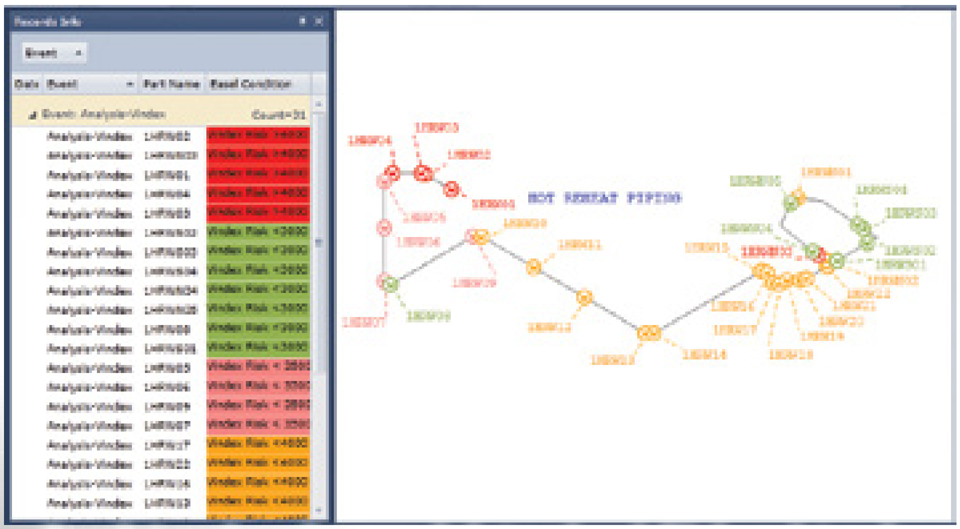
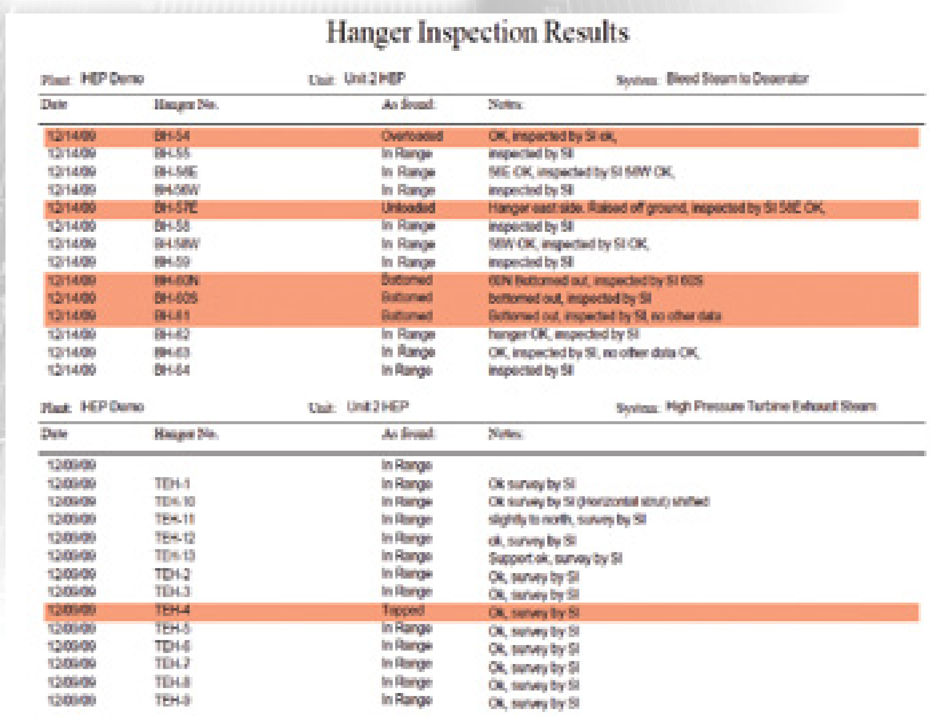


Figure 3: A sample graphics screen displaying color-coded Vindex analysis results.



Hanger Inspection Results

Plant: HEP Demo | Unit: Unit 2 HEP | System: Bleed Steam to Deaerator

Date	Hanger No.	As found	Notes
12/14/09	BH-54	Overloaded	OK, inspected by SI ok,
12/14/09	BH-55	In Range	inspected by SI
12/14/09	BH-56E	In Range	56E OK, inspected by SI 56W OK,
12/14/09	BH-56W	In Range	inspected by SI
12/14/09	BH-57E	Unloaded	Hanger east side. Raised off ground, inspected by SI 58E OK,
12/14/09	BH-58	In Range	inspected by SI
12/14/09	BH-58W	In Range	58W OK, inspected by SI OK,
12/14/09	BH-59	In Range	inspected by SI
12/14/09	BH-60N	Bottomed	60N Bottomed out, inspected by SI 60S
12/14/09	BH-60S	Bottomed	bottomed out, inspected by SI
12/14/09	BH-61	Bottomed	Bottomed out, inspected by SI, no other data
12/14/09	BH-62	In Range	hanger OK, inspected by SI
12/14/09	BH-63	In Range	OK, inspected by SI, no other data OK,
12/14/09	BH-64	In Range	inspected by SI

Plant: HEP Demo | Unit: Unit 2 HEP | System: High Pressure Turbine Exhaust Steam

Date	Hanger No.	As found	Notes
12/09/09		In Range	
12/09/09	TEH-1	In Range	Ok survey by SI
12/09/09	TEH-10	In Range	Ok survey by SI (horizontal strut) shifted
12/09/09	TEH-11	In Range	slightly to north, survey by SI
12/09/09	TEH-12	In Range	ok, survey by SI
12/09/09	TEH-13	In Range	Support ok, survey by SI
12/09/09	TEH-2	In Range	Ok, survey by SI
12/09/09	TEH-3	In Range	Ok, survey by SI
12/09/09	TEH-4	Topped	Ok, survey by SI
12/09/09	TEH-5	In Range	Ok, survey by SI
12/09/09	TEH-6	In Range	Ok, survey by SI
12/09/09	TEH-7	In Range	Ok, survey by SI
12/09/09	TEH-8	In Range	Ok, survey by SI
12/09/09	TEH-9	In Range	Ok, survey by SI

Figure 4: A sample hanger inspection report

A successful long-term HEP program is built on the ability to trend the data which will require effective data management system. PlantTrack is a state-of-the-art software designed to provide the essential tools for the efficient execution of such a program:

- a detailed set of drawings with a consistent labeling convention for the components in the system,
- a centralized vault of related data,
- an easy interface with other analysis program, and
- a quick and easy way of extracting selected information and reporting.

Structural Integrity Performs Vibration Testing on EDGs

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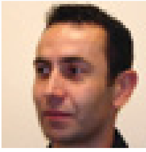

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Structural Integrity (SI) assisted a U.S. based nuclear power plant with troubleshooting of high vibration levels of their fleet of emergency diesel generators (EDG). The EDG high vibration has been an issue for these machines for several years and the plant attempted to rectify the condition by implementing various mitigating solutions with varying degrees of success. Over the course of a few months we collected vibration data during the regularly scheduled EDG surveillance testing. The data was collected using five tri-axial accelerometers at over 40 locations (see Figure 1) during diesel roll, at no load and full load conditions, and during coast down. Impact testing was also performed with the purpose of identifying natural frequencies of individual generator parts.

The results identified a couple of potential sources of elevated vibration. The review of velocity spectra pointed towards rotor imbalance and bearing misalignment on some of the EDGs. Other machines also exhibited signs of a soft foot under the generator housing and the skid of the EDG. Resonance condition was not found as a contributor to the overall vibration levels. Based on the findings, we made several mitigation recommendations to the plant; some of which are currently being implemented.

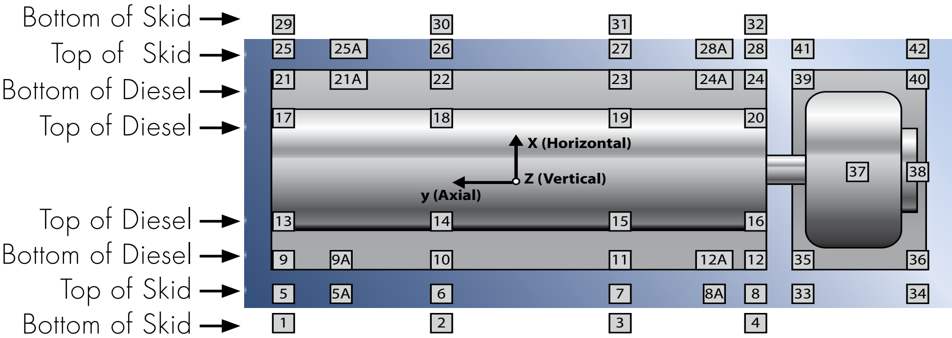

Figure 1. Measurement Locations (Top View)

Assessment of Small Bore Piping in Preparation for Power Uprate

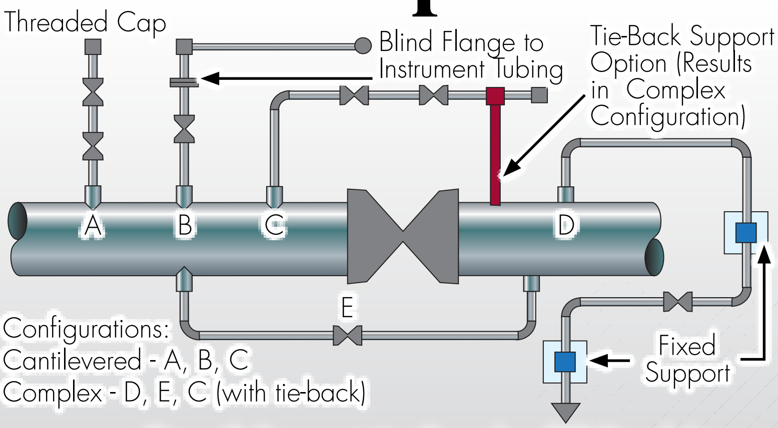

Figure 2. Representative Examples of SB Branch Lines

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Recently, we completed a comprehensive assessment of numerous small bore (SB) branch lines (< 2.5" Dia.) for a US-based nuclear plant preparing to implement extended power uprate (EPU). Several examples of representative lines are provided in the diagram in Figure 2. The purpose of the assessment was to identify lines with the potential for increased susceptibility to flow-induced vibration (FIV) failures (on account of higher flow rates associated with

EPU operation), and suggest mitigation strategies to reduce the likelihood of failure. More than 1,000 lines were assessed on five different systems (Main Steam, Feedwater, Extraction Steam, Condensate, and Heater Drains), and more than 60 lines were determined to require some form of support modification and/or additional engineering assessment.

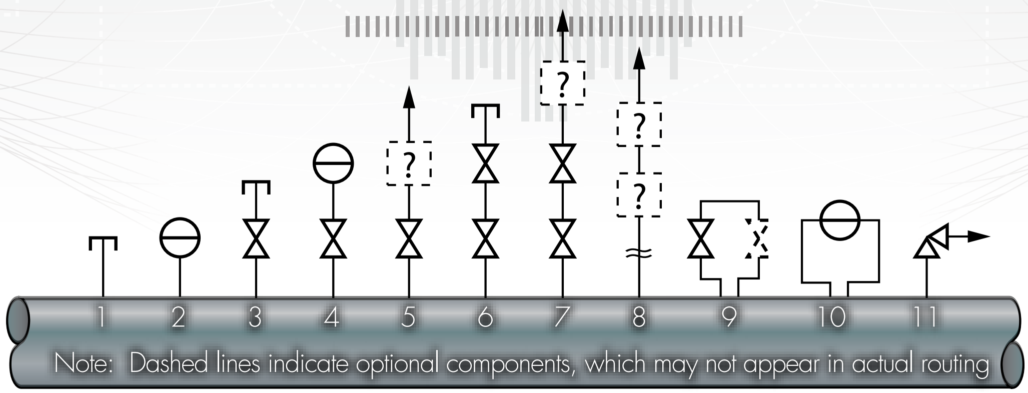
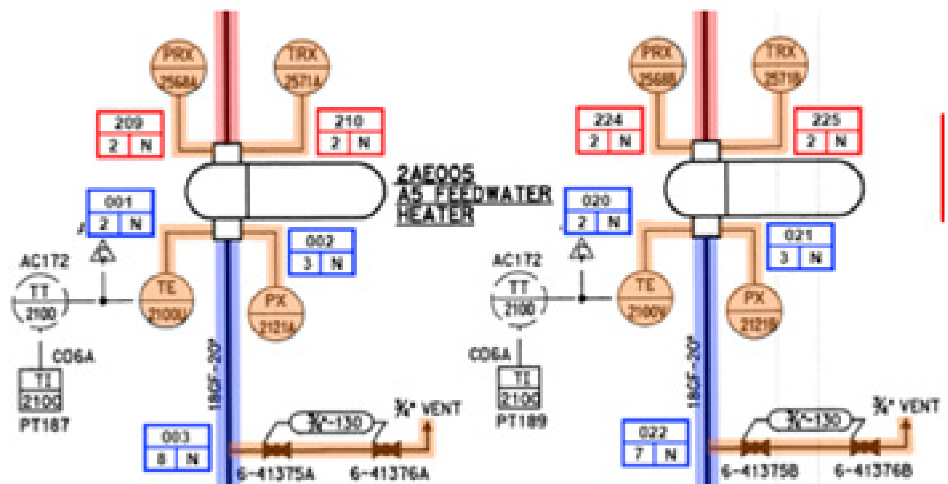


Figure 3. P&ID Markups and Accompanying Tables

The initial work began by determining the total population of SB lines to be assessed. We reviewed and marked-up P&ID and Isometric drawings for the applicable systems, and generated tables summarizing relevant details (ID, location, size, etc.) – see Figure 3. The routing and support configuration of each line was inferred from the drawings, and standardized according to the diagram in Figure 4. A set of qualitative screening criteria were generated to reduce the number of lines of interest (for example, eliminating lines of Type-1 and Type-2 configuration based on relatively-high expected natural frequencies). The results of the initial assessment were used to segregate and prioritize the total population for follow-up field verification.



Index ID	P&ID Loc		Large Bore Line ID	Valve IDs	Instrument IDs
	#1	#2			
CD-436	G-3	D-6	18GF-10"	5A-36139K SV-3934K	---
CD-437	F-3	D-3	18GF-10"	RTV-5A-9176K RTV-5A-36066K	dPS-9176K

Figure 4. SB Line Configuration Types

We performed verification walkdowns during the refueling outage to confirm the data inferred from the drawings and document any discrepancies. Photographs and as-built dimensions were obtained for all of the high-priority locations (those with the greatest apparent potential for FIV problems). Impact testing was performed to confirm the natural frequencies for SB lines of particular concern. The walkdown results were used to update the initial assessment, assigning a susceptibility rating to each line (on a 1-to-5 scale).

In order to complete the assessment, the lines with elevated susceptibility ratings were examined in detail. Piping analyses were performed for certain SB lines to identify expected natural frequencies and potential vibratory stresses when subjected to conservative loads. Several lines were eliminated from further evaluation by obtaining additional information about operational conditions. For other lines, revised support configurations were suggested, including tie-back restraints for a number of cantilevered lines (as shown in Figure 2). Where required, modifications will be incorporated during the next refueling outage.

Based on the above-described work, the plant has confidence that they will not experience FIV-related SB piping failures during EPU implementation.

SHORT RANGE GWT USING ELECTROMAGNETIC ACOUSTIC TRANSDUCERS (EMAT)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Pipeline and plant operators frequently encounter challenges inspecting short inaccessible sections of pipelines that are obstructed by pipeline supports or through wall penetrations, air to soil interfaces at riser locations and various other obstructions. These difficult-to-inspect locations are often adjacent to exposed and easily accessible areas that can be comprehensively examined using Visual Examination techniques and/or Conventional Ultrasonic Thickness (UT) testing, although even for the exposed sections conventional inspection can be a time-intensive endeavor and not comprehensive.

These inaccessible pipeline segments often are configured in close proximity to valves, bends and other appurtenances that limit the ability to use conventional Guided Wave Testing (GWT). Structural Integrity has acquired and developed new technology in the form of a short range GWT technology that leverages Electromagnetic Acoustic Transducer (EMAT) Sensors to improve the ability and resolution to non-destructively examine these areas. Our EMAT inspection system offers several advantages:

- The sensors can be placed on rough and/or corroded surfaces. Rust/scale that could detach from the surface and stick to the magnetic sensors should be removed to avoid damage to the sensor coil.
- No couplant is required.
- The sensors work through paints, Fusion Bonded Epoxy (FBE), and other thin coatings. The amount of acceptable sensor liftoff for carbon steel materials depends on excitation frequency, but typically has a maximum between 1.0mm and 3.0mm.
- 100% volumetric inspection can be completed.
- Pitch-Catch configuration eliminates near field allowing placement of sensors adjacent to obstructions.
- Normalization gate provides self-calibration for guided wave applications.
- Due to operation in a higher frequency regime, greater resolution of defects can be obtained than conventional GWT.

TECHNOLOGY OVERVIEW

The EMAT probe consists of a permanent magnet and a conducting coil that is pulsed with an AC voltage signal. The interaction of the current flowing in the coil and the magnetic field produced by the magnet results in small forces in conductive materials (Figure 1 left). These small forces, known as Lorentz forces, cause the small mechanical perturbations that constitute the guided wave.

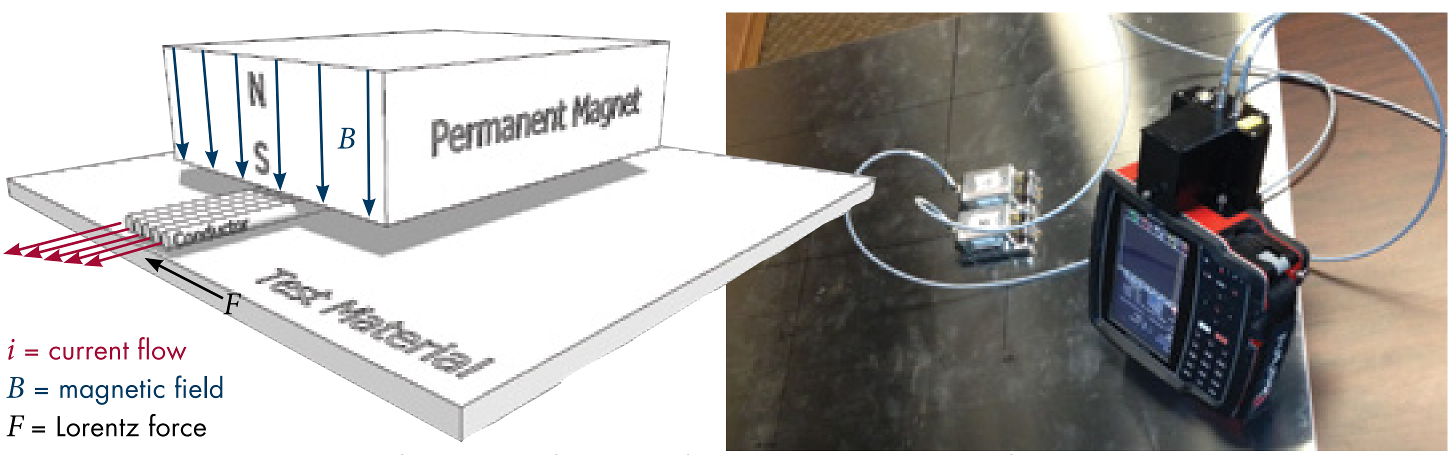

Figure 1 (Left) Schematic of the Lorentz force and (Right) photograph of inspection system

Structural Integrity's portable, handheld EMAT inspection system is shown in Figure 1. The electronics unit is approximately the same size as a conventional UT scope and each probe (transmitter and receiver) is roughly the size of a closed fist.

INSPECTION OF PIPELINE UNDER SUPPORTS

As an example application, we have has shown that Short Range (SR)-GWT can be used to successfully detect Stress Corrosion Cracking (SCC) under clamped supports. We performed SR-GWT on two 10" diameter, three 6" diameter, and three 2" diameter stainless steel (SS) piping segments with artificially fabricated Outer Diameter Stress Corrosion Cracking (ODSCC). The piping contained both circumferentially and axially oriented ODSCC. Furthermore, several of the ODSCC flaws also contained simulated external corrosion pitting and several additional flaws contained external corrosion pitting with no ODSCC. The defect manufacturing process that was used produced realistic closed-face cracks.

As shown in Figure 2, two different EMAT configurations were used to detect axial and circumferential cracking. For circumferentially oriented ODSCC, a normal incidence technique was used with the transmitter and receiver placed directly adjacent to one another and several inches back from the support clamp edge. For axially oriented cracking, an oblique incidence pitch-catch technique was used with the transmitter and receiver placed on opposite sides of the support clamp.

A total of 38 flaws in the various test samples were evaluated with the SR-GWT EMAT technique. Several of the ODSCC flaws also contained simulated external corrosion pitting and several additional flaws contained external corrosion pitting with no ODSCC. A detection rate of 100% was achieved for all examined flaw areas (several areas contained multiple flaws) using the high-frequency guided wave technique. Figure 3 shows an example SR-GWT encoded data scan.

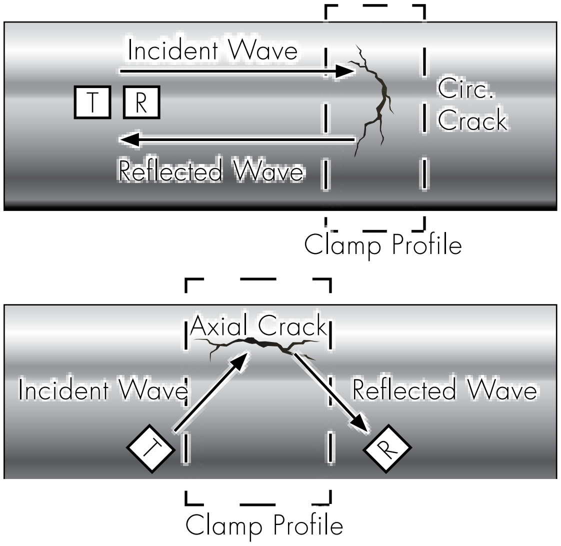

Figure 2 Schematic of the EMAT test configurations used for detecting ODSCC.

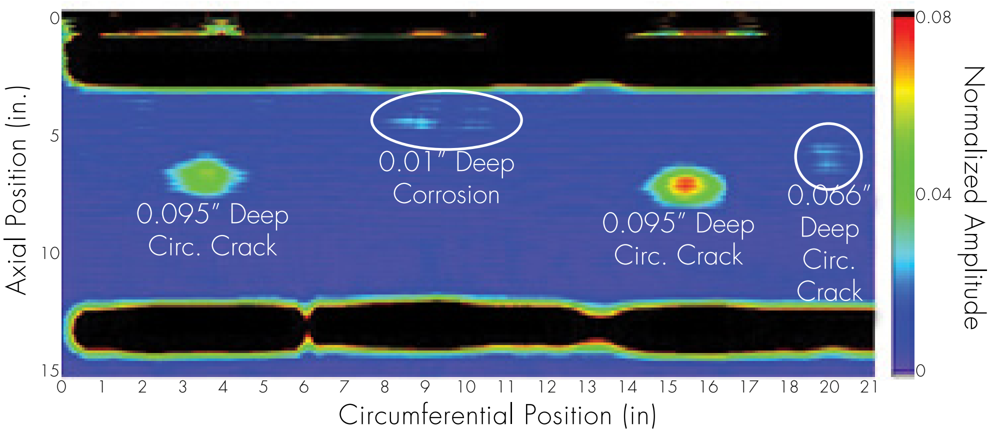

Figure 3 Unrolled pipe display or "C-Scan" showing the detection of several ODSCC and corrosion defects under a clamped support on a 6" diameter pipe.

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