2021 | VOLUME 50

Structural Integrity Associates, Inc.®

NEWS & VIEWS

1-877-4SI-POWER www.structint.com

SI FatiguePRO for Hydrogen Fueling Station Assets

CEO Message

MARK W. MARANO | *President and CEO*
mmarano@structint.com

Looking back since my arrival at SI in February 2020, we have all faced considerable adversity. However, I am pleased to say that Structural Integrity is on solid footing and continues to support our clients and meet the challenges of a rapidly changing energy landscape. SI never wavered on our priorities with regard to taking care of our Associates, Clients and investing in technology to fulfill our Mission to be "the most trusted provider of best in value, innovative, fully integrated asset life cycle solutions." I am most proud of our Associates and how they have continued to put the client first, address challenges, and maintain our strategic investment focus to deliver long-term client success in the ever-changing power generation landscape.

This 50th edition of the SI News & Views newsletter continues to highlight our Talent & Technology and captures the diverse capabilities of the SI team to deliver on our Mission. We continue to invest in three strategic areas to drive additional value for our clients: Advanced Analytics, Monitoring, and Digital Simplification. The in-depth technical investment in these three areas has resulted in more advanced, cost-effective solutions for clients. Some of those successes are highlighted here and leverage decades of success serving clients with proven solutions.

Our Oil & Gas team business unit has leveraged material and operational insights with digital services to support clients meet safety & reliability requirements outlined by the Mega Rule in a streamlined fashion. For our Nuclear Power industry clients, probabilistic fracture mechanics methods supported by SI technology have achieved regulatory acceptance to help clients optimize inspection intervals (highlighted in issue #49) and is leveraging this expertise to address margin related to vessel heat up and cool down criteria, highlighted in this issue. The SI Process & Pressure Vessel Team is also leveraging SI fracture mechanics technology to extend pressure vessel life in support of the hydrogen economy, which is highlighted in this issue. And for our associates serving the broader energy industry, our Energy Services Group (ESG), we continue to advance asset monitoring for critical equipment in fossil power plants with three (3) active projects involving 20+ monitoring locations streaming material integrity insights in real-time. Lastly, the SI Critical Infrastructure Team is making considerable advancement leveraging expert analytical methods and tools to address complex structural needs across all the industries we serve.

As you read through the articles, please keep in mind it is my number one priority to advance SI technology through our research & development efforts and continue to invest in our existing commercialized products and services.

U.S. DEPARTMENT OF ENERGY

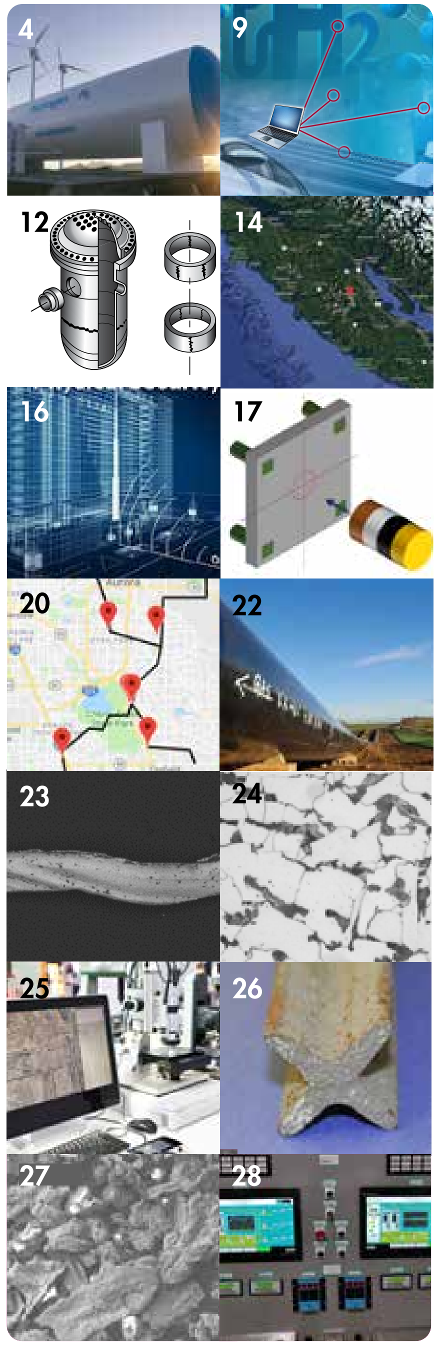
SI RECEIVES DOE ADVANCED NUCLEAR FUEL GRANT | **Nuclear Fuel Performance Modeling & Simulation**

BILL LYON & WENFENG LIU

The nuclear industry desires to enhance accident tolerance and improve fuel utilization for Light Water Reactors (LWRs). This can be achieved through the utilization of innovative fuel designs. One proposed fuel concept is to use metallic fuel (uranium zirconium alloy) in place of the current UO2 ceramic design in LWRs. The desired characteristics of accident tolerance are high flow rate, low operating temperature, and less modification to plants. Metallic fuel can help achieve these metrics and makes it an attractive design concept for near-term deployment. However, it may take decades to generate the necessary data from experimental irradiation programs to qualify the use of metal fuel in LWRs. It may take even longer to discover any important performance issues from the operation of metallic fuels in an LWR environment.
To speed innovation, Structural Integrity Associates is working with University of Tennessee to enhance experimental data with advanced analytical tools to model the thermo-mechanical and structural behavior of metallic fuel designs. Under a DOE Office of Nuclear Energy grant, the SI-led Team is developing analytical tools to model metallic fuel structural behavior and fuel performance to allow nuclear plant designers and operators as well as nuclear regulators to perform quantitative evaluations in support of licensing and implementation. The project will leverage the modeling and simulation capabilities developed from the DOE's NEAMS and CASL programs to assist fuel qualification and licensing activities aided by SI's expertise in thermo-mechanical modeling of nuclear fuel material phenomena. The work by the team aims to foresee potential problems, which in turn, can inform metallic fuel behavior and potential benefits for other reactor designs such as Advanced Reactors being developed under the DOE ARDP (Advanced Reactor Development Program).

VOLUME 50 | **NEWS AND VIEWS**

In this Issue

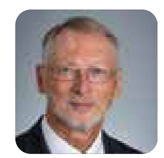


What's All the Buzz About Hydrogen!

Standards Development

DANIEL PETERS
Associate, Pressure Vessels and Piping
Structural Integrity Associates, Inc.
dpeters@structint.com

THOMAS PASTOR
Vice President, Codes & Standards
HSB Global Inspection & Engineering Services
Thomas_Pastor@hsb.com



Anyone who is following climate change issues and the expansion of the use of renewable energy would have seen the subject hydrogen popping up all over the place. Just do a Google search using the following words "*hydrogen renewable energy climate change*" and dozens of links will be displayed promoting the use of green or renewable hydrogen, made from the electrolysis of water powered by solar or wind, as indispensable in achieving climate neutrality.

According to the U.S. Department of Energy (2020), hydrogen energy storage (HES) offers unique benefits beyond the potential for long-term, seasonal energy storage as stated in the Energy Storage Grand Challenge Roadmap. Examples include grid leveling and stabilization services and coupling with intermittent renewable energy sources to enable reliable, emission-free electricity. Figure 1 is a graphic highlighting how hydrogen can play a central role in both bidirectional and one-way energy storage.

A RECENT NEWS STORY REPORTED:

Hydrogen initiatives are accelerating globally.

200+ large-scale projects have been announced across the value chain, with a total value exceeding $300 billion

30+ countries have national hydrogen strategies in place, and public funding is growing

Traditionally, hydrogen is produced in a steam-methane reforming process where methane reacts with steam under 45-375 psi (3-25 bar) pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Hydrogen produced in this manner is often referred to as '**gray hydrogen**' since it relies on the use of a fossil fuel and produces carbon dioxide as a byproduct. But with the expansion of low-cost renewable energy, the majority of the large hydrogen production projects underway around the world are making hydrogen via electrolysis. Hydrogen produced in this manner is referred to as '**green hydrogen**'.

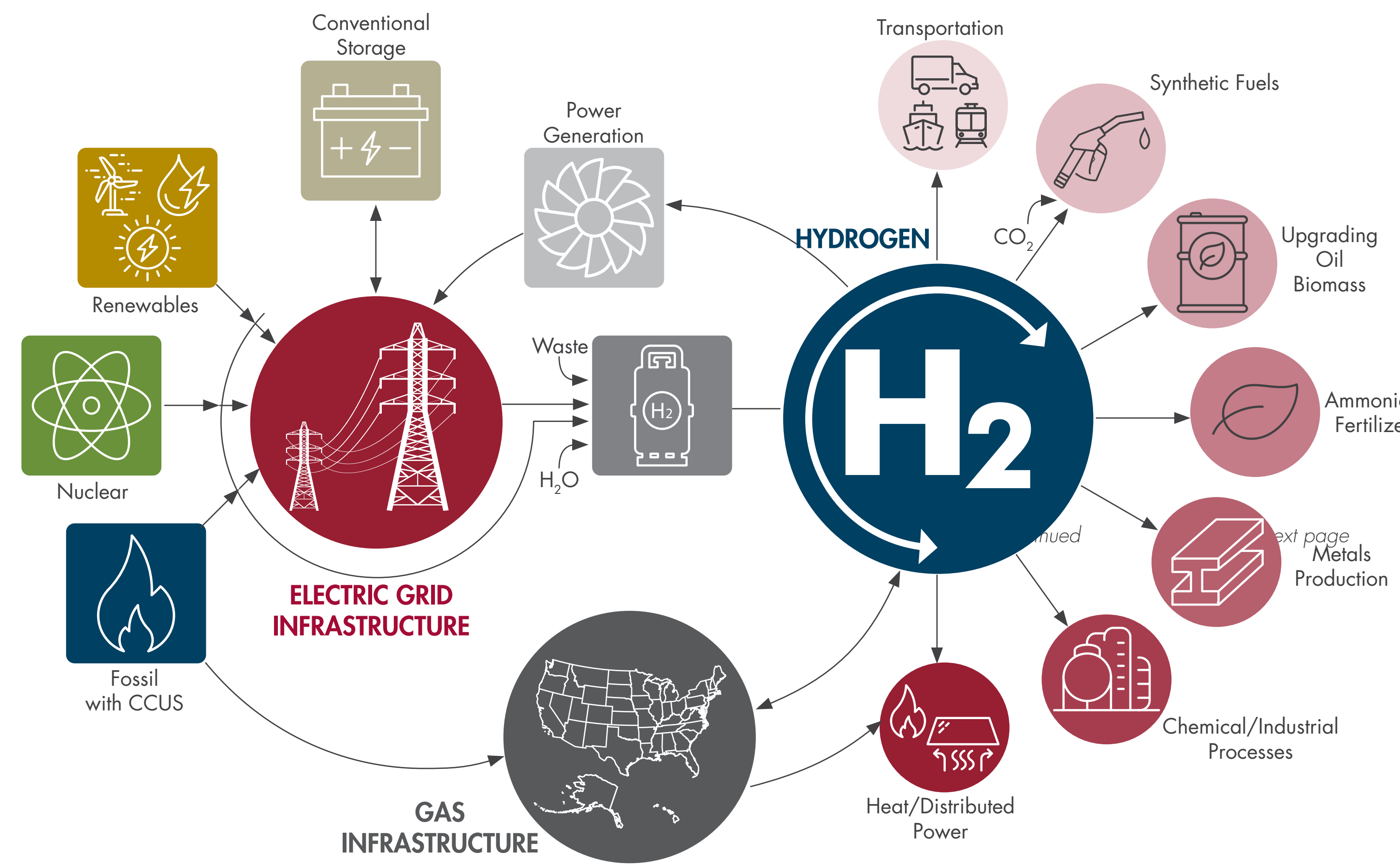


FIGURE 16. The H2@Scale vision: hydrogen can play a cenral role in both bidirectional and one-way energy storage[145]
Ref: DOE Energy Storage Grand Challenge Roadmap

Here is a short list of hydrogen projects underway around the world as reported in the news:

1. HyDeal Ambition (67GW)
   - Location: Multiple sites across Western Europe, starting in Spain in southwest France, and then extending to eastern France and Germany.
   - H2 output: 3.6 million tonnes per year
2. Asian Renewable Energy Hub (15GW)
   - Location: Pilbara, Western Australia
   - Planned use of H2: Green hydrogen and green ammonia for export to Asia.
3. AquaVentus (10GW)
   - Location: Heligoland, Germany
   - Power Source: Offshore Wind
   - H2 output: one million tonnes per year
4. Helios Green Fuels Project (4GW)
   - Location: Neom, a planned city in the northwest Saudi Arabia
   - Power source: Onshore wind and solar
   - Planned Use of Hydrogen: to produce green ammonia, which would be transported around the world and converted back into H2 for use as a transport fuel.

On a mass basis, hydrogen has nearly three times the energy content of gasoline [120 MJ/kg for hydrogen versus 44 MJ/kg for gasoline]. But there are challenges storing and transporting hydrogen. The low volumetric density of hydrogen makes it quite expensive to store and transport it in gas or liquid forms. [To exist as a liquid, H2 must be cooled below its critical point of 33K (-240°C, -400°F)] Alternatively, to store hydrogen as a gas economically, it typically needs to be compressed between 350-700 bar (5,000 - 10,000 psi). Either of these methods is energy intensive and costly. One option that has also received a lot of attention is converting hydrogen to ammonia using a process called the Haber-Bosch process.

Ammonia has several desirable characteristics that suggest its use as a medium to store hydrogen. It can be liquefied under mild conditions (Thomas and Parks, 2006). The vapor pressure of ammonia at room temperature is 9.2 bar (121 psi G). Its physical properties are similar to those of propane, meaning that it can be stored in a simple, inexpensive pressure vessel. Ammonia also has a large weight fraction of hydrogen; hydrogen makes up approximately 17.6% of the mass of ammonia. When these two factors are combined, the result is a liquid that is simply contained, with a volumetric hydrogen density about 45% higher than that of liquid hydrogen. This is why many companies are looking at the option of producing hydrogen using excess renewable energy and then converting it to ammonia. The ammonia is then transported around the world, where at its final destination would once again be converted back to hydrogen for use in power generation, transportation, and even residential cooking and heating.

Based on the information presented above, it comes as no surprise that HSB and SIA have been receiving numerous inquiries about constructing pressure vessels for production and storage of hydrogen and ammonia. Some of you may be old enough to remember the talk about the developing hydrogen economy in the early 2000's. During that timeframe ASME committees carried out much work to develop rules within its standards for the generation, storage, and transport of hydrogen. Today rules exist for the construction of pressure vessels and piping within Section VIII and B31.12 to be used in the production and transport of hydrogen. Let's take a closer look at the rules within the ASME standards, and some of the manufacturing challenges.

ASME Standards and Hydrogen

Infrastructure equipment made to store and handle hydrogen during its production, distribution and use is critical to the successful implementation of hydrogen as an energy storage medium. ASME has had standards used in the design and manufacture of hydrogen vessels for many years. In recent years, ASME has focused on standards related to the hydrogen.

There are many different designs used in the construction of vessels for hydrogen storage and transportation. A common design uses ASME Section VIII, Divisions 2 and 3 (VIII-2 & VIII-3) for a seamless pipe with the ends hot formed to a hemispherical dome on each end made of low alloys steels. Similar cylinders have a composite wrapped steel liner leveraging VIII-3 and Section X as Composite Reinforced Pressure Vessels (CRPV's). There are also ASME Section X cylinders which are composites with stainless-steel end bosses for connections on each end.

ASME Section VIII, Division 1 (VIII-1) is the most used standard for the design and construction of pressure vessels around the world. The scope of VIII-1 is for vessels with pressures generally not exceeding 3000 psi (20 MPa) and is common for low pressure storage vessels. VIII-1 has the largest design margin (3.5) and typically uses lower strength steels, known for higher ductility. ASME developed VIII-2 in the late 1960's. Today, it has two classes of vessels with a design margin of 3.0 and 2.4. ASME VIII-3 has been published since 1997 and is generally for pressure vessels over 10 ksi (70 MPa) with the lowest design margin of 1.8.

Many applications in the hydrogen economy, however, are requiring higher pressures to make transport of the gas more economical (Office of Energy Efficiency & Renewable Energy, 2016). Due to its low energy volume, most cars are operating with a high-pressure tank (vessel) of 10,000 psi (69 MPa) containing 5 kg of compressed hydrogen. These cars are typically filled at stations with storage vessels that are 15,000 psi (103 MPa).

ASME VIII-2 has many higher strength materials allowing lighter weight and more economical vessels. However, fatigue becomes a more prevalent issue due to the higher stresses. Evaluation of the life of the vessels in key critical areas and establishment of an in-service inspection program is critical to long term safe operation. VIII-2 includes a fatigue assessment methodology for most materials permitted for construction but leaves addressing the hydrogen environment up to the designer.

ASME acknowledges that it does not cover many cases of environmental effects such as hydrogen. ASME Section II-D, Nonmandatory Appendix A A-702 contains general information regarding

hydrogen damage, embrittlement, blistering, and cracking. However, little specific guidance is provided to the designers of hydrogen equipment. ASME formed a special "Project Team on Hydrogen Tanks" to develop rules for design in hydrogen environments in the early 2000's. The committee consisted of industry representatives and worldwide researchers involved in high-pressure hydrogen infrastructure. The rules first appeared in 2007 in ASME VIII-3 in KD-10 "Special Design Requirements for Vessels in High Pressure Gaseous Hydrogen Transport and Storage Service".

KD-10 captured the industry experience along with recommendations for testing for hydrogen service. This included criteria such as the relevance of the hydrogen partial pressure of hydrogen 6,000 psi (seamless) and 2,500 psi (welded). KD-10 mandated evaluation of fatigue cracking using fracture mechanics and required Manufacturer's to test materials for fatigue crack growth rate (da/dN) and the threshold for hydrogen assisted cracking (KIH). Fatigue crack growth rate and KIH testing has since been completed by laboratories worldwide, including Sandia National Lab, Savanah River National Lab, NIST, and Japan Steel Works on two common industry materials (SA-372 and SA-723) used for storage vessel construction. Code Case 2938 was first published in early 2019 to eliminate the need for Manufacturers to perform redundant testing to comply with KD-10. This testing showed significant increase in crack growth rate and limitations of critical crack size compared to the materials used in an inert environment. Other standards for supporting hydrogen storage tanks include ASME Section X that contains requirements for fiber-reinforced thermosetting plastic pressure vessels. This standard is used both for cylinders of fully composite materials and the CRPV's which are manufactured to VIII-3 and ASME Section X Appendix 8 (Class III).

Hydrogen storage also relies on piping and piping components for connection of the vessels to storage vehicles, etc. ASME B31.12 (2008) responded to the need for piping and piping components in the hydrogen market. This standard references other B31 standards to incorporate "best practices", such as B31.3, Process Piping; B31.1,Power Piping; B31.8, Gas Transmission and Distribution Piping Systems; B31.8S, Managing System Integrity of Gas Pipelines; and VIII-3.

Continued on next page

An additional challenge for many operators will be the life management. The fracture mechanics design approach of ASME VIII-3 or even the fatigue based approach of an ASME VIII-2 vessel will result in a vessel with a finite life. Some equipment was installed less than ten years ago is already exceeding the design life. Requalification of vessels in fatigue service is not new. ASME PCC-3, Inspection Planning Using Risk Based Methods, contains methodology for requalifying vessels in cyclic service that has been in use for decades. The method allows for continued use of the vessels beyond the design basis with a proper program of asset management, maintenance of the design basis documents, tracking of in-service cyclic usage, and periodic inspection for plausible failure modes. And of course, consideration of jurisdictional requirements should not be overlooked.

Unfortunately for many end-users, it is not uncommon to develop an in-service inspection program to be considered during design or installation. Even simple seamless cylinders are often mounted in racks making disassembly of the system necessary to access even the OD of the cylinders.

Methods for evaluation of many of the hydrogen damage modes, if found, are contained in API 579-1 / ASME FFS-1, Fitness for Service Standard. Many of these damage assessment procedures can be implemented, including evaluation of the continued life of the vessel using fracture mechanics. However, consideration of the effects of hydrogen embrittlement from KD-10 and Code Case 2938 should be considered.

There have been several case studies recently regarding the use of the methods in the ASME standards for life assessment in hydrogen environments, particularly with Code Case 2938. Discussions at the ASME Pressure Vessels and Piping (PVP) conference, as well as with the study group has led to additional study about lower pressure hydrogen and the effect on fatigue life. This will be published at the upcoming ASME PVP 2021 Conference and will show that even at pressures as low as 1 bar of hydrogen, there can be substantial detrimental effect on the life of hydrogen equipment (Ronevich and San Marchi, 2021). This could have significant future ramifications in all parts of ASME's hydrogen codes and standards, including ASME VIII-1 or other low pressure vessels.

SUMMARY

The need to dramatically reduce CO2 emissions and meet global warming goals will drive market changes that will impact all our lives for decades to come. In the last 10 years, we have seen exponential growth in renewable energy in the form of solar and wind, with decreasing costs as mass production efficiencies are achieved. As stated earlier, many countries are betting on hydrogen to be one of the key components in achieving our environmental goals. All of this will drive the demand for pressure equipment to be used in the production, storage, and transmission of energy storage media such as hydrogen and ammonia.

ASME continues to evolve and advance its standards to keep pace with technology and the research supporting it. Many industries in the past have gone through similar evolutions to ensure that the equipment and personnel using it are able to function safely and design for the unknowns. A key aspect of the long-term success of the hydrogen economy will be not only in design, but in successful safe operation of the equipment over time in a cost effective manner. ASME will continue to develop standards for supporting the entire life-cycle of hydrogen equipment.

Footnotes

Office of Energy Efficiency & Renewable Energy. (2016 July 16). *5 Things to Know when Filling Up Your Fuel Cell Electric Vehicle.* https://www.energy.gov/eere/articles/5-things-know-when-filling-your- fuel-cell-electric-vehicle

Ronevich, J., & San Marchi, C. (2021) *Materials Compatibility Concerns for Hydrogen Blended into Natural Gas, PVP2021-62045.* (Proceedings of the ASME Pressure Vessels and Piping Conference, PVP2021). New York, NY: ASME.

Thomas, G., & Parks, G. (2006 February). *Potential Roles of Ammonia in a Hydrogen Economy.* U.S. Department of Energy.

U.S. Department of Energy. (2020 December 20). Energy Storage Grand Challenge Roadmap. https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Grand%20Challeng e%20Roadmap.pdf

SI FatiguePRO for Hydrogen Fueling Station Assets

Vessel Life Cycle Management

ERICK RITTER
eritter@structint.com

DANIEL PETERS
dpeters@structint.com

Initial introduction of many of the hydrogen fueling stations to support this rapidly growing demand were installed around 2010. There were many designs of cylinders developed and installed at that time, many with known limitations on the life of the equipment due to the high pressures involved and cyclic fatigue crack growth issues due to hydrogen embrittlement. The designs were often kept relatively simple to lower their costs often with little or no considerations for in-service inspection or potential end of life considerations. Others involved innovative designs with reinforcing wrapping to try to enhance the life of the vessels, but by doing so, these designs limited the access to the main cylinder wall for in-service inspection.

Many of these vessels are now reaching or passing the design life established by ASME. This is resulting in problems for operators of this equipment as some jurisdictions will not allow the vessels to operate beyond the design life without inspection or re-rating of the vessels to extend the fatigue life. SI's FatiguePRO is a commercial software solution which has been addressing this exact concern for over 25 years.

Hydrogen, one of the newest forms of energy storage is amazingly, not all that new. The term "hydrogen economy" was coined by John Bockris during a talk given in 1970 at a General Motors (GM) Technical Center.

The Hydrogen Council was formed in 2017 as a global CEO led initiative to accelerate significant investment in the development and commercialization of the hydrogen and fuel cell sectors and encourage key stakeholders to increase their backing of hydrogen as the future of energy.

Several auto manufacturers have released fuel cell cars commercially, with manufacturers such as Toyota and some Chinese automakers planning to increase production of these cars into the hundreds of thousands in the next decade.

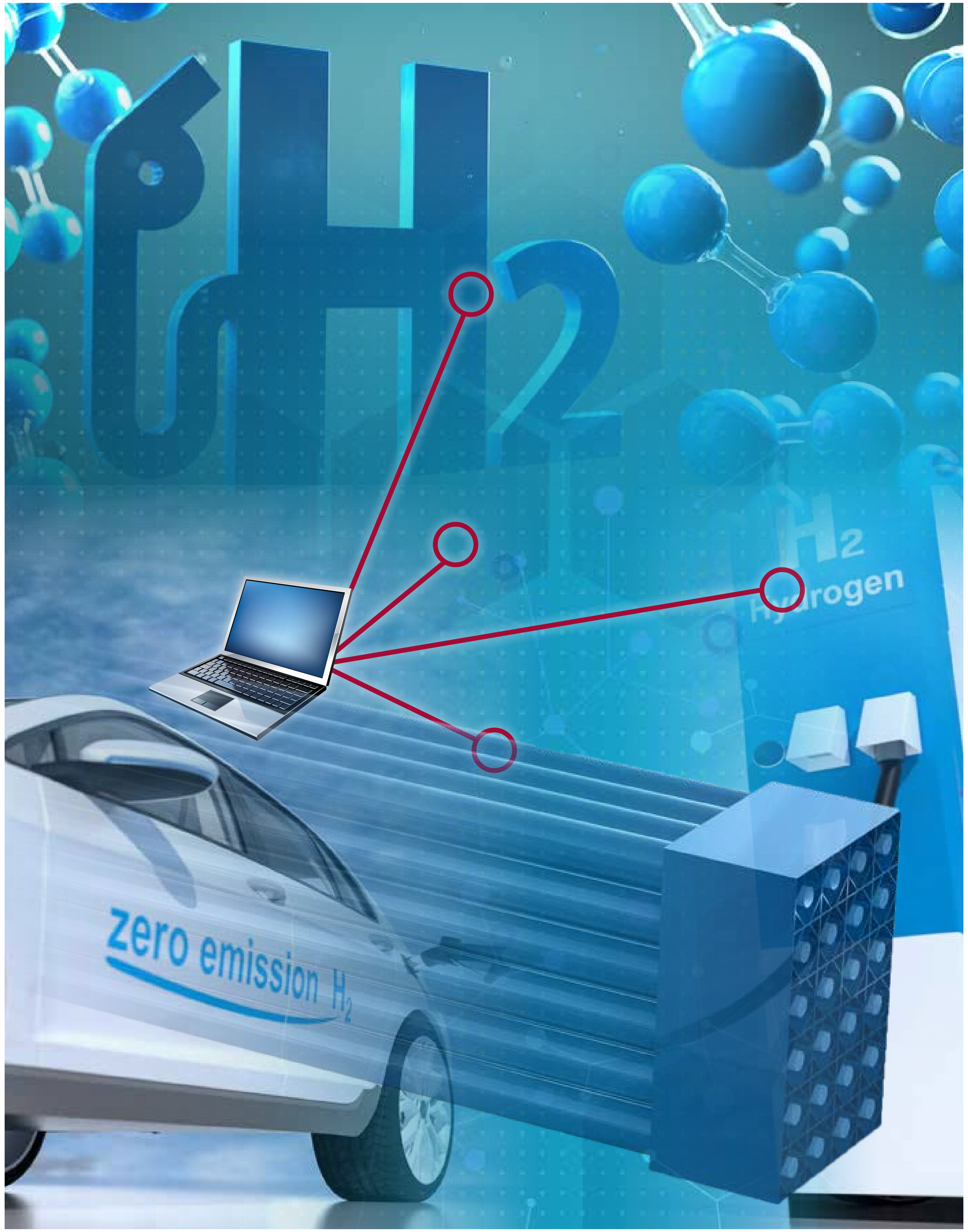
Hydrogen storage vessels typically have the life based on fracture mechanics crack growth methods found in ASME Section VIII, Division 3. This methodology assumes an initial flaw size exists in the vessel which is at the threshold of being detected by the non-destructive examination techniques used during construction. The calculation method grows the crack by considering a "design histogram" of operational scenarios to determine the number of cycles to failure. The philosophy would be that the vessels, if inspected in the future and a flaw is not found, could have their life expectancy reset and considered to be "as new" relative to crack growth.

The issue is that many of the cylinders either:

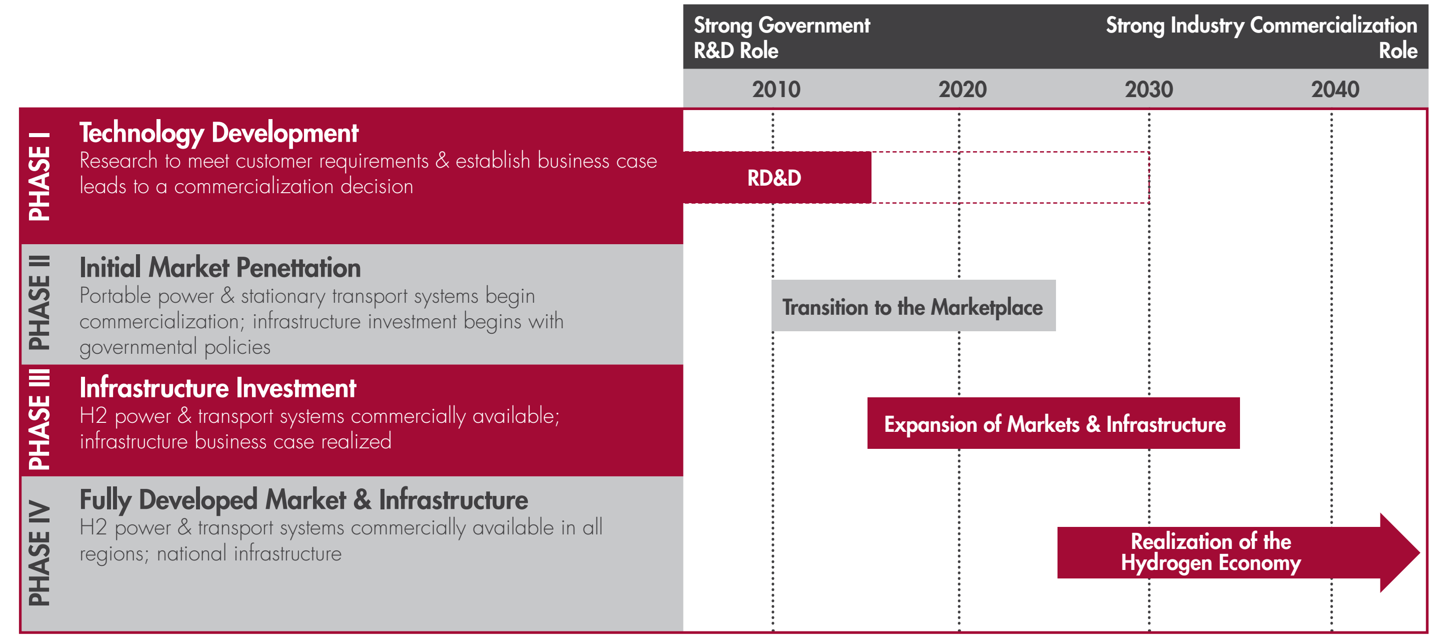
1. Are mounted too close together to allow for inspection in service
2. Have an external wrap which limits inspection from the outer diameter (OD)
3. Do not want to "lose their purge" which would result in costly down time to regain a pure environment of hydrogen
4. Do not have built in pressure cycles monitoring systems

Numerous companies in California are not able to continue operations of their equipment that has reached the end of the "design life". However, it has been shown that the calculation of life of the vessels is often performed on a very conservative basis, compared to actual operating fill cycles. The actual life can be almost three times greater than originally predicted 10 years ago during the design phase.

Continued on next page



VOLUME 50 | **NEWS AND VIEWS** | HYDROGEN ECONOMY

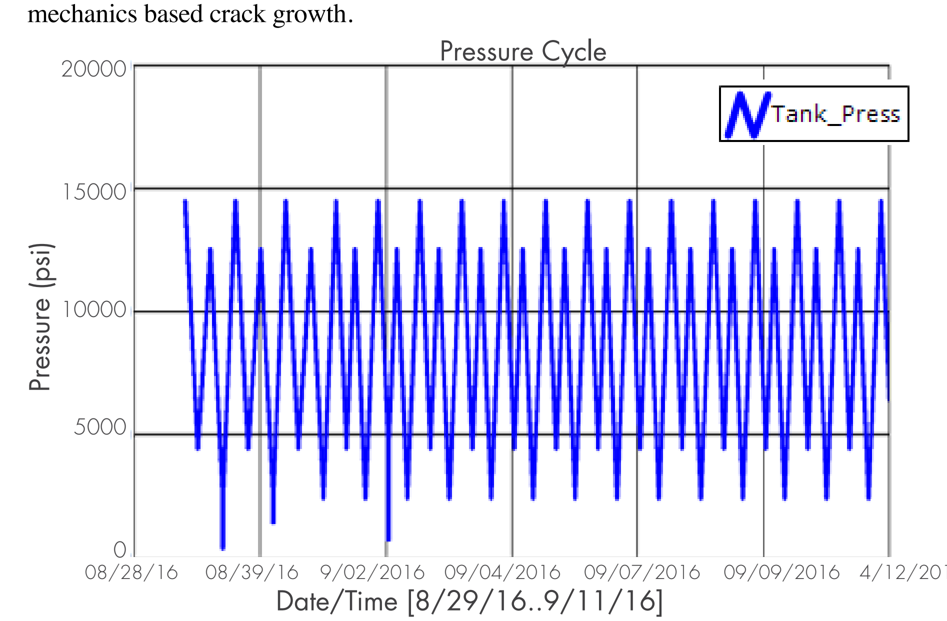


The key is to incorporate actual pressure time history data for the equipment from a monitoring system and use that to eliminate the conservatism from the initial design. The hydrogen cylinders are not typically filled perfectly to a specific pressure and refilled when the pressure drops to an exact pressure. Real world factors such as truck delivery schedules work into the actual operation of the cylinders, decreasing the magnitude of the actual range of pressure cycles achieved compared to that of the design.

SI has a history of over 25 years of developing and deploying software for this exact methodology for industrial applications, satisfying regulators in many industries within the power generation markets, including rigorous demands of the nuclear industry. SI initially developed both FatiguePRO and Creep-FatiguePRO through work with the Electric Power Research Institute (EPRI).

SI's FatiguePRO contains the ability to monitor pressure time history data for use in prediction of life in pressure equipment. This technology is now being implemented in requalification and extending the life of hydrogen storage equipment. Jurisdictional authorities have accepted this approach and the vessel's life can be extended.

This software can either be stand alone or coupled with SI's commercial Asset Integrity Management (AIM's) platform for online monitoring of multiple sites and systems. AIM's provides a complete asset integrity management system for storage of all records related to specific equipment and allows for the direct integration of pressure monitoring for the long monitoring of fracture mechanics based crack growth.



References

Ronevich, J. A., C. San Marchi, et al. "Exploring Life Extension Opportunities of High-Pressure Hydrogen Pressure Vessels at Refuelling Stations", Proceedings of the ASME Pressure Vessels and Piping Conference, Paper #PVP2021-61815, 2021.

'Hydrogen economy' (2019) Wikipedia. Available at: https://en.wikipedia.org/wiki/Hydrogen_economy (Accessed: 5 September 2021).

Reactor Vessel Integrity

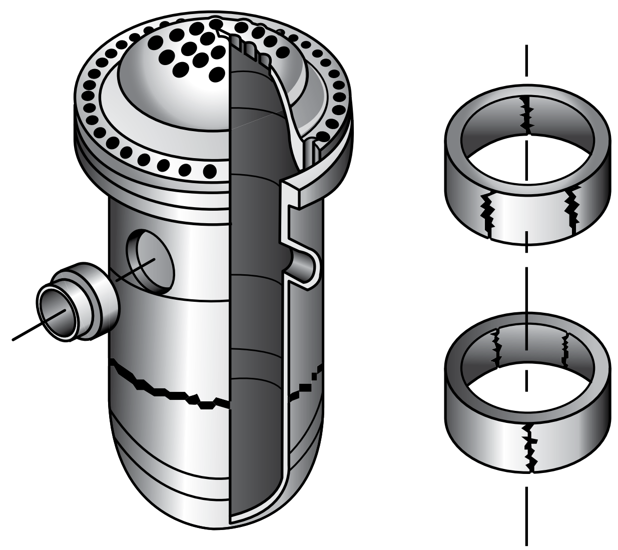
Fracture Toughness Criteria

TIM GRIESBACH
tgriesbach@structint.com

DAN DENIS
ddenis@structint.com

The integrity of the nuclear reactor pressure vessel is critical to plant safety. A failure of the vessel is beyond the design basis. Therefore, the design requirements for vessels have significant margins to prevent brittle or ductile failure under all anticipated operating conditions. The early vessels in the U.S. were designed to meet Section VIII of the ASME Boiler and Pressure Vessel Code and later Section III. ASME Section III included requirements for more detailed design stress analyses also included a fracture mechanics approach to establish operating pressure-temperature heatup and cooldown curves and to assure adequate margins of safety against brittle or ductile failure incorporating the nil-ductility reference temperature index, RTNDT. This index is correlated to the material reference fracture toughness, KIC or KIa.

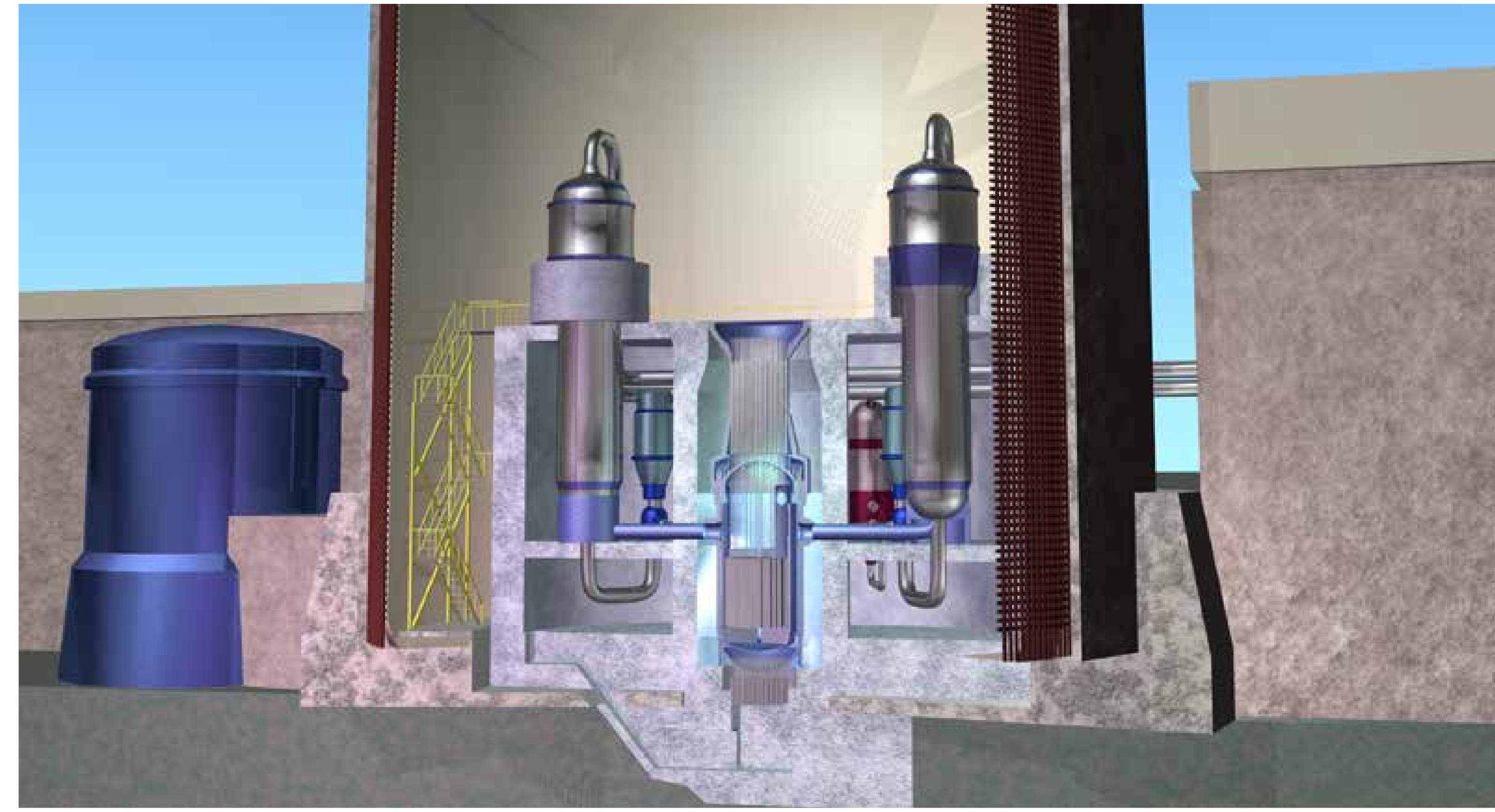
Radiation embrittlement is a known degradation mechanism in ferritic steels, and the beltline region of reactor pressure vessels is particularly susceptible to irradiation damage. To predict the level of embrittlement in a reactor pressure vessel, trend curve prediction methods are used for projecting the shift in RTNDT as a function of material chemistry and fluence at the vessel wall. Revision 2 of this Regulatory Guide is being used by all plants for predicting RTNDT shift in determining heatup and cooldown limits and hydrostatic test limits.



In 1988 the ASME Code approved the Section XI Non-Mandatory Appendix G, "Fracture Toughness Criteria for Protection Against Failure". This appendix replaced the Section III, Appendix G for heatup and cooldown limits in operating plants when it became mandatory according to 10CFR Part 50, Appendix G, "Fracture Toughness Requirements". As plants continue to age, the effect of radiation damage on vessel materials has caused a narrowing of operating heatup and cooldown limits for PWRs and an increase of the hydrostatic test temperatures for BWRs that may cause hardships for plant operation.

Structural Integrity Associates, Inc. has specialized expertise in managing reactor vessel embrittlement and vessel integrity. Tim Griesbach is chairman, of the ASME Section XI Working Group on Operating Plant Criteria, the group with the responsibility for ASME Section XI, Appendix G that establishes the Code criteria for heatup and cooldown limits and pressure tests. This Working Group has made significant advancements over the past 15 years for improved heatup and cooldown limits.

VOLUME 50 | **NEWS AND VIEWS** | NUCLEAR POWER SUSTAINABILITY



SI can provide technical support in a number of areas related to reactor vessel embrittlement and vessel integrity, including:

- P-T curve development
  - For multiple RPV regions including vessel shell, welds, flanges and nozzles
  - NRC approved PTLR method for BWR P-T limit curves
- Materials evaluation in accordance with Reg. Guide 1.99, Rev. 2
  - Establish initial RTNDT values
  - Compute adjusted reference temperatures (ARTNDT)
  - Establish credibility of multiple data sets for revised chemistry factor (CF) values
- Third party review of surveillance program results or implementation
- BWRVIP Integrated Surveillance Program (ISP) implementation
  - “Conversion” of old surveillance program into ISP
  - Implementation of new test results when applicable
- Training on reactor vessel integrity and P-T limit curves
- Low Temperature Over Pressure (LTOP) setpoint evaluation
- Pressurized Thermal Shock (PTS) evaluation
- Cold Overpressure Mitigation System (COMS) setpoint evaluation
- Evaluation of projected vessel properties and P-T limits for license renewal applications
- Upper shelf energy (equivalent margins) assessment for vessel end-of-life and for license renewal
- Vessel fluence evaluation
  - Transware Enterprises is on SI’s approved vendor list
- Technical Specification and FSAR revisions

SI is currently working with a number of utilities to review data from the BWRVIP ISP, incorporate these surveillance data results and updated fluence evaluations into revised P-T limit curves.

TRU Compliance Equipment Testing Project

Equipment Testing and Certification to Assess Risk

KATIE BRAMAN
kbraman@structint.com

Using a risk-based approach derived from various seismic standards from the Institute of Electrical and Electronics Engineers, TRU and BC Hydro will develop a synthetic test motion in three axes, mount the equipment on a triaxial shake table at TRU's testing partner's facility, and test at increasing levels until various levels of damage are observed.

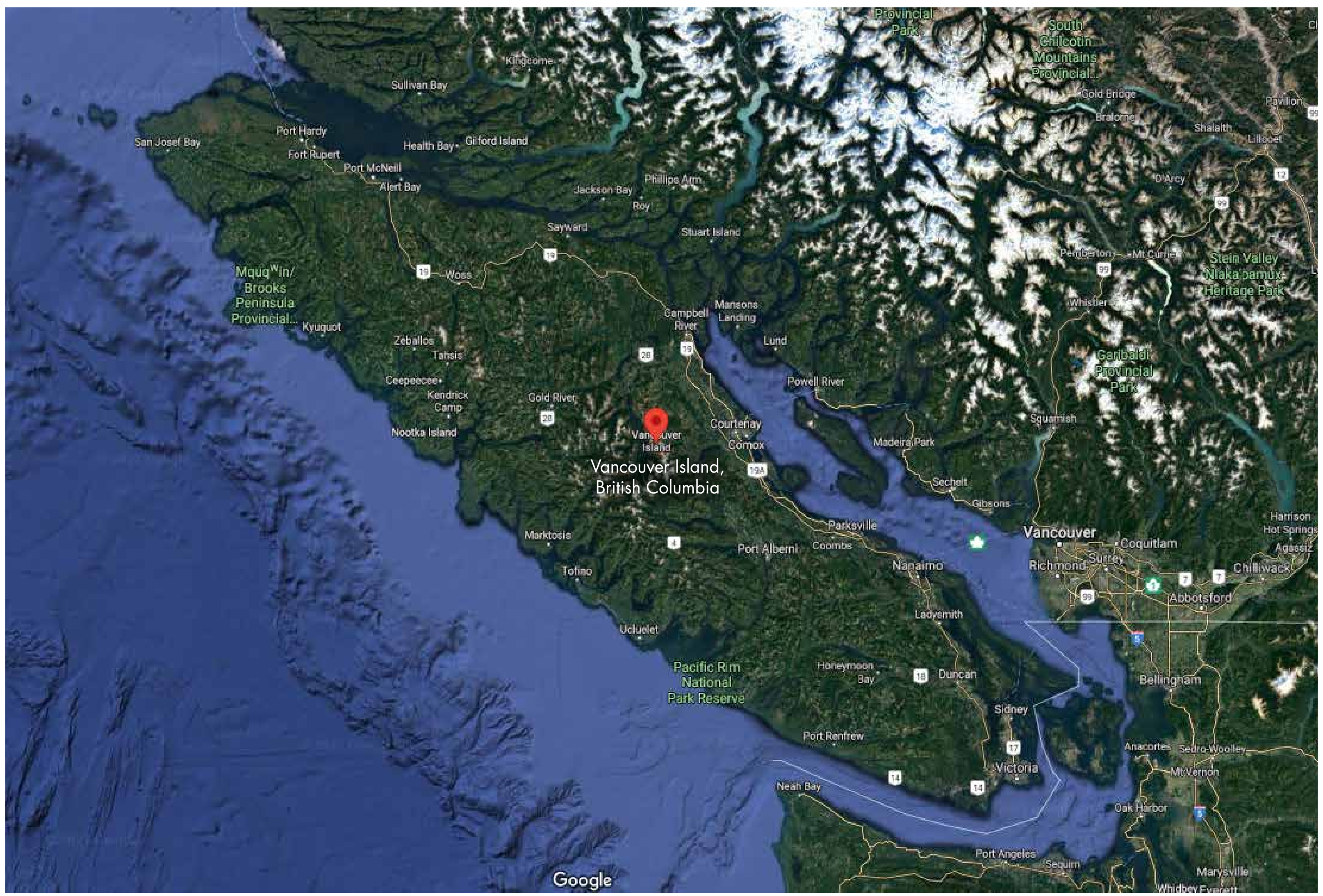


FIGURE 1. Ladore Dam Spillway, Image courtesy BC Hydro
Ref: https://www.mycampbellrivernow.com/wp-content uploads/2021/01/John-Hart-Dam.jpg

March 18, 2021

TRU Compliance, the accredited product certification body of Structural Integrity Associates, has been awarded a contract to assist BC Hydro in qualifying and better understanding the seismic vulnerability of critical equipment used to control its spillway gates. As part of the larger efforts to seismically upgrade the John Hart, Ladore, and Strathcona dams along the Campbell River system on Vancouver Island, British Columbia, BC Hydro is procuring equipment that allows precise flow control of the water going over the spillway. Reliable equipment is needed to prevent possible overtopping or having uncontrolled water flow through the spillway.

Using a risk-based approach derived from various seismic standards from the Institute of Electrical and Electronics Engineers, TRU and BC Hydro will develop a synthetic test motion in three axes, mount the equipment on a triaxial shake table at TRU's testing partner's facility, and test at increasing levels until various levels of damage are observed. The goal is to document the damage levels until complete failure is observed. The outcomes of this testing will not only qualify the equipment for use in the facilities but will also allow BC Hydro to better estimate the seismic margin of the spillway systems at other generating facilities. The rich test data will allow informed risk-based decision making to guide BC Hydro as it manages its hydroelectric assets into the future and continue to enable them to provide safe and reliable power to its 1.8 million customers.

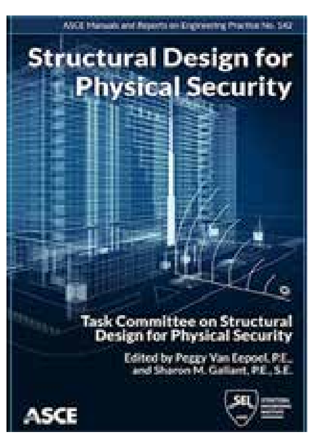
FIGURE 2. Project location

Structural Design for Physical Security

Structural Integrity's Own, Andy Coughlin Published by American Society of Civil Engineers, ASCE.

Andy Coughlin's work has been published in the ASCE Structural Design for Physical Security: State of the Practice. The Task Committee on Structural Design prepared the publication for Physical Security of the Blast, Shock, and Impact Committee of the Dynamic Effects Technical Administration Committee of the Structural Engineering Institute of ASCE. Andy wrote Chapter 10 on Testing and Certification for Physical Security and assisted on several other chapters.

Structural Design for Physical Security, MOP 142, provides an overview of the typical design considerations encountered in new construction and renovation of facilities for physical security. The constant change in threat tactics and types has led to the need for physical security designs that account for these new considerations and anticipate the environment of the future, with flexibility and adaptability being priorities. This Manual of Practice serves as a replacement for the 1999 technical report Structural Design for Physical Security: State of the Practice and is intended to provide a roadmap for designers and engineers involved in physical security. It contains references to other books, standards, and research.



TOPICS INCLUDE

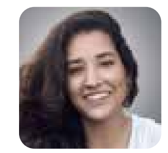
- Threat determination and available assessment and criteria documents,
- Methods by which structural loadings are derived for the determined threats,
- Function and selection of structural systems,
- Design of structural components,
- Function and selection of window and facade components,
- Specific considerations for retrofitting structures,
- Testing methodologies, and
- Bridge security.

This book will be a valuable resource to structural engineers and design professionals involved with projects that have physical security concerns related to explosive, ballistic, forced entry, and hostile vehicle threats.

Of particular note is the publication of the process by which products can be tested and certified to achieve physical security performance in blast, ballistics, forced entry, and vehicle impact. Often unclear or overly specific requirements hamper the application of quality products which protect people and assets from attack. The certification process below shows how approved agencies, like SI's TRU Compliance, play a role in testing, evaluating, and selecting products for use in critical physical security applications, rather than relying solely on the claims of the manufacturers. TRU's certification program is the first of its kind to receive IAS Accreditation for the certification of physical security products.

Porting SI's ANACAP Concrete Model into LS-DYNA

Advanced Structural Analysis



LIVIA MELLO
lmello@structint.com

SHARI DAY
sday@structint.com

One of Structural Integrity Associates' (SI) strengths is combining state-of-the-art software with material science expertise to solve difficult structural and mechanical problems. A notable example in recent years is the Aircraft Impact Analysis (AIA) performed by SI for NuScale Power, using the ANACAP concrete material model. With SI's support, NuScale's Small Modular Reactor (SMR) building design passed NRC's comprehensive inspection, bringing NuScale's SMR technology one step closer to market [N&V Vol. 47 p. 5].

SI's success in AIA is due not only to our team's capabilities but also due to the capabilities of our proprietary concrete constitutive model, ANACAP, developed by Joe Rashid, Robert Dunham, and Randy James of ANATECH, now part of SI. Modeling reinforced concrete, which is both nonhomogeneous and anisotropic, is often a challenge in advanced structural analysis. However, ANACAP has a long track record of accurately capturing nonlinear concrete response in structural systems subjected to static, impact, and seismic loads. Its application goes beyond AIA; it has also been utilized in several of SI's commercial building, bridge infrastructure, nuclear plant, and hydroelectric facility projects.

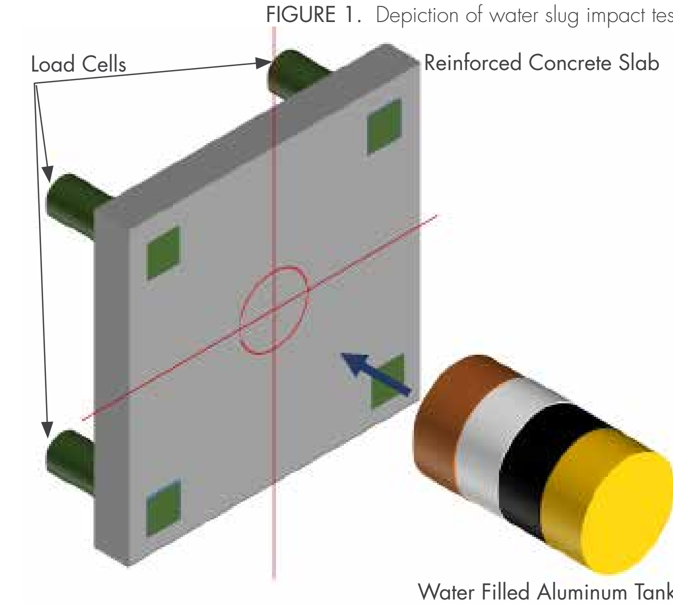
ANACAP has the ability to account for cyclic degradation, multi-axial cracking, load-rate effects, aging, creep, shrinkage, crushing, confinement, concrete-reinforcement interaction, and high-temperature softening behavior. The combination of these features results in an exceptional representation of concrete intricate behavior. It also leads to more accurate results when compared to standard finite element "built-in" concrete material libraries, all the while being implemented within the same standard finite element formulation.

With the purpose of expanding ANACAP's reach and better attend to our clients' safety-related needs, SI is integrating the concrete model into the specialized structural analysis software LS-DYNA, an explicit transient dynamic finite element code. Explicit finite element solvers are typically required to evaluate shock, blast, impact, drop, and other complex loading scenarios.

Following the Nuclear Energy Institute (NEI) 07-13 guidance, this software coupling must be extensively tested and verified for a wide range of problems representative of missile impacts on reinforced concrete slabs. One of these problems is presented here--a water slug impact test (WS test), in which a water-filled cylindrical aluminum tank impacts a reinforced concrete slab at a high velocity, as depicted in Figure 1.

Continued on next page

FIGURE 1. Depiction of water slug impact test



In LS-DYNA, the WS test is simulated using a half symmetric model that includes the load cell connection, as illustrated in Figure 2. The pipes connected to the bearing plates are modeled, and the bolts running through pipes that tie the slab to the load cell are also modeled. Contact surfaces are set up between the concrete and load cells as well as between the bearing plates and nuts securing the tie rod bolts. The model includes a symmetry boundary condition on the vertical cut along the center of the slab. The ends of the load cells are fixed in the lateral direction to represent support from the reaction test frame. The loading is simulated with an applied pressure over a semi-circular area.

Analysis results are shown in Figures 3 through 6, in comparison with the test data. Figures 3 and 4 provide comparisons of the displacement histories at two points along the horizontal centerline of the impact location. Point D8 is at the center of the impact and point D6 is off-center, as shown in Figure 2. These plots show that the analytical results are in good agreement with the measured experimental data, which indicates that the concrete model for the slab is performing well in simulating the actual concrete response.

Figure 5 compares the total reaction force in the direction of the impact calculated from the analysis to that measured in the test. The higher initial peak in the data is due to the hardness of the tank's front-end cap, which is not modeled in the analysis and produces a higher initial impact force in the experiment. Figure 6 compares the impulse of the total reaction force between the test data and analytical results. Also included in this plot is a dashed line representing the final value of the impulse calculated as the mass times the initial impact velocity of the water tank. The plot not only shows a close relationship between experimental and analytical results, but it also shows that the analysis captures the total impulse converging to the initial momentum of the impactor.

Snapshots of maximum principal strain in the concrete slab are shown in Figure 7,

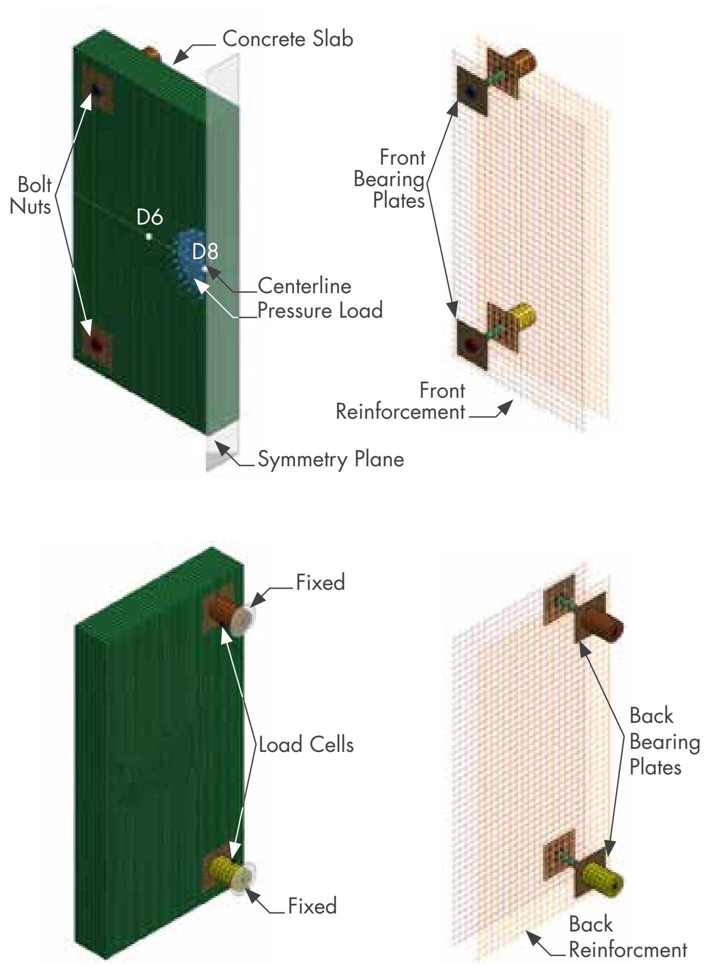


FIGURE 2. Schematic of LS-DYNA model

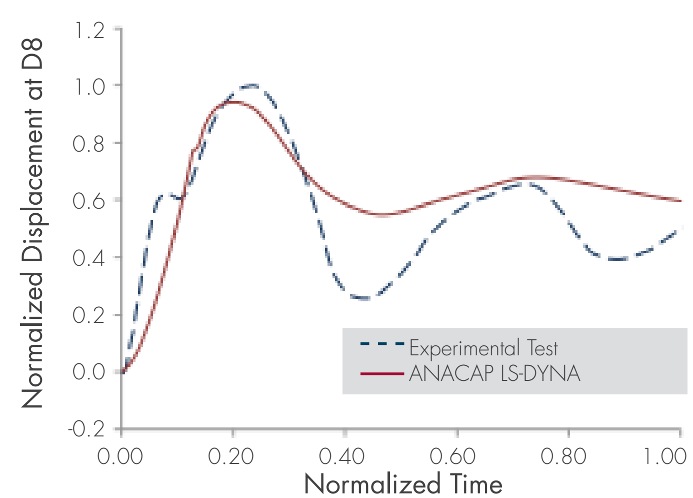


FIGURE 3. Displacement evolution at point D8

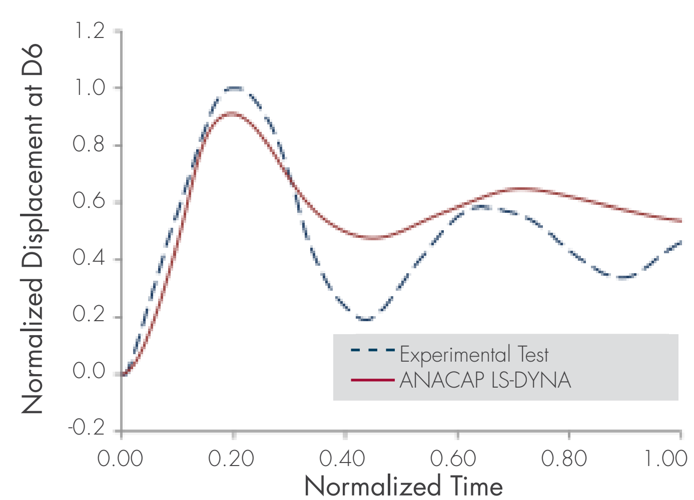


FIGURE 4. Displacement evolution at point D6

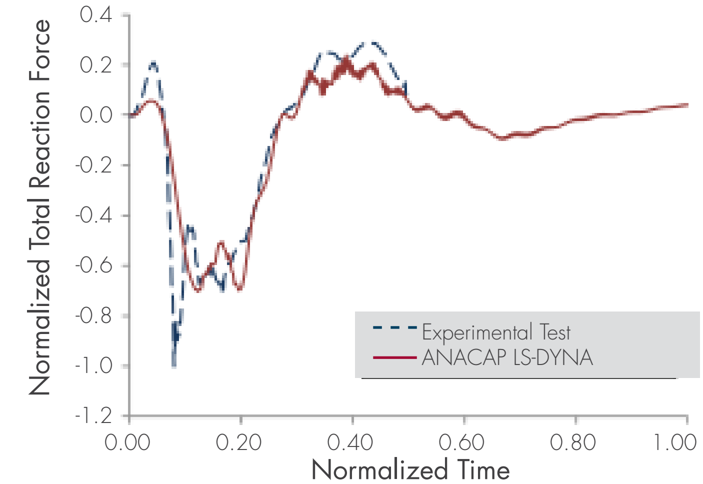


FIGURE 5. Total reaction force evolution in direction of impact

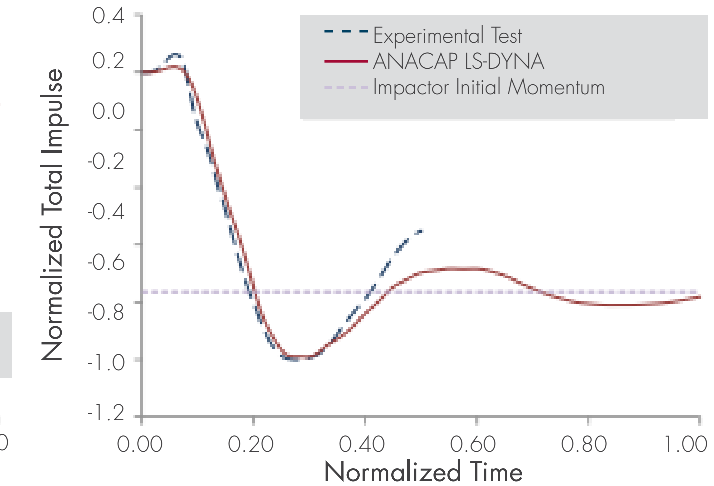


FIGURE 6. Impulse of total reaction force

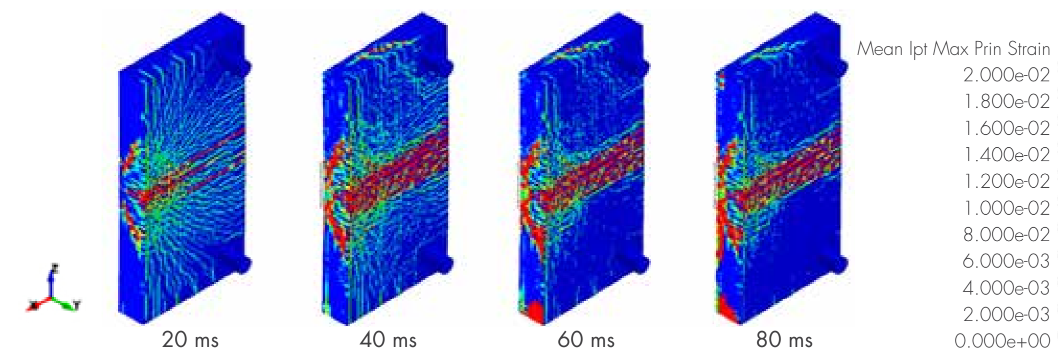


FIGURE 7. Snapshots of maximum principal strain on the concrete

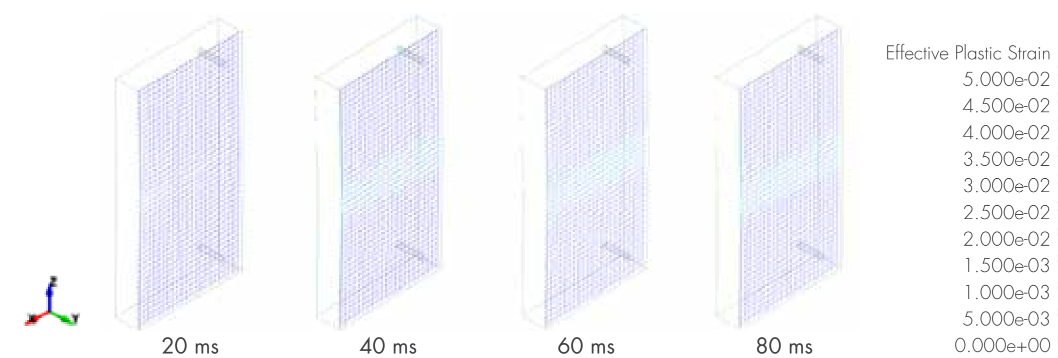


FIGURE 8. Snapshots of accumulated plastic strain in reinforcement on back face of slab

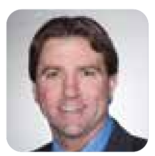
with a view from the back of the slab at solution time states of 20, 40, 60, and 80 milliseconds. This figure shows that heavy cracking damage develops in the slab without perforation, which is consistent with observations of the experimental results. This figure also shows that the concrete model can capture the closure of some of the initial cracking as the slab oscillates. Although ANACAP does not allow for any of the formed cracks to fully heal, it does allow for crack closure and consequent load-carrying capacity under compression and shear.

Snapshots of accumulated plastic strain in the bending reinforcement on the back face of the slab are shown in Figure 8. We see moderate yielding of the bars, but the plastic strain remains below 5%, which is the assumed strain rupture criteria. This indicates that the damage is sufficient to yield a few reinforcing bars but that slab failure due to bending does not occur, which is again consistent with what was observed during the test.

Based on these results, the ANACAP/LS-DYNA simulation reproduces the correct structural response and correlates well with the damage sustained by the slab documented in the WS test. This validation, combined with additional verification and validation problems in the suite of software testing SI performs, provides confidence that SI's ANACAP model has been successfully integrated into LS-DYNA, and that the material routine can capture the complexities of reinforced concrete behavior for advanced analysis applications such as AIA.

Material Verification for Oil and Gas Clients

Pipeline Integrity Solutions



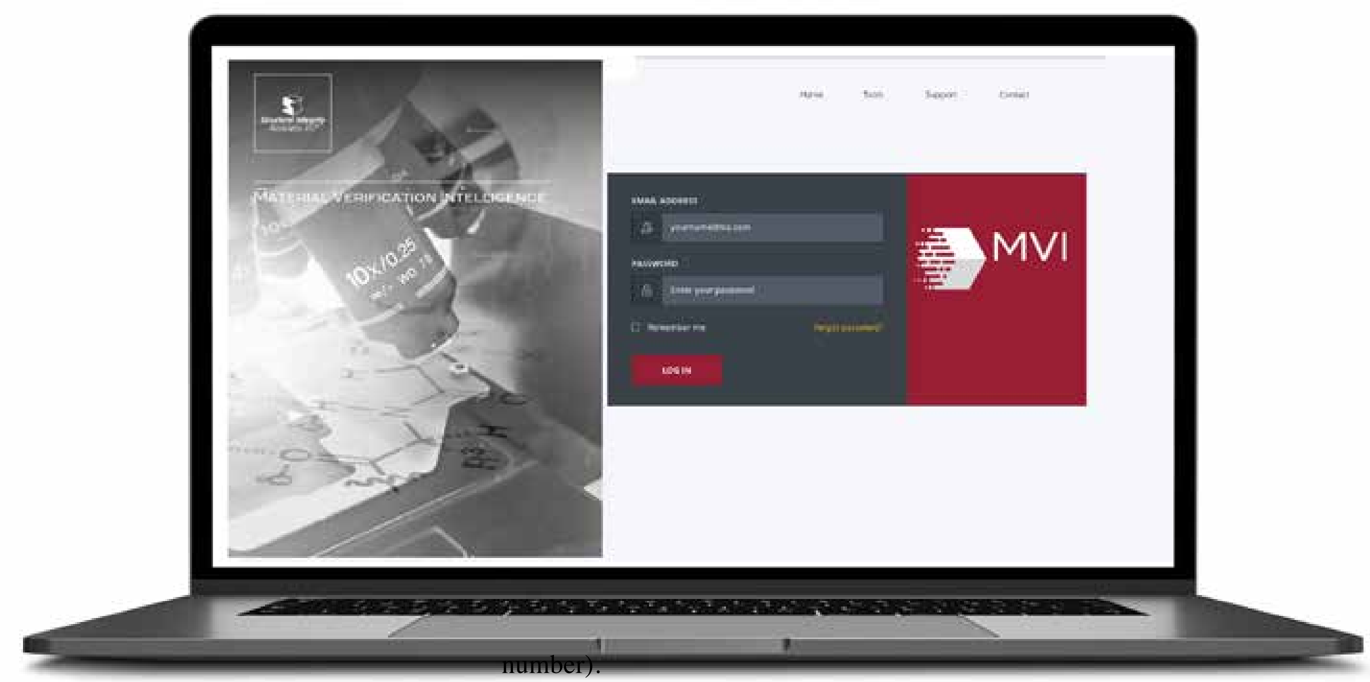
SCOTT RICCARDELLA
sriccardella@structint.com

ROGER ROYER
jvanvelsor@structint.com

On October 1, 2019, the Pipeline and Hazardous Materials Safety Administration (PHMSA) published amendments to 49 CFR Parts 191 and 192 in the Federal Register, issuing Part 1 of the Gas Transmission Mega-Rule or "Mega-Rule 1". In advance of Mega-Rule 1, SI developed field protocol and supported leading industry research institutes in validating in-situ Material Verification (MV) methodologies. SI has continued to provide MV consulting support to our clients in response to Mega-Rule 1, ranging from program development and implementation to in-situ field data collection and analysis.

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

VOLUME 50 | **NEWS AND VIEWS** | OIL & GAS SAFETY & RELIABILITY



To support our clients in complying with the new regulations, SI has invested in developing a program and staff to perform "in the ditch" non-destructive MV testing to collect the pipeline attributes required in the absence of TVC records, including grade prediction. In addition, SI has supported multiple clients by developing and implementing turnkey MV Programs and Procedures to address the new regulatory requirements for material property verification.

Key elements of this program typically include:

- Roles and Responsibilities Identification (Customized for each client)
- Personnel Qualifications
- TV&C Records Review
- Population Grouping and Sampling
- Site Selection, Feasibility, and Planning
- MV Testing: In-Situ and Laboratory
- Post Verification and Data Integration
- Conflict Resolution and Increased Sampling Protocol
- Regulatory Notification of Alternative and Expanded Sampling in Accordance with §192.18

SI has developed custom training programs to cover all of these areas and look forward to assisting our existing and future clients as we continue to expand our service offerings to support regulatory requirements.

To get started with MVI, visit si-megarule.com/mvi. If you wish, an SI expert can assist you with developing the required MV procedures, support program setup and management.

Oil and Gas Pipeline Intel

Industry Regulation Insights

PRCI June Technical Committee Meetings

Structural Integrity Associates (SI) recently attended the PRCI June 2021 Technical Committee (TC) Meetings. SI is also planning to support the upcoming PRCI NDE workshop scheduled for October 2021 as well as future committee meetings. SI will continue to engage and support industry with PRCI. As a researcher for PRCI, SI is pleased to support industry in the development and evaluation of new technology and methods that can enhance pipeline safety and reliability. SI continues to support the development of new tools and analytical methods to help advance crack management, material verification, NDE inspections, and pipeline integrity management and share our experience with PRCI and industry. Please contact us with any questions regarding our involvement or how SI can support your pipeline safety and reliability objectives.

SI Presenting at the 2021 AGA Operations Conference on "Responding to Cracks and Crack-Like Defects for Mega-Rule 1".

Structural Integrity is pleased to partner with Duke Energy to present on Mega-Rule 1 requirements for the Analysis of Predicted Failure Pressure (192.712). Procedures, tools and practical applications will be presented along with specific case studies. In addition, methods to address additional requirements for evaluating cyclic fatigue will also be presented. This presentation will be at the AGA Fall Operations Conference in Orlando, FL scheduled for October 6, 2021 at 10:45 AM in the Integrity Management track. Additional detail on the event can be found at the following site: www.aga.org/OpsConf2021

Materials Laboratory Case Studies

Case Study #1 | Manufacturing – Process Upsets

WENDY WEISS
wweiss@structint.com

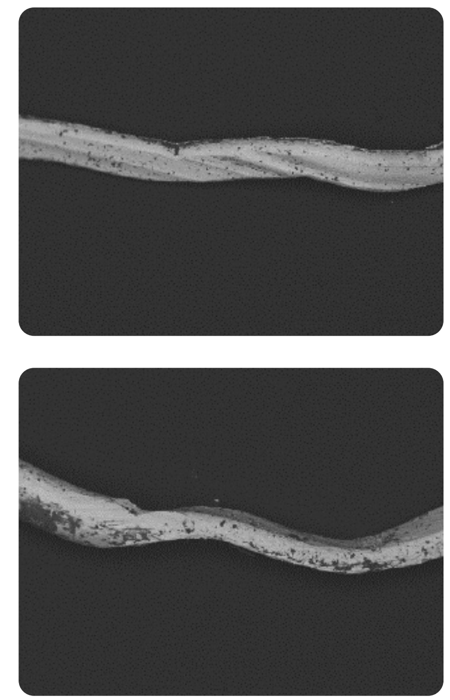


FIGURE 1. SEM images of the particle

Element	Weight %
Chromium	17.9
Manganese	3.8
Iron	63.5
Nickel	7.4
Molybdenum	0.4

Element	Weight %
Carbon	4.2
Oxygen	1.5
Aluminum	0.2
Silicon	0.9
Chlorine	0.1

THE PROBLEM

A small metallic particle that had contaminated a product line was brought to SI's Materials Laboratory for analysis. The goal of the analysis was to identify the particle's composition to help identify its original source.

TTHE SOLUTION

The particle was examined and documented in a scanning electron microscope (SEM) as shown in Figure 1. The particle was several millimeters long and appeared to have been originally round in cross-section with subsequent mechanical deformation. The particle exhibited intermittent areas of a surface deposits that appeared black in the SEM images.

An area that was relatively free of the surface deposit was analyzed using energy dispersive X-ray spectroscopy (EDS) to identify the element present in the base material. The EDS analysis are provided in the table. The particle was attached to an aluminum planchet with a piece of carbon tape, so much of the carbon is from the sample preparation. The EDS results indicated the particle was essentially an iron-based metal with approximately 18% chromium and 8% nickel, which is consistent with Type 304 stainless steel. Knowing the composition, the manufacturer is investigating possible sources.

TEST METHOD DETAIL

EDS provides qualitative elemental analysis of materials based on the characteristic energies of X-rays produced by the SEM electron beam striking the sample. Using a light element detector, EDS can identify elements with atomic number 5 (boron) and above. Elements with atomic number 13 (aluminum) and higher can be detected at concentrations as low as 0.2 weight percent; lighter elements are detectable at somewhat higher concentrations. As performed in this examination, EDS cannot detect the elements with atomic numbers less than 5 (beryllium, lithium, helium or hydrogen). The relative concentrations of the identified elements were determined using semiquantitative, standardless quantification (SQ) software. The results of this analysis are semi-quantitative and indicate relative amounts of the elemental constituents.

Materials Laboratory Case Studies

Case Study #2 | Manufacturing – Supply Chain Upsets

FIGURE 1. The submitted samples of material.

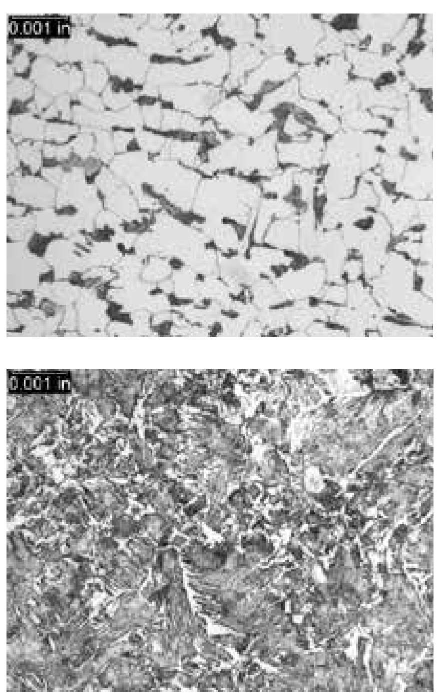


FIGURE 2. The typical microstructures from the marked sample TOP and the unmarked sample BOTTOM

THE PROBLEM

A manufacturer noticed recent material provided by a supplier was not performing as well as what had been provided previously, and asked SI's Materials Laboratory to investigate.

THE SOLUTION

Two pieces of stock material were submitted for analysis (Figure 1). The sample marked as F was the most recent material supplied to a manufacturer and the unmarked sample was the material that had been previously supplied. The newer material was not performing as expected and SI was asked to compare the two samples to identify any differences.

Cross sections were removed from both samples and prepared for metallographic examination. The microstructures from each are shown in Figure 2. The newer material (sample marked "F") had a microstructure consisting of pearlite in a ferrite matrix. The previously supplied material had a microstructure consisting of Widmanstätten ferrite and bainite. Hardness measurements were made on each prepared sample. The F sample had an average hardness of 66.7 Rockwell B and the unmarked sample had an average hardness of 90 Rockwell B. The measured hardness values were consistent with the observed microstructures.

The pearlitic microstructure and lower hardness value indicate that the newer material would have a lower tensile strength than the older material, which was likely the reason it was not performing as expected in its final application. Armed with this information the manufacturer has the information necessary to resolve the issue with the supplier.

TEST METHOD DETAIL

Metallographic examination involves mounting the cross-section, then grinding, polishing and etching. In this case, the carbon steel material was etched with a 2% Nital solution. The prepared sample was examined using an optical metallurgical microscope for examination at magnifications up to 1000X. The images shown were originally taken at 500X.

VOLUME 50 | **NEWS AND VIEWS** | FAILURE ANALYSIS

Materials Laboratory Case Studies

Case Study #3 | Infrastructure Upgrades – Material Verification

Sample ID	Average Hardness (HV)	Approximate UTS (ksi)
C1-1	144.2	69
C1-2	147.6	70
C2-1	192.2	89
C2-2	198.6	92
C2-3	169.6	79

THE PROBLEM

Structural Integrity received several sections of core reinforcing steel from a client performing work at a local university gymnasium (Figure 1). SI's client need to have an understanding of the material tensile strength in order to obtain the appropriate replacement material.

THE SOLUTION

Cross-sections were removed from each of the five samples and prepared for hardness testing. The hardness testing was performed as follows:

- Shimadzu Microhardness Tester (HMV-2) –1.961 N load
- Unit calibrated with a 206 Vickers (HV) sample block
- Five readings were made on each sample

The five hardness readings from each sample were averaged and used to estimate the approximate UTS, and the results are provided to the right.

FIGURE 1. The core reinforcing steel samples in the as-received condition.

HARDNESS VS. TENSILE STRENGTH

Hardness is a measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasion, while ultimate tensile strength is the maximum stress that a material can withstand while being stretched or pulled before breaking. Because hardness can often be measured much more readily than tensile strength, it is convenient to use hardness to estimate tensile strength. Hardness correlates linearly to ultimate tensile strength through the empirical (although theoretically explained) equation H=UTS/k. Tensile strength estimates based on hardness should be used for guidance only and should not be used as set reference values. Some material conditions, especially cold work, can change the relationship between the tensile strength and hardness profoundly.

Materials Laboratory Case Studies

Case Study #4 | Infrastructure Upgrades – Materials Analysis

THE PROBLEM
Structural Integrity received a section of an original star member from one of Austin's Moonlight Towers (Figure 1). The material was suspected to be a ductile or malleable cast iron and the company refurbishing the towers needed to determine a suitable replacement material. SI was asked to perform materials testing on the sample to determine its chemical composition, measure its tensile strength, and evaluate the microstructure to determine the material type.

THE SOLUTION
A portion of the star member was submitted for tensile testing and quantitative chemical analysis. Based on the compositional analysis, and particularly the carbon content, the star member is a low carbon steel and not a cast iron. The composition is consistent with UNS G10050 or ASTM A29 Grade 1005. The material was found to have a tensile strength of about 50 ksi and a yield strength of about 30 ksi.
A cross-sectional sample from the star member was prepared for evaluation using standard laboratory techniques. The prepared sample was examined using a metallurgical microscope for evaluation of the microstructure, which is shown in Figure 2. The microstructure consisted of perlite, nonmetallic inclusions, and casting voids/flaws in a ferrite matrix. The microstructure is consistent with a low carbon steel and is not indicative of a ductile or malleable cast iron. The microstructure also showed significant deformation, presumably from forming the star shape (Figure 3). It is not clear if the casting voids/flaws present in the material indicate the material was originally cast and then formed, or if they are just indicative of the quality of the material at the time of manufacture (i.e., the component is not a casting).

With the information from this analysis, the company performing the refurbishment was able to select a suitable material to replace the old, original Moonlight Tower star members.

FIGURE 1. The star member shown in the as-received condition.

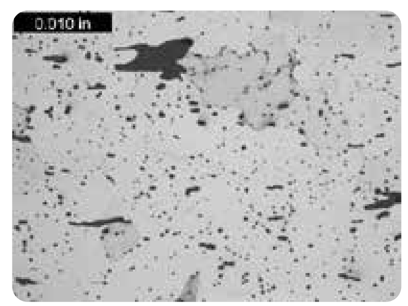


FIGURE 2. The typical star member microstructure.

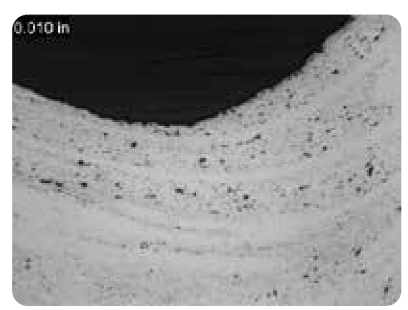


FIGURE 3. Deformation in the microstructure.

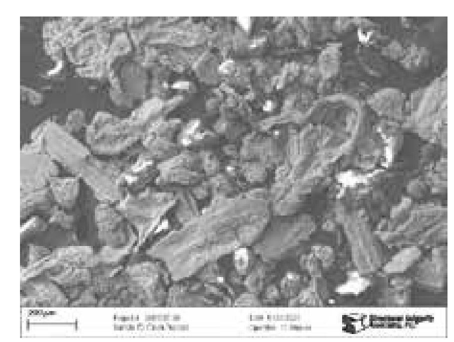
MOONLIGHT TOWERS
The moonlight towers in Austin, Texas, are the only known surviving moonlight towers in the world. They are 165 feet (50 m) tall and have a 15-foot (4.6 m) foundation. A single tower originally cast light from six carbon arc lamps, illuminating a 1,500-foot-radius (460 m) circle brightly enough to read a watch. installed, allowing citywide blackouts in case of air raids. (source: Wikipedia)

Materials Laboratory Case Studies

Case Study #5 | Process Upsets – Condition Analysis

FIGURE 1. The filter shown in the as-received condition.

FIGURE 2. The yellow color is the original appearance of the filter.



THE PROBLEM
A filter was removed from a stator cooling system after pressure differential sensors indicated it may be blocked. The filter was submitted to SI's Materials Laboratory for analysis to help identify the material blocking it.

THE SOLUTION
The filter was visually examined and documented in the as-received condition as shown in Figure 1. The submitted sample had a perforated plastic shell that covered an inner filter. The outer plastic was removed to provide access to the filter underneath. Figure 2 shows close images of the filter, which was yellowish-white with much of its surface covered in gray colored debris/deposit.

A portion of the filter was scraped to remove the deposits. Another portion of the filter was removed and soaked in Methyl Ethyl Ketone (MEK) to remove the debris present on the filter. The solvent evaporated and the remaining particles were collected. Both samples were analyzed in a scanning electron microscope using energy dispersive X-ray Spectroscopy (EDS) to identify the elements present.
The results are provided in Table 1. The results indicate that the filter debris was primarily copper oxide. Plant personnel reported that copper contamination could be occurring in the system, so these findings appeared to be consistent with plant information. With their suspicions confirmed, plant personnel were able to move forward with mitigation steps for keeping the filters from becoming blocked.

Element	Material Removed from Filer	Particles from MEK Wash
Carbon	4.9	ND
Oxygen	13.4	18.5
Aluminum	0.2	1.3
Silicon	0.4	4.2
Sulfur	0.1	0.3
Chlorine	0.1	0.1

Element	Material Removed from Filer	Particles from MEK Wash
Chromium	0.3	1.6
Iron	0.4	4.0
Nickel	ND	0.4
Copper	79.7	68.4
Tin	0.4	1.3

Structural Integrity Associates, Inc.®

1-877-4SI-POWER www.structint.com

Computer-Based Process Controls

Application of computer-based process controls for new systems and upgrades to existing water and waste treatment processes.

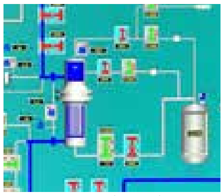
VALUE

- Expertise in water & waste processes
- Cost effective designs that meet specific requirements
- Customer service

EXPERIENCE

- Control system for new equipment and processes
- Upgrades to aging/obsolete PLC-based controls
- Replacement of antiquated electromechanical controls

Benchtop Test System



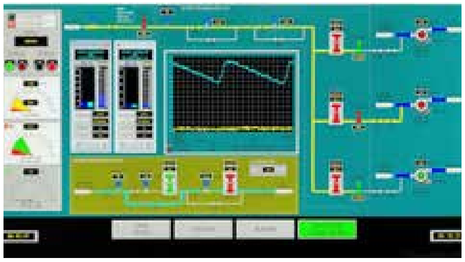
HMI Backwash & Precoat

SYSTEMS

- Integrated control system includes both a PLC (programmable logic controller) and a HMI (human-machine interface)
- For upgrades to existing controls, the PLC and HMI may be housed in an existing control panel if feasible
- Use of a remote I/O (Input/Output) panel allows system operations to be performed in an operator-friendly environment (e.g. low radiation dose area, etc.)

Main HMI Panel

Remote I/O Panel



HWC System Diagram

SERVICES

- Turnkey solutions - all design and development by Structural Integrity
- Control panel fabrication
- Benchtop Test system design and fabrication
- Factory acceptance/validation testing
- End-user training
- Plant start-up support

PROCESSES

- Deep Bed Demineralizers
- Resin Cleaning and Regeneration Systems
- Filter Demineralizer Systems
- Chemical Feed Systems
- Filtration Systems
- Redundant HMIs offer flexibility and reliability
- Custom-designed graphics meet plant specific requirements, standards and preferences

HARDWARE & SOFTWARE

- Hardware - Allen Bradley, Emerson
- Software - FactoryTalk®, Proficy®

Learn more about our computer-based process control and additional chemistry and materials offering: www.structint.com/chemistry-and-materials

For more information, go to:

www.structint.com/news-and-views-50