INSPECTION TRENDS

AUGUST 2024

THE MAGAZINE FOR MATERIALS INSPECTION AND TESTING PERSONNEL

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Voltage Vortex Voids in Pipeline Welding

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Stand Out with CWI Endorsements

DARYL PETERSON

You have passed the Certified Welding Inspector (CWI) examination. Now, you are eager to use this certification to make yourself rich. Excuse me while I chuckle. The reality is that new CWIs struggle to obtain good CWI jobs. The internet is filled with posts from disappointed CWIs who can't find jobs, and it is likely because they lack industry experience. Employers are looking for CWIs with experience, but what does that mean?

Most employers are looking for a CWI to be well-rounded and have experience in nondestructive examination and quality assurance (QA) and/or quality control (QC). What is QA/QC experience? It means the CWI understands quality systems. Quality systems include quality manuals, project-specific quality plans, inspection and test plans, nonconformance reporting and corrective action handling and resolution, and more. They also include process controls, welding procedure specifications (WPSs), welder qualification/certification, preheating, and more. Most new CWIs do not have this type of experience.

So, how can a CWI improve their skill set better to position themselves for employment in the inspection field? Additional certifications and endorsements are options. I will focus on CWI endorsements.

I would first recommend that the CWI take their Part C to the code they work with, or if they took their Part C on a code they don't work with, I would strongly encourage them to pursue endorsements for the code(s) they work with. That will demonstrate that the CWI has a better understanding of those specific codes and their associated requirements. I also highly recommend the welder performance qualification (WPQ1) and welder procedure qualification (WPQ2) endorsements. They demonstrate that the CWI understands qualifications much better than the average CWI. The vast majority of WPSs that I review are technically incorrect, especially the prequalified ones. There is a great need in our industry for improved qualifications.

The advantages of these endorsements are that they are affordable, they significantly reduce the cost of the CWI nine-year recertification (recertification by endorsement), and the cost of maintaining most of them is covered with the CWI renewal/recertification, as opposed to getting certifications from another organization. The cost of maintaining multiple certifications can get expensive quickly.

In summary, the AWS endorsements are a cost-effective way to gain and demonstrate the proficiency and knowledge that prospective employers desire in employees. After nearly 40 years in this field, I still learn new things every day. I am truly blessed to have had and continue to have outstanding mentors and peers, especially in the AWS Member Network. I highly encourage all CWIs to visit the AWS Member Network and soak in the experience of this profession's finest people, ask questions, and share some of your knowledge on subjects. The greatest attributes a CWI can have are the commitment to continuing education and making every day better than yesterday. IT

DARYL PETERSON (*daryl.peterson@outlook.com*) is quality manager at Central Maintenance and Welding, Lithia, Fla. He's an AWS SCWI and ASNT Level III, API 653, and SSPC PCI Level II inspector.

AWS Hosts Nine-Year Seminar at Headquarters

AWS held a nine-year recertification seminar for Certified Welding Inspectors (CWIs) from May 10 to 15 at AWS World Headquarters in Miami, Fla. Rick Suria, a Senior (CWI) and Certified Welding Educator, was the instructor. He is also the owner of Industrial Technology & Inspection LLC in Cape Coral, Fla.

Attendees of the seminar included the following: Christopher H. Weeks, Christopher T. Butkiewicz, Daniel J. Phagwa, David J. Gonzales, Erik Stone, Gregg W. Ganas, Jeffery K. Smith, Jeffrey L. La Cagnina, Jeffrey T. Iley, Jerry W. Cagle, Jesse R. Comeaux, Jose M. Perez, Kelvin J. Houston, Nathan N. Jacobson, Richard J. Baudoux, Roger M. Lugo, William A. Jolly, William F. Behnke, William Stoddard, and James Goodwin.

The attendees of the Certified Welding Inspector nine-year recertification seminar posed in front of AWS World Headquarters, Miami, Fla.

ASNT Launches Education Platform and Qualification Process for Training Organizations

ASNT, Columbus, Ohio, has announced new developments in its education and certification departments.

- The organization upgraded its education platform at *education.asnt.org*. The learning management system provides users with a seamless enrollment process and enables them to complete various education offerings, including webinar series, certification prep courses, and ASNT NDT Classroom eLearning courses. This change means the organization's different training products are now available in one place.
- Starting in late summer 2024, ASNT certification services will launch a new accreditation process for nondestructive examination (NDE) training organizations in the United States to become Authorized Training Organizations (ATOs). This initiative aims to elevate the standards and quality of NDE training. ATO accreditation necessitates that training organizations conduct a comprehensive assessment of their programs, guaranteeing that their policies and procedures are well defined, standardized, documented, and effectively executed. By achieving recognition as an ASNT ATO, institutions demonstrate their commitment to delivering high-quality NDE training services and showcase a dedication and commitment to continuous quality improvement. It shows that the organization actively encourages feedback, continuously enhances its services, improves performance, and effectively manages risk.

American Securities to Sell Acuren

American Securities LLC, New York, N.Y., a U.S. private equity firm, entered into a definitive agreement to sell ASP Acuren Holdings Inc., the parent company of Acuren, Tomball, Tex., a provider of nondestructive examination, engineering and lab testing, and rope access technician solutions, to Admiral Acquisition Ltd, St. Peter Port, Guernsey. The transaction values the business at $1.85 billion.

During its four-and-a-half-year partnership with American Securities, Acuren delivered organic growth while completing 12 acquisitions to support long-term growth, strengthen service capabilities, expand its geographic footprint, and further improve operational efficiency.

Talman Pizzey, CEO of Acuren, said, "We have had a phenomenal partnership with American Securities, and their support has enabled Acuren to further its leading brand within inspection services. We are at an important and exciting inflection point of the company, and we are excited at the opportunity to continue growing our market-leading position with our new partners."

Evident Serves as Exclusive Sponsor at the 20th World Conference on Non-Destructive Testing

Evident, Waltham, Mass., a developer of nondestructive examination (NDE) technologies, was the exclusive sponsor of the 20th World Conference on Non-Destructive Testing (WCNDT). The conference, which took place from May 27 to 31 at the Songdo Convensia in Incheon, South Korea, provided insights into advanced NDE technologies and methodologies.

As an exclusive sponsor, the company received exclusive advertising inside and outside the conference center, exclusive placement of the company's logo on the conference website and conference bags, and a permanent presence on the cover page of all conference publications and sponsor posters, among other benefits.

Evident's Industrial Division President Karen Smith delivered the welcome address, and company experts presented on critical topics and challenges facing the NDE industry. The company also showcased its products and services, including automation solutions, phased array flaw detectors, thickness gauges, handheld x-ray fluorescent analyzers, and videoscopes.

GelSight Partners with PRAGMA on Integrated Solution for NDE

GelSight, Waltham, Mass., a tactile intelligence technology company, is collaborating with PRAGMA, a manufacturer of portable instruments and integrated systems for nondestructive examination (NDE) and an expert in NDE 4.0 technologies, to provide integrated solutions to the NDE market. The joint solution incorporates GelSight's tactile sensing technology directly into the PragmaFlex instrument platform, which is embedded with Pragma3D software, to provide more in-depth data and analysis of surface characteristics for NDE.

GelSight's technology uses 3D imaging to map surface finish and defects of any material at the micron level. Integrating the company's tactile sensing technology directly with the 3D position encoding capabilities of the PragmaFlex platform provides users with a comprehensive view of the valuable information they need when inspecting parts and surfaces. The Pragma3D software then allows for data fusion with ultrasound, eddy current scans, optical 3D scans, CAD, and more.

"We are excited about how this new integrated solution will improve fully automated NDT workflows," said GelSight's CEO Youssef Benmokhtar. "By combining GelSight tactile sensors with the PragmaFlex platform, users now have access to micrometer-level measurement data that can be fused with data from different modalities for deeper surface inspection and analysis."

Waygate Technologies and Rhinestahl CTS Join Forces

Waygate Technologies, Huerth, Germany, a Baker Hughes business and provider of nondestructive examination (NDE) solutions for industrial inspection, and Rhinestahl Customer Tooling Solutions (Rhinestahl CTS), Mason, Ohio, a provider of aircraft engine tooling and support services and equipment, have partnered to upgrade borescope inspections with two-way communication.

As a result of a recently signed joint technology development agreement, Rhinestahl's FutureDriveNG+ turning tool is now capable of two-way communication with Waygate Technologies' Mentor Visual iQ+ (MViQ+) video borescope. FutureDrive rotates the engine based on MVIQ+ borescope commands. This new technology automates image and measurement capture during rotation, saving key information, such as blade number, as part of metadata, thereby improving turn-around time and accuracy.

Rhinestahl's FutureDriveNG+ turning tool is now capable of two-way communication with Waygate Technologies' Mentor Visual iQ+ video borescope.

"We continue to lead innovation with industry partners to assist and automate video borescope inspections," said Mike Domke, general manager visual at Waygate Technologies. "Together, we are delivering more efficient and accurate solutions for engine inspections." IT

BY NEIL MANSFIELD

DIFFERENCE MAKER

AWS District 1 Director Tim Kinnaman has influenced many lives

My name is Neil Mansfield, and I am a recently retired vocational welding/metal fabrication teacher. AWS District 1 Director and welding educator Tim Kinnaman, a welder for over 45 years, is a mentor who made a difference in how I taught my students. He helped me expand their knowledge of welding fundamentals and shape their welding and problem-solving skills.

Tim Kinnaman shows a VR machine to a JROTC cadet student who never welded before.

A mentor is usually an older, wiser, more knowledgeable, more skilled, and experienced person who becomes a teacher and parental figure to you. You admire this person and try to emulate how they conduct themselves in their day-to-day interactions and, in my case, their integrity in Certified Welding Inspector (CWI) nondestructive examination (NDE) weld evaluations, welding, and workmanship. This person guides, motivates, inspires, and teaches you the value of taking pride in your work as a welder/fabricator and, even more so, as a vocational teacher.

Kinnaman was the person who came into my teaching life when I first started out in my vocational education career more than 20 years ago at Assabet Valley Regional Vocational Technical High School in Marlborough, Mass. By that time, he had a wealth of experience as a welder in numerous industries, including nuclear submarine construction, commercial transportation, mechanical repair, and, at the time I met him, as a pipe welder, shop foreman, welding training program instructor, and supervisor for Ocean State Technical Services in Providence, R.I. Because of his upbringing, his approach was to go out of his way to help, mentor, and teach others. This was evident when I invited Kinnaman to one of my advisory meetings and met him for the first time. I first noticed his ethos: lead by example. Kinnaman conducts himself with honesty and integrity as a person, a skilled welder, and a self-employed CWI and NDE weld inspection business owner.

When I worked with Kinnaman and watched him teach my students as a guest speaker and do live welding demonstrations in our school's welding/fabrication shop, I quickly realized that his approach to welding began with asking "Why" and was always followed with a hands-on answer. Most importantly, Kinnaman's lessons always drew upon the foundations of welding science, filler wire selection, filler wire and base metal compatibilities, shielding gases, and metallurgy as well as workmanship as a welder.

Kinnaman was brilliant at teaching and introducing welding and material science concepts to both young and old. I, too, was a student as Kinnaman taught on the shop floor, welding hood-down as atoms changed into liquid and gas states. All my students and the teachers had their notebooks open and pencils sketching and writing what Kinnaman was sharing. It was stuff you couldn't learn on YouTube. You had to be there and make eye contact with Kinnaman as he shared his knowledge.

A Relationship That's Changed Lives

Over 15 years have passed since Kinnaman arrived at our school through the recommendation of AWS Boston Section Chair Tom Ferri. I asked Kinnaman to join our advisory committee, and it's been a life-changing experience just having Kinnaman as a mentor to me and as an advisory member of our welding fabrication program. Generations upon generations of students have benefited from having Kinnaman advise, teach, and make suggestions to improve our welding/fabrication program. Kinnaman's mentorship of my welding students has significantly changed their lives. Many of them have gone on to become skilled tradespeople and owners of self-employed mobile welding businesses and other fabrication businesses. Our welding hats are off, and we salute Kinnaman for his dedication and caring for our students. Kinnaman makes a difference each time he shares his knowledge, wisdom, and passion for the world of welding with the next generation of welders.

As Kinnaman's mentee, I have been taught countless aspects of welding, starting at the atomic level by discussing material science, whether on hour-plus phone calls, over coffee, or at school advisory meetings. Kinnaman took me under his guidance. I am forever grateful to have had people like Kinnaman in my life. One way or another, we have all had a Tim Kinnaman in our lives, a person who has helped us along the way, a true mentor who teaches you and takes time to listen to your questions and, as a welder, shows you hands-on approaches with age-old knowledge, wisdom that only comes with time and experience. Kinnaman is a skilled craftsman with in-depth knowledge of welding codes, welding procedure specifications, and procedure qualification records. What this man can solve in welding and building with his two hands is amazing.

Thank you for all you have done for so many. As the old U.S. Navy saying goes, "Fair winds and following seas," meaning best of luck.

Highlights of a Distinguished Career

Here are some noteworthy highlights of Kinnaman's engagements with vocational schools and AWS membership education:

- Proctoring CWI exams in New England and all over the U.S.
- Teaching metallurgy and welding science to AWS New England members at vocational schools via classroom instruction and hands-on shop demonstrations.
- Serving as an advisory board member for over 15 years at vocational schools in welding and fabrication.
- Being a guest speaker who has introduced the art of science in welding and metallurgy to the next generation.

Kinnaman has been an evaluation judge for senior student projects. His approach and input are invaluable in teaching students how to present themselves and showcase their welding and fabrication projects and knowledge to a panel of judges.

He has encouraged my program to invest in virtual reality (VR) welding machines to enhance how students learn about welding. Thanks to Kinnaman and an advisory team, we now have seven VR welding machines.

Kinnaman has played a key advisory role in providing feedback from his business on welding training and weld inspections for our program.

He encouraged me to attend an ASNT meeting in Rhode Island. Soon after, I began teaching my students visual testing, magnetic particle testing, and penetrant testing methodologies. As a vocational teacher, I give Kinnaman credit for nudging me to develop an NDE curriculum for my students in weld inspections. Since then, I have placed students as Level I and II ASNT NDT inspectors.

Kinnaman has taught AWS classes on welding electricity, welding arc, filler wire, shielding gases, and material science.

He has extensive knowledge and understanding of welding metallurgy. On my drive home from teaching, we had countless phone conversations about materials science. Kinnaman would answer all my questions, and thanks to him, I adjusted my curriculum to teach the fundamentals of material science and weld metallurgy.

The Journey of Learning Continues

Kinnaman's approach to mentorship, craftsmanship, welding science, material science, and welding curriculum set me on a splendid journey that changed how I taught my students. I continue to learn from Kinnaman's countless lessons about welding, CWI matters, NDE, and metallurgy.

Just recently, on a cold New England winter day, over a lunch that lasted nearly four hours as we discussed CWI and NDE weld evaluations, Kinnaman once again volunteered his time to mentor a fellow U.S. Navy veteran of mine, Steel Worker U.S. Navy Seabee David, who is studying and preparing to take the 40-hour seminar and the CWI exam. There's no better person to ask than Kinnaman when you have key questions about welding inspections and CWI career pathways. IT

NEIL MANSFIELD (*flyingsparks202@gmail.com*) is an AWS CWI and Certified Welding Educator, blacksmith artist, and part-time welding and material sciences instructor.

Bendable X-Ray Detector Scans Pipes and Flat Objects

The NOVO 10BN bendable detector features two modes: bent for pipes 6 in. and over and flat for pipes below 6 in. and flat items. The detector delivers high-resolution x-ray images at 99 microns, and its thin, light body can be positioned in tight places. It complies with ISO 17636-2, *Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors*, Class B from 4 mm and upwards. The device is compatible with the company's previous generation systems and is included in the Discovery III system.

NOVO DR Ltd.
novo-dr.com

Wireless Borescopes Capture Video in Out-of-Reach Areas

The Extech BR450W series of video borescopes inspects difficult-to-reach targets in building, automotive, and plant maintenance applications. The BR450W-D dual HD wireless and BR450W-A2 two-way articulating wireless provide users with remote control and display, documentation, sharing options, and an intuitive user interface that streamlines troubleshooting of hard-to-reach spaces. The series connects via Wi-Fi to the Extech ExView App for remote viewing of the 1280 × 720-resolution image. Users can capture images, videos, and audio recordings through the app; share them with customers and colleagues; and use the information to identify and document problems during an inspection. The BR450W-D dual HD wireless video borescope is designed for HVAC and hard-to-reach electrical, attic, and crawlspace inspections. It has a dual-view 5.5-mm (0.21-in.) camera on a 1.5-m (4.9-ft), IP67-rated probe to capture and share crisp images and videos. The BR450W-A2 two-way articulating wireless video borescope is purpose-built for automotive, industrial, and commercial building inspections. It features a two-way, 1.5-m (4.9-ft) articulating IP67-rated probe, approved for brake and transmission fluid, diesel fuel, unleaded gasoline, engine oil, and CPC hydraulic fluid.

Teledyne FLIR
flir.com

Report Examines NDE Market Outlook, Trends, and Growth

Non-Destructive Testing (NDT) And Inspection Global Market Report 2024 offers comprehensive market insights and detailed estimates for numerous segments and subsegments. According to the report, market size is expected to reach $13.01 billion in 2028 at a compound annual growth rate of 7.7%. The growth in the forecast period can be attributed to rising urbanization, a rise in research and development activities, and a growing demand for nondestructive examination (NDE) services for power generation. Major trends in the forecast period include advancements in digital radiography, increasing ultrasonic testing innovations, increasing use of robotics and automation, use of infrared thermography, a focus on digital NDE and data analytics, and product innovations. The market covered in this report is segmented by technique (magnetic particle testing, ultrasonic testing, visual testing, etc.), method (surface inspection, volumetric inspection, etc.), and vertical (manufacturing, oil and gas, aerospace, and others). Technological advancement is listed as a key trend shaping the NDE and inspection market.

The Business Research Co.
thebusinessresearchcompany.com

Ultrasonic Thickness Gauge Transforms into Three-in-One Platform

The Krautkrämer CL Go+ ultrasonic precision thickness gauge measures cast and stamped metal components made from materials such as aluminum, steel, copper, and bronze. It is also effective for machined workpieces, tubes, chemically milled components, metal plates, plastics, composites, and glass. The tool works for components utilized in the automotive and aerospace industries. It can be upgraded to a three-in-one platform, functioning as a corrosion thickness gauge, flaw detector, or both. The gauge offers a measurement precision of 0.001 mm (0.0001 in.) and powerful data management capabilities. The device uses advanced techniques and automatic gain control for stable readings under diverse conditions. It optimizes accuracy with high-resolution A-Scan, gates, finite impulse response up-sampling, interpolated zero-cross measurement, and various calibration modes. Additional practical features include a 5-in. clear and responsive display for advanced indoor and outdoor visibility, large readouts to eliminate eye strain, and a superior screen-to-body ratio. Its lightweight and single-hand operation make it easy to use, while its ambidextrous design enables left or right-hand operation.

Waygate Technologies
bakerhughes.com/waygate-technologies

IT FEATURE

BY THOMAS R. HAY

Applications of Drones in Nondestructive Examination

How this contemporary aerial device can help in the inspection of assets in inaccessible locations

Drones, also known as unmanned aerial vehicles (UAVs), have become valuable tools for nondestructive examination (NDE) of various structures thanks to their ability to access hard-to-reach areas, provide high-resolution imagery, and collect data safely and efficiently. This article offers an overview of typical drone applications in NDE, including advantages and examples.

Overview

Drones can safely and conveniently assist NDE functions, such as visual inspection, by capturing detailed images and videos of structures and allowing inspectors to assess surface conditions, corrosion, cracks, and other defects. Fitted with thermal cameras, drones can detect temperature variations, which may identify issues such as heat leaks, faulty electrical components, and insulation problems in buildings or industrial equipment supporting mechanical integrity programs. Light detection and ranging (LiDAR) equipped drones use laser technology to create 3D point clouds and digital elevation models, which are valuable for assessing the geometry and condition of structures and detecting deformations and settlements. Drones with sufficient payload can carry ultrasonic sensors to measure the thickness of materials and identify defects within them. This feature is commonly used to support the NDE of pipelines, tanks, and bridges. Drone-collected data can be processed through advanced software and analytics tools to create detailed reports, including 3D models, heat maps, and defect visualizations, facilitating more informed decision-making.

Drones can also be used to efficiently screen aboveground storage tanks during external inspections of tanks and containment area assessments in accordance with the American Petroleum Institute (API) *Standard 653, Tank Inspection, Repair, Alteration, and Reconstruction*, or the Steel Tank Institute/Steel Plate Fabricators Association (STI/SPFA) *SP001, Standard for the Inspection of Aboveground Storage Tanks*. From above, the drone can visually assess the boundaries of the containment area and screen the tank for containment area deficiencies, including large cracks in the concrete or liner tears. Similarly, the drones may be used to assess the general condition of the tank shell and roof — Fig. 1. Areas of paint breakdown and surface corrosion are accurately tracked, and a targeted visual inspection is performed based on the initial screening assessment of the tank farm.

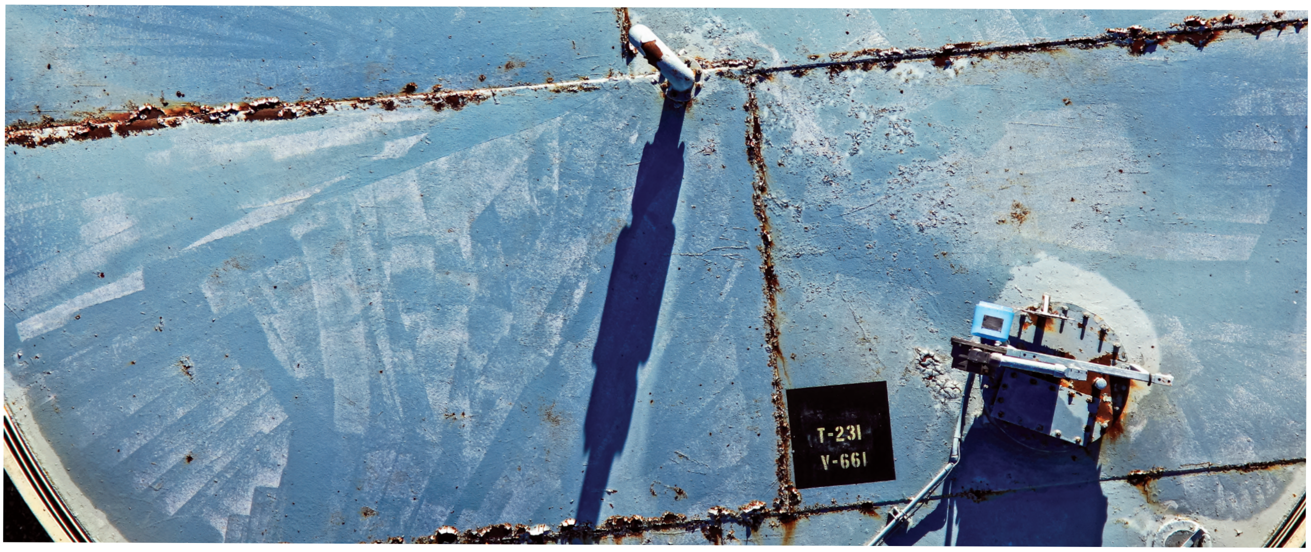
Common Features of Drones Used in NDE

Drones used in NDE often have several standard features and capabilities designed to facilitate efficient and accurate inspections. The main feature is a high-resolution camera, including visible light cameras, which capture detailed visual images and videos of the inspected structure. High-resolution drone cameras typically have a minimum of 12 megapixels (MP), but many models have 20 MP or higher. Higher megapixels result in sharper and more detailed images. The camera's sensor size can affect image quality and low-light performance. Larger sensors generally capture more light and provide better image quality. Standard sensor sizes for drone cameras include ½.3-in., 1-in., and Advanced Photo System type-C (APS-C), which can vary slightly. NDE drone cameras often have fixed lenses designed for aerial photography. Depending on the camera's intended use, the lens type may be wide-angle or zoom. The aperture size determines the amount of light that enters the camera. A lower f-stop number (e.g., f/2.8) indicates a larger aperture, which is better for low-light conditions. Some NDE drone cameras have adjustable apertures for greater control.

NDE drones often have autonomous flight capabilities, allowing them to follow preprogrammed flight paths or waypoints. This ensures consistent and repeatable data collection. Many modern NDE drones are equipped with obstacle avoidance sensors (e.g., LiDAR and ultrasonic) to detect and avoid obstacles in their flight path, enhancing safety and reducing the risk of collisions. NDE drones are designed for stability and may include advanced stabilization systems and wind-resistant capabilities, essential for maintaining image quality during inspections. Extended battery life is crucial for conducting lengthy inspections without frequent interruptions for recharging or battery swaps. Some drones come with swappable batteries for continuous operation. Drones used in NDE applications should be able to carry additional payloads such as sensors, cameras, or testing equipment. Payload capacity varies among different drone models. Many NDE drones offer real-time data transmission to a ground station or remote operator, allowing inspectors to monitor the inspection in progress and make immediate decisions

Fig. 1 — Drone footage is confirmed against site maps to inventory above-ground storage tanks. The tank roof, shell, and piping systems within the containment area are screened for coating breakdown and surface corrosion. These areas are targeted for follow-up visual inspection with standard pit gages and ultrasonic thickness testing. (Photo credit: TechKnowServ Corp.)

Fig. 2 — (Right) Overhead view of a fiberglass-reinforced plastic (FRP) tank farm enables rapid assessment of the tank coating, bulging, and other integrity metrics. (Below) Tank-specific roof footage showing surface corrosion at roof welds. In addition to ultrasonic thickness testing, the welded areas were cleaned, surface pits were measured, and the square footage for recoating was calculated. (Photo credit: TechKnowServ Corp.)



based on the collected data. NDE drones are typically operated remotely using a dedicated controller or software interface, allowing inspectors complete control over the drone's movements and data collection.

Application Examples

Drone NDE of Amusement Park Rollercoasters

Visual inspection of rollercoaster supporting steel structures is generally performed with extended-range man lifts and often uses rope access technicians. The process is discontinuous when using manlifts for amusement park NDE because the man lifts must be maneuvered from one location to another. Man lifts also do not provide 100% coverage around a supporting pipe column, and a single joint may be required to be inspected from two or three man lift positions to access the entire surface of a typical rollercoaster steel pipe column. The NDE inspection is a multiple-person job with a qualified operator and NDE technician on the platform and ground personnel for traffic control. Fall protection is required at all times during the inspection.

Drone NDE of rollercoasters permits the NDE inspector to assess the ride's critical areas without needing a man lift. Cracked joints or suspected crack joints are noted and specified for further investigation using an NDE rope access team and an NDE team from a man lift. Significant cost savings can be achieved by using backup NDE inspection methods only for the targeted areas pinpointed by the drone NDE. Additionally, due to the difference in cost, the inspection frequency can be increased compared to NDE performed from a man lift or using a rope-access team. It should be noted, however, that supplemental inspection will almost always be required to support drone NDE to confirm findings.

Drone NDE of Remotely Located Agricultural Assets

Remotely located agricultural assets include steel storage tanks, fiberglass storage tanks, irrigation infrastructure, and other production-sustaining assets. In addition to being remotely located, access to these assets by land may be risky due to soil conditions. From a safety perspective, working at heights is generally not advisable if an accident occurs. Figure 2 shows a drone surveying and a 20,000-gal FRP tank farm for tank perpendicularity, bulging, coating condition, containment area, and shell integrity. The drone screens a tank farm cost-effectively and alerts the NDE inspector if more detailed inspections are required.

Conclusions

Drones allow the efficient screening of assets for deficiencies that may require a more detailed follow-up inspection. Drone NDE is a worthwhile financial investment that minimizes safety risks to the NDE technician and, in some cases, provides access to critical areas that may not be easily inspected.

Field inspection of welds is an access-driven process where traditional access is provided via boom lifts, scaffolding, and rope access. These access options come with significant costs and safety risks. While direct access to welds using the above methods will still be required in many cases, drone-assisted weld inspection can rapidly screen difficult-to-access areas and identify defects that require follow-up inspection. As a result, the cost and safety risks inherent to direct access methods can be reduced significantly. IT

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IT FEATURE

BY JEFFRY STRAHAN

Voltage Vortex Void Anomaly in Downhill Pipeline Welding

The procedure, inspection, causes, and solutions are discussed

In 2022, while performing a welding procedure specification (WPS) test for a major gas company, a novel weld defect was discovered during the destructive testing of the pipe. These defects were found in the nick-break sections removed to visually inspect the interior weld metal structure. The defects were scattered through the final or cap passes and the weld layers under and adjacent to the cap passes.

The weld testing was requested and scheduled with a local pipeline welding contractor. This company is regularly utilized by many regional and national pipeline companies and is known to produce acceptable work consistently. A meeting was held before the scheduled test date, and the contractor and their welding crews discussed and agreed upon the testing parameters. This procedure was to be proven and added to the manual of welding procedures, which this gas company would use in subsequent work.

Welding Procedure

The procedure called for the X70M pipe to be welded with a downhill progression, and the welds were to be done with a Lincoln 5P+ root and hot pass sequence, followed by fill and cap passes with an LH90D electrode. This procedure has been proven in previous utilization to decrease the welding time on the heavy-wall, large-diameter pipe of the gas systems found throughout America and in foreign countries. Other procedures, like the one proposed by the gas company, have shown that welding times seen in large-diameter pipe welding scenarios could be significantly reduced and that weld defects prone to procedures using cellulosic electrodes could be reduced or eliminated. These perennial problems include but are not limited to, most principally, the prevalence of cracking due to hydrogen embrittlement and cracking due to weld-strength mismatch when welding the newer, higher-tensile pipe materials, such as X70 and X80. For these reasons, many companies use high-speed, high-deposition electrodes that fit into the downhill, low-hydrogen category. The electrode used for some time in this type of welding was classified as an E7048 electrode and had performed well in this capacity, giving welders and welding contractors a faster welding electrode in the vertical (5G) position and the unlimited (6G) positions.

This test, for which the voltage vortex void (VVV) defect was first observed, was a routine WPS test for the gas company to have a downhill, low-hydrogen procedure in its welding procedure manual. In this way, they would have a procedure that a contractor would use or adhere to when performing production welds. The test pipe was secured and was compliant with the materials test report (MTR) for the X70M grade. The electrode supplied was also found to comply with the lot numbers, specifications, and classification for downhill, low-hydrogen shielded metal arc welding (SMAW). Cleaning and preparation were conducted per WPS guidelines, and fitups were approved by the welding inspector present, with appropriate fitup dimensions and high/low meeting company welding manual requirements. Proper preheat was done, and welding was allowed to proceed, starting with a 5P+ root pass, progressing through the hot pass, and completing the interior welds with a hot fill pass.

Problems Found

The welding inspector observed that the welders began to have problems with the fill and cap electrode, LH90D, and several instances of "stub out" (or electrode sticking) were seen and commented on to the welders. The issue discussed was the increased travel speed needed for the LH90D and how traveling at slower-paced speeds, normal in cellulosic work, had to be abandoned to avoid electrode sticking and weld contamination. Welding progressed with intermittent electrode sticking issues, and restarts were made after some grinding and wire brushing.

After thirteen fill passes with LH90D, the 0.750-in. wall thickness pipe was flush-filled and ready to be capped, continuing with the LH90D electrode. Per the WPS, the welders turned down their amperages to affect a fuller cap weld. From the twelve o'clock position to the three o'clock position, the welders had several issues with electrode sticking and arc cessation. Careful observation by the inspectors resulted in restarts being first ground with an angle grinder and then wire-brushed before welding could be resumed. The welders objected to the grinding and prep work for restarts and stated that restarts didn't necessarily need to be ground and brushed, as the new restart reheated and melted the stub-out material as the weld was reinitiated. As the results demonstrated, this occasion was one of the more important aspects of this procedure's necessities.

Examination

The welding was completed, and the necessary test coupons were retrieved, resulting in all test specimens being taken to an independent testing laboratory.

All material procurement, consumable material provided, test sample fitup, and welding were monitored and closely observed by two competent Certified Welding Inspectors (CWIs). The pipe and the filler materials were documented to be clean, dry, and without any negative conditions before welding. All welding parameters and weld testing environments were documented, with all testing samples being designed, taken custody of, and transported to the independent laboratory, which is well known for its integrity and quality of workmanship.

Fig. 1 — Voltage vortice in nick-break samples.

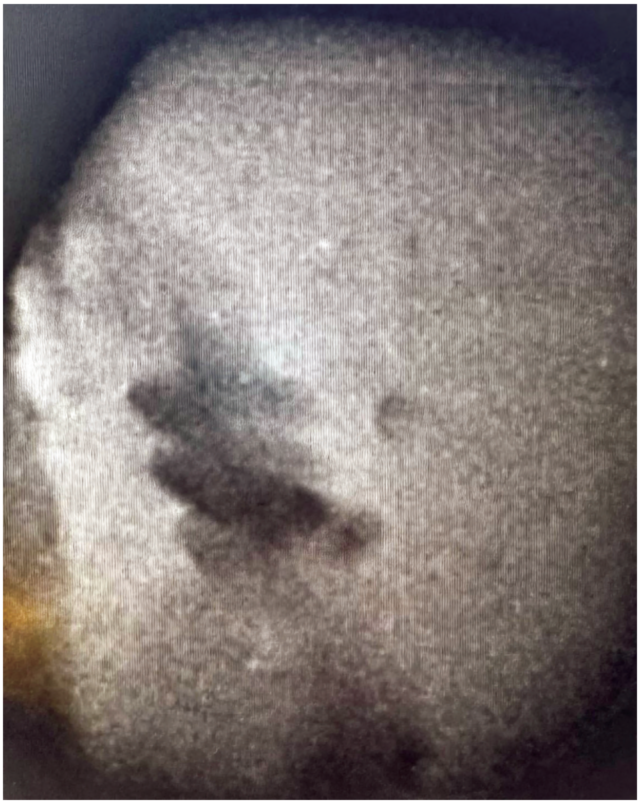

Fig. 2 — A lateral view x-ray of a voltage vortice.

The welding equipment provided and personally owned by the test welders was inspected and documented, including make, models, and serial numbers. Output voltages and amperages were checked, documented, and confirmed within WPS limits. Weather conditions were clear and mild, and the work was not done in any adverse conditions or extremes of temperature. Welding was started and completed inside the contractor's shop area, with roll-up doors closed and fumes ventilated outdoors. Fitup and welding were completed in one day, and the coupon preparation was started and completed on the second day of the testing sequence.

After two days, the testing laboratory contacted the CWI and expressed concerns over indications found in some nick-break samples. Pictures of those unknown structures were sent to the CWI and were determined to be unknown and without explanation — Figs. 1 and 2. The CWI proceeded to the testing facility and took possession of the nick-break samples to examine and assess defect type and origin. Numerous inspecting colleagues were consulted without recognition or understanding of how such a defect could be produced.

Cause and Solution

Three weeks later, after careful consideration and reflection on the testing parameters and the composite contributions to the testing samples, the nature and method of producing the anomalies were determined.

When welding with high-speed, low-viscosity welding rods, such as LH80D, LH90D, or any E7048 variant, welders need a warmup or practice time to adjust to the high deposition rates of those electrodes. If they do not get that practice time, their frequency of stub out or freezing the electrode to the workpiece will contribute to the presence of this defect.

In addition to the practical factor of manual manipulation and technique mastery, the welding power source also plays a significant part in creating favorable conditions, which bring about the vortex voids in the weld metal. In particular, the increased open circuit voltage (OCV) features of portable welding machines in the last decade have been seen to be a factor that drives the presence of VVVs. It is common knowledge that with the SMAW processes, the voltage of the welding machine and its potential for striking and starting a weld is at its highest point while the welding arc is open and no welding is taking place. The current or amperage is set to a setting that the machine will adjust to as the welding arc is initiated, begins, rises, and falls as the welding work progresses. When these two factors are combined in what is known as the *drooping curve* character of SMAW machines, it may be observed that the voltage, after having initiated the arc and breaking down the parent metals' resistance to current flow, will drop to a level of potential or voltage that will maintain the arc in the weld and it, too, will increase and decrease as the arc length is varied by the operator and as the resistance of the cables and other entities in the current loop are manipulated. This voltage potential and its variableness are usually benign to the weld as it progresses. However, with the advent of higher and higher OCV found on the newest models of machines, the prevalence of VVVs has increased. This contributes to that prevalence by combining stub out and high OCV.

When the welder is working with the downhill, low-hydrogen electrodes and the rate of travel is too low (the LH electrodes produce adequate deposits at nearly twice the average inches per minute rates), the possibility of stub out is increased. When welding at high amperages, such as 150-170 A, using 3⁄16 in. (4.78 or 5 mm) and especially on the cover passes, the weld metal is quite liquid and has a low viscosity. Combine this phenomenon with a high OCV, such as 93 or 98 OCV, and the production of VVVs can occur. This happens quite rapidly (less than 1 second) and varies in volume due to several factors all occurring simultaneously. The VVV event occurs when the welder is welding, the weld metal is in a very liquid state, and the OCV is low, as the current needed is flowing and the weld is progressing. Next, the welder stubs out, the OCV jumps to its maximum, and a voltage jolt occurs, trying to reignite the arc but without success. The VVV is produced and solidified in the weld metal at that moment. Depending on the power source, the VVV will manifest itself as a three-pronged anomaly (see Fig. 1) not visible to the naked eye. The defects are not highly detectable by radiographic examination (RT) or ultrasonic examination (UT) and appear as lighter-density spots, similar to radiographic artifacts or droplet images to the radiographic interpreter (see Fig. 2). To physically view the VVVs, one must observe them in the destructive testing coupons, such as in a nick break. They have been incorrectly identified as hard spots (martensite), piping porosity, or simple porosity in spherical presentations. The most curious observation of the defect is that they will always be found in groups of three, which is a function of the welding power source generator construction.

The most important aspect of recognizing the VVV is what they produce in the weld's mechanical properties. They are local hard spots due to the rapid cooling of the weld metal so that they can be localized martensite. They will always snap and break as a whole unit, starting a crack or underbead failure. Currently, scanning electron microscopy is being used to determine the microhardness of the interior surfaces of the vortices.

Conclusion

For the inspector, pipe boss, or welding supervisor, the most important aspect is to be aware of the conditions in which voltage vortices may occur:

- **1.** Welding with downhill low-hydrogen electrodes like E7048, LH80D, or LH90D;
- **2.** Welding with welding machines that have high OCV, such as 90 or higher; and
- **3.** Using welders with limited or no experience welding with downhill low-hydrogen electrodes. Knowing this and being diligent in the inspection and weld observance duties, those responsible for the weld quality must watch for any weld interruptions involving an electrode freezing or sticking to the weld. When this occurs, the inspector or supervisor must require the affected weld area to be thoroughly ground out and prepped before continuing with the weld progression, not allowing the weld to be remelted and restarted by simply starting with a new electrode, as this will most likely not burn out the hardened VVV.

The benefits of this method of welding large-diameter pipe with large wall thicknesses are apparent. Weld times may be reduced by as much as half, and the welds are not as susceptible to hydrogen embrittlement as with cellulosic products due to the low hydrogen nature of the electrode class. However, careful observation by the welding supervisory or inspection personnel is vital to avoid the mechanical and metallurgical problems that the VVV will manifest, and this care must be taken to ensure sound welds. IT

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IT FEATURE

BY ROBERT GOODWIN AND CHAD UMBEL

ROPE ACCESS for Nondestructive Examination

Learn about the fundamentals, implementation, regulations, and certifications of this skilled access technique often used in welding inspection

Rope access is a flexible form of work positioning that allows workers to access remote and hard-to-reach locations — such as offshore platforms, high-rise buildings, and bridges — safely and efficiently without cradles, scaffolding, or platforms. Using ropes and specialized equipment, the technique makes ascending, descending, and navigating across structures possible. The rope-access system secures workers, allowing them to work at height or in confined spaces, often with reduced risk compared to other methods of working at height.

Generally, a two-rope system is employed: the working rope supports the worker, and the safety rope provides back-up fall protection. Rope access benefits include increased safety for the worker and cost savings for the client.

Rope Access Certification for the Welding Inspector

Qualifications for inspection personnel are gained over a period of years, and it makes sense to invest in additional qualifications to enhance their value. Rope access certification, particularly Industrial Rope Access Trade Association (IRATA International) certification, is an international qualification that includes a rigorous testing process, similar to inspection qualification. Admittedly, rope access is not for everyone. It requires patience, attention to detail, interest in technical systems and equipment, and a certain level of physical fitness. If it's a good fit for the right individual, rope access can significantly increase the scope and range of application

Welding and inspection using rope access in the offshore environment. (Photo courtesy of Rigging International Group.)

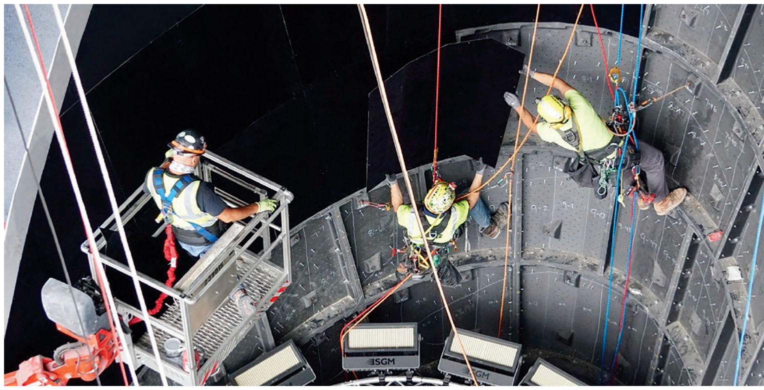
for a welding inspector's skillset and bring greater value to employers and customers. Many major asset management companies have rope-access programs and recognize the value that they can offer clients.

Why Use Rope Access

Modern rope-access equipment, techniques, and training can be combined to produce a safe, versatile, efficient, and cost-effective way to solve vertical access problems. Some of its benefits are as follows:

Safety: Independently certified rope-access technicians uphold an enviable safety record and few lost time incidents while working on rope.
Versatility: Technicians can apply the techniques in various environments, from confined-space penstocks to massive concrete structures to complicated steel installations. Unlike traditional access methods, custom rope-access solutions can be designed to fit multiple applications quickly and inexpensively.
Efficiency: Systems are installed and dismantled quickly and often require fewer personnel than traditional access methods. Rapid deployment minimizes downtime and limits disruption to facility operations. Reduced hours at risk are a considerable advantage over other access methods.
Cost: Fewer personnel, faster completion, less equipment, and minimal downtime mean lower costs.

Ultrasonic examination (UT) using rope access. (Photo courtesy of Rigging International Group.)



Rope access used in conjunction with a boom lift for an LED installation in a stadium. (Photo courtesy of Rigging International Group.)

Rope access can be used for structural inspections, repairs, coating application and stripping, re-installation of insulation, and welding inspection. Production facilities with vessels that need regular inspections often fail to include adequate catwalk access and can be too congested for mobile platforms. Specific structures like bridges, dams, roofs, and amusement park rides do not lend themselves to scaffolding or other traditional methods. If the facility is located offshore, space is at a premium. Rope access is often preferred because it requires less manpower and equipment.

Although rope access is a good fit with most inspection work, it is not a good fit or necessary for all. For example, new construction and major renovations usually include scaffolding structures, which would provide access solutions for all trades, including inspectors.

Rope-Access Implementation

There are several ways to get started with rope access, such as subcontracting, acquisition or partnership, and program development, but it can also take a blended approach.

SUBCONTRACTING: The benefits of this method include the fact that the company has specialist expertise in rope-access methodology, and it can be a cost- and time-effective option if rope access is a small portion of the overall business. This method allows the relationship to grow and evolve with your needs. For example, the subcontractor could provide training, IRATA Level 3 supervision, key personnel, or turnkey service. Another significant advantage is talent recruitment — becoming certified takes a week, but new IRATA Level 1 technicians require much more supervision and become more productive and efficient with experience. The disadvantages are that there's no direct control over the program, employees, or equipment, and it can be expensive if rope access represents a high volume of business.

ACQUISITION OR PARTNERSHIP: The company acquires specialist expertise in rope-access methodology and assumes direct control over the program. This method can jumpstart the program regarding personnel, equipment, and client relationships and strategically combine other goals, such as movement into other markets, regions, and services. However, this method is a significant investment and takes time and resources. Furthermore, finding the right fit can be challenging.

PROGRAM DEVELOPMENT: This method includes oversight (management and supervision), technician competency (training program), and equipment management. A rope-access program is like any other program in which organization, leadership, teamwork, and communication are essential.

Regulations and Standards

Rope access is governed by strict safety protocols and guidelines to ensure the safety of the operators. Four organizations mainly regulate the method: the Occupational Safety and Health Administration (OSHA), the American National Standards Institute (ANSI), the Society of Professional Rope Access Technicians (SPRAT), and IRATA International. OSHA is a required regulation, while the others are voluntary.

Inspection and weld repairs using rope access inside a vessel. (Photo courtesy of Rigging International Group.)

The RIG Rope Access Team competes in Petzl Rope Trip, a rope-access competition. (Photo courtesy of Rigging International Group.)

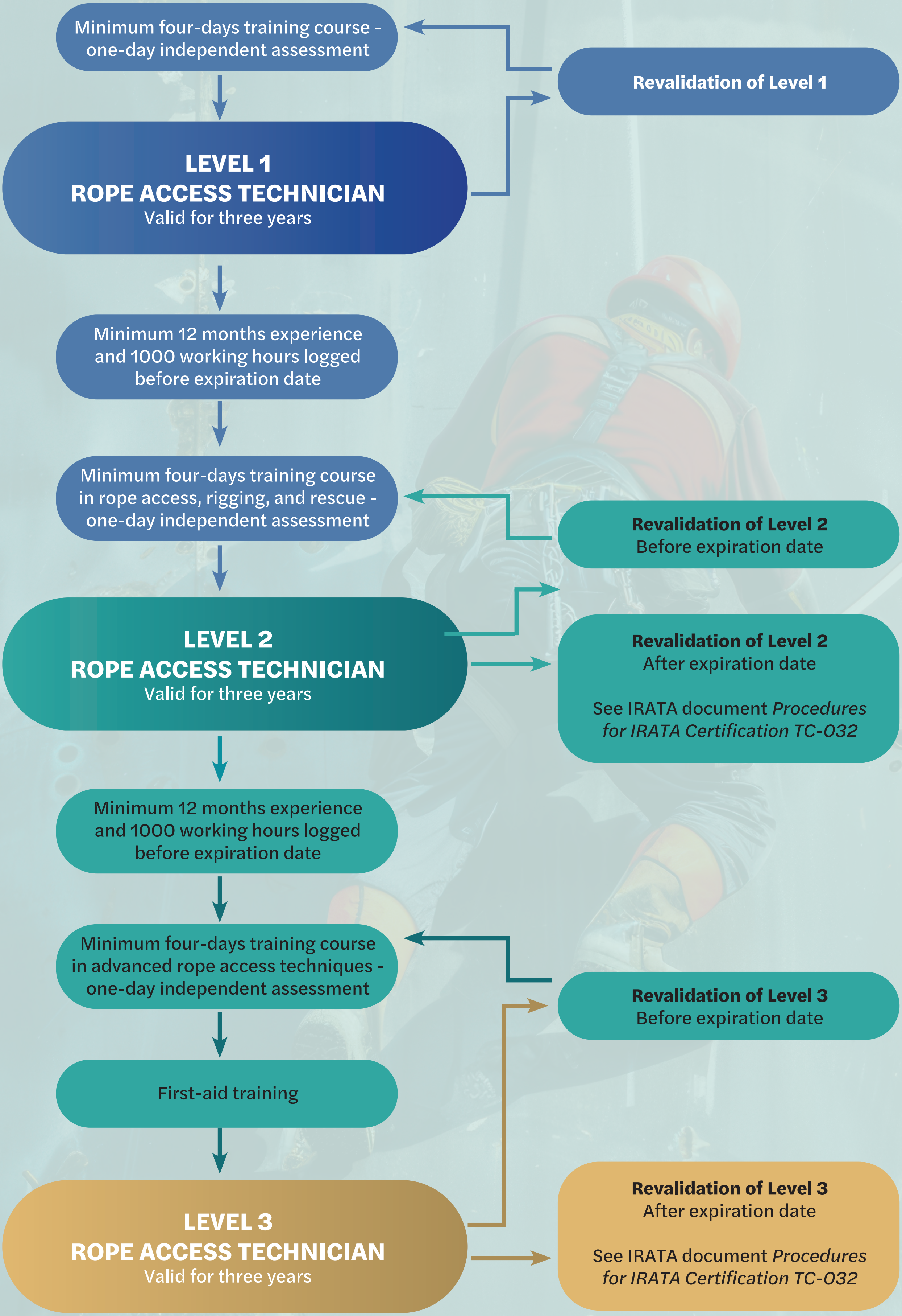
General OSHA requirements apply to rope access, including personal protection equipment (PPE), training, emergency preparedness, and providing a safe workplace. However, OSHA does not attempt to provide specific guidance for rope access methods within their current standards.

ANSI has recently released a standard for rope access. However, this standard is not widely used or accepted.

IRATA Requirements and Guidance

IRATA International provides robust guidelines for a safe work system and encourages career progression for rope access technicians. Each technician must recertify every three years to demonstrate that they maintain the necessary abilities to work safely. Technicians may also progress through three levels as time, experience, and training allow, each demanding a greater knowledge of the rope access skills necessary at the worksite.

IRATA International Training, Assessment, and Certification Scheme



IRATA requirements for company membership are as follows:

- Must be an incorporated entity (registered company),
- Documented rope-access operating and training procedures,
- Employment of an IRATA Level 3 technician as the technical authority,
- Compliance with Intelligence Carry On Program (ICOP) for operations and training,
- Abide by IRATA bylaws and articles of association,
- All employees must be IRATA certified (first aid and cardiopulmonary resuscitation [CPR] for Level 3s),
- Employ a rope-access manager, and
- Be subject to audit in accordance with the membership audit cycle.

IRATA Certification Requirements. The IRATA training scheme includes class-based learning, theoretical and practical testing, and field experience. The goal is competent technicians who support a safe, quality program. An audited training member company must deliver training. **The levels of qualification within the IRATA system are as follows:**

- **Level 1.** A rope-access technician who is able to perform a specified range of rope-access tasks under the supervision of a Level 3 Rope Access Safety Supervisor.
- **Level 2.** An experienced rope-access technician who is able to perform more complex tasks under the supervision of a Level 3 Rope Access Safety Supervisor.
- **Level 3.** An experienced rope-access technician who is responsible for understanding and implementing the rope-access procedures, method statements, and associated risk assessments as well as,
  a) is able to demonstrate the skills and knowledge required of Levels 1 and 2,
  b) understands the elements and principles of IRATA's safe system of work,
  c) is conversant with relevant work techniques and legislation,
  d) has an extensive knowledge of advanced rope access rigging and rescue techniques, and
  e) holds an appropriate and current first aid certificate.

A Level 3 can become a Rope Access Safety Supervisor.

SPRAT Requirements and Guidance

In contrast to IRATA, SPRAT has few requirements for member companies. SPRAT specifications are as follows:

- Required to hold a company membership,
- Minimal program requirements and no audits,
- Program oversight by a rope-access program, administrator with minimal qualifications needed, and
- Technicians must hold rope-access certification, and it is recommended that this certification meets the SPRAT scheme.

SPRAT certification requirements are as follows:

- Training is required for initial certification,
- Training is recommended for recertification,
- Supervisory requirements include a recommendation for Level 3, and
- Upgrade requirements are 500 hours and six months.

Final Thoughts

Rope-access program and certification considerations include geographical location and client requirements. If a client requires IRATA, then SPRAT will not meet that standard because IRATA requirements are more stringent and enforced by audit. Likewise, IRATA member companies can only employ IRATA-certified technicians.

IRATA is the largest rope-access organization worldwide and is recommended for international projects and clients with global assets. IRATA provides more rigorous certifications, detailed standards, and an audited membership.

SPRAT is the largest rope-access organization based in the United States. It is more flexible, has less stringent standards, and does not require audits.

Similar to an inspection program, a rope-access program needs a strong foundation based on rigorous standards. Both IRATA and SPRAT promote rope-access standards and safety, and more information is available on their respective websites, ***irata.org*** and ***sprat.org***. IT

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THE ANSWER IS

BY ALBERT J. MOORE JR.

Q I'm a new Certified Welding Inspector (CWI) working with a fabricator as a welder. I started my career as a welder, but I don't want to limit myself to being a welder forever. It seemed like passing the CWI would be a good way of advancing my career. The CWI seminar covered a lot of interesting material, but it was new to me. I have a question about fatigue and its importance to a welder or an inspector. I would like to learn more about the subject and how it affects welding and inspection. Can you explain briefly about the subject and the sketches showing where cracks are likely to form and what the graph is all about? The instructor touched on the topic during the CWI review, but I didn't absorb everything.

A The subject of fatigue is tough to cover in 100 words or less, so strap yourself in. This is going to take some time to cover.

Fatigue is the accumulated damage that occurs when a connection or member (i.e., a beam or girder) is subjected to cyclic loading. A member or connection subjected to a load that fluctuates over time can develop cracks that ultimately lead to a structural collapse. When the cyclic load exceeds a threshold value, a small amount of damage results. Over time, the damage accumulates and initiates a crack. With additional load cycles, the crack continues to propagate slowly at first, but the crack growth rate increases with additional cycles of loading and unloading.

To illustrate the principle, imagine you grasp a length of steel wire at opposite ends. Now, you bend the wire back and forth. Eventually, the length of the wire will break, and you will have two pieces of wire. Each time you bend the wire one way or the other, it is considered to be a load cycle. The bending increases the unit stress inside and outside the bend radii. The outside bend radius is loaded in tension, and the inside bend radius is loaded in compression. As you bend the wire in the opposite direction, the nature of the extreme fiber stress is reversed. What was in tension is now in compression; what was in compression is now in tension. With each cycle of bending, some damage is incurred by the wire. Eventually, the wire will break. If the radius of the bend is large, the magnitude of the extreme fiber stress is low, and the number of load cycles will be high before failure occurs. If the bend radius is small, the unit stress at the outside and inside radii are high, and fewer load cycles are necessary to cause the wire to break.

Now, change the conditions of our wire experiment slightly. Add a small notch near the mid-length of the wire and bend the wire back and forth. You will notice the bend will center on the notch. The magnitude of the unit stress at the notch will be higher than in the un-notched wire, and the bend radius will be much smaller. It will take fewer cycles of bending the wire back and forth to cause it to break. It takes fewer load cycles because of the stress intensification due to the presence of the small notch. Geometric features like welding members of different thicknesses or widths, undercuts, or overlaps act like the notch in the wire. They magnify the stress in the area of the changing geometry. Notches are often called stress risers because the stresses are concentrated at the notch.

Another consideration is how materials respond to a force or applied load. This wire experiment differentiates between elastic behavior and plastic behavior. For this demonstration, we use a length of wire without a notch and extend the wire several inches beyond the edge of a table. Apply a small load to the far end of the wire extending over the table's edge. You will observe the end of the wire deflecting in the direction of the applied load. Remove the load, and the wire springs back to its original position. This is an example of elastic behavior. Increase the load by a small amount, and the wire will deflect more. With each increase in load, the deflection will be greater, but the wire springs back to its original position. Eventually, the load will be large enough that the wire will deflect, but when the load is removed, the wire will not return to its original position; we see that the wire is permanently deflected or deformed. The wire is now exhibiting plastic behavior. The unit stress at the outside of the bend radius has exceeded the yield strength of the wire, so the wire does not spring back to its original position. While the deflection caused by the load within the elastic range is recoverable, the portion of the load above the yield point (in the plastic range) is not recoverable because the atoms in the area of the bend have slipped past each other, resulting in a permanent bend.

Modify the experiment by making a small notch in the wire at about mid-length and position the wire so the notch is located just beyond the edge of the table. The load required to cause the wire to permanently bend (i.e., the load required to cause the unit stress in the area of the notch to exceed the material's yield point) is less than the wire without the notch. It takes less load to cause the wire to bend because of two factors: first, the notch reduces the cross-sectional area, and, second, the notch acts as a stress intensifier.

What's the connection between the demonstrations just completed and fatigue cracking? We learned that at low loads where the unit stress is within the elastic range, the wire with a constant diameter (i.e., no notches) can undergo many cycles of loading and unloading before (if ever) a crack initiates and, ultimately, the wire fractures. However, when the geometry is changed with the introduction of a notch, the wire will fail after fewer load cycles. The notch represents a change in geometry that multiplies the unit stress, possibly into the plastic range, because the notch is said to be a stress riser. The unit stress

Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

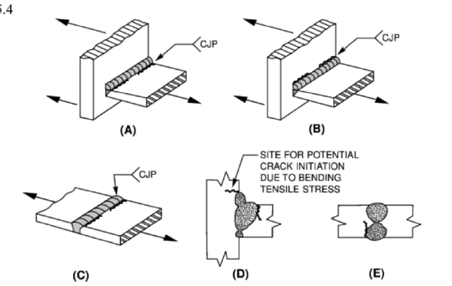
Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 5—Welded Joints Transverse to Direction of Stress (Cont'd)				
C	44 × 10⁸	10 [69]	From weld extending into base metal or along weld metal	5.4 

Fig. 1 — This is an excerpt from AWS D1.1, Table 4.5, that depicts typical corner joint and butt joint connections. The stress category is C. C_f is a constant that appears in the formulas that are used to calculate the stress range. When the stress range exceeds the threshold value, F_{TH}, fatigue must be considered by the designer. Perhaps of most interest to the inspector performing an in-service inspection are the sketches indicating where fatigue cracks are most likely to initiate.

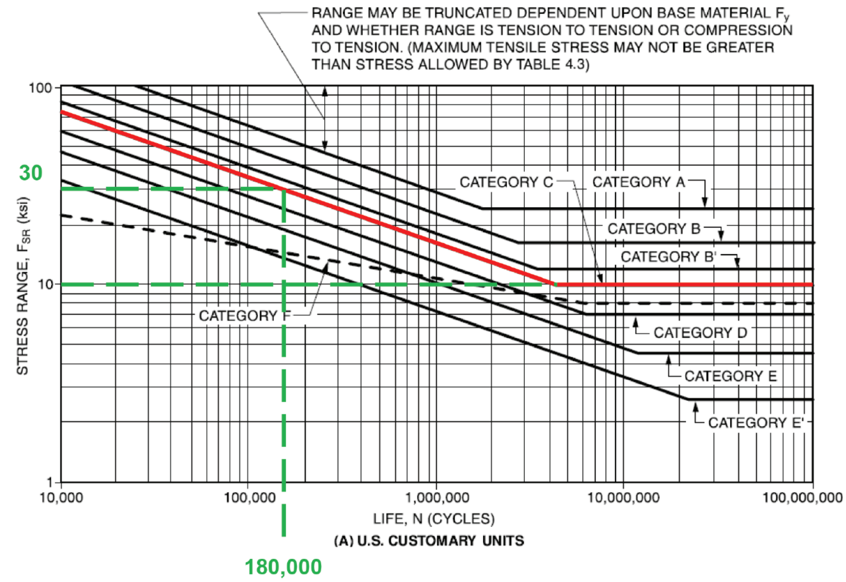


Fig. 2 — This is an S-N plot taken from AWS D1.1, Figure 4.16. The first thing to note is that the vertical and horizontal axis are logarithmic. Next, the stress category C for the connections in Fig. 1 is highlighted in red. A cyclic load with a magnitude of less than 10,000 lb/in.² (10 ksi) would plot below the blue line (i.e., the endurance limit), so fatigue cracking should not be a concern. If the magnitude of the cyclic load is increased (i.e., more than 10 ksi, let's say 30 ksi), fatigue must be considered. When a cyclic load of 30 ksi is applied (the green dashed line), one draws a horizontal line across the graph beginning at the left axis toward the right until it intersects the red line that plots stress category C. A vertical line (green dashed line) starts at the point of intersection of the green line, and the red line is dropped to intersect the horizontal axis. The intersection of the dashed vertical green line and the horizontal axis approximates the 30 ksi load cycles that can be applied before a fatigue crack is likely to initiate. In this example, it looks to be about 180,000 cycles of loading and unloading.

in the area of the notch is several times higher than it is for the un-notched wire. Weld discontinuities and abrupt changes in geometers are often called notch-like stress risers because their influence is very similar to the notch in the wire.

How does all this relate to fatigue cracking? That's a good question. The wire experiments demonstrate some factors that influence the probability of fatigue cracks developing when a weldment is placed into service.

Factors that influence fatigue life of a connection are as follows:

- The magnitude of the load that is subject to change,
- The number of load cycles, and
- The geometry of the connection.

It's time to get into the thick of it.

AWS D1.1/D1.1M, *Structural Welding Code — Steel*, provides guidelines to the designer for determining if fatigue is a design consideration. The clause covering fatigue is more extensive now than it was 40 years ago. The first thing that needs to be determined is whether the magnitude of the fluctuating load exceeds a threshold value. In other words, the load that changes must be large enough to be a concern. In the case of a bridge, a car passing over the bridge represents a changing load, but it is rather inconsequential. What is concerning is the number of fully laden trucks or loaded rail cars passing over the bridge. The passenger car might weigh 5000 lb (5 kips), but the fully loaded truck weighs 50,000 lb (50 kips), and the loaded rail car might weigh in at 80,000 lb (80 kips). The magnitude of the changing load is due to the car being below the threshold value, so fatigue is not a concern. However, the magnitude of the changing load that results when the loaded truck or rail car is above the threshold value is a concern. After a sufficient number of load cycles, the accumulated damage can result in one or more cracks. The location of the cracks will most likely be where there is a notch-like discontinuity.

AWS D1.1 also categorizes the welded connections into stress categories. They include butt joints, T-joints, corner joints, complete joint penetration groove welds with the backing left in place, complete joint penetration groove welds with the backing removed, etc. They are grouped as Category A, Category B, through Category F. The sketches of the various welded connections are included in Fig. 1. The higher the letter value, the more likely fatigue cracking is a problem.

These figures are used in conjunction with the S-N plots depicted in Figure 4.16, which are also found in AWS D1.1 — see Fig. 2. In this case, the plots only apply to nontubular connections.

The magnitude of the cyclic load does not include the dead load of the member being investigated. In the case of a simple span, the load changes over time due to the live load (e.g., a loaded truck moving across a single-span bridge deck). If the bridge is a continuous span extending over more than two supports, the magnitude of the load is the absolute value of the cyclic load that reverses (the sum of both compression and tension without regard to the mathematical sign of the load).

The designer determines what stress category applies to the connection being designed. AWS D1.1 has several formulae the designer uses to compare the magnitude of the cyclic load to the threshold value (F_{th}) assigned to the connection. If the threshold value is exceeded, fatigue must be considered.

A moment connection in an office building must support the dead loads of the steel frame and the concrete deck, but the connection will be subjected to an increased load during a snowstorm. The unit stress due to the snow load might increase to something above 30 ksi during a major snowstorm. The increased load will disappear as the snow melts. Assume the moment connection is a stress category C connection. The threshold value is 10 ksi, and it is exceeded during each snowstorm. Assuming there are three months of winter and there is one major snowstorm per week, there would be 12 major snowstorms each year, with each snowstorm representing one 30 ksi cyclic load. It would take 180,000/12 = 15,000 years before a fatigue crack would form. Office buildings, hotels, schools, etc., are considered statically loaded and are not expected to experience issues with fatigue cracking. They have a useful life that is much too short to experience fatigue.

Change the structure to a bridge where automobiles and fully laden trucks pass over it. The magnitude of the cyclic load due to the automobiles is less than the threshold value of 10 ksi. Thousands of automobiles pass over the bridge on any given day, but they will not generate the stresses necessary to produce fatigue cracks. However, fully loaded trucks are another story. Each truck represents a cyclic load of 30 ksi, well above the threshold value. Should enough trucks pass over the bridge, fatigue cracks will result. For our example, five trucks per hour pass over the bridge between 6:00 a.m. and 6:00 p.m. Between 6:00 p.m. and 6:00 a.m., only one truck per hour passes over the bridge. In total, 72 trucks pass over the bridge per day, or 504 trucks per week. It would take 357 weeks to reach 180,000 cyclic loads or about 6.8 years before fatigue cracks could be expected to initiate. At first, the cracks would propagate slowly, but in short order, the growth rate, being exponential, would lead to failure.

As the bridge approaches the expected 180,000 load cycles, inspection should be conducted more frequently so the cracks are detected while they are still small, and there is time to develop a repair plan. An inspection plan will typically include more frequent inspections to ensure the repairs are undertaken before the cracks reach a critical size, causing the bridge to collapse.

I hope this explains how the S-N graph helps the designer consider cyclic loads and the potential for developing fatigue cracks.

The inspector needs to know whether the weldment is a statically or cyclically loaded structure so the correct acceptance criteria is used for the inspections. If the inspector is performing in-service inspections, the Table 4.5 sketch shows the inspector what areas need close scrutiny to detect cracks in the early stages of forming.

It is unlikely the fatigue crack is going to develop near the midpoint of a beam unless there is a change in geometry (i.e., the width or thickness changes) or there is a geometric feature like a gouge or a butt joint that wasn't ground smooth. However, the toes of the welds of a moment connection are a location that is likely to develop fatigue cracks if the weld contains notch-like discontinuities such as an undercut, overlap, or slag inclusion or the weld is backgouged with incomplete joint penetration, etc. But do not overlook the fact that the toes of welded T-joints are naturally notch-like stress risers and prone to developing fatigue cracks. Often overlooked is the presence of a mislocated hole that was repaired by welding. The inspector may not be aware of repaired holes, or they may be ground flush and easily overlooked. A mislocated hole incorrectly repaired by welding is a fatigue crack waiting to happen.

I hope I have given you some information about how the S-N graphs are used, how some connections are more tolerant of cyclic loads, and how geometric features can influence the longevity of a structure. The connections that have the lowest threshold values (F_{th}) are the connections most likely to develop fatigue cracks, and welds that have notch-like discontinuities are most likely to develop fatigue cracks. In comparison, welds that are ground smooth and welds that are free of stress risers are more resistant to fatigue cracks.

Structures are only as strong as their weakest link. Those connections that are more prone to developing fatigue cracks must be closely monitored as they approach their useful life. As an inspector, you can use the information provided by AWS D1.1 to inspect steel better as it's being fabricated and perform more productive in-service inspections. IT

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