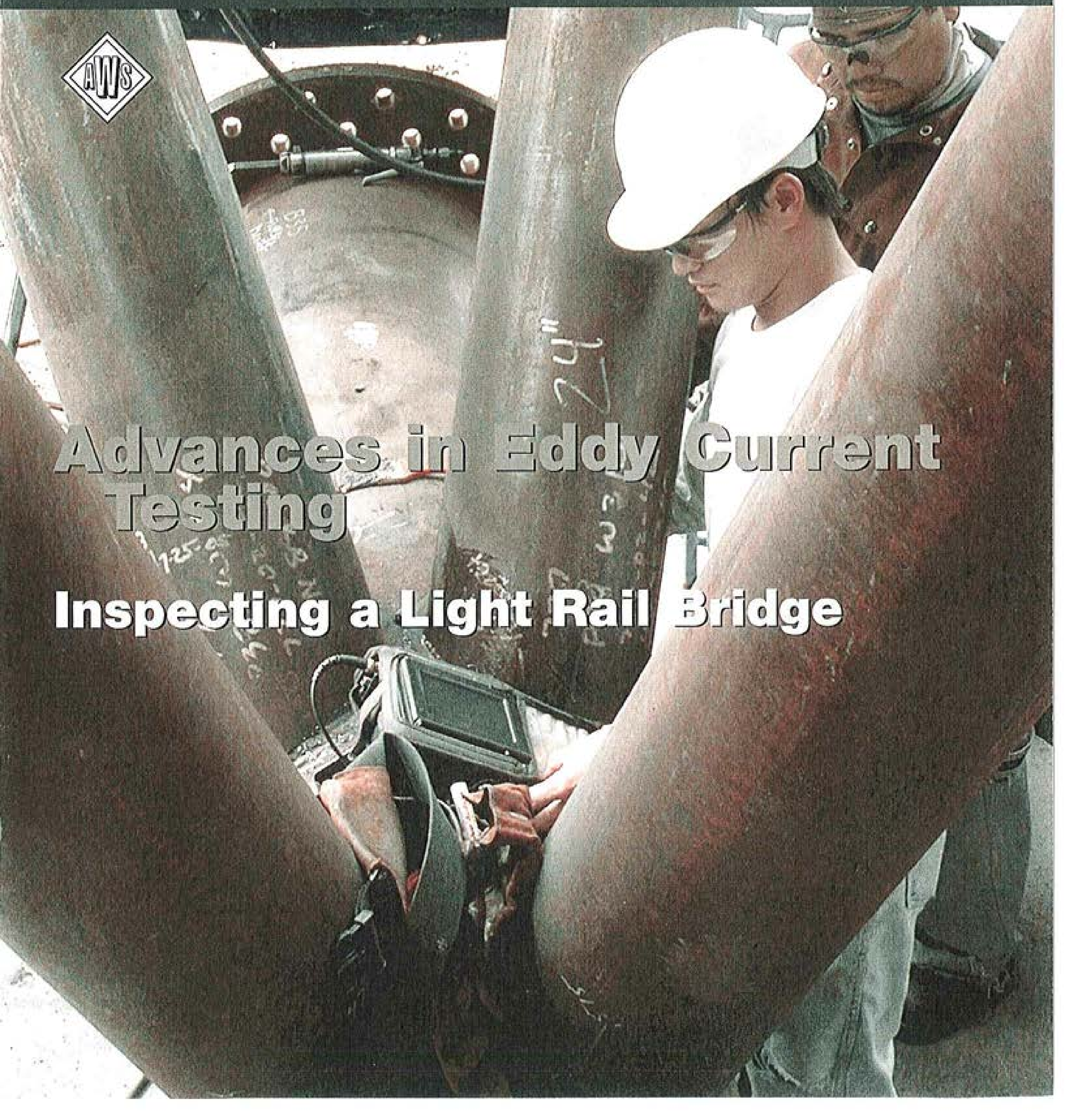
JANUARY 2006 — WINTER • VOLUME 9 • NUMBER 1

INSPECTION TRENDS

THE MAGAZINE FOR MATERIALS INSPECTION AND TESTING PERSONNEL



Advances in Eddy Current Testing

Inspecting a Light Rail Bridge

Inspection Program for a Light Rail Bridge

A short fabrication time and complex T-Y-K joints presented challenges during construction and inspection of a steel tubular bridge

BY GARY GARDNER

Fig. 1 — The bridge services the Phoenix, Ariz., light rail network and spans Tempe Town Lake. Here the last segment is being hoisted for setting at the northeast abutment. At right, parallel to the new bridge, is the historic 1912 single-track truss bridge that is still in use.

A recent challenge for Stinger Welding, Coolidge, Ariz., was fabrication of a steel tube-structure bridge to link the Phoenix, Ariz., light rail network with the east-valley communities across Tempe Town Lake (a section of the normally dry Salt River contained by upstream and downstream inflatable dams) — Fig. 1.

The cyclically loaded truss bridge has two parallel spans between the north and south abutments (to bear both north- and southbound tracks), and is supported in midspan by nine Y-shaped concrete piers. Tubular cross-diaphragms, located at both abutments and at the nine piers, interconnect the parallel trusses — Fig. 2. Disc bearings, two on each abutment and two atop each pier, control bridge movement. A concrete deck will be poured on stay-in-place decking. Details of the project are outlined in Table 1.

The structure was engineered for fabrication in segments to optimize structural strength vs. weight, to enable transportation to the job site, and to modularize erection.

The artistic design directed that the structural members be round (tube/pipe) and covered with unflattened expanded metal to reflect light outward from computer-sequenced multi-colored high-intensity LEDs mounted within the triangular cross section of each truss. The lighting effect will "chase" a train as it crosses the bridge. Additional information and

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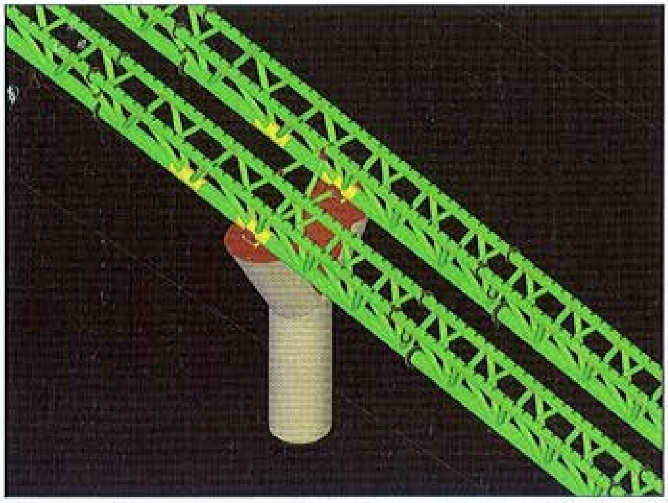

Fig. 2 — CAD illustrations of several segments connected at bolted flanges over piers.

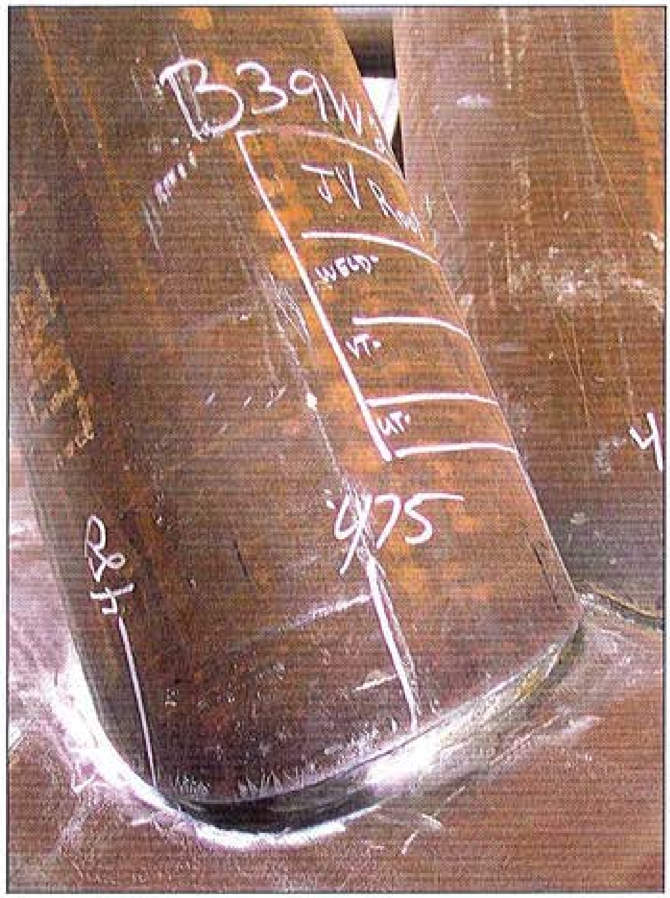

Fig. 3 — Typical root pass, ground and prepared for subsequent welding. Note marking of groove depth measurements and piece mark identification above check-box.

construction photos maybe viewed at *www.valleymetro.org/rail/ConstructionSections/Tempe%20Town%20Lake%20Bridge. html.*

The principal members of the project were Valley Metro Rail (VMR), owner, project administration; Buster Simpson, artist, designer; T Y Lin International, Tempe, Ariz., structural design, engineer of record; PCL Civil Constructors, Inc., prime contractor; Stinger Welding Inc., steel fabricator; and AMEC Earth & Environmental, Tempe, Ariz., nondestructive examination. Each of the parties involved offered significant expertise and exhibited a high level of cooperation. Teamwork was a feature of the project throughout its duration.

Materials Used

The original design specified ASTM A618 pipe in various diameters and wall thicknesses. Since Federal Transit Administration (FTA) funding was involved, domestic materials were required (a policy Stinger Welding ardently supports). The lead time for A618, domestic or imported, was at least one year for several of the size and wall thickness combinations; sources would often not quote some sizes at all or would require a huge mill purchase for each size plus wall. With the contractually imposed six-month fabrication time for the bridge (including receipt of material), the material selection had to be broadened but yet meet the 50 ksi minimum material yield strength for all members.

Requests were submitted to use API line pipe in Grades X52 to X60 and for permission from the FTA to use imported pipe

Table 1 — Technical Details of the Project

Span length (distance between abutments)	Two parallel spans, each 1530 ft long
42 segments (21 per span)	Lengths from 46 to 94 ft; 1200 lb/ft average weight; 16 swept; all cambered
Four top chords in positive moment loading (over piers and abutments)	18-in. Schedule 100 pipe (1.156-in. nominal wall thickness), API 5L PSL2 Grade X60
Four top chords in negative moment loading (free-span areas)	18-in. Schedule XS pipe (0.5-in. nominal wall thickness), API 5L PSL2 Grade X52
Two bottom chords, positive and negative loading	24-in. Schedule 60 pipe (0.969-in. nominal wall thickness), API 5L PSL2 Grade X60
880 diagonal braces	10-in. API 5L PSL2 Grade X52, Schedule 120 (0.844-in. wall) in positive moment segments, Schedule XS (0.5-in. wall) in negative moment segments
12 tube diaphragms and 220 cross braces between top chords	8-in. API 5L PSL2 Grade X52, Schedule XS (0.5-in. wall)
Flanges, plates, stiffeners	1- to 2.25-in.- thick A709/A572 Grade 50 types 2 and4
FCAW-G filler	37,500 lb Tri-Mark; < 8 mL/100 g hydrogen
GMAW metal core filler	1,200 lb Tri-Mark; < 4 mL/100 g hydrogen
SAW solid wire filler	9,500 lb Lincoln; < 4 mL/100 g hydrogen
8940 headed stud anchors	5- × 0.875-in.-diameter, fluxed, automatically welded
Bolted connections	1.25-in.-diameter A325 bolts; turn-of-nut tensioning; all connections slip critical
Finish	SSPC SP-10 blast; minimum 2 mils DFT epoxy-based zinc-rich primer

Fig. 4 — UT technician and CWI Dennis McNamara verifying depth of groove after grinding a root pass.

since two sizes and wall thicknesses were not available from domestic sources. FTA response time was not in tune with a fabricator accustomed to fast-turn-time operations, but approvals were granted. Another round of material chasing ultimately led to suppliers with materials that required on-site inspection prior to purchase to verify dimensions, form, and traceability.

Weld and Joint Design

The project design engineers offered fabricators the rare opportunity to make comments and recommendations about welding processes, filler metals, joint configurations, and inspection before the plans and specifications were written (and before the project was let to bid). Stinger Welding's engineering and quality assurance groups contributed the information needed by the engineers to make the structure more reliable and easier to manufacture.

Since the maximum material yield strength requirement for all members in the structure was 52 ksi, both carbon steel and low-alloy filler metals having 58 ksi minimum yields were acceptable. Although preheating requirements were minimal on this project, low-hydrogen materials were selected for their consistently high-quality welds that result in an insignificant additional cost after inspection and rework are factored.

The realities of this project, which required structural controls per AWS D1.1, *Structural Welding Code — Steel*, meant that rework had to be minimized because of cost control, time constraints, and a contractual limitation of two rework cycles at any location.

Both fillet and groove welds were fabricated with gas shielded flux cored arc welding (FCAW-G) or with gas metal arc welding (GMAW) with metal core wire. Partial joint penetration (PJP) welds were used only in fabricating the bridge bearings.

Pipe butt-joint splices and pipe-to-flange (corner) joints were welded using single-wire submerged arc welding (SAW). All such joints were complete joint penetration (CJP) welds made using speed-controlled rollers in the 1G (rolled) position with backing.

Internal pipe stiffeners (CJP corner joints) were semiautomatically welded using metal core GMAW in the 2G position with backing also using speed-controlled rollers to maintain an optimum travel rate. For both reliability and deposition speed, only the spray transfer mode was used.

Diagonal brace members were welded with FCAW-G in 6GR

Fig. 5 — End of thin-wall diagonal member being thermally cut on CNC equipment. The length, end-for-end clocking, asymmetric "fish-mouths," and bevel angle are simultaneously cut.

configurations (out-of-position/all-position, open-root/without backing). Even though procedure qualification testing allowed more latitude, D1.1 Fig. 3.9 joint details were followed — a more conservative approach that lent itself well to inspection.

A reversed approach was used in welding the diagonals. Typically, per D1.1, a welder would make the root (backing weld) pass, measure the depth, then add enough filler to make the weld size. This method is acceptable for a few joints — thin-wall branch members and branch attachment angles near 90 deg. Otherwise, if the root pass was shallow (did not begin at the inside of the branch pipe), a great deal of buildup was needed to make an adequate weld size. Ultrasonic testing (UT) would then be difficult, plus the apparent size of each weld would vary noticeably. The approach used in this job was to make the root pass, grind it back to a given minimum depth (Fig. 3), visually inspect (to make sure the grinder didn't go all the way through the root pass), measure to verify the depth, then fill and cap using external measurements. A side benefit was less rework due to the high-quality ground surface preparation for subsequent weld filling of the groove.

Developing In-House Weld Gauges

Conventional weld gauges were of little use. Simple go/no-go depth gauges and the equivalent of fillet gauges were fabricated and calibrated in-house for quick, accurate, repeatable weld measurements — Fig. 4.

Early in the job, measurements were taken at six locations around each diagonal at each end and written on the pipe with

Fig. 6 — Evaluations of test coupons having known defects to develop and validate UT procedure. Witnesses include VMR QA, Level III technicians from both VMR's and Stinger's independent contract inspection services, and Level II inspectors involved in the procedure development.

paint markers. Once the go/no-go gauges were established as reliable, measurements were no longer recorded, and a paint stripe indicated that the correct minimum depth existed.

Design and Implementation of the Quality Assurance and Control Plan

The inspection program required a multifaceted, proactive approach. To form and sustain an effective inspection program for this project, the QC department needed ready access to information and personnel in a number of internal and external departments. All stakeholders on this project made extraordinary efforts to work as a team, which significantly enhanced the work flow.

Contractual requirements stipulated that Stinger Welding contract third-party inspection for all nondestructive examination on the structure and that an outside AWS CWI with up-to-date credentials be physically present at all times when welding was being performed.

Material Traceability

Since the project required material management identical to that for a fracture-critical job according to AWS D1.5, *Bridge Welding Code*, an identical tracking method was used. Per standard procedure, receiving inspection "serialized" incoming stock with the purchase order, line item, and a unique heat number code. In subsequent cutting operations, production personnel, trained and experienced in this procedure, transferred the traceability data and piece-numbered each detail cut from stock.

Traceability of filler materials was accomplished through the use of adhesive stickers attached to the carton by receiving inspection. When pulled from inventory by welders, the sticker was transferred to the wire spool to ensure traceability.

Material marking was permissible with low-stress stamps, but this method is fraught with problems (i.e., continually verifying that only low-stress stamps are used, location and legibility of marks for later viewing, etc.). Paint pens were the selected marking method. Although obliterated by subsequent abrasive blasting, paint marking proved effective since it was convenient for all parties and legible from a distance. Since marking records had to be included in the project documentation prior to blasting as a matter of routine, the traceability records, therefore, endured.

Traceability data were documented (transferred to a multi-purpose log that also recorded welding and inspection data) for each truss assembly by the third-party CWIs while they made their rounds inspecting welds, joint fitups, and root preparations, and while auditing material marking, current certifications for welders, machine calibrations, conformance to welding procedure specifications (WPSs), etc. Stinger's inspection team then audited these records for accuracy and completion.

Fig. 7 — UT inspector Stephen Tekoseno testing an open-root CJP weld. Welder Pedro Leyva looks on to make sure his welding is acceptable.

Procedure Qualifications

Since diagonal members were to be complete-penetration welded from the outside of the pipe without backing, and since one-side CJP welds without backing are not prequalified, D1.1, Section 4.12.4 governed the required procedure qualification testing. Carefully designing the tests and limiting the variables complied fully with the code, reduced the number of tests that were required, and posed no undue limitations on the parameters for the WPSs to be written based on these tests. A constant bevel angle of 40 deg was selected to allow easy access to the root pass by welders and inspectors, to give a weld sectional area that did not require excessive passes and filler metal (and potential for inclusions), and to make a single parameter that could be easily plugged into the cutting system for the diagonals.

The diagonals were too complex to be manually cut, so specialized CAD software, a firmware interface, and CNC thermal cutting equipment were integrated. This system simultaneously cut and rotationally aligned the asymmetric "fish-mouth" on each end within 0.5 deg, beveled the included welding angle, and cut each diagonal to length with the allowance for root openings within 0.05-in. tolerance — Fig. 5. Fabricating this struc-

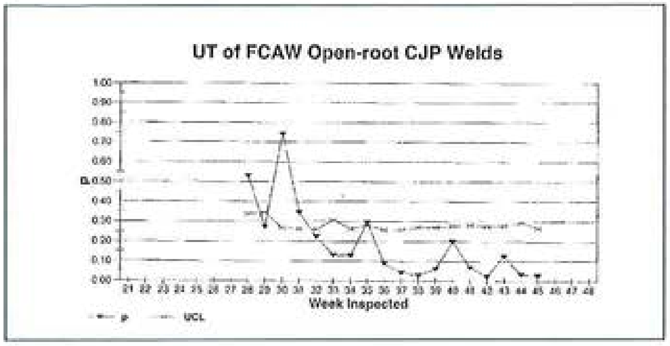

Fig. 8 — A "p" chart showing a statistical analysis of the number of welds initially inspected (first-pass inspection, submitted to UT just after cooling) that showed a UT indication. The upper control limit (UCL) is statistically derived from the number of welds inspected. The lower control limit (LCL) is not shown since it is meaningless in this application (zero is the effective LCL). Whether or not the "p" values lie within the control limits indicate whether a process is in control or not in control. The unusually high level of indications early on represents both indications as well as geometric reflections. P values, and therefore rework, fell off rapidly as experience was gained in both welding and UT inspection.

ture within the time frame and budget would not have been possible without such a system.

Welder Performance Qualification

The scope of this job necessitated training and testing welders in several processes and positions (particularly FCAW in 6GR and 6G, GMAW, and SAW using rollers) because of the quantities of welds involved and since viable automation was not available for the open-root welding.

D1.1 Section 4.26(5) and Table 4.10 specify the minimum qualification requirements that welders must meet for open-root welding of T-Y-K joints. Attention had to be paid to the NDE size limits for indications that were more stringent in production welding than those for qualification testing of personnel. In other words, a welder who successfully passed a 6GR test could not assume the worst was behind him.

UT Inspection Procedure Development and Technician Certification

D1.1 Section 6.27 specifies the minimum requirements for UT of T-Y-K joints, 6.27.1 specifies the procedural requirements, and 6.27.2 specifies requirements for technicians. Five joint coupons, with and without defects, were welded and evaluated to satisfy all parties that a testing procedure was as follows:

- Effective in finding and sizing real-world defects in all joint configurations;
- Effective in eliminating false indications, which would create unnecessary rework and potentially degrade the reliability of the structure; and
- Able to be performed effectively andrepeatably by adequately trained and tested personnel — Fig. 6.

Weld Inspection

Tracking of welding and weld inspection was controlled by paint-marking a check-box at each weld that was to be completed by fitters, root welders, fill welders, visual inspectors, and UT technicians as each weld progressed. Recording the check-box data in logs ensured that all operations were completed, all welds were inspected, all rework was recorded and reinspected, and two-direction accountability existed for each weld. Two-direction accountability means that someone would be able to select any weld and locate its record, and also be able to select any record and locate the weld.

The inspection status of welds was made obvious by Inspection's placement of a prominent paint mark on every member adjacent to each weld (yellow band = visually inspected and accepted; green band = UT inspected and accepted); inspection status of a completed truss segment was similarly marked at the same location on each end (green band = all welds inspected and accepted; segment may be moved from the fabrication bay to the line assembly area; no mark = no move).

Visual inspection (VT) of all joints and ultrasonic testing (UT) of CJP welds were the effective and agreed-upon methods employed. All joints presented fairly straightforward inspection demands, with the distinct exception of the open-root welding of the diagonal braces.

Although numerous test coupons were fabricated to validate the UT procedure and to certify the technicians, and although these coupons were seemingly identical to the production joints, problems nevertheless arose in testing the joints for the diagonal members.

Fabricators in the Southwest typically specialize in structures made with plate or on pipelines. Structures incorporating CJP welding of T-Y-K joints using round elements are uncommon; therefore, those who provide the UT inspection of such structures in the Southwest are typically unfamiliar with the intricacies involved.

A pattern in the location of UT indications was quickly noticed, and the validity of the UT procedure became suspect. Nearly every joint exhibited apparently large defects at its most easily welded area. During "exploratory surgery" of several of these indications (careful carbon-arc gouging), no inclusions of any kind were found. Ultrasonic testing technician Stephen Tekoseno (Fig. 7), who was brought in from offshore oil rig territory for this project, applied some by-the-book theory, performed some calculations, drew some sketches, and determined the cause of the nonexistent indications, which turned out to be geometric reflections. He then trained the other UT techs, including Valley Metro's contract Level III technician, in interpreting and eliminating what, in fact, was a nonproblem — Fig. 8.

Until the understanding of requirements and the performance of welders and inspectors were well established (through classroom evaluation, testing, in-process inspection, and spot checks), more frequent inspections and checks of work in process were required. Rapid feedback between inspectors and welders promoted closed-loop process control of the welding, shortened learning curves, significantly reduced rework, and provided the welders with cause and effect training. Root cause and corrective action became a built-in feature, and the welders were eager to further improve their skills.

As the project progressed and knowledge was gained, some tasks were transferred from Inspection to Production. Checking root openings, inspecting root/backing passes, and measuring the root grind-back depth were transferred. Production assumed more responsibility and gained experience in the benefits of applying process controls, and these features were verifiable by UT.

Lessons Learned

The recommended calibration tolerances typical of welding machine manufacturers' recommendations are too loose to provide for the process controls needed in open-root welding. Codes specify neither tolerances nor process control requirements — the user must identify and adopt rational calibration parameters.

Creating a computerized database prior to the beginning of fabrication would be time well spent for the collection and maintainance of records for weld inspection.❖

Acknowledgments

Many thanks are extended for the timely and pertinent article Tubular TYK Fabrication and Inspection, by Clifford "Kip" Mankenberg, which was published in *Inspection Trends*, Fall 2004, Volume 7, Number 4. That article and subsequent e-mail exchanges with Mr. Mankenberg simplified production and inspection considerably.

The author would also like to acknowledge the contributions of T. Y. Lin, Dan Heller, and Dennis Trefren (P.E.s); Valley Metro Rail QA, Toni Cottrill (P.E., CWI); Valley Metro Rail Engineering, Doaa Aboul-Hosn and Joel Mona (P.E.s); AMEC Earth and Environmental NDT group, Tom Bemrich (Level III), Jon Buseman (manager, Level II, CWI), Dennis McNamara (Level II and CWI), Chris Caraway, and Stephen Tekoseno (UT Level IIs with much experience in T-Y-K), Harold McFarland, and Mel Barron (CWIs); Stinger Welding Management: Procurement, Nancy Henderson; Engineering, Guy Vaccaro and Henry Gan (P.E.); CAD, Marek Kulbacki; Production, Eddie Hallam and Rob Garcia; and President Carl Douglas.