UPDATE ON NCHRP 14-35
ACCEPTANCE CRITERIA OF CJP STEEL BRIDGE WELDS EVALUATED USING ENHANCED ULTRASONIC METHODS

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Update to T-17
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This investigation was sponsored by TRB under the NCHRP Program. Data reported are work in progress. The contents of this presentation has not been reviewed by the project panel or NCHRP, nor do they constitute a standard specification, or regulation.
Project Objectives

- Develop guidelines to evaluate CJP welds in steel bridges using “enhanced” UT based on updated acceptance criteria
  - “Updated” = engineering based rather than based on workmanship

- Develop proposed modifications to the existing AASHTO/AWS D1.5 Bridge Welding Code

- Project is divided into multiple Phases
  - Phase II results are under panel review
Literature Review Main Findings

- PAUT/TOFD is not RT
  - The physics is different
  - Acceptance criteria will be different in terms of:
    - Format
    - Objectives
- Other industries recognize that acceptance criteria must account for sensitivity and variability of the NDE method
  - Detection limitations exist
  - There is error and variability in sizing defects
A few words about acceptance criteria

- To develop rational acceptance criteria for any NDT method, the reliability associated with the method as a whole must be considered.
  - In other words, while one aspect is related to actually “finding” a defect, the other is characterizing it (e.g., size, type, orientation).

- One cannot say that there is any specific POD associated with a given NDT method
  - POD is directly tied to the person performing the test, the circumstances of the test, etc.

- Literature review revealed that all FFS based acceptance criteria which utilized enhanced UT attempt to address these issues
Probability of Rejection

- Probability of Detecting a Defect
- Probability of Rejecting a Detected Defect
- Probability of Rejecting a Defect

Defect Size (mm) vs. Probability

- Defect size 2 mm with a probability of 0.4 for detecting a defect and 0.8 for rejecting a detected defect.
The desired POR can be achieved one of two ways:

- Set the allowable flaw size in the acceptance criteria small enough to account for the fact that the flaw sizing procedures may undersize the defect.

-OR-

- Develop flaw sizing procedures that specifically incorporate conservatism which would tend to oversize flaws more often than undersize them.
Literature Review Main Findings

- Combined PAUT and TOFD common in other industries
  - Methods complement each other
  - Other industries consistently found most reliable strategy is to combine these in order to replace RT

- Planar vs Volumetric Defects
  - Other industries do not distinguish when acceptance criteria are based on UT
  - Conservatively assume all defects are planar
Analytical Program

- All defects were assumed to be planar for the analytical studies using FFS
  - Otherwise can’t use FFS, fatigue or fracture calculations

- Need to determine if enhanced UT can reliably characterize volumetric defects
  - Must establish if volumetric discontinuities can be reliably detected, characterized, and sized with reasonable accuracy
    - Examine existing fatigue data
    - Otherwise, treat volumetric discontinuities as crack-like
Analytical Program

- Two scenarios checked for planar defects:
  - Prevent growth under fatigue loading
  - Prevent fracture during service life

- Parametric study includes:
  - Equal thickness & thickness transition butt welds
  - Plate thickness varied from 0.5” to 4”
  - Aspect ratio (a/c ratio) varied from 0.01 to 1.5
  - Through-thickness defect position:
    - Mid-depth, quarter point, & near surface
Results of Parametric Study

- Compared to ASME Code Case 2235
  - Acceptance criteria for use of UT in lieu of RT
    - Partial safety factors
      - 1.4 – Stress
      - 1.2 – Flaw Size
      - 1.2 – $K_{IC}$
    - Allowable stresses (37-67% of $F_y$)
    - LEFM only (No FAD)
      - $K_{IC}$ obtained from CVN requirements (51-167 ksi√in)
    - Did not consider fatigue limit state

- BS 7910 (Fitness-for-Service)
  - Option 1 FAD
  - Higher stresses (75% of $F_y$)
Comparison to ASME Code Case 2235

- Flaw sizes typically conservative compared with ASME CC 2235 for high strength steels or high stress ranges

- ASME CC 2235 tends to be slightly conservative for lower strength steels or high fracture toughness
  - Depth typically within 3/16” for similar defect length
Thickness Transition Butt Welds

- Performed FE analysis of various thickness transitions to evaluate effect of SCF
  - Flange transitions assumed for thickness $\geq 1''$
  - Web transitions assumed for thickness $= 0.5''$

- Greatest SCF occurred at transitions with greatest relative change in thickness
  - $1''$ to $2''$ & $2''$ to $4''$
T and Corner Joints Loaded Parallel to Weld

- Found to be similar to equal thickness butt weld
  - Negligible stress concentration
  - Tried to determine “equivalent thickness” to simplify to flat plate with similar $K_I$ value
- Crack types modeled in FE
  - Root cracks
  - $\frac{1}{4}$ point
  - Surface cracks
T Joints Loaded Perpendicular to Weld

- Stress concentration at weld toes
  - Performed FE modeling of various geometries
  - Plotted the stresses along a path along the top and bottom weld toes
Proposed Experimental Program

Objective:

- Develop scanning and evaluation procedures to incorporate into AWS D1.5
Original Proposed Experimental Program

- Perform “round robin” exercise to evaluate variability of proposed procedures
  - Circulate plates to fabricators to simulate shop testing
  - Attach plates to elevated test frame to simulate field testing
- Need to consider both detection and sizing capabilities
- Radiography and destructive examination to verify actual flaw dimensions
- Compare rejection rates of proposed procedures with conventional UT and AWS Annex K
S-BRITE POD “Bridge”
Experimental Program Overview

- Analytical program FFS revealed that critical defect sizes were very small in some cases
  - This will require specimens with very small defects
    - For POD, even smaller defects need to be reliably detected
  - Raises concerns over defect detection with current workforce and technologies
- Propose an initial round robin to evaluate the state-of-practice using enhanced UT
Initial Round Robin

- Performed either in laboratory and/or shop
  - Ideally observed by member of Research Team
- 3 to 5 technicians will be asked to:
  - Size flaws using procedure provided by RT and AWS Annex K
    - Can use TOFD or combined TOFD/PAUT
  - Size flaws using their own procedures, if available
  - Will not be asked to perform conventional UT
    - May skew results due to scanning same plates with multiple methods
Laboratory Testing \textit{(After Initial Round Robin)}

- Update specimen matrix (if needed) and fabricate specimens
  - Use data from initial round robin
  - May require more rigorous FFS analysis to develop less conservative critical crack size limits

- Incorporate best practices in scanning procedures

- Fish & Associates scan all plates
  - PAUT only
  - TOFD only
  - Combined PAUT/TOFD
Laboratory Testing *(After Initial Round Robin)*

- **Evaluate**
  - Defect detection
  - Sizing differences
- **Develop finalized scanning procedures**
- **Perform radiographic testing**
  - Compare detection and length sizing
- **Destructive verification of a select number of specimens to verify sizing estimates**
Second Round Robin

- Evaluate field and laboratory testing using finalized flaw procedure
  - Compare to AWS D1.5 conventional UT and Annex K
  - Rotate inspectors through different sets of specimens so that plates are not scanned with multiple methods
- Shop testing in bridge fabrication shops or typical shop fabrication environment
- Field testing at S-BRITE Center
  - Control specimens scanned at Bowen Lab
Proposed Experimental Program

- Investigate flaw characterization methods and associated reliability

- Types of defects included in test matrix
  - Lack of Fusion
  - Slag Inclusions
  - Internal Porosity
  - Embedded Cracks
  - Surface Fatigue Cracks
Proposed Experimental Program

- Narrow Gap Improved Electro-slag Weld
  - Difficult to create defects in specimens
    - Process fully automated and can’t start/stop
  - Real concern is related to detection and attenuation due to possible large grain size
  - Proposed to fabricate specimens with small SDH and EDM notches to determine if there are issues with NGI-ESW
    - Basically use calibration type specimens to first determine if there is even an issue with the modern ESW process
Future Phases

- Execute experimental work
  - Fabricate specimens with flaws
  - Develop testing procedures
  - Conduct round robin testing
  - Develop rejection/acceptance criteria

- Develop draft guidelines for AWS
  - Include considerations on economic impact

- Revise draft guidelines and develop ballot language to allow for incorporation into AASHTO LRFD and AWS D1.5
  - Project end date April 2018
Questions