Non-Destructive Evaluation of Fracture Critical Members Fabricated from AASHTO M244 Grade 100 (ASTM A514/A517) Steel

FHWA Office of Bridges and Structures
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Agenda

• Background
  • Sherman-Minton Bridge
  • Technical Advisory 5140.32
  • Hernando de Soto Bridge
  • December 13, 2021 Memo “Non-Destructive Testing of Fracture Critical Members Fabricated from AASHTO M244 Grade 100 (ASTM A514/A517) Steel”

• Technical Discussion

• Memo Implementation Discussion

• Open Discussion
Background
Background: Sherman-Minton Bridge

- Double-decked steel tied arch built in 1961.
- Carries Interstate 64 over the Ohio River
- Dual 800 ft. spans.
- Tie fabricated from “T-1” steel.
Sherman-Minton Bridge – Welding Investigations

- Cracking first documented in 1981
- Comprehensive investigation began in summer 2011
  - Documenting cracks
  - Conducting material testing
  - Installing bolted retrofits
Sherman-Minton Bridge – Welding Investigations

- 704 tie girder CJP butt welds.
- NDT identified discontinuities in over 80% of the web plate butt welds

Diaphragm lug

- Lateral bracing gussets CJP tee welds to tie girder.
- 88 welds.
Sherman-Minton Bridge - Closure

- Removal of 3rd lateral gusset plate found a discontinuity of concern. Bridge closed Friday, Sept. 9, 2011.
- Bridge remained closed for 5 months to complete repairs

Source: Indiana DOT, used with permission

Fracture mechanics predicted crack was a critical size for brittle fracture if ambient temperature dipped below 30°F.
Technical Advisory 5140.32

• Released September 12, 2011, shortly after Sherman-Minton closure
• Recommends that bridge owners:
  • Review inspection records to ensure components fabricated from T-1 steel have been regularly and appropriately inspected,
  • Follow up on deficiencies, prioritizing components primarily in tension (arch ties, hangers, truss members), and
  • Verify the soundness of all butt welds in tension in members fabricated prior to FCP adoption

Source: FHWA
Background: Hernando de Soto Bridge

- Steel tied arch built in 1973.
- Carries Interstate 40 over the Mississippi River
- Dual 900 ft. spans.
- Tie fabricated from ASTM A514.

Source: Michael Baker International
Hernando de Soto Bridge – Tie Girder Fracture

Source: Michael Baker International
Yellow and green regions were surface breaking hydrogen cracks from fabrication. About 6.5” x 1” and 5” x 1.2”.

Blue region was 1st brittle extension sometime after fabrication. Broke surface on inside of box, not outside.

Orange region (both images) was 2nd brittle extension. Broke through outer box surface sometime before 2016.

Pink region was 3rd brittle extension. Happened after 2019.

Source: Arkansas DOT
December 13, 2021Memo

• Requires that State DOTs:
  • Identify bridges with fracture critical members fabricated from T-1 steel without requirements to meet the provisions of the AASHTO/AWS FCP and document them in the FCM inspection procedures¹
  • Supplement hands-on inspection of T-1 FCMs with Non-Destructive Evaluation verifying the soundness of butt welds in tension²
    • Unless previous verification has been documented
    • Previous verification needs have been performed a minimum of 48 hours after original welding (≤ 2" thick, 72 hours for > 2" thick)
  • Classify rejectable indications (using AASHTO/AWS criteria) as critical findings³
  • Report an inventory of bridges with T-1 FCMs and actions taken to perform verification and follow up on findings⁴

¹ 23 CFR 1.36, 23 CFR 650.313  
² 23 CFR 1.36, 23 CFR 650.313  
³ 23 CFR 1.36, 23 CFR 650.313  
⁴ 23 CFR 1.36, 23 CFR 650.315
Technical Discussion
What is “T-1” Steel?

Steel with a yield strength greater than 100 ksi ($F_y \geq 100$ ksi)

- US Steel first markets “T-1” (1952)
- Likely earliest use of T-1 in bridge
- Sherman-Minton Bridge fabricated (1961)
- Hernando de Soto Bridge fabricated (1973)
- ASTM A 514 and A 517 first published
- AASHTO FCP first published
- FCP incorporated into AASHTO/AWS D1.5
- 1995
- Sherman-Minton Bridge closed
- Hernando de Soto Bridge closed
- 2011
- 2021

Aliases:
- ASTM A514
- ASTM A517
- Grade 100
- Quench and Tempered (Q&T)
- Heat-treated steel

Source: FHWA
What is the AASHTO/AWS Fracture Control Plan?

• Implemented first in 1978 as the AASHTO “Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members”

• Since 1995, included as Clause 12 of AASHTO/AWS D1.5 “Bridge Welding Code” as “AASHTO/AWS Fracture Control Plan (FCP) for Nonredundant Members”

• Provides supplemental requirements for materials, processes, procedures, inspection, and repair for welds in the fabrication of fracture critical members
What is Hydrogen Cracking?

• Hydrogen likes to be a molecule (H₂).
  • Energy from welding dissociates H₂ into two atomic H’s.
    • Atom hydrogen (H) can easily move through a metallic crystal.
      • Reconstituting H₂ in the crystal causes internal stress and cracking.

Source: FHWA

Migrates toward tensile stress....
What is Hydrogen Cracking?

It’s a weld, there will always be tensile residual stress. Restraint also influential.

This can be controlled in fabrication.

Q&T steels are tempered martensite, martensite is susceptible. Weld procedure also influential.

Source: FHWA

Aliases:
- Delayed cracking.
- Cold cracking.
- Hydrogen assisted cracking.
- Hydrogen induced cracking.
- Hydrogen embrittlement
Memo Implementation
How Can State DOTs Identify Bridges Subject to the Memo?

• Ultimately, will require review of bridge records
  • Materials used: contract plans, as-builts, shop drawings, mill certs
  • Location of butt welds: shop drawings

• File review can be narrowed by filtering NBI data:
  • Item 92A (Fracture Critical Details) = “Y”
  • Item 27 (Year Built): 1959 (likely earliest use) to 1995 (unless State adopted 1978 AASHTO guide specification)
How Should States Report the Inventory?

• Submit data to the Division Office
  • Method agreed to between State DOT and Division Office
  • Inventory to include all bridges with FCM fabricated from T-1

• Four data items:
  a. Bridge Number → verification that T-1 FCM identified in procedures (Metric 16)
  b. Month and year of soundness verification
  c. Whether verification identified rejectable indications (Yes/No)
  d. If (c.) is Yes, Month and year critical finding was resolved → (Metric 21)

• Items b, c, and d would be NA if bridge has T-1 FCMs, but no butt welds in tension
What Type and Coverage of NDE is Required?

• Refer to clause 6 of AASHTO/AWS D1.5:2015 (now Clause 8 in D1.5:2020), which covers welding inspection
  • Requires 100% RT and UT of butt welds in tension for fabrication
  • Radiographic testing will be physically difficult in-situ → UT will satisfy the requirements of the memo

• Part C of Clause 6/8 sets forth procedures and standards for ultrasonic testing of groove welds
  • Equipment qualification and calibration
  • Evaluation procedures
  • Challenge – D1.5 does not provide minimum performance qualifications for NDE personnel
What is a “Rejectable Indication”?

- Refer to Clause 6 of AASHTO/AWS D1.5:2015 (now Clause 8 in D1.5:2020)
  - Part D – Weld Acceptance Criteria
  - Table 6.3 (2015)/8.3 (2020) – “UT Acceptance-Rejection Criteria – Tensile Stress”
Open Discussion