New AASHTO Guide Specs. For Removal of FCM Designation

Robert J Connor, PhD – Purdue University
Matthew H Hebdon, PhD – Virginia Tech
Jason B Lloyd, PhD, PE – NSBA
Cem Korkmaz – Purdue University
Francisco J Bonachera Martin – Purdue University

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FCM Designation and Consequences

- Fracture-Critical Member (FCM): Steel tension member/component which failure results in collapse/loss of serviceability
- FCM involves fabrication per AASHTO/AWS D1.5 Section 12
  - Fracture Control Plan = Base metal, process, consumable, inspection reqs.
  - One time expense
  - These have been successful in **PREVENTING** brittle fractures
- FCM involves Fracture-Critical Member Inspection (NBIS)
  - 24-month default interval, hands-on along the length of the member
  - FCM Inspection is expensive through the life of the bridge
  - These might not be effective in **DISCOVERING** signs of future fracture

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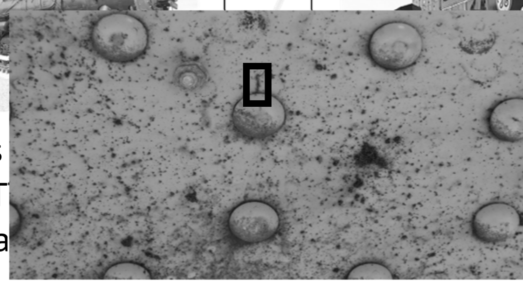
Issues with FCM Inspection

- What do you get from FCP + NBIS? **MORE INSPECTIONS**
- Differences between bridges are not factored in
- Hands-on inspections are not uniform/reliable/homogeneous
  - Human eye looking for hairline indications



1950s … o FCP
ADT … V
E' fla … e detailing

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Redundancy: Are all FCMs "Critical"?

- FCM fracture is rare, collapse due to FCM fracture is most rare
- Most of the bridges the underwent FCM failures provided service
  - Exc: Silver Bridge hanger fracture led to collapse (1967)
- Most FCM failures would not have been detected by inspection
  - Exc: Lafayette St Bridge (St Paul, MN) fracture stemmed from a fatigue crack
- Fracture triggers (CIF, poor welds, brittle steel) are not allowed
- We take advantage of redundancy:

Assume the failure happens and check capacity in the faulted state.

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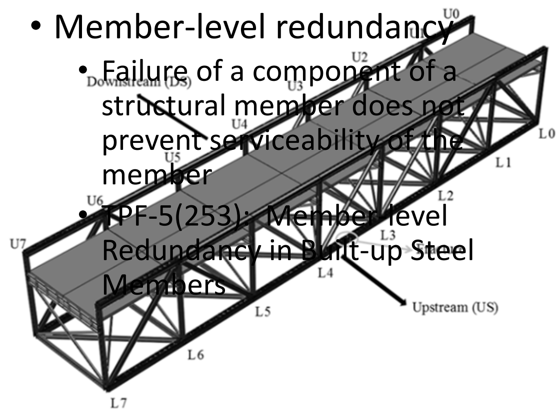
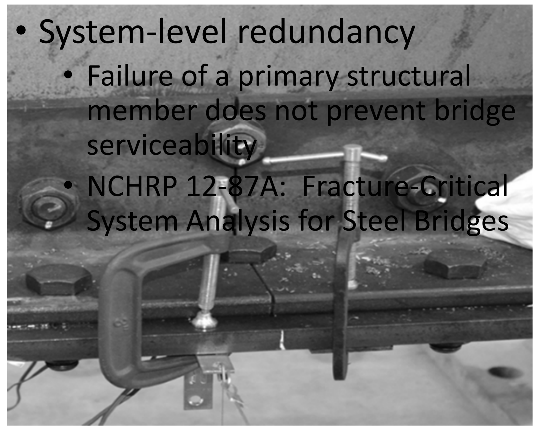
Research Projects in Steel Bridge Redundnacy

- Two main types of redundancy
- Member-level redundancy
  - Failure of a component of a structural member does not prevent serviceability of the member
  - TPF-5(253): Member-level Redundancy in Built-up Steel Members



- System-level redundancy
  - Failure of a primary structural member does not prevent bridge serviceability
  - NCHRP 12-87A: Fracture-Critical System Analysis for Steel Bridges



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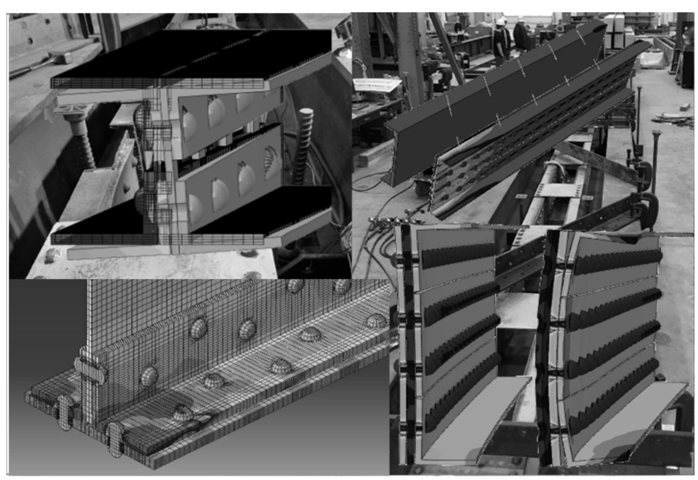
TPF-5(253): Research Program

- Multiple fracture tests
  - Flexural Members
  - Axial Members
- Fatigue after fracture
  - Only flexural
- Load-transfer test
  - Truss Chord
- Dozens of FEA models to develop provisions



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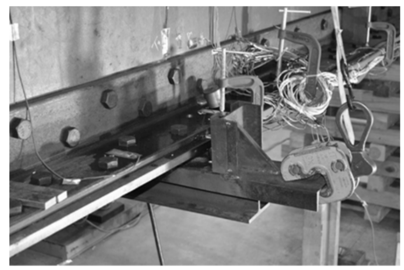
TPF-5(253): Fracture Tests

- Notch a component
  - Controlled location (angle/cover plate)
    - Not looking at initial fatigue life – already documented
  - Crack growth through fatigue to critical length (LEFM)
- Cool beam → ensured lower shelf behavior
  - Warmest was -60F….some as cold as -120F
  - Eliminates "but you had good steel" comment
- Apply load to induce a fracture
  - And then….nothing happened
  - Needed to drive a "wedge" into the crack!!



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NCHRP 12-87A: Research Program

- Research stems from FHWA 2012 Memo: SRM vs. FCM
- Develop advanced analysis methods (FEA) applicable to inventory:
  - Old and new, two-girder bridges to tied-arch bridges
  - Benchmarked with available data from actual FCM failures:
  - Neville Island Bridge, Hoan Bridge, etc.
- Load combinations for evaluation of redundancy:
  - Take into consideration that the bridge is in the faulted state
- Performance criteria in the faulted state
- Published as NCHRP Report 883

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Load Combos for Redundancy Evaluations

- Structures built to the FCP
  - $Redundancy\ I^{*}\ (1 + DA_R)(1.05\ DC + 1.05\ DW + 0.85\ LL)$
  - $Redundancy\ II^{**}\ \ 1.05\ DC + 1.05\ DW + 1.30\ (LL + IM^{***})$
- Structure not built to the FCP
  - $Redundancy\ I^{*}\ \ (1 + DA_R)(1.15\ DC + 1.25\ DW + 1.00\ LL)$
  - $Redundancy\ II^{**}\ \ 1.15\ DC + 1.25\ DW + 1.50\ (LL + IM^{***})$

* Applies to SRMs only ** Applies to SRMs and IRMs *** 15%

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IRM Guide Specification: Fundamentals (I)

- Existing members and new designs (riveted or bolted)
- Flexural and axial members
- Strength criteria to assess internal redundancy
- Fatigue criteria to determine inspection interval (not FCM inspection)
- Provisions “keep you in a box” in terms of:
  - General criteria
  - Member proportions AND condition
  - Must have remaining fatigue life in “unfaulted condition”
  - Faulted condition = one component failed

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IRM Guide Specification: Fundamentals (II)

- Not all members will meet provisions
- Passing member classification: Internally Redundant Member (IRM)
- Easy application based on P/A, Mc/I type calculations
  - Stress amplification
  - Or addition of secondary moments
- Determine interval for “Special Inspection of IRMs”
  - Objective to identify broken components
  - Depth of Special Inspections determined by owner
- Routine safety inspections are not changed
- **<u>Not</u>** intended to be used to justify leaving a broken component in place for extended period

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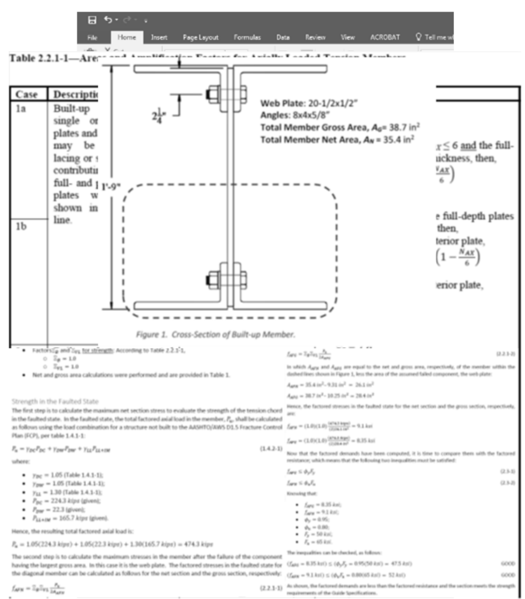
IRM Spec: Application

- Simple analysis methodology
  - P/A, Mc/I type of calculations
  - Spreadsheet might be all needed
- Specific provisions for different member types:
  - Flexural vs. axial
  - Multi- vs. two-component
  - Numerous illustrations
- Application examples



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IRM Spec: Impact on Inspection Intervals

- Case I members:

  Infinite unfaulted fatigue life
  - Ia: Infinite faulted fatigue life
  - Ib: Finite faulted fatigue life

    Calculate Y_{REM} in faulted state (N_f)

Calculated Remaining Minimum Fatigue Life N_f (Years)	Maximum Permitted Interval (Years)
$N_f < 20$	Larger of 2 years or $0.5N_f$*
$N_f \geq 20$	10

*The calculated inspection interval may be rounded up to the next even year interval.

- Case II members:

  Finite unfaulted fatigue life

  $N_f = Y_f(1.0 - N_u/Y_u)$

Calculated Remaining Minimum Fatigue Life N_f (Years)	Maximum Permitted Interval (Years)
$N_f \leq 5$	Smaller of 2 years or $0.5N_f$*
$5 < N_f < 20$	$0.5N_f$**
$N_f \geq 20$	10

*The calculated inspection interval may be rounded up to the next half-year interval.
**The calculated inspection interval may be rounded up to the next even year interval.

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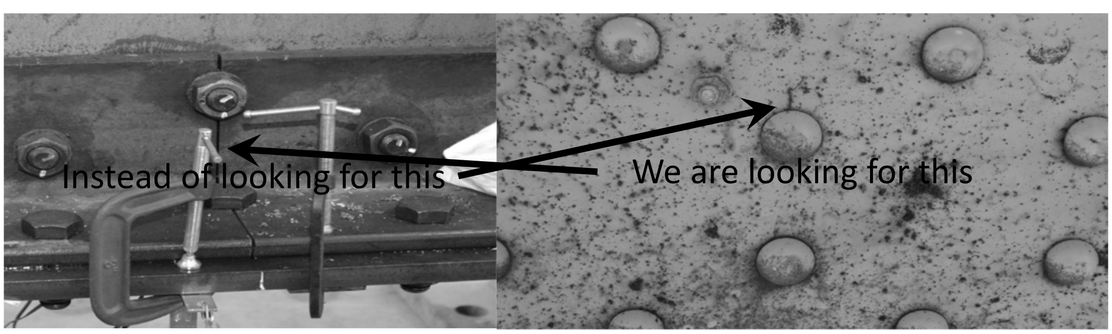
IRM Spec: The Real Major Advantage

- Inspection is targeting broken (cut, severed) components
  - No need to look for hairline minuscule crack = higher detection rates
  - Inspection effort on par with potential consequences



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SRM Guide Specification: Fundamentals

- Existing bridges and new designs
- Applies to the majority of the inventory:
  - Girder (I-, tub-, through-), truss, tied-arch
- Strength evaluation in the faulted state (two load combinations)
- If member is **SRM** there is **no need to perform any "special" inspection**
- Provisions "keep you in a box" in terms of:
  - General criteria
  - Bridge condition
  - Must not have details known to be problematic
  - Faulted condition = one member failed

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SRM Guide Specification: Application

- Analysis requires use of advanced FEA tool
  - Originally Abaqus, but other software packs are being evaluated
- Guidance for material models, meshing, analytical procedures, failure scenarios, interaction (contact) modeling, connections, etc.
  - Shear stud tensile behavior research
- Performance criteria in the faulted state tailored for FEA results
  - Ex: Effective slab width in composite section in faulted state?
- The application of the guide specification is complex but

WISCONSIN DOT GOT 20+ BRIDGES OF THE FCM INSPECTION LIST!!!

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Moving Forward

- Both Guide Specifications have been approved by AASHTO SCOBS
  - Supporting documents are available too
  - WisDOT has already utilized Guide Specs
- We can design/evaluate for fracture
  - Rational decisions supported on available data and analysis
  - There are no buckling critical members!
- Approaching an integral/unified approach to fracture
  - Better allocation of bridge owner's resources
  - Encourage good practices against fracture (HPS, built-up members, etc.)
  - Allow to focus on potential problems

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Redundancy is not New

- Two-winged aircraft are acceptable as failure RISK is low
  - Consequence high
  - Likelihood low
- Modern steel bridges?
  - Likelihood low (FCP)
  - Consequence low (IRM/SRM)

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S-BRITE

- Steel Bridge Research, Inspection, Training, and Engineering Center

S-BRITE TRAINING COURSES

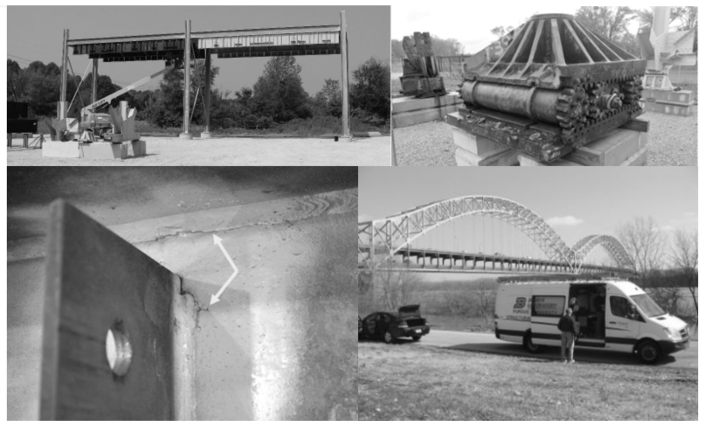
Bridge Inspection Certification for INDOT Fracture-Critical and Complex Bridge Inspection

REGISTER ONLINE

Course Offerings

Course Title	Course Date	Host Location	Comment
Design of Steel Bridges for Fatigue & Fracture	TBD		2-1/2 day course at Purdue or 2-day course out-of-state
High Strength Structural Bolting	TBD		1-1/2 day course at Purdue or 1-day course out-of-state
Implementing Effective Retrofits on Selected Steel Bridge Details	TBD	Purdue University	2 full day course Currently by invitation only
Inspecting Steel Bridges for Fatigue	October 15-16, 2018 Registration Open	Purdue Unviersity	1-1/2 day course at Purdue or 1-day course out-of-state
Welding in an Infrastructure System	TBD		1-day course

Participants of each course will receive breakfast, lunch, booklet of training materials, case studies, hands-on exercises, and CEU/PDH's for the course. Each course is designed around experience-based learning, taking advantage of the expansive S-BRITE Center Bridge Component Gallery and the Purdue University Bowen Laboratory resources to provide a comprehensive training experience.



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Questions?

Thank you very much!

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