RECENT NBIS CHANGES RELATED TO STEEL TENSION MEMBERS

2023 Bridge Inspection Workshop

February 23, 2023
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NSTMs, SRMs, IRMs !!!

….OH MY

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RECENT UPDATES TO THE NBIS

- In June 2022 the NBIS was updated to reflect the results of recent research on the concepts of FCMs
  - Specifically: Title 23 Code of Federal Regulations (CFR) Part 650.305 Subpart C, National Bridge Inspection Standards

- The term FCM is no longer recognized in the NBIS
  - Replaced with a new term, and new terms added
    - Nonredundant Steel Tension Member (NSTM)
    - System Redundant Member (SRM)
    - Internally Redundant Member (IRM)
  - What are all these new classifications and what does this mean for inspection?

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RECENT UPDATES TO THE NBIS - NSTM

- "Nonredundant Steel Tension Member" (NSTM)

  "A primary steel member fully or partially in tension, and without load path redundancy, system redundancy or internal redundancy, whose failure may cause a portion of or the entire bridge to collapse."

- "Fracture Critical Member"

  "A steel primary member or portion thereof subject to tension whose failure would probably cause a portion of or the entire bridge to collapse."

- The take away?
  - *NSTM = FCM for all practical purposes regarding inspection*

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RECENT UPDATES TO THE NBIS - SRM

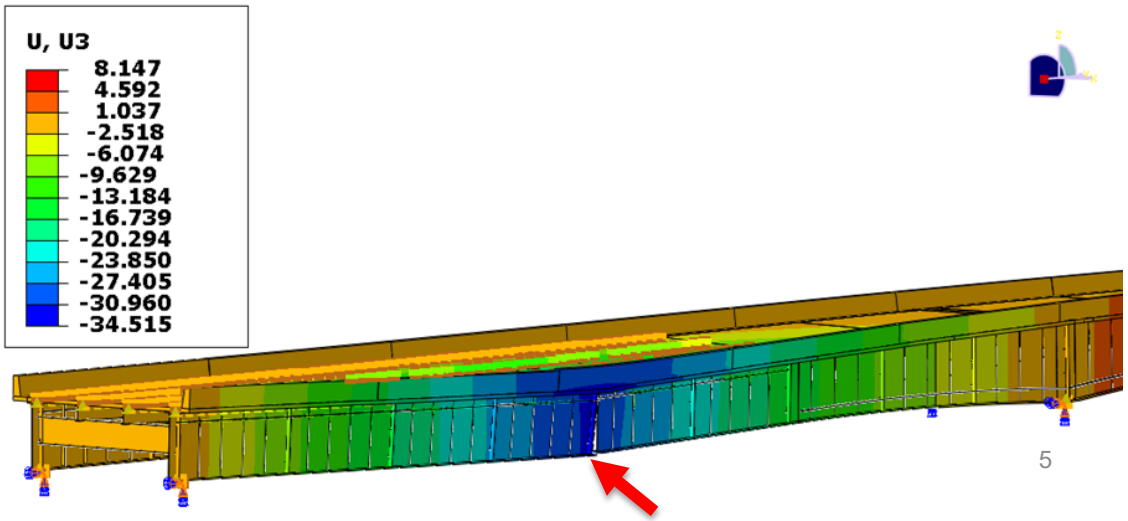
- "System Redundancy / System Redundant Member" (SRM)

  "A redundancy that exists in a bridge system without load path redundancy, such that fracture of the cross section at one location of a primary member will not cause a portion of or all of the bridge to collapse."

- The take away?
  - If an SRM fractures, collapse will not occur
    - e.g. FEA analysis of two-girder bridge that shows minimal damage in faulted state
  - Arms-length inspection is

    not required as small

    cracks don't matter



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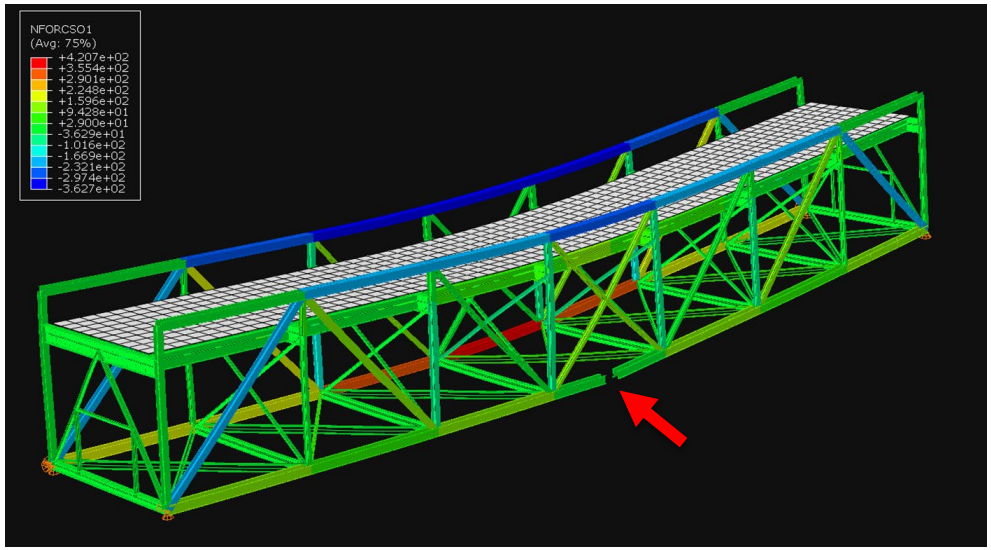
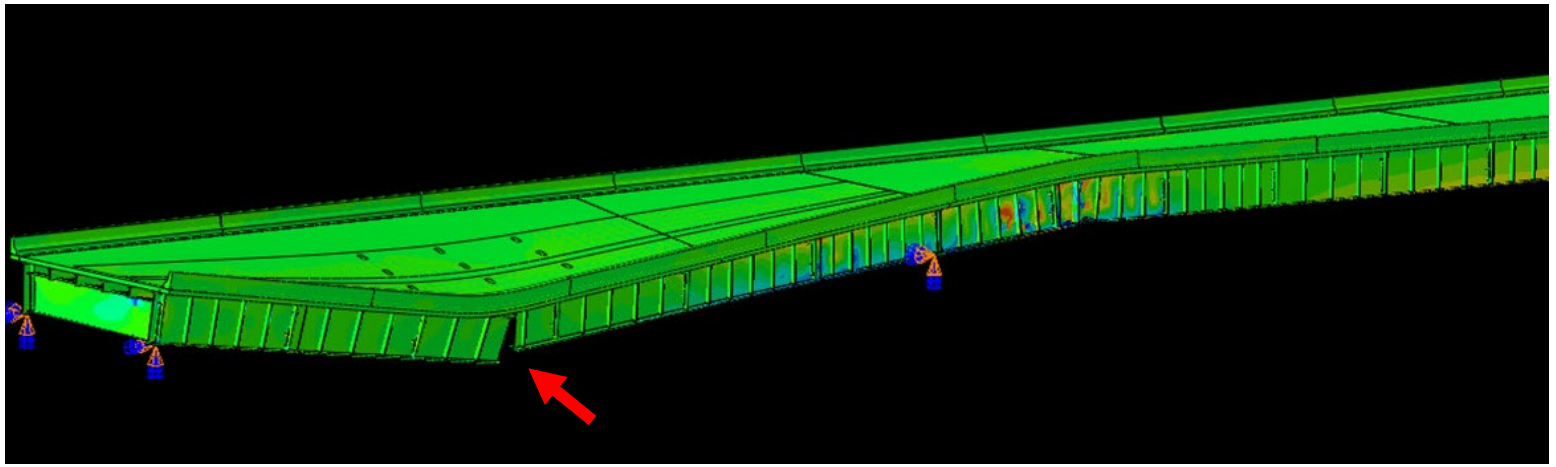
RECENT UPDATES TO THE NBIS - SRM



TYPICAL SRM FINITE ELEMENT ANALYSIS



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RECENT UPDATES TO THE NBIS - IRM

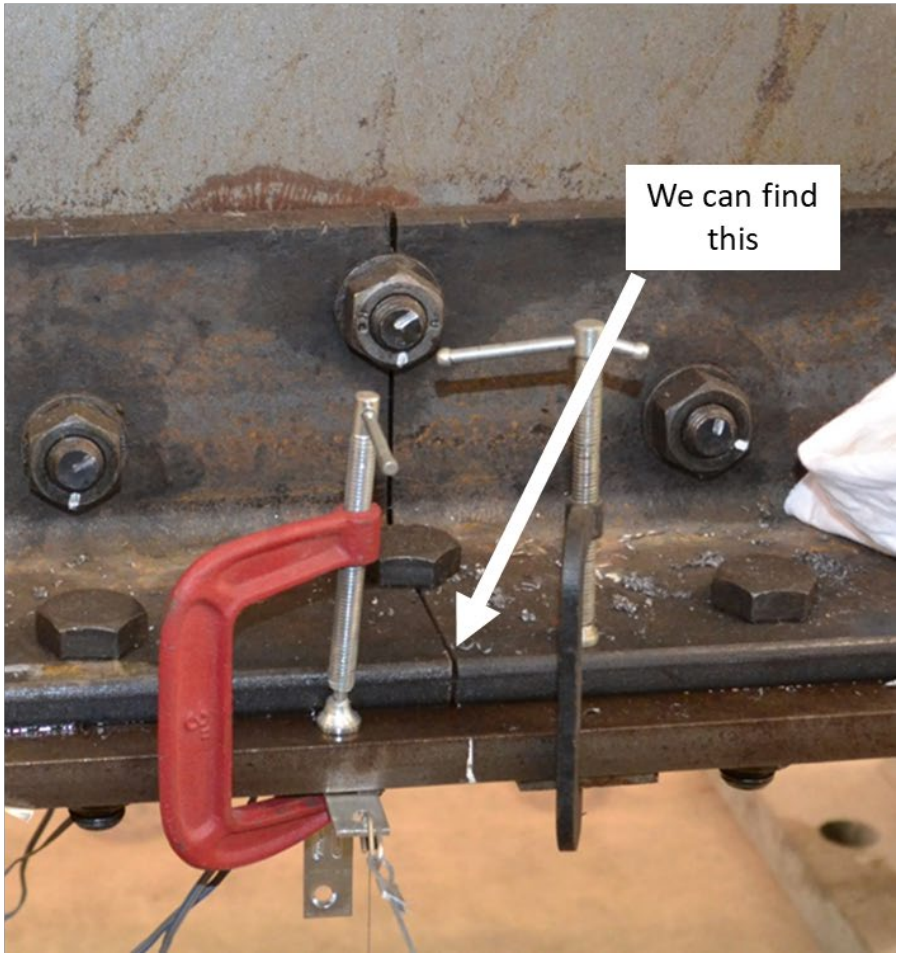
- "Internal Redundancy / Internally Redundant Member" (IRM)

  A redundancy that exists within a primary member cross-section without load path redundancy, such that fracture of one component will not propagate through the entire member, is discoverable by the applicable inspection procedures, and will not cause a portion of or the entire bridge to collapse.

- The take away?
  - If a **component** of an IRM fractures, complete member failure will not occur
    - e.g. fracture of one CP of a riveted member will not result in member failure
  - Arms-length inspection is not required as small cracks don't matter

RECENT UPDATES TO THE NBIS - IRM

"Internal Redundancy / Internally Redundant Member" (IRM)



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INSPECTION PLAN/MANAGEMENT

- Long-term inspection planning and management can and will differ depending on member designation
- Must have a specific written plan for each member type
  - NSTM
  - SRM
  - IRM
- Recommended/required strategies for each of the above member designations will follow

INSPECTION PLAN/MANAGEMENT - NSTM

- NSTMs are effectively viewed the same as the former FCM
- Things that are the same:
  - NSTMs must be identified on the inspection plans
    - Note, FCM = NSTM, so if you see FCM on older design plans, treat them like an NSTM unless told otherwise (i.e., unless they were reclassified as an SRM or IRM)
    - Per the CFRs "NSTM Inspection" is defined as:
      - "NSTM inspection. A hands-on inspection of a nonredundant steel tension member."
    - Note that this infers that all surfaces must be inspected
      - i.e., both sides of a plate girder web
      - Inside and outside of box members (like tie girders)
    - Inspectors must have successfully "passed" NSTM training course
    - Procedures regarding critical findings must be followed:
      - Per NBIS requirements (covered in 2 week course)
      - Additional local agency requirements

INSPECTION PLAN/MANAGEMENT - NSTM

- Things that are different:
  - NSTMs may be inspected at intervals up to 48 months
    - This is optional (i.e., an owners is *not required* to go to 48 months)
    - Interval is set based on of two "methods" utilized
  - Method 1 – For NSTM inspection at intervals ≤24 months
    - "Agencies are required to develop and document a policy based on factors such as structure type, design, materials, age, condition, environment, annual average daily traffic and annual average daily truck traffic, history of vehicle impact damage, loads and safe load capacity, and other known deficiencies."
    - Intervals may be as short as 12 months based separate FHWA criteria
      - To be discussed

INSPECTION PLAN/MANAGEMENT - NSTM

- Method 1 - ≤48 months provided FHWA defined criteria are met:
  - Year Built (Item B.W.01) ≥ 1979 [Year Built (Item 27) ≥ 1979] and fabricated in accordance with a fracture control plan.
    - Reason: Recognition of the reduced likelihood of fracture provided by the FCP
  - NSTMs have no fatigue details with finite life, history of fatigue cracks, nor pin and hanger assemblies.
    - Reasons:
      - Recognition of the very low probability of cracking due to primary stresses in bridges with infinite life.
      - A bridge with a calculated infinite fatigue life could have cracking due to out-of-plane distortion (*which is not calculated*) and hence, a "history of cracking" of any kind is not acceptable.
      - Obvious concerns with pin/hanger criticality and consequence of failure
  - NSTM Inspection Condition (Item B.C.14) ≥ 6 [Superstructure Condition Rating (Item 59) ≥ 6, and Substructure Condition Rating (Item 60) ≥ 6, and Critical Feature Inspection, Fracture Critical Details (Item 92A) = Y24]
    - Reason: Overall "good" condition of the bridge is viewed as a positive characteristic

INSPECTION PLAN/MANAGEMENT - NSTM

- Method 1 - ≤48 months provided FHWA defined criteria are met:
  - Inventory Load Rating Factor (Item B.LR.05) ≥ 1.0 [Inventory Rating (Item 66) ≥ 1.0, when expressed as a rating factor].
    - Reason: Rating factors greater than 1.0 effectively mean the bridge is capable of carrying design loads without concerns associated with overstressing.
  - Routine Permit Loads (Item B.LR.08) = A or N.
    - Reason: A bridge that is capable of carrying routine permit loads, or does not carry routine permit loads is viewed as a positive characteristic

INSPECTION PLAN/MANAGEMENT - NSTM

- When the 48-month criteria are not met, maximum interval is 24 months

!!UNLESS!!

The NSTM Inspection Condition (Item B.C.14) ≤ 4

[Superstructure Condition Rating (Item 59)

OR

Substructure Condition Rating (Item 60) ≤ 4

AND

Critical Feature Inspection, Fracture Critical Details

(Item 92A) ≤ Y12],

Means bridge is already on 12 month or less interval

THEN

The inspection interval shall be ≤ 12 months.

INSPECTION PLAN/MANAGEMENT - NSTM

- Method 2 - ≤48 months
- Agency must develop its own risk-based methodology
  - Method 1 criteria need not apply
- Resulting intervals may be 12, 24, or 48 months
  - Shorter frequencies are acceptable
- What is an "accepted method"
  - We suggest reviewing a method developed through an FHWA project at Purdue University

Parr M.J., Connor R.J. Bowman M., "A Method for Determining the Interval for Hands-on Inspection of Steel Bridges with Fracture Critical Members", Journal of Bridge Engineering, American Society of Civil Engineers, Vol. 15, No. 4, July/August 2010, pp. 352-363

Or

"A Method for Determining the Interval for Hands-on Inspection of Steel Bridges with Fracture Critical Members - Final Project Report, R.J. Connor, M. J. Parr, Submitted to Federal Highway Administration, (FHWA), Washington, DC, November 2008 – (Available upon request)

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INSPECTION PLAN/MANAGEMENT – SRM

- SRM – System Redundant Member
- **Definition:**

A primary steel member in tension, or with a tension element, that is without load path redundancy but has redundancy in the bridge system, such that fracture of the cross-section at one location of the member will not cause a portion of or the entire bridge to collapse. (AASHTO SRM Guide Spec. 2022)

- In other words, it has been shown that if the entire member were to fail, the bridge would not be expected to collapse
  - The take away? It is not an NSTM (or FCM)
- Therefore, it may be treated as a redundant member and is not required to receive hands-on in-service inspections
  - Prior to implementation, a detailed NSTM inspection is required for a baseline data
- However, changes to the bridge or the condition of specific members could warrant a reclassification to NSTM over time
  - Owners must develop evaluation criteria for when members should be reviewed to ensure they still qualify to classified as an SRM
  - e.g., severe section loss, impact damage, repair/retrofitting, appearance of fatigue cracks, etc.

INSPECTION PLAN/MANAGEMENT – SRM

- SRMs must be identified on the design plans for new bridges
  - This is required for fabrication and long-term inspection management
- For existing bridges SRMs should also be documented and identified for development of inspection plan
  - This would require relabeling a member as an SRM that was formerly and NSTM or FCM
- The inspection must be capable of reliably identifying damage in the SRMs similar to what is required for load path redundant member (LPRM)
  - May require a Special Inspection be performed at some interval, established by the owner, to access some locations
  - There is no required interval or maximum interval for such inspections
- Important to recognize that a single bridge may contain LPRMs, NSTMs, SRMs, and IRMs with each requiring specific inspection strategies

INSPECTION PLAN/MANAGEMENT – IRM

- IRM – Internally Redundant Member
- **Definition:**

A primary built-up steel member in tension, or with a tension element, that has redundancy within the cross-section, such that fracture of one element will notpropagate through the entire member. (AASHTO IRM Guide Spec. 2022)

- In other words, it has been shown that if an individual component of the member were to fail, the entire member would not be expected to fail
  - The take away? It is not an NSTM (or FCM)

INSPECTION PLAN/MANAGEMENT – IRM

- Therefore, it may be treated as a redundant member with the inspection scope and interval as determined in the AASHTO IRM Guide Specifications
  - Prior to implementation, a detailed NSTM inspection is required for a baseline
- However, changes to the bridge or the condition of specific members could warrant a reclassification to NSTM over time
  - Owners must develop evaluation criteria for when members should be reviewed to ensure they still qualify to classified as an IRM and to ensure the required interval has not changed
  - e.g., severe section loss, reduction in remaining fatigue life, impact damage, repair/retrofitting, appearance of fatigue cracks, etc.

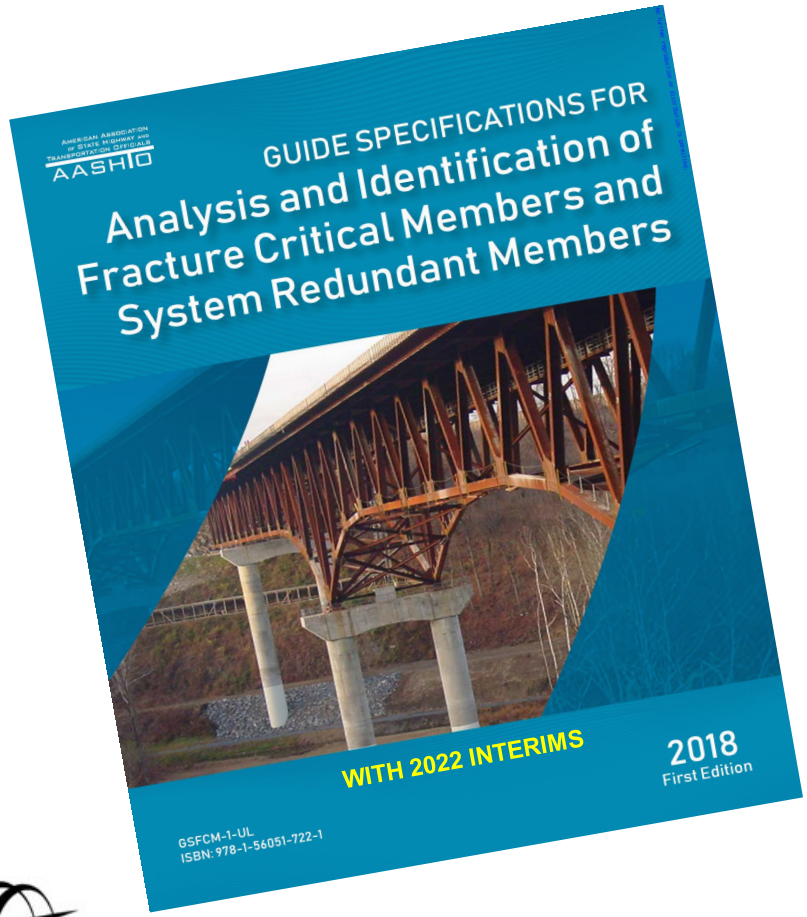
INSPECTION PLAN/MANAGEMENT – IRM

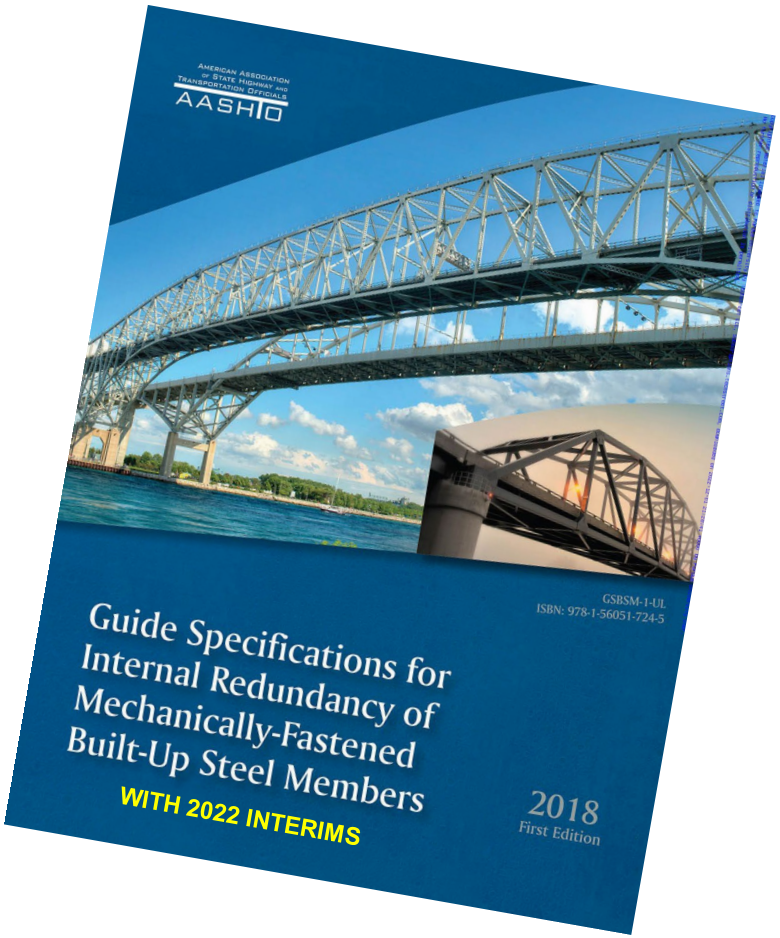
- IRMs must be identified on the design plans for new bridges
  - This is required for fabrication and long-term inspection management
- For existing bridges IRMs should also be documented and identified for development of the inspection plan
  - This would require relabeling a member as an IRM that was formerly and NSTM or FCM
- The inspection must be capable of reliably identifying damage in the IRMs
  - This requires implementation of Special Inspections as defined below

"….an inspection of sufficient depth to reliably detect severed or fractured components and other conditions deemed important in a member identified as an IRM. To meet the objectives of the Special Inspection for IRMs, it is understood that special access equipment may be required for some bridges, while for others it may be possible to reliably detect broken components from the ground using normal visual inspection techniques.

- Important to recognize that a single bridge may contain LPRMs, NSTMs, SRMs, and IRMs with each requiring specific inspection strategies

WHAT ARE ACCEPTABLE METHODS TO CLASSIFY A MEMBER AS AN SRM OR IRM?





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QUESTIONS ?

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IMPLEMENTATION OF AASHTO GUIDE SPECIFICATIONS

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SPR 4631 - Evaluation of the Potential Benefits of Implementing the AASHTO Guide Specifications for the Analysis and Identification of Fracture Critical Members and System Redundant Members

Project conducting an exploratory study for a few of the bridges in the state of Indiana where both the IRM and SRM Guide Specifications are evaluated for implementation on a set of bridges within the state of Indiana.

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US 41 White River Bridge

- US 41 over White River in Gibson County
- 16-span, Steel Two-Girder Twin Bridges
- Built in 1958,
- ADT (2021): 11,322; Truck Percentage: 26%
- Has pin and hanger
- Field instrumented as part of SPR-3472, in July 2011
  - Evaluation of Effects of Super-Heavy Loading on the US-41

US 41 White River Bridge

- IRM Evaluation Critical Steps
  1. General requirements (screening criteria) [Sections 1.4 and 1.5]
  2. Strength capacity in the faulted state check [Sections 2.1 and 2.3]
     a) Fracture on the net section
     b) Yielding on the gross section
  3. Fatigue life estimates [Section 2.5]
     a) Unfaulted State
     b) Faulted State
     c) Total Remaining Fatigue Life
  4. Maximum Interval for Special Inspections [Section 3]

Summary of Results

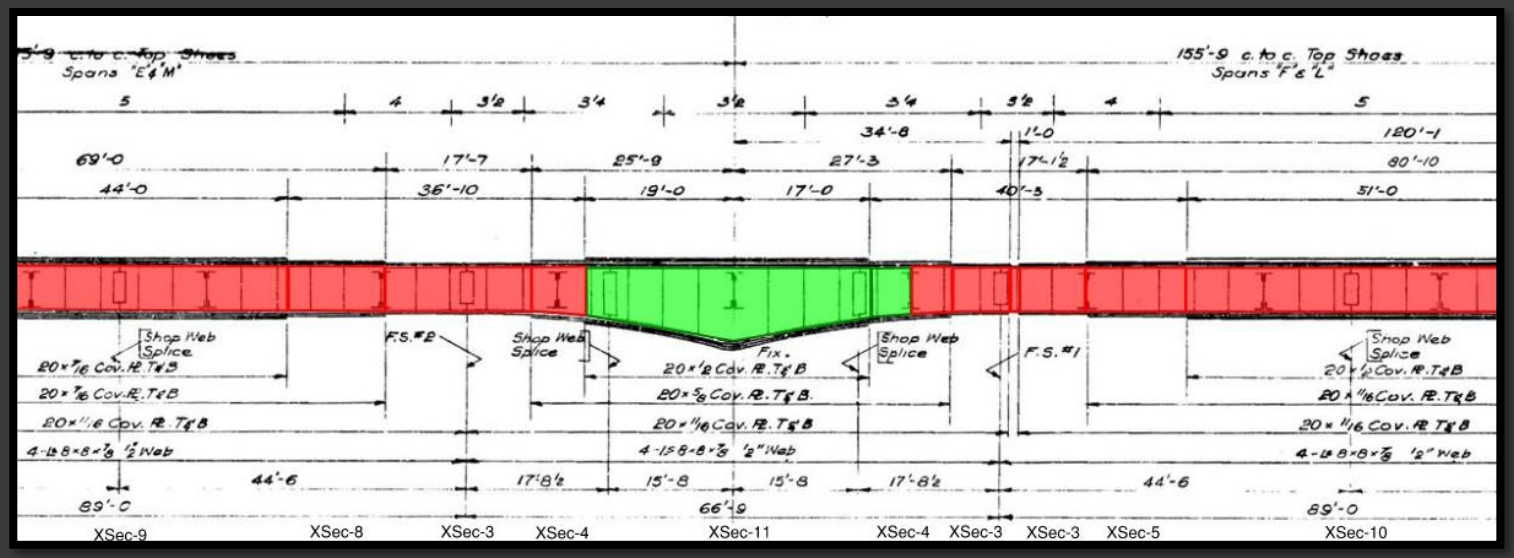
Strength check =	OK	OK or NG	GS 2.1 & 2.3
Fatigue case =	II	I(a), I(b), II	GS 2.5
Stress range in unfaulted state, Δf_{UFS} =	3.64	ksi	
Controlling stress range in faulted state, Δf_{FS} =	5.86	ksi	
Controlling faulted state remaining fatigue life, Y_{REM}	**30.6**	Years	
Total remaining fatigue life, N_f	**8.3**	Years	GS Eq. 2.5.3-1
Maximum Interval for Special Inspections =	**6.0**	Years	GS 3

US 41 White River Bridge

- Areas not passing screening criteria for IRM (% of girder length):
  - Lack of cover plates
    20 locations per girder (~3%)
  - Pin and hanger - 4 locations per girder (~0.5%)

US 41 White River Bridge

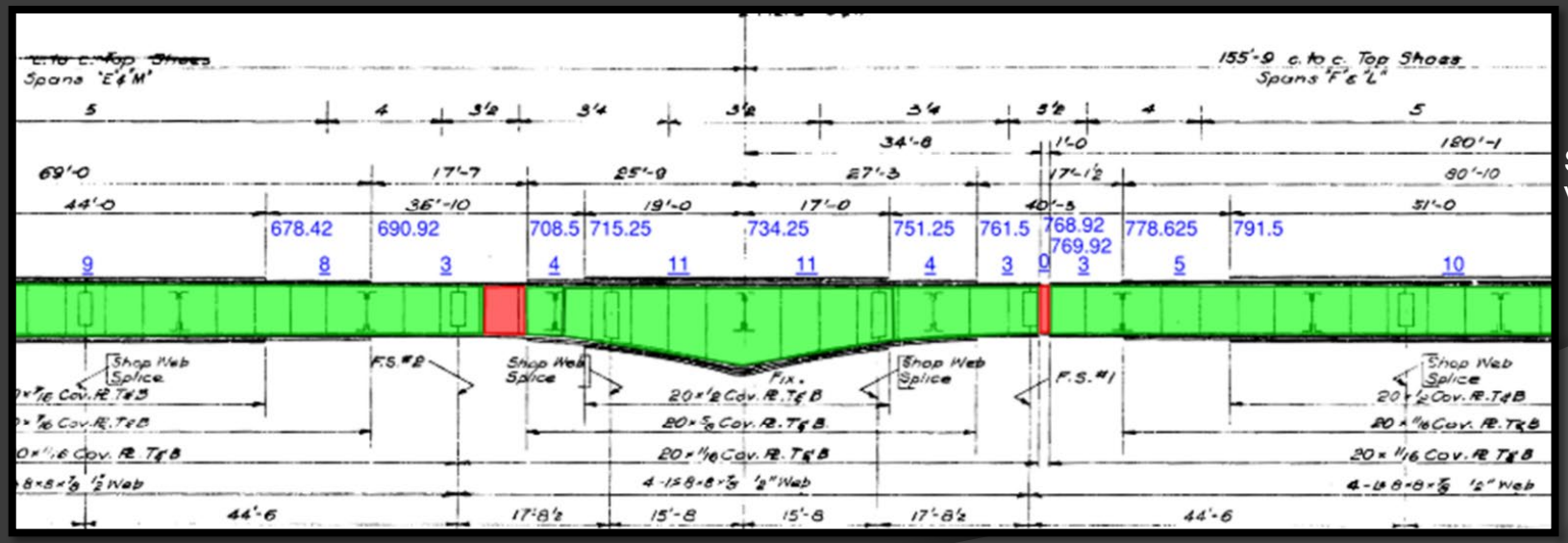
- Using fatigue truck loads, majority members were IRMs, but no real benefit in terms of inspection due to low remaining fatigue life in faulted state



- However, 2012 Long Term Monitoring Data:
  - Lower effective stresses (~45% Max)
  - Lower total cycles per day (~66% Max)
  - Composite action

US 41 White River Bridge

- Using measured stress ranges and cycles; nearly 94% of the main girders of the bridge are eligible for “Special Inspections” at a frequency of 10 years
- Evaluation and report completed including inspection plan
- INDOT Submission to FHWA for approval in progress



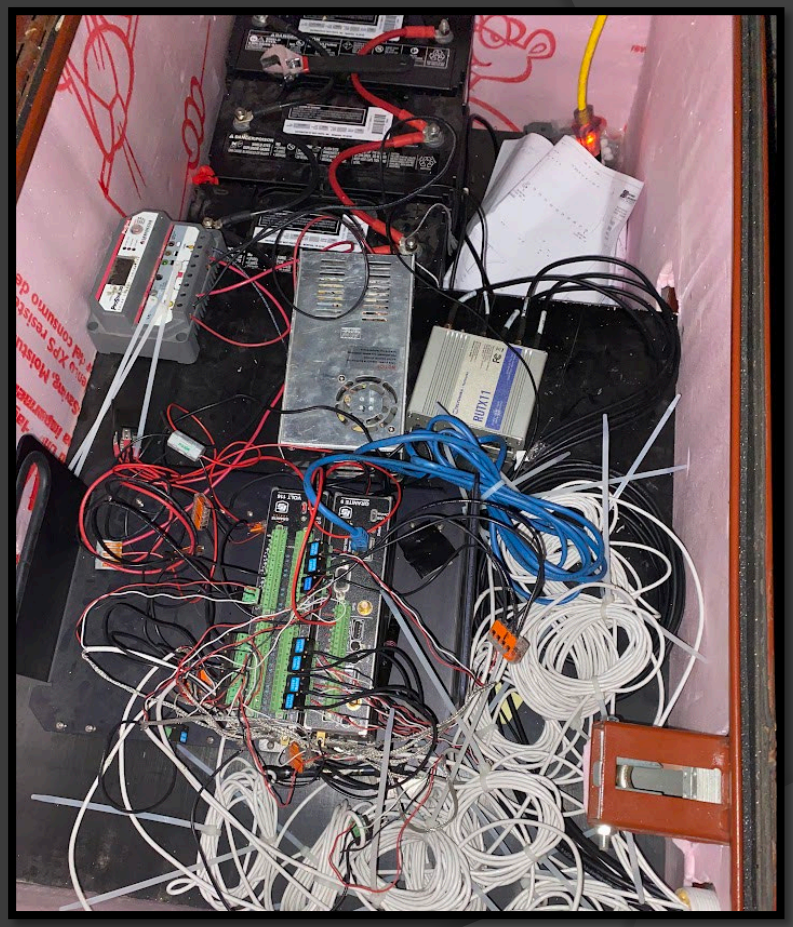
Sample Elevation View Results

I74 Bridge over Wabash River

- I-74 over Wabash River in Vermillion County
- Twin bridges with 5 main spans with 12 approach spans
- Built-up two-girder system with “added” girder
- Built in 1958
- ADT: 17,156: Truck Percentage: 59%

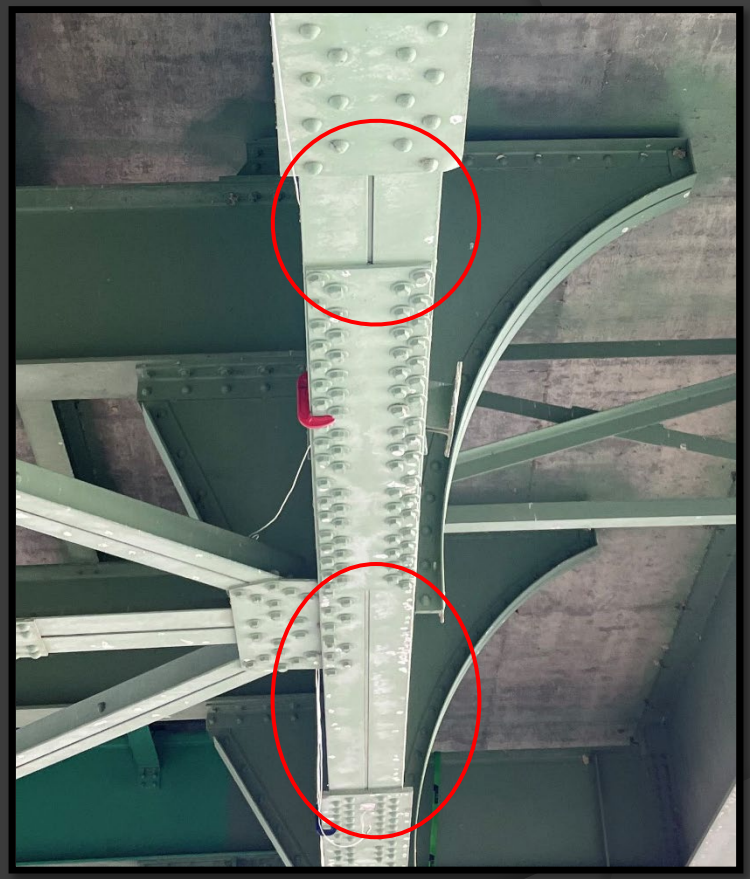
I74 Bridge over Wabash River

- Similar to US-41 White River Bridge, found that fatigue life was an issue that limited implementation benefits
- Based on US-41 observations, decided to instrument the bridge and collect in-service stress range
  - Completed in Jan 2023



I74 Bridge over Wabash River

- Preliminary indications:
  - Lower effective stresses (Less than 50% of stresses due to Fatigue Truck)
  - Lower total cycles per day
- Suggesting 10-year frequency for Special Inspection for about 75% of bridge length
- “Failing” areas do not pass screening criteria due to lack of any cover plates



Min Stress Range: 1.5

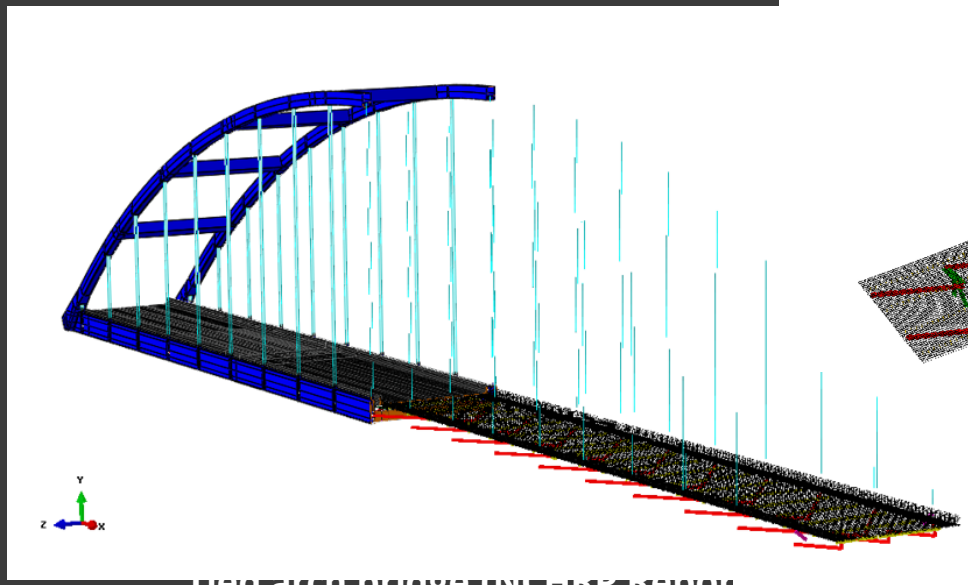
Average Stress Range	SG 1		SG 2		SG 6		SG 7	
Distance from Pier 7	56.95		56.95		163.67		163.67	
Descriptor	Lowest Expected Fatigue Life				Max Positive Moment Region			
Xsec Type	XSec-1		XSec-1		XSec-2		XSec-2	
Shear Studs	No		No		Yes		Yes	
	Bot Flange		Bot Flange		Bot Flange		Bot Flange	
Girder	Left Girder		Right Girder		Left Girder		Right Girder	
0.375	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
0.75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1.75	25702	137746.6563	13937	74693.60938	8723	46749.82813	25523	136787.3281
2.25	2127	24227.85938	27687	315372.2344	2406	27405.84375	1224	13942.125
2.75	1982	41219.40625	2709	56338.73438	906	18841.96875	181	3764.234375
3.25	559	19189.42188	393	13490.95313	320	10985	12	411.9375
3.75	231	12181.64063	94	4957.03125	75	3955.078125	0	0
4.25	73	5603.890625	18	1381.78125	6	460.59375	1	76.765625
4.75	3	321.515625	1	107.171875	4	428.6875	0	0
5.25	2	289.40625	1	144.703125	0	0	0	0
5.75	2	380.21875	0	0	1	190.109375	0	0
6.25								
6.75								
7.25								
7.75								
8.25								
8.75								
	30681	241160.0156	44840	466486.2188	12441	109017.1094	26941	154982.3906
		Effective Stress		Effective Stress		Effective Stress		Effective Stress
	7.86	1.99	10.40	2.18	8.76	2.06	5.75	1.79
BrR Effective Stress (Unfaulted)		6.15		6.15		5.29		5.29
Ratio		**0.324**		**0.355**		**0.390**		**0.339**
Cycles per day		1126.5		1638.0		540.6		1115.4

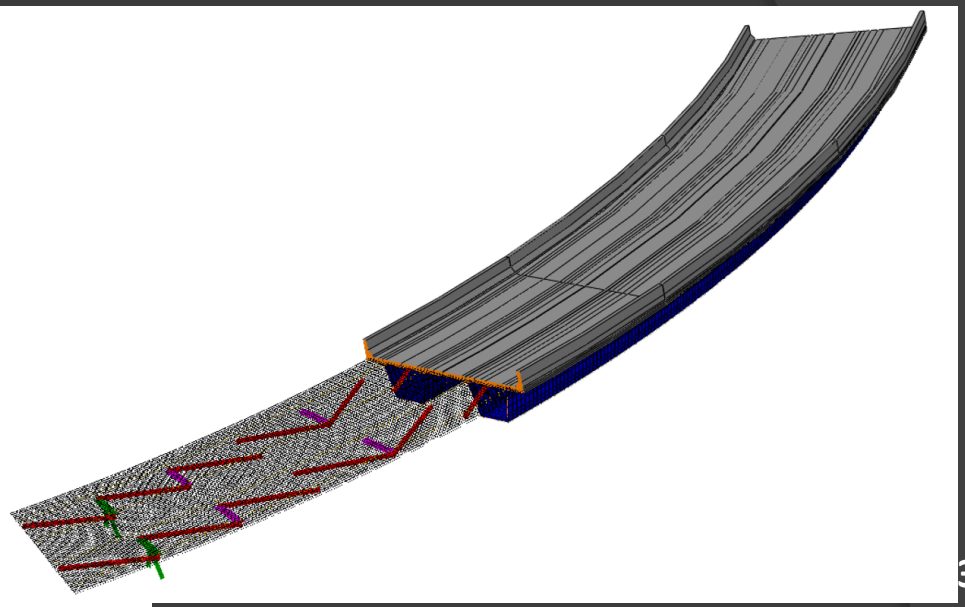
Observations – IRM Guide Spec. Implementation

- NSBA IRM spreadsheets – a good tool to evaluate specific X-sections
  - However, implementing on long girders a bit tedious due to many moment checks and X-section changes
  - We prepared macros and scripts to automate the process directly obtaining data from BrR
  - Ideally, this should implemented into BrR by AASHTO for full automation
- While members in older bridges may be IRMs, fatigue may limit inspection intervals when life based on calculation
  - Simple targeted field instrumentation has big payoff however
- Currently Evaluating some riveted trusses as part of project. Stay tuned for these results!

SPR-4631 SRM – Efforts

SRMs Examples





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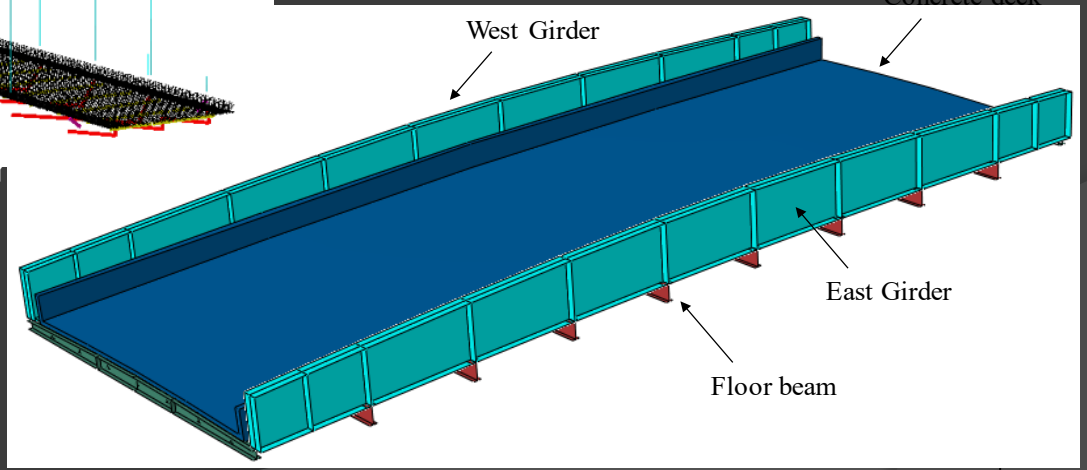

Through Girder Bridge (NCHRP Report 883)

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Summary

- Many recent positive changes to the NBI
- Finally addressing the concept of redundancy in steel tension members in a rational way
  - Based on over a decade of research and decades of performance
- New AASHTO Guide Specifications allow the development of rational inspection strategies for new and existing steel bridges where redundancy is of concern