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RISK ASSESSMENT, WHAT SAY YOU?

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REDUNDANCY

DAKOTAS STEEL BRIDGE FORUM
2025

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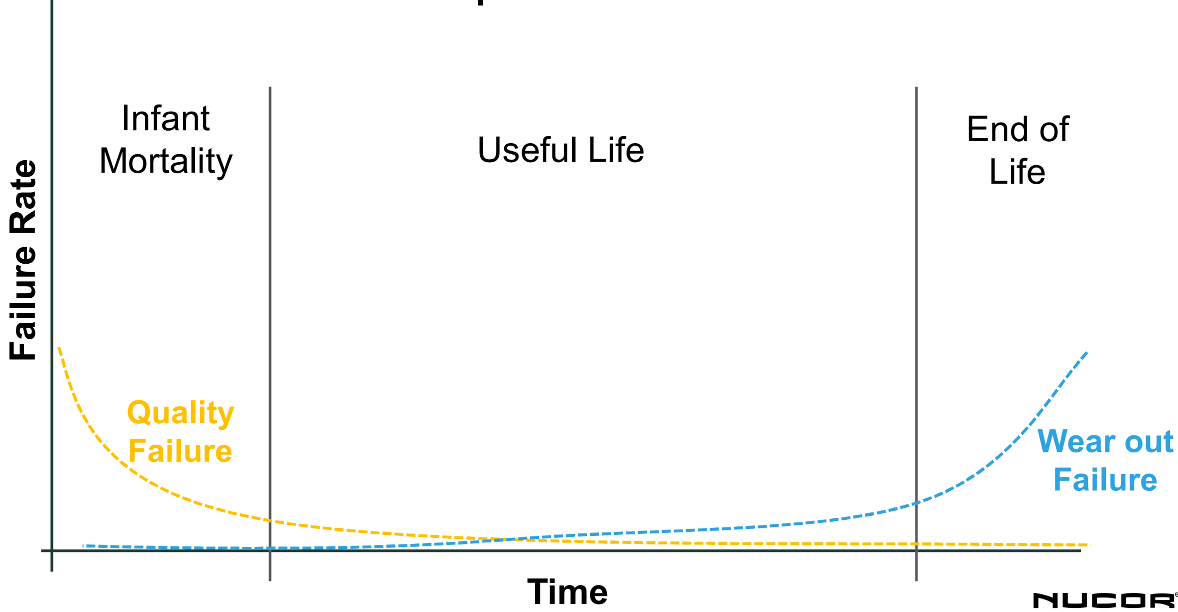
BATHTUB CURVE | RISK-BASED INSPECTION



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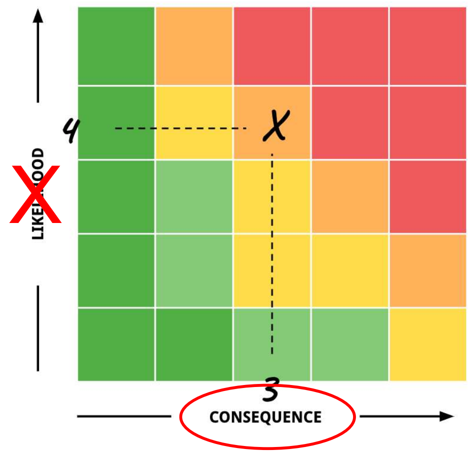
RISK ANALYSIS…
A MATTER OF LIKELIHOOD AND CONSEQUENCE



Risk: Exposure to the possibility of structural safety or serviceability loss during the interval between inspections. It is the combination of the **probability** of the event and its **consequence**. – (23 CFR 650.305)

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MILTON-MADISON BRIDGE
Continuous Truss – Built 1929, Replaced in 2014

Diggelmann, L. M., Connor, R. J., & Sherman, R. J. (2013). *Evaluation of Member and Load Path Redundancy on the US-421 Bridge Over the Ohio River*. Washington DC, USA.

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- Sufficiency rating 33/100
- Superstructure condition rating = “Poor”,
- Bridge was load posted for about 3 - 4 tons

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Shaped Charges

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MILTON-MADISON BRIDGE OVER OHIO RIVER

- **First blast**: 0.13” total deflection
- **Second blast**: 0.39” total deflection

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REDUNDANT? OR NOT?

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BRIEF HISTORY LESSON

- **Before 1965** – No AASHTO specs for fatigue:
  - Modern fatigue design – after 1974
- **Before 1968** – No bridge inspections:
  - Point Pleasant Bridge (1967) – routine
  - Mianus River Bridge (1983) – hands-on (1987)
- **Before 1978** – No fracture control plan (FCP)
- **Before 1988** – No distinct bridge welding code:
  - Bridge welding code was consolidated with building welding code prior to 1988
- **Before 2000's** – No understanding of CIF

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FCM FRACTURES

Lafayette Bridge (1968, 1975)
Neville Island Bridge (1976, 1977)
Dan Ryan Rapid Transit Structure (1969, 1978)
Green River Bridge (1968, 1992)
Hoan Bridge (1972, 2000)
US 422 over Schuylkill River (1965, 2003)
Diefenbaker Bridge (1960, 2011)
Mathews Bridge (1953, 2013 barge impact)
Delaware River Turnpike Bridge (1954, 2017)
I-40 Hernando DeSoto Bridge (1973, 20?)

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That's 45 years of practice with zero known incidences of occurrence.

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STEEL BRIDGES - 1960s vs 2020s

1960s	2010s/2020s
Limited computer structural analysis	3D Non-linear finite element analysis
No explicit fatigue design provisions	Load & distortion fatigue problem solved
No special fabrication QA/QC	Fracture Control Plan per AASHTO/AWS
High-toughness materials not economically feasible	High-toughness steels readily available
No knowledge of constraint-induced fracture (CIF)	Designers avoid CIF details (SIMPLE!)
Limited shop inspection	Significant advances in NDT
No understanding of redundancy modes	Advanced understanding of system & internal redundancy

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NATIONAL BRIDGE INSPECTION STANDARDS (NBIS) 2022
(AND ASSOCIATED FHWA MAY 9TH MEMO)

New or Redefined Redundancy Terms:

- Internal Redundancy NEW
- Load Path Redundancy NEW
- System Redundancy NEW
- Nonredundant Steel Tension Member (NSTM) NEW
- NSTM Inspections NEW
- Risk-based Inspection Interval NEW
- ~~Fracture Critical Member~~ (removed)

PC: Ohio DOT (dot.state.oh.us)

Effective June 6, 2022, with 24-month implementation period ending June 6, 2024.

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Nonredundant steel tension member is the new term for fracture critical member. (i.e., NSTM = FCM)

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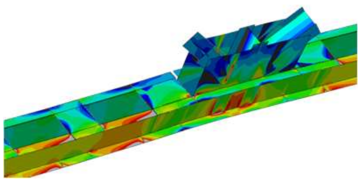
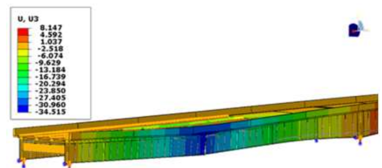
Internally Redundant Member (IRM)



System Redundant Member (SRM)



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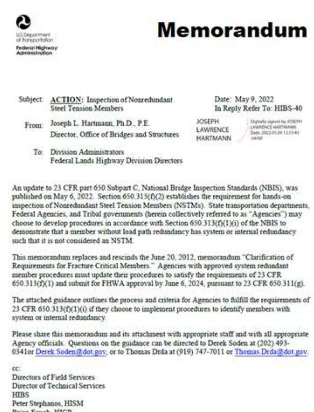
FHWA MEMO – MAY 6, 2022; 4(d):

"AGENCIES <u>MAY CHOOSE</u>…TO DEMONSTRATE THAT A MEMBER WITHOUT LOAD PATH REDUNDANCY HAS *SYSTEM* OR *INTERNAL* REDUNDANCY SUCH THAT IT IS NOT CONSIDERED AN NSTM." (23 CFR 650.313(f)(1)(i))


U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: **ACTION:** Inspection of Nonredundant Steel Tension Members
Date: May 9, 2022
In Reply Refer To: HIBS-40

From: Joseph L. Hartmann, Ph.D., P.E.
Director, Office of Bridges and Structures
JOSEPH LAWRENCE HARTMANN

To: Division Administrators
Federal Lands Highway Division Directors

An update to 23 CFR part 650 Subpart C, National Bridge Inspection Standards (NBIS), was published on May 6, 2022. Section 650.315(f)(2) establishes the requirement for hands-on inspection of Nonredundant Steel Tension Members (NSTMs). State transportation departments, Federal Agencies, and Tribal governments (herein collectively referred to as "Agencies") may choose to develop procedures in accordance with Section 650.313(f)(1)(i) of the NBIS to demonstrate that a member without load path redundancy has system or internal redundancy such that it is not considered an NSTM.

This memorandum replaces and rescinds the June 20, 2012, memorandum "Clarification of Requirements for Fracture Critical Members." Agencies with approved system redundant member procedures must update their procedures to satisfy the requirements of 23 CFR 650.313(f)(1) and submit for FHWA approval by June 6, 2024, pursuant to 23 CFR 650.311(g).

The attached guidance outlines the process and criteria for Agencies to fulfill the requirements of 23 CFR 650.313(f)(1)(i) if they choose to implement procedures to identify members with system or internal redundancy.

Please share this memorandum and its attachment with appropriate staff and with all appropriate Agency officials. Questions on the guidance can be directed to Derek Soden at (202) 493-0341or Derek.Soden@dot.gov, or to Thomas Drda at (919) 747-7011 or Thomas.Drda@dot.gov.

cc:
Directors of Field Services
Director of Technical Services
HIBS
Peter Stephanos, HISM
Brian Fouch, HICP

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U.S. Department of Transportation
Federal Highway Administration

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What is "load path redundancy"?

For the purposes of NSTM identification, FHWA considers bridges with three or more primary load-carrying members to be load path redundant. A determination of system or internal redundancy is not required for load path redundant members.

What is in Section 650.313(f)(1)(i)?

(i) A State transportation department, Federal agency, or Tribal government may choose to demonstrate a member has system or internal redundancy such that it is not considered an NSTM. The entity may develop and submit a formal request for FHWA approval of procedures using a nationally recognized method to determine that a member has system or internal redundancy. FHWA will review the procedures for approval based upon conformance with the nationally recognized method.

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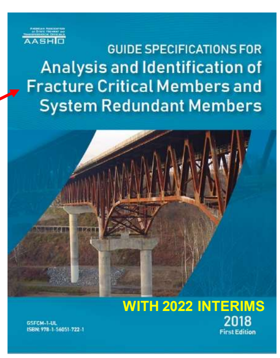
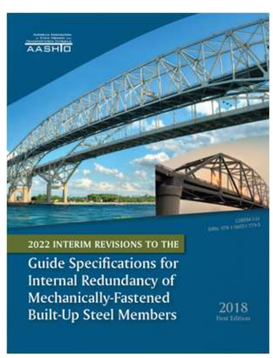
FROM MAY 2022 MEMO:

FHWA considers the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members* and AASHTO *Guide Specification for Internal Redundancy of Mechanically-Fastened Built-Up Steel Members* to be nationally recognized methods to determine that a steel member has system or internal redundancy (23 CFR 650.313(f)(1)(i)(B)).

Title Change Coming!





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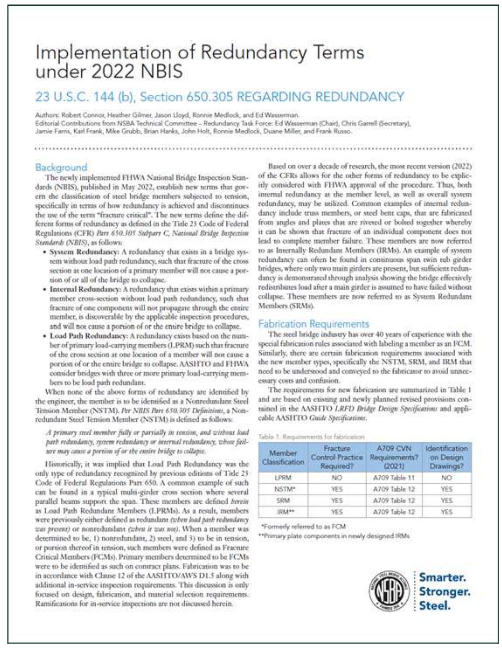
WHITEPAPER…

NSTM / SRM / IRM RECOMMENDATIONS FOR FABRICATORS & DESIGNERS



Implementation of Redundancy Terms under 2022 NBIS

23 U.S.C. 144 (b), Section 650.305 REGARDING REDUNDANCY

Authors: Robert Connor, Heather Gilmer, Jason Lloyd, Ronnie Medlock, and Ed Wasserman.
Editorial Contributions from NSBA Technical Committee – Redundancy Task Force: Ed Wasserman (Chair), Chris Garrell (Secretary), Jamie Farris, Karl Frank, Mike Grubb, Brian Hanks, John Holt, Ronnie Medlock, Duane Miller, and Frank Russo.

Background

The newly implemented FHWA National Bridge Inspection Standards (NBIS), published in May 2022, establish new terms that govern the classification of steel bridge members subjected to tension, specifically in terms of how redundancy is achieved and discontinues the use of the term "fracture critical". The new terms define the different forms of redundancy as defined in the Title 23 Code of Federal Regulations (CFR) *Part 650.305 Subpart C, National Bridge Inspection Standards (NBIS)*, as follows:

- **System Redundancy:** 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.
- **Internal Redundancy:** 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.
- **Load Path Redundancy:** A redundancy exists based on the number of primary load-carrying members (LPRM) such that fracture of the cross section at one location of a member will not cause a portion of or the entire bridge to collapse. AASHTO and FHWA consider bridges with three or more primary load-carrying members to be load path redundant.

When none of the above forms of redundancy are identified by the engineer, the member is to be identified as a Nonredundant Steel Tension Member (NSTM). *Per NBIS Part 650.305 Definitions*, a Nonredundant Steel Tension Member (NSTM) is defined as follows:

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.

Historically, it was implied that Load Path Redundancy was the only type of redundancy recognized by previous editions of Title 23 Code of Federal Regulations Part 650. A common example of such can be found in a typical multi-girder cross section where several parallel beams support the span. These members are defined *herein* as Load Path Redundant Members (LPRMs). As a result, members were previously either defined as redundant *(when load path redundancy was present)* or nonredundant *(when it was not)*. When a member was determined to be, 1) nonredundant, 2) steel, and 3) to be in tension, or portion thereof in tension, such members were defined as Fracture Critical Members (FCMs). Primary members determined to be FCMs were to be identified as such on contract plans. Fabrication was to be in accordance with Clause 12 of the AASHTO/AWS D1.5 along with additional in-service inspection requirements. This discussion is only focused on design, fabrication, and material selection requirements. Ramifications for in-service inspections are not discussed herein.

Based on over a decade of research, the most recent version (2022) of the CFRs allows for the other forms of redundancy to be explicitly considered with FHWA approval of the procedure. Thus, both internal redundancy at the member level, as well as overall system redundancy, may be utilized. Common examples of internal redundancy include truss members, or steel bent caps, that are fabricated from angles and plates that are riveted or bolted together whereby it can be shown that fracture of an individual component does not lead to complete member failure. These members are now referred to as Internally Redundant Members (IRMs). An example of system redundancy can often be found in continuous span twin tub girder bridges, where only two main girders are present, but sufficient redundancy is demonstrated through analysis showing the bridge effectively redistributes load after a main girder is assumed to have failed without collapse. These members are now referred to as System Redundant Members (SRMs).

Fabrication Requirements

The steel bridge industry has over 40 years of experience with the special fabrication rules associated with labeling a member as an FCM. Similarly, there are certain fabrication requirements associated with the new member types, specifically the NSTM, SRM, and IRM that need to be understood and conveyed to the fabricator to avoid unnecessary costs and confusion.

The requirements for new fabrication are summarized in Table 1 and are based on existing and newly planned revised provisions contained in the AASHTO *LRFD Bridge Design Specifications* and applicable AASHTO *Guide Specifications*.

Table 1. Requirements for fabrication

Member Classification	Fracture Control Practice Required?	A709 CVN Requirements? (2021)	Identification on Design Drawings?
LPRM	NO	A709 Table 11	NO
NSTM*	YES	A709 Table 12	YES
SRM	YES	A709 Table 12	YES
IRM**	YES	A709 Table 12	YES

*Formerly referred to as FCM
**Primary plate components in newly designed IRMs

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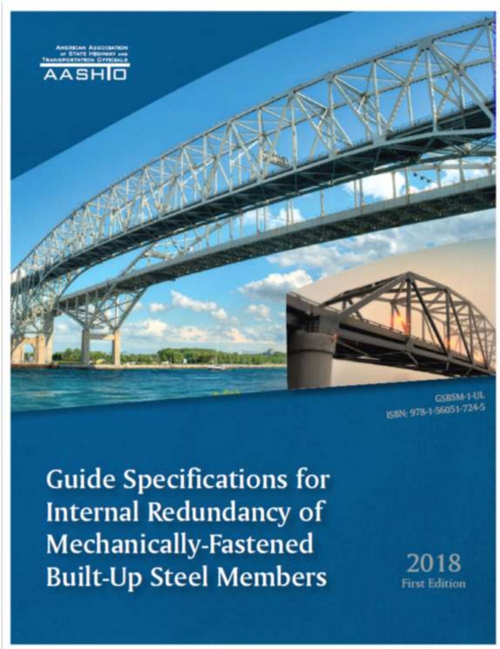

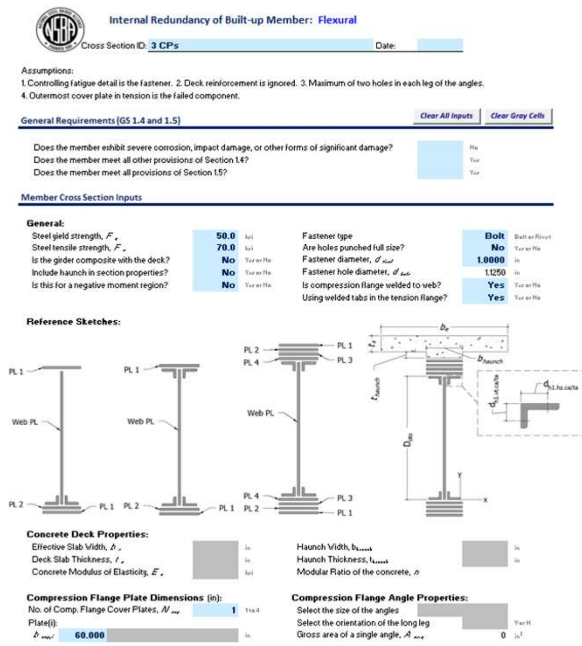

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METHODOLOGY FOR IRMs:

1. Screening Criteria
2. Check fatigue life in *unfaulted* state
3. Check strength in *faulted* state
4. Check fatigue life in *faulted* state
5. Calculate Special Inspection Interval

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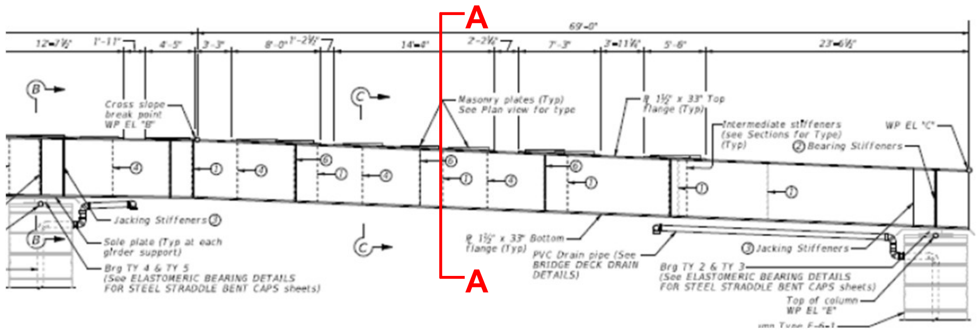
STACKED GIRDER LAYOUT, (82 FT. SPAN)

- A709-50W steel
- Drilled 1-1/8” bolt holes
- F_y = 50 ksi, F_u = 70 ksi
- $(ADTT)_{SL}$ = 2,000
- g = 1% (annual growth rate)



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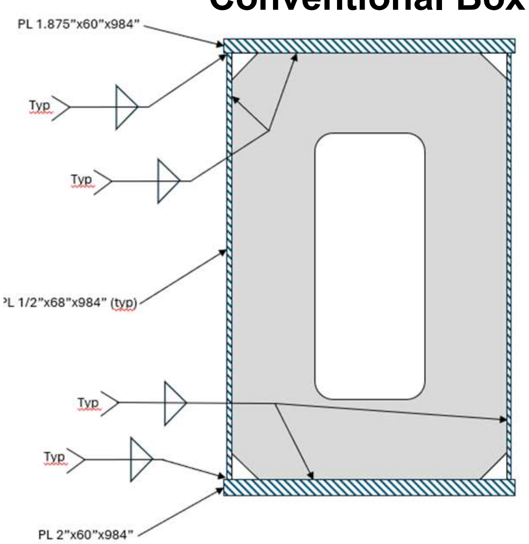
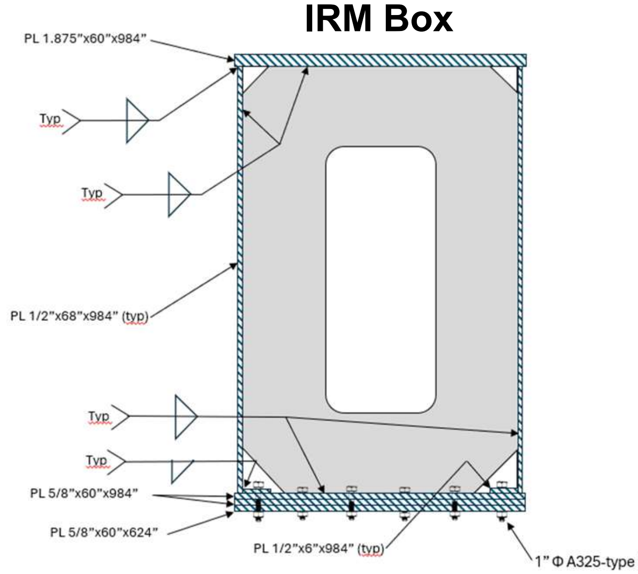
SECTION A-A

Conventional Box



IRM Box



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IRM EVALUATOR INPUTS…

General:

Steel yield strength, F_y	50.0	ksi	Fastener type	Bolt	Bolt or Rivet
Steel tensile strength, F_u	70.0	ksi	Are holes punched full size?	No	Yes or No
Is the girder composite with the deck?	No	Yes or No	Fastener diameter, d_{fast}	1.0000	in
Include haunch in section properties?	No	Yes or No	Fastener hole diameter, d_{hole}	1.1250	in
Is this for a negative moment region?	No	Yes or No	Is compression flange welded to web?	Yes	Yes or No

Compression Flange Plate Dimensions (in):

No. of Comp. Flange Cover Plates, N_{ccp} 1 (1 to 4)

Plate(i):

$b_{ccp,i}$	60.000	in
$t_{ccp,i}$	1.8750	in

Note: Plate 1 is always the outer-most CP. See Ref sketchs.

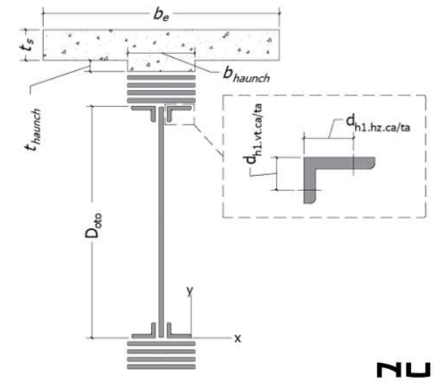
Tension Flange Plate Dimensions (in):

No. of Tension Flange Cover Plates, N_{tcp} 3 (1 to 4)

Plate(i):

$b_{tcp,i}$	60.000	60.000	60.000	in
$t_{tcp,i}$	0.6250	0.6250	0.6250	in

Note: Plate 1 is always the outer-most CP, see Ref Sketches



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DESIGN LOADS

Redundancy II Load Case:

- HL-93 design trucks
- IM = 15% (not on lane)
- Multiple presence factors
- γ_{DC} = 1.05, γ_{DW} = 1.05, γ_{LL} = 1.30
- γ_{FATI} = 1.75, γ_{FATII} = 0.80

(Unfactored)

Section	M_{DC1} (kip-ft)	M_{LL+IM} (kip-ft)	M_{FAT+IM} (kip-ft)
A-A	16,300	4,430	2,150

Unfaulted Member Section Properties:

Assumed no failed components

Gross Section Properties: Unfaulted (composite if applicable)

Composite			Noncomposite		
$\bar{y}_{G,COMP}$	-	in	$\bar{y}_{C,G,NC}$	33.5	in
$c_{G,COMP}$	-	in	$c_{G,NC}$	35.4	in
$A_{G,COMP}$	-	in^2	$A_{G,NC}$	299.0	in^2
$I_{xG,COMP}$	-	in^4	$I_{xG,NC}$	312,844.5	in^4
$S_{xG,COMP}$	-	in^3	$S_{xG,NC}$	8,831.7	in^3

Net Section Properties: Unfaulted (composite if applicable)

Composite			Noncomposite		
$\bar{y}_{N,COMP}$	-	in	$\bar{y}_{N,NC}$	34.7	in
$c_{N,COMP}$	-	in	$c_{N,NC}$	36.6	in
$A_{N,COMP}$	-	in^2	$A_{N,NC}$	289.4	in^2
$I_{xN,COMP}$	-	in^4	$I_{xN,NC}$	300,704.8	in^4
$S_{xN,COMP}$	-	in^3	$S_{xN,NC}$	8,224.5	in^3

Faulted Member Section Properties:

Assumed failed component is Tension Cover PL 1 (outer-most cover plate)

Gross Section Properties: Faulted (composite if applicable)

Composite			Noncomposite		
$\bar{y}_{AFG,COMP}$	-	in	$\bar{y}_{AFG,NC}$	38.6	in
$c_{AFG,COMP}$	-	in	$c_{AFG,NC}$	39.8	in
$A_{AFG,COMP}$	-	in^2	$A_{AFG,NC}$	261.5	in^2
$I_{x,AFG,COMP}$	-	in^4	$I_{x,AFG,NC}$	259,986.4	in^4
$S_{x-AFG,COMP}$	-	in^3	$S_{x-AFG,NC}$	6,526.9	in^3

Net Section Properties: Faulted (composite if applicable)

Composite			Noncomposite		
$\bar{y}_{AFN,COMP}$	-	in	$\bar{y}_{AFN,NC}$	39.4	in
$c_{AFN,COMP}$	-	in	$c_{AFN,NC}$	40.7	in
$A_{AFN,COMP}$	-	in^2	$A_{AFN,NC}$	256.2	in^2
$I_{x,AFN,COMP}$	-	in^4	$I_{x,AFN,NC}$	251,372.9	in^4
$S_{x-AFN,COMP}$	-	in^3	$S_{x-AFN,NC}$	6,183.4	in^3

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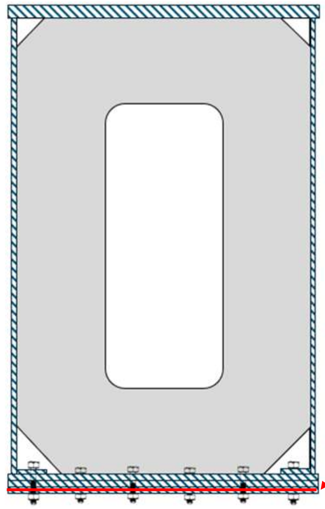
Faulted Condition



THE PROCESS -

1. Screening Criteria - PASS
2. Check fatigue life in unfaulted state - INFINITE
3. Check strength in faulted state - PASS
4. Check fatigue life in faulted state - ?
5. Calculate Special Inspection Interval - ?

FATIGUE LIFE IN FAULTED STATE

Effective Fatigue Stress Range & Max Fatigue Stress Range in Faulted State:

Noncomposite Section:

$f_{AFN} = \beta_{AF}(M_{FAT+IM} / S_{x\text{-}AFN}) =$	**4.8 ksi**	GS Eq. 2.1.2-1

$$(\Delta f)_{max} = (\gamma_{FATI}/\gamma_{FATII})(\Delta f)_{eff} = 10.5 \text{ ksi}$$

Cat. C, therefore **FINITE** life

Total faulted state remaining fatigue life, Y_{REM}	**43.4**	Years	MBE 7.2.5.1	Faulted fatigue life?	OK
Case I or II for faulted state?	**I(b)**	I(a), I(b), II	GS 2.5		

Total Remaining Fatigue Life:

No. of accumulated years in unfaulted state, N_U	0.0	Years	GS 2.5.3
Total fatigue life only in **unfaulted** state, Y_u	∞	Years	GS 2.5.3
Total remaining fatigue life only in **faulted** state, Y_f	43.4	Years	GS 2.5.3
Total remaining fatigue life, $N_f = Y_f(1-N_u/Y_u)$	43.4	Years	GS Eq. 2.5.3-1

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SECTION B-B RESULT SUMMARY

- Passed screening criteria
- Possessed positive fatigue life - unfaulted state
- Passed strength checks – faulted state
- Possessed positive fatigue life - faulted state

Qualifies as IRM

- Next – calculate Special Inspection Interval

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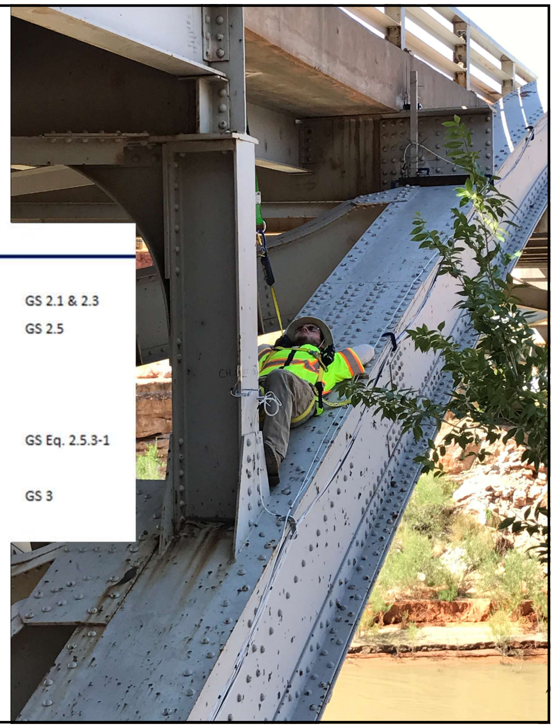
SUMMARY & INSPECTION INTERVAL

Summary of Results

Strength check =	OK	OK or NG	GS 2.1 & 2.3
Fatigue case =	I(b)	I(a), I(b), II	GS 2.5
Stress range in unfaulted state, Δf_{UFS} =	2.51	ksi	
Controlling stress range in faulted state, Δf_{FS} =	4.80	ksi	
Controlling faulted state remaining fatigue life, Y_{REM}	43.4	Years	
Total remaining fatigue life, N_f	43.4	Years	GS Eq. 2.5.3-1
Maximum Interval for Special Inspections =	**10.0**	Years	GS 3



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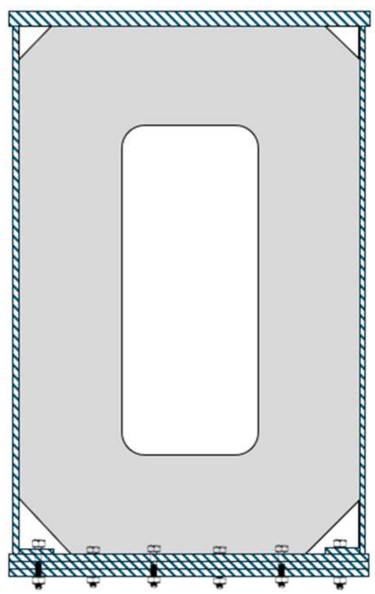
Is there a more optimized alternate design?



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Assumed Fractured

Trial	Plate 1 Thickness (in.)	Plate 2 Thickness (in.)	Plate 3 Thickness (in.)	Meets Strength Req.?	Remaining Fatigue Life in Faulted Condition	Special Inspection Interval
1	0.625	0.625	0.625	Yes	43.4 yrs	10 yrs

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Assumed Fractured

Trial	Plate 1 Thickness (in.)	Plate 2 Thickness (in.)	Plate 3 Thickness (in.)	Meets Strength Req.?	Remaining Fatigue Life in Faulted Condition	Special Inspection Interval
1	0.625	0.625	0.625	Yes	43.4 yrs	10 yrs
2	0.5	0.625	0.75	Yes	Infinite yrs	10 yrs

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Assumed Fractured

Trial	Plate 1 Thickness (in.)	Plate 2 Thickness (in.)	Plate 3 Thickness (in.)	Meets Strength Req.?	Remaining Fatigue Life in Faulted Condition	Special Inspection Interval
1	0.625	0.625	0.625	Yes	43.4 yrs	10 yrs
2	0.5	0.625	0.75	Yes	Infinite yrs	10 yrs
3	0.9375	0.9375	-	No	-	-

Misses gross section yield limit by 8%

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Assumed Fractured

Trial	Plate 1 Thickness (in.)	Plate 2 Thickness (in.)	Plate 3 Thickness (in.)	Meets Strength Req.?	Remaining Fatigue Life in Faulted Condition	Special Inspection Interval
1	0.625	0.625	0.625	Yes	43.4 yrs	10 yrs
2	0.5	0.625	0.75	Yes	Infinite yrs	10 yrs
3	0.9375	0.9375	-	No	-	-
4	0.625	1.25	-	Yes	48.3 yrs	10 yrs

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Assumed Fractured

Trial	Plate 1 Thickness (in.)	Plate 2 Thickness (in.)	Plate 3 Thickness (in.)	Meets Strength Req.?	Remaining Fatigue Life in Faulted Condition	Special Inspection Interval
1	0.625	0.625	0.625	Yes	43.4 yrs	10 yrs
2	0.5	0.625	0.75	Yes	Infinite yrs	10 yrs
3	0.9375	0.9375	-	No	-	-
~~4~~	~~0.625~~	~~1.25~~	~~-~~	~~Yes~~	~~48.3 yrs~~	~~10 yrs~~

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Assumed Fractured

Trial	Plate 1 Thickness (in.)	Plate 2 Thickness (in.)	Plate 3 Thickness (in.)	Meets Strength Req.?	Remaining Fatigue Life in Faulted Condition	Special Inspection Interval
1	0.625	0.625	0.625	Yes	43.4 yrs	10 yrs
2	0.5	0.625	0.75	Yes	Infinite yrs	10 yrs
3	0.9375	0.9375	-	No	-	-
~~4~~	~~0.625~~	~~1.25~~	~~-~~	~~Yes~~	~~48.3 yrs~~	~~10 yrs~~
5	0.75	1.125	-	Yes	39.8 yrs	10 yrs

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Assumed Fractured

Trial	Plate 1 Thickness (in.)	Plate 2 Thickness (in.)	Plate 3 Thickness (in.)	Meets Strength Req.?	Remaining Fatigue Life in Faulted Condition	Special Inspection Interval
1	0.625	0.625	0.625	Yes	43.4 yrs	10 yrs
2	0.5	0.625	0.75	Yes	Infinite Life	10 yrs
3	0.9375	0.9375	-	No	-	-
~~4~~	~~0.625~~	~~1.25~~	~~-~~	~~Yes~~	~~48.3 yrs~~	~~10 yrs~~
5	0.75	1.125	-	Yes	39.8 yrs	10 yrs
I-Beam	*36 x 1.0*	*36 x 1.5*	*36 x 1.5*	*Yes*	*Infinite Life*	*10 yrs*

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IRM INSPECTION ADVANTAGE (RISK-BASED):

Member Type	Reduced Intervals	Max Extended Interval (Method 1*)	Max Extended Interval (Method 2**)	Inspection Type
LPRM	12 months (risk based)	48 months	72 months	Unchanged: routine
NSTM	12 months (risk-based)	48 months	48 months	Unchanged: hands-on
SRM	12 months (risk based)	48 months	72 months	Routine
IRM	12 months (risk based)	120 months (48 months)	120 months (72 months)	IRM Special Insp. (Routine inspection)

*Method 1: Interval determined by a "simplified" assessment of risk (criteria are defined in NBIS)
**Method 2: Interval determined by a "more rigorous" assessment of risk using a Risk Assessment Panel (RAP) and documented as a formal policy.

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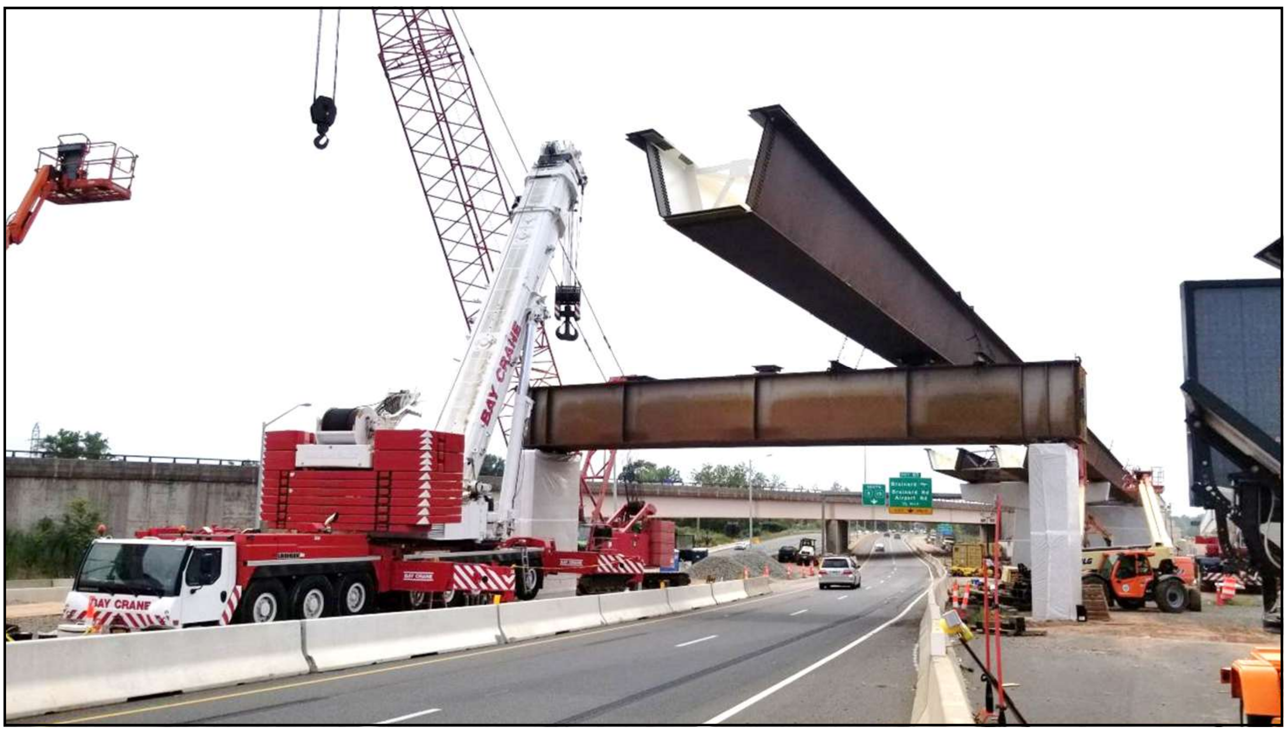

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IRM CONSIDERATIONS: FABRICATION COST & WEIGHT

COST APPROXIMATIONS: Listed to

1. Fillet-welded box (fillets on outside of box or [NSTM]
2. Built-up bolted I-girder (+1-2%) [IRM]
3. Built-up bolted box girder (+15-18%) [IRM]
4. CJP-welded box girder (+17-20%) – [NSTM]
   Don't use CJPs!

WEIGHT APPROXIMATIONS: Listed to

1. Built-up bolted I-girder
2. Welded box girders (10-14% heavier)
3. Built-up bolted box girder (16-20% heavier)

These are "front" costs only…consider life cycle costs (NSTM inspections 10-15x $)

Consider POD of inspections…

Consider wholistic safety related to arms-length inspection requirements…

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SAFETY

- ❖ Bridge inspection is directly motivated by pursuit for safety
- ❖ 2015 Purdue study for INDOT found:
  - Congested crash rate increased **24x** on Indiana interstates with queue ≥ 5 min
  - And safety of the inspection crews?
- ❖ Intend to find damage *before* it's an issue:
  - What about Probability of Detection (POD)?
  - Are we able to find what we think we can find?

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FINAL THOUGHTS & WRAP-UP

REDUNDANCY & INSPECTION:

- Goes without saying that IRMs are more redundant than welded boxes
- Faulted state strength capacity calculations are very conservative (on-going research)
- Special inspection intervals are very conservative
  - 95% confidence interval, SF = 2, fracture propagation unlikely
- IRMs are robust against over height vehicle impacts
- POD of fractured plate is very high – changes the inspection reliability without compromising safety

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THANK YOU

NUCOR CORPORATION

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