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Hale Boggs Cable Stayed Bridge – Inspection, Fatigue Analysis & Repair

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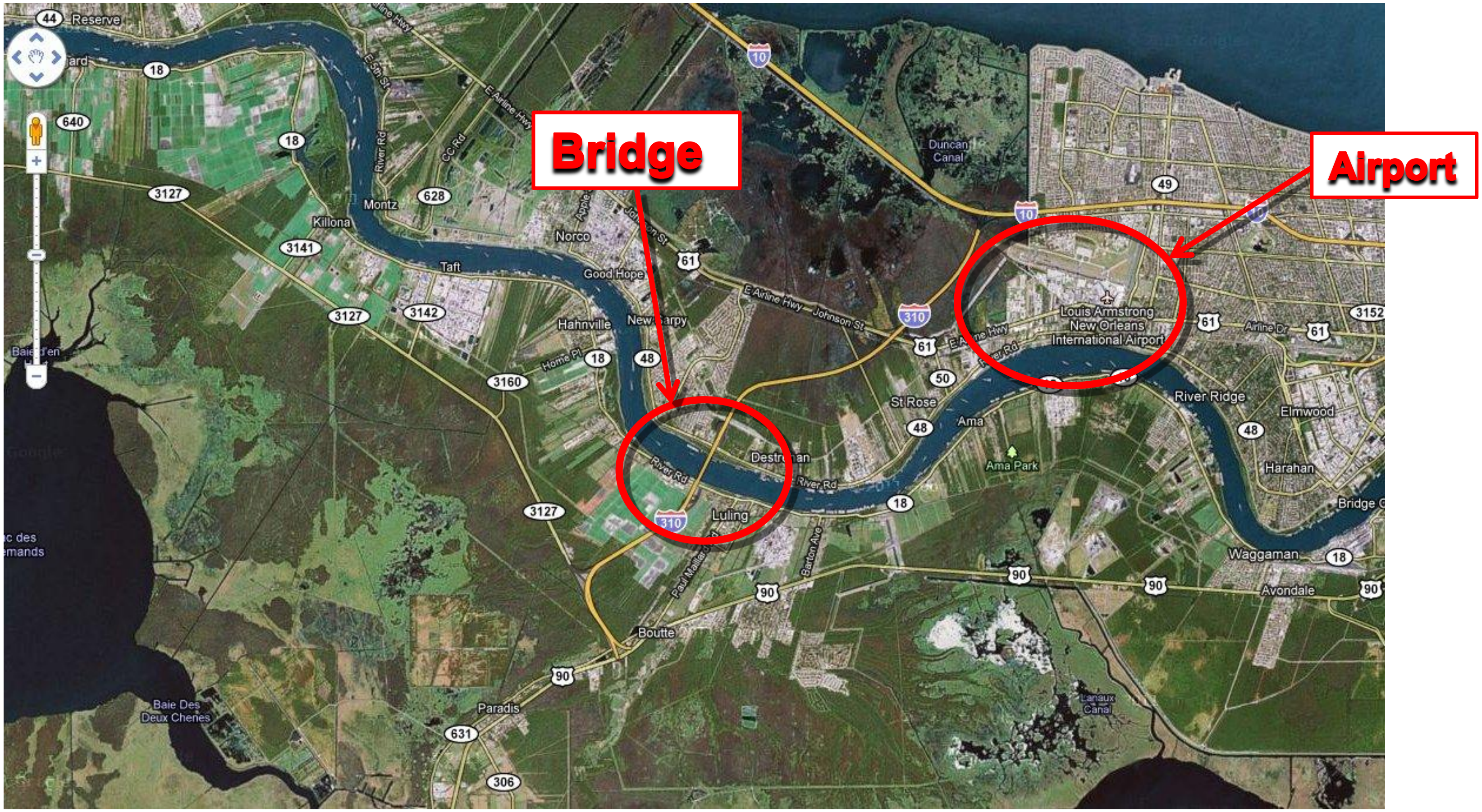
- **Paul Norton – Part I**
  - Introduction
  - Inspection findings
  - Scope of work

- **Jian Huang – Part II**
  - Fatigue evaluation procedure and specifications
  - 3-D structural analysis
  - Fatigue stress ranges
  - Remaining mean/safe fatigue lives
  - Conclusions and recommendations
  - Repair plans

Location of Hale Boggs Bridge



Interstate I-310 over the Mississippi River between Destrehan and Luling.
Also known as the Luling Bridge.

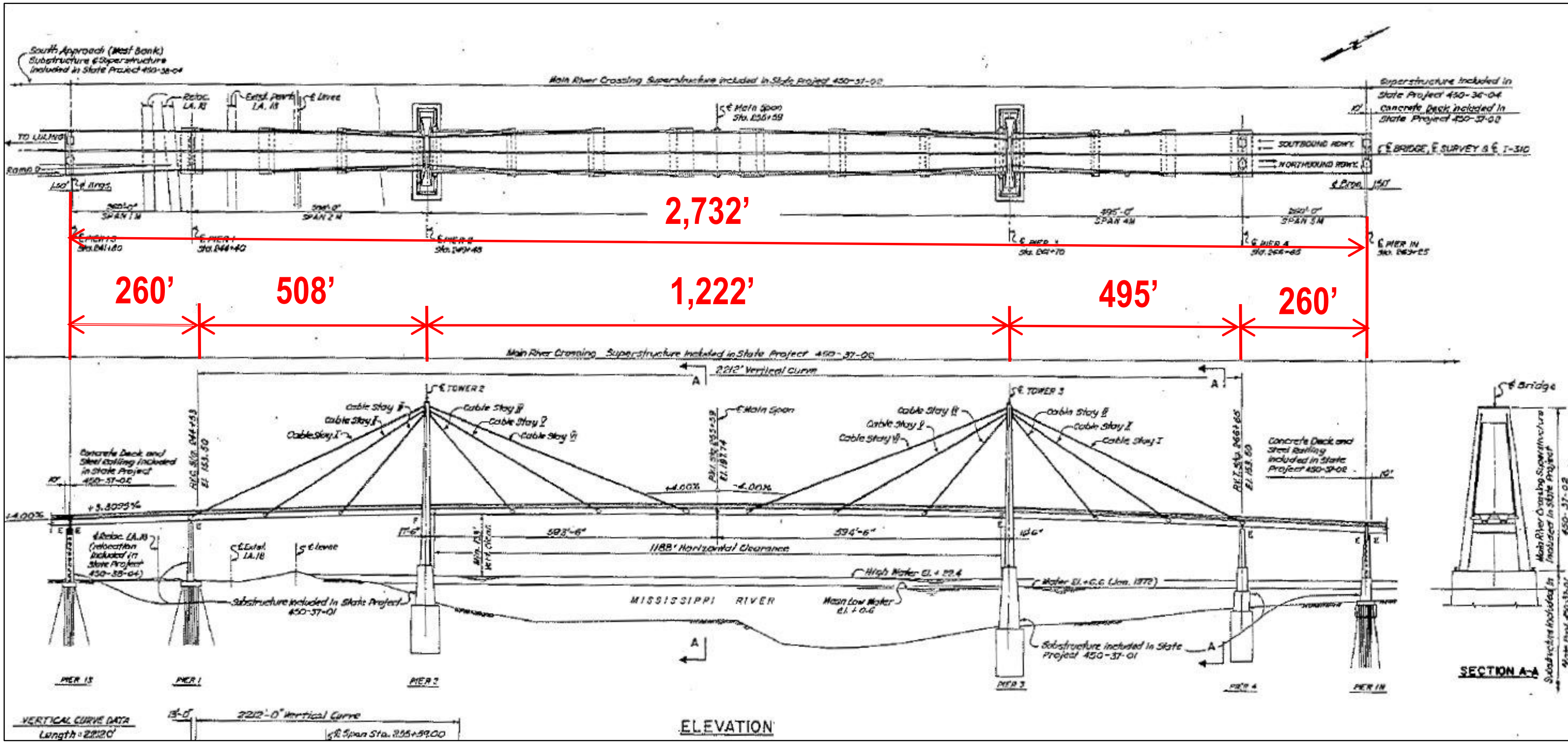
Hale Boggs Cable Stayed Bridge

- Bridge open to traffic in Oct. 1983
- The third major cable stayed bridge in the United States
- The first cable stayed bridge added to the interstate highway system

Hale Boggs Cable Stayed Bridge

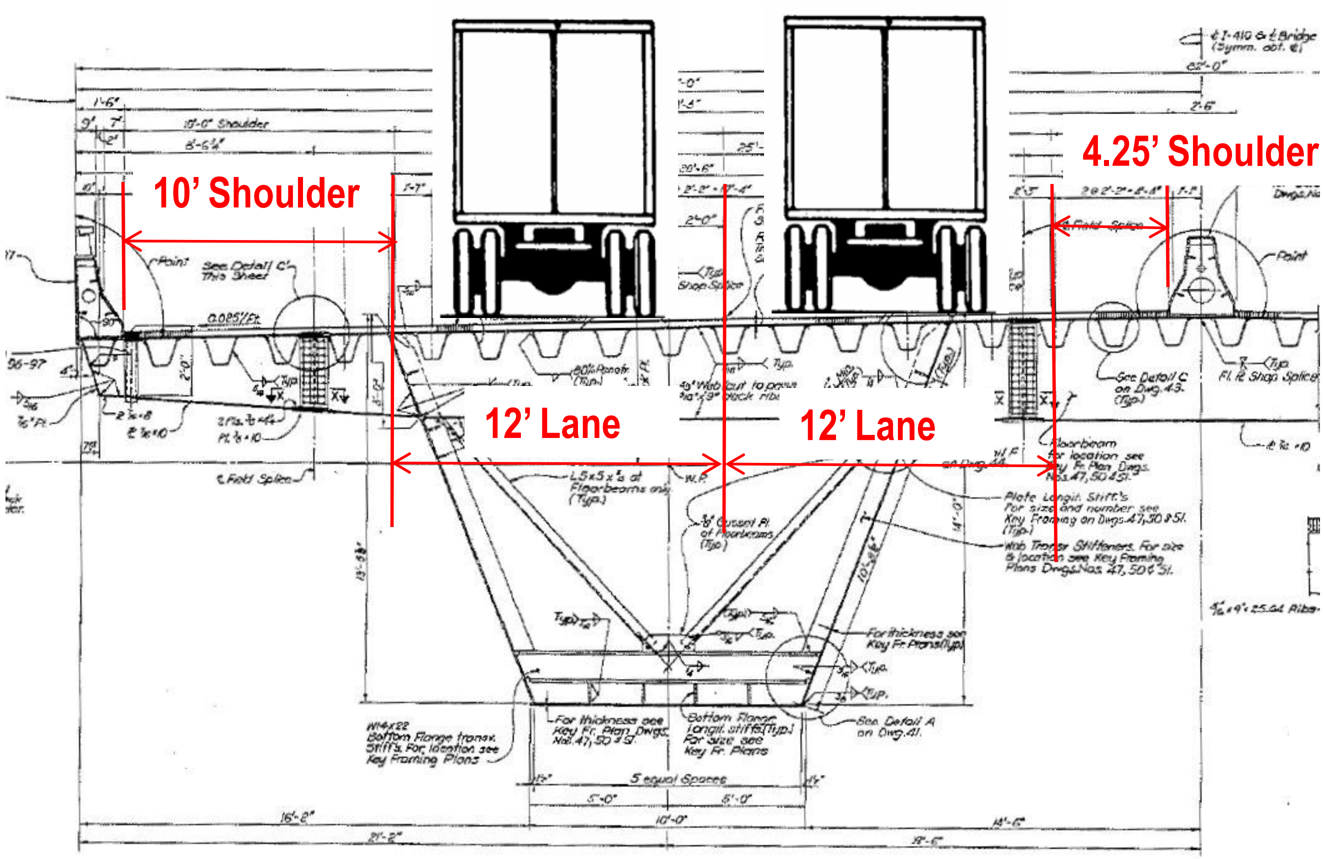
- ❑Weathering steel towers and superstructure
- ❑Orthotropic deck (first in cable stayed bridges in US)

Plan and Elevation of the Bridge



The main river crossing is a cable stayed bridge having a total length of 2,732 ft.

Cross Section of the Bridge



SECTION E-E

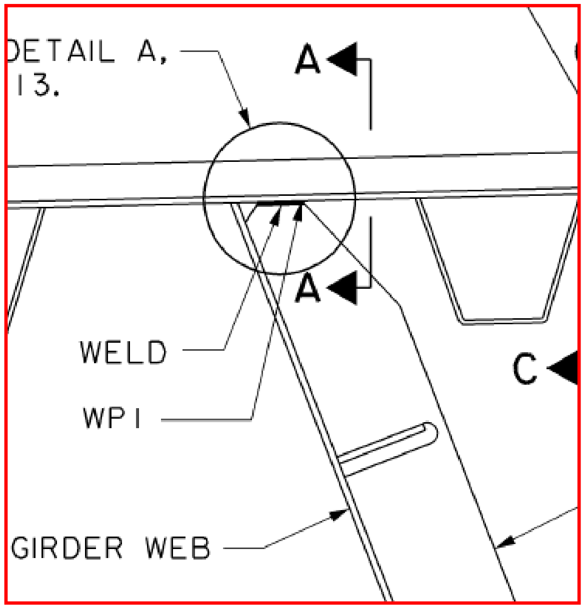
- 2-Steel tub girders connected with floor beams and diaphragms
- 82 ft bridge width

Problem Statement

- **Major Rehabilitation Project**
  - \$28M – Replacement of All Cables
- **Our recent bridge inspection found:**
  - Cracks occurred in the deck plate and the fillet weld at the connection of the box girder web transverse stiffener to the orthotropic deck (112 cracks out of 800+ total locations).
  - Cracks exhibited only in the outboard web of the box girders (under the outside wheel line of traffic in each direction).
  - Cracks in other components (lifting lugs & cross girder)

Crack in orthotropic deck plate at end of transverse stiffener weld

Crack



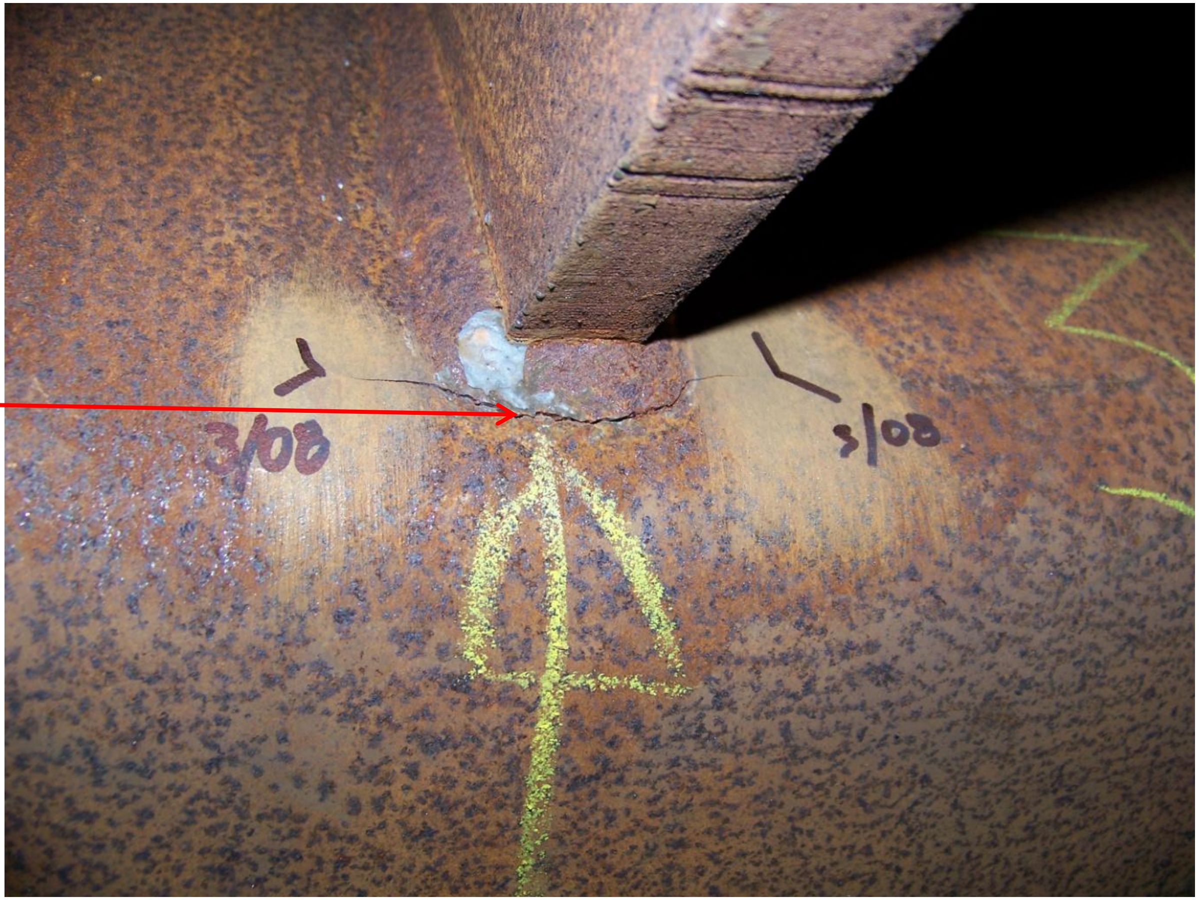
Crack Location

- 75 Cracks in Orthotropic Deck Plate
- 37 Cracks in Weld Only

Transverse Stiffener

Crack in orthotropic deck rib at Lifting Lug

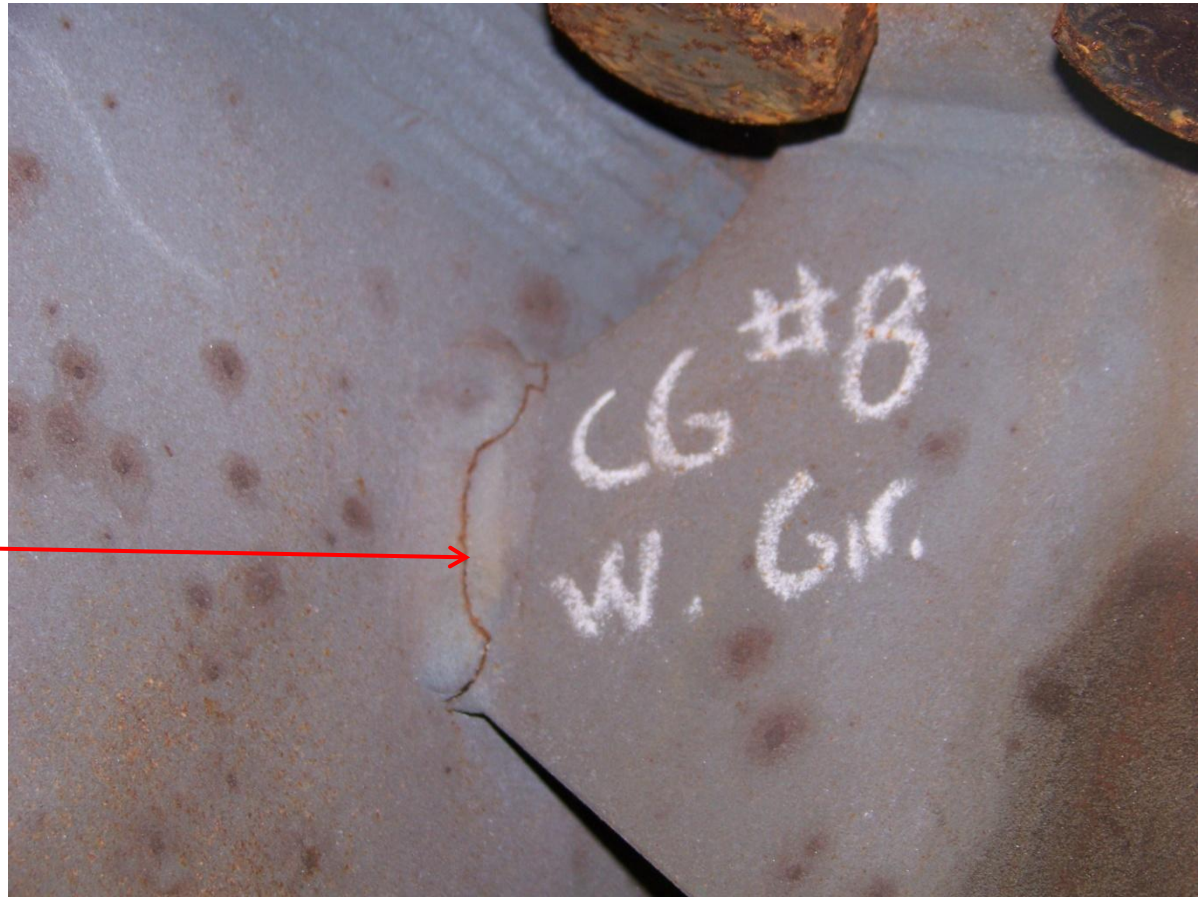
Crack



- ❑ 13 Cracks in Orthotropic Deck Rib

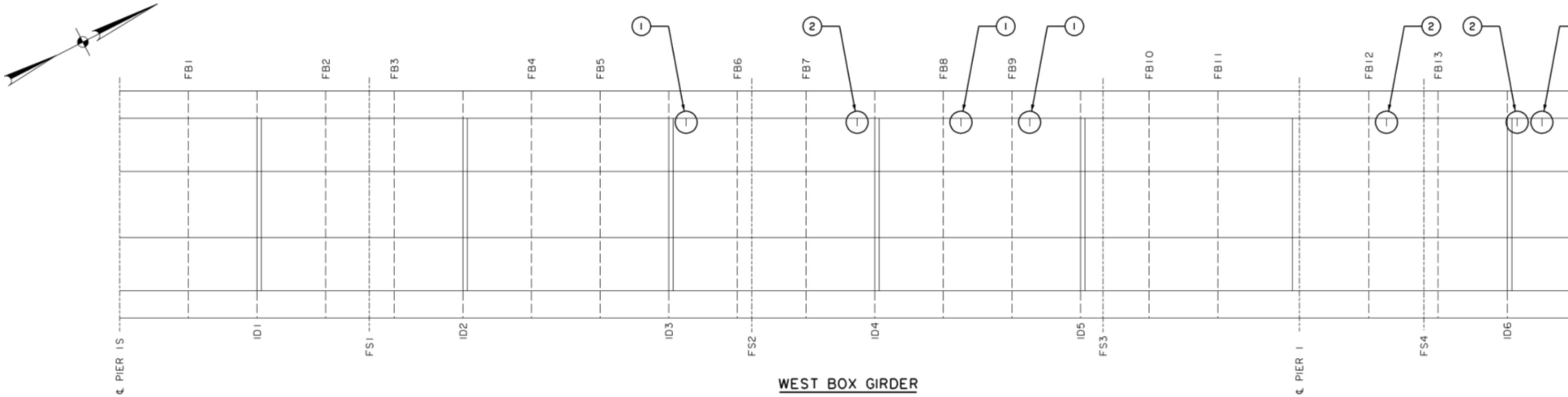
Crack inside cross girder at internal diaphragm

Crack

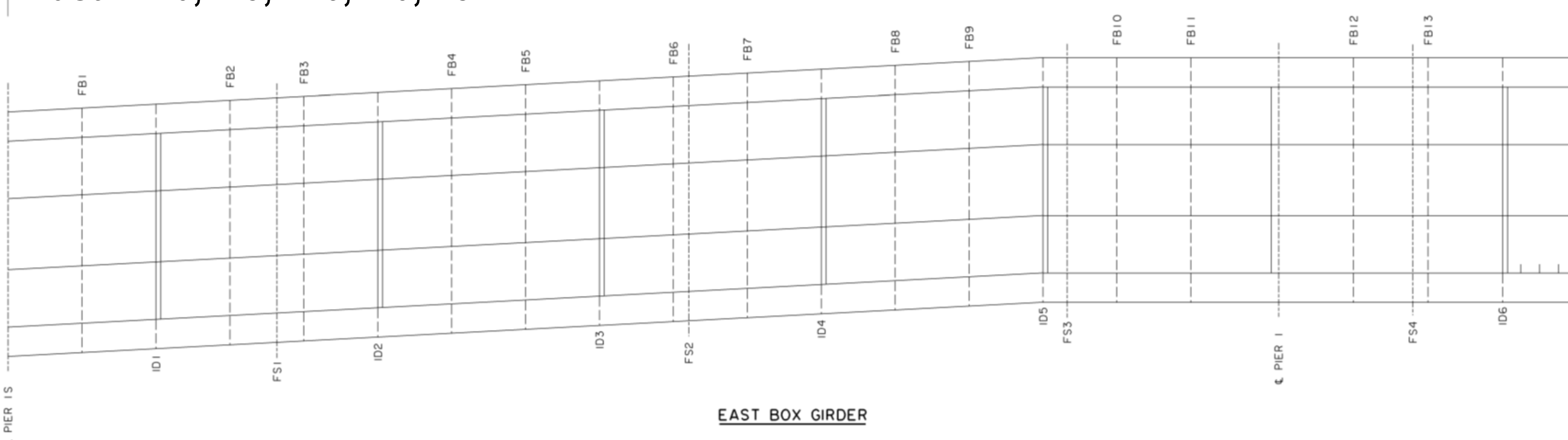


- 3 Cracks in Cross Girders

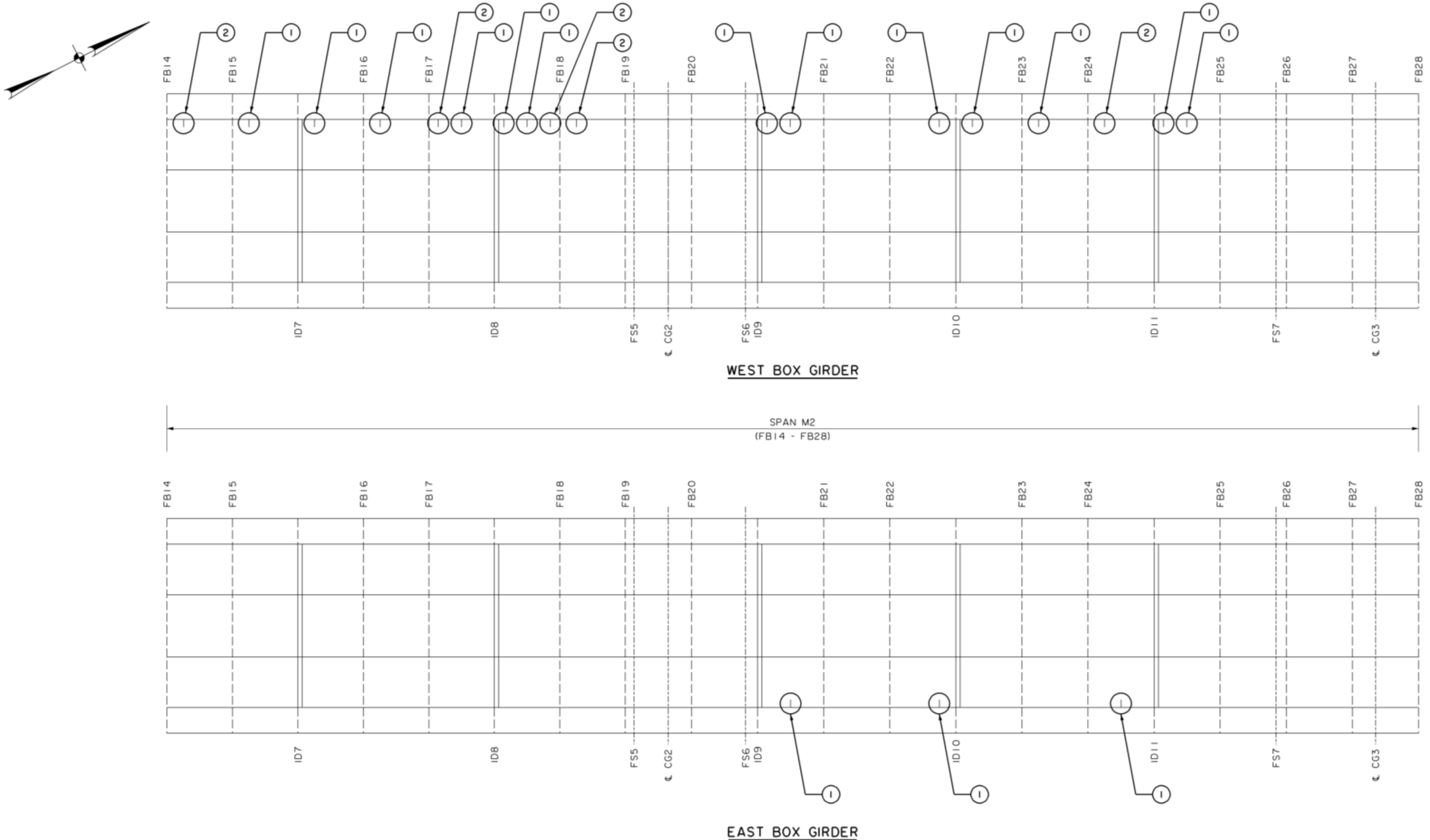
Crack Locations



- West = 4, 27, 27, 15, 5
- East = 0, 3, 16, 10, 5



Crack Locations



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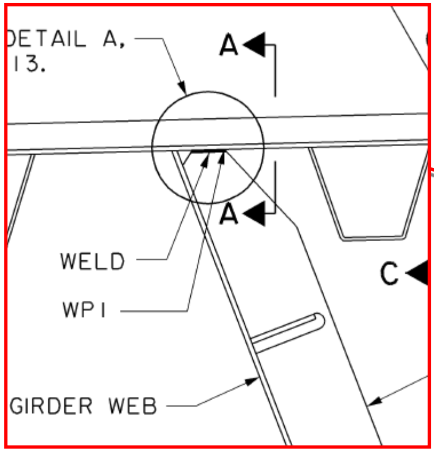
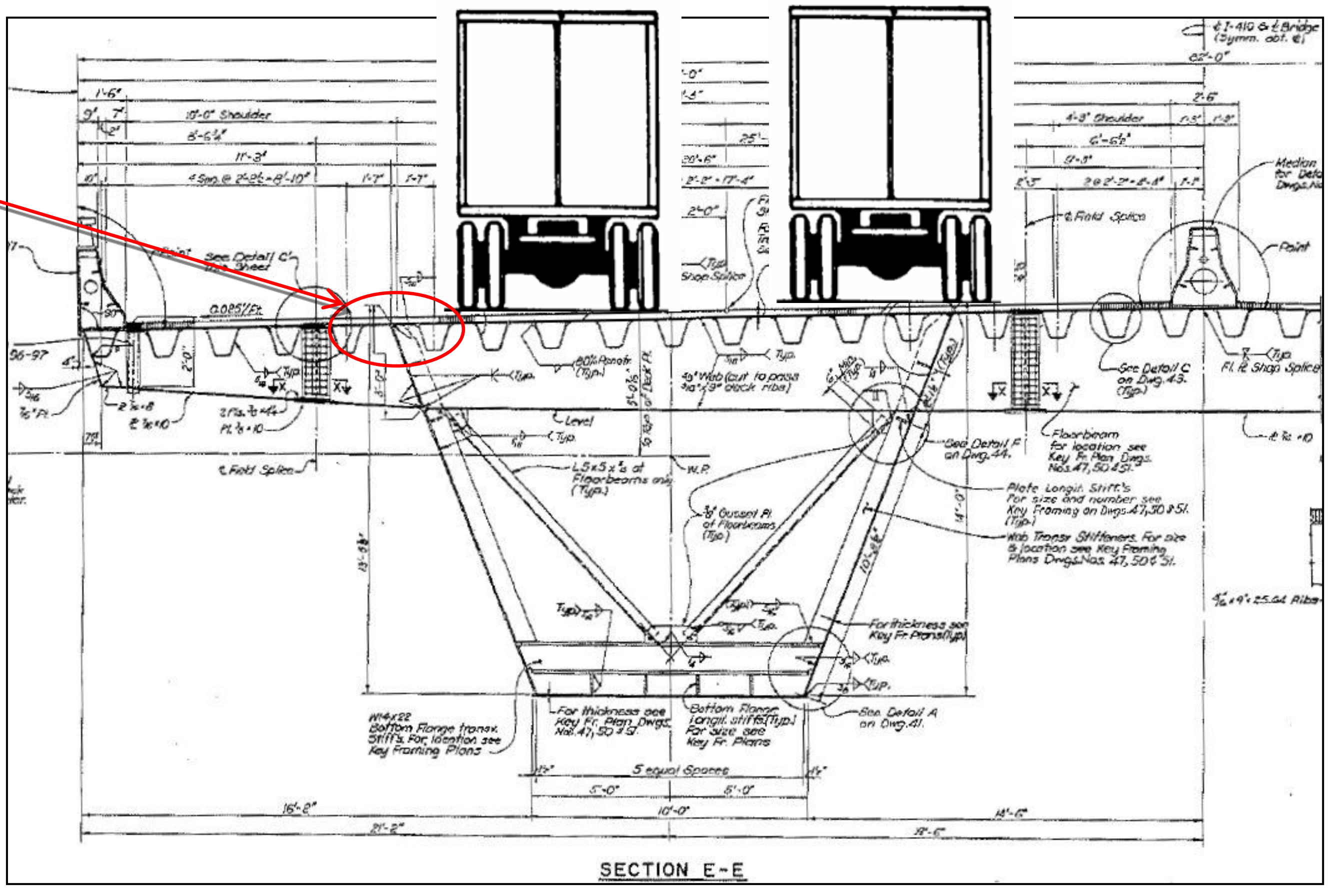
Crack Location



Crack Location

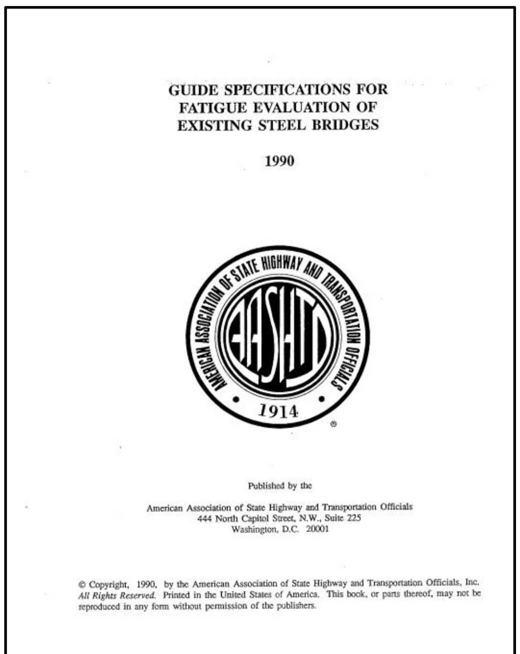


Scope of Work

- Determine the stress levels in the problematic area
- Perform a fatigue evaluation of the critical area
- Calculate the remaining mean fatigue and safe fatigue lives of the critical details
- Develop the repair plans

Fatigue Evaluation Procedure and Specifications

- **The fatigue analysis was performed in accordance with**
  - AASHTO *Guide Specifications for Fatigue Evaluation of Existing Steel Bridges*, 1990 with interims through 1995
  - NCHRP 299, *Fatigue Evaluation Procedures for Steel Bridges*


GUIDE SPECIFICATIONS FOR
FATIGUE EVALUATION OF
EXISTING STEEL BRIDGES

1990

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS
AASHTO
1914

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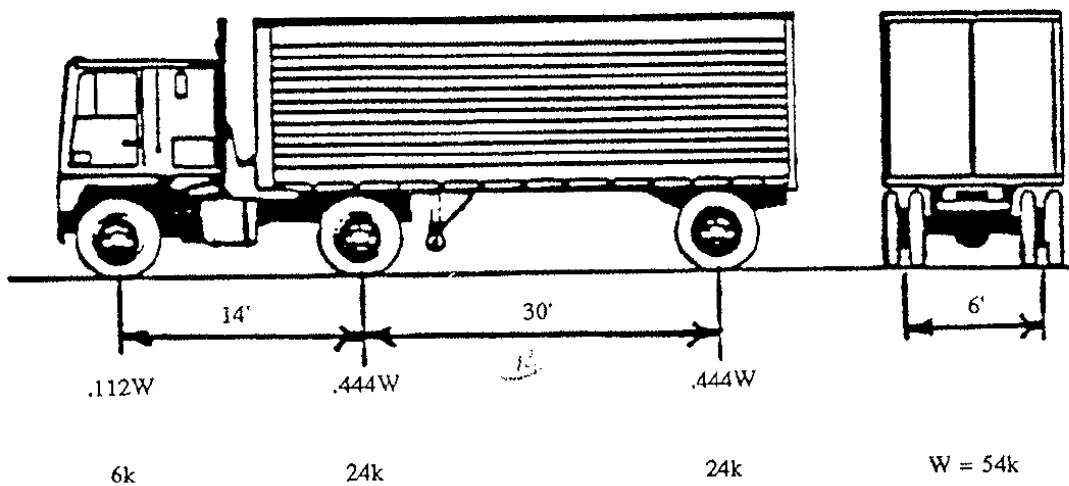
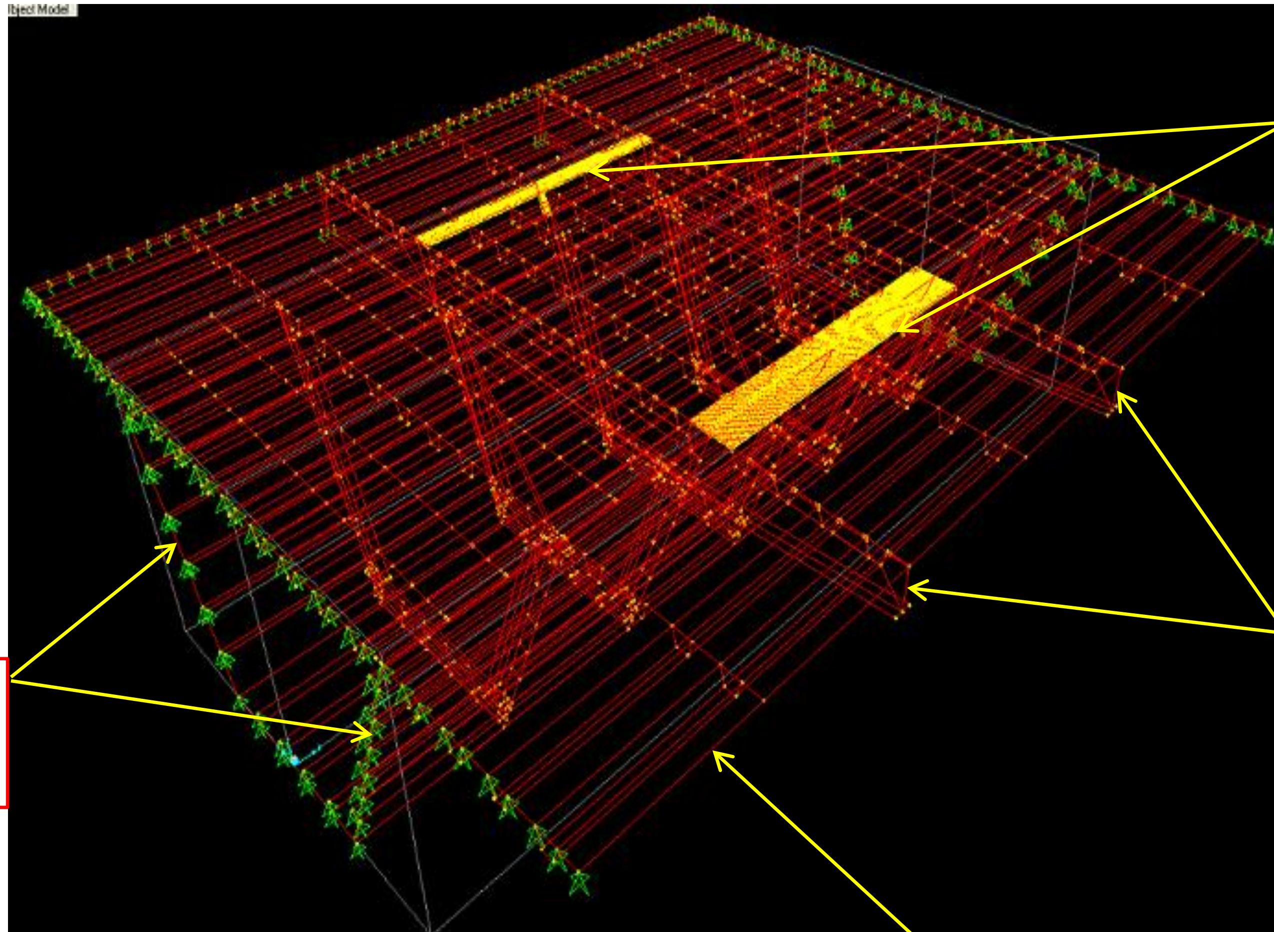


3-D Structural Analysis Model

- **Modeling features:**
  - SAP2000 program
  - Modeling: Longitudinal segment, Transverse half section
  - Shell elements
  - Refined shell element size, max. 1”x1” mesh in the area of interest
  - Edge constraint between intersecting shell elements
  - Boundary joints at the centerline of the bridge: free but fixed rotation about the bridge direction
  - Boundary joints at ends of the analyzed segment: fixed translations and free rotations

General View of the 3-D Analysis Model



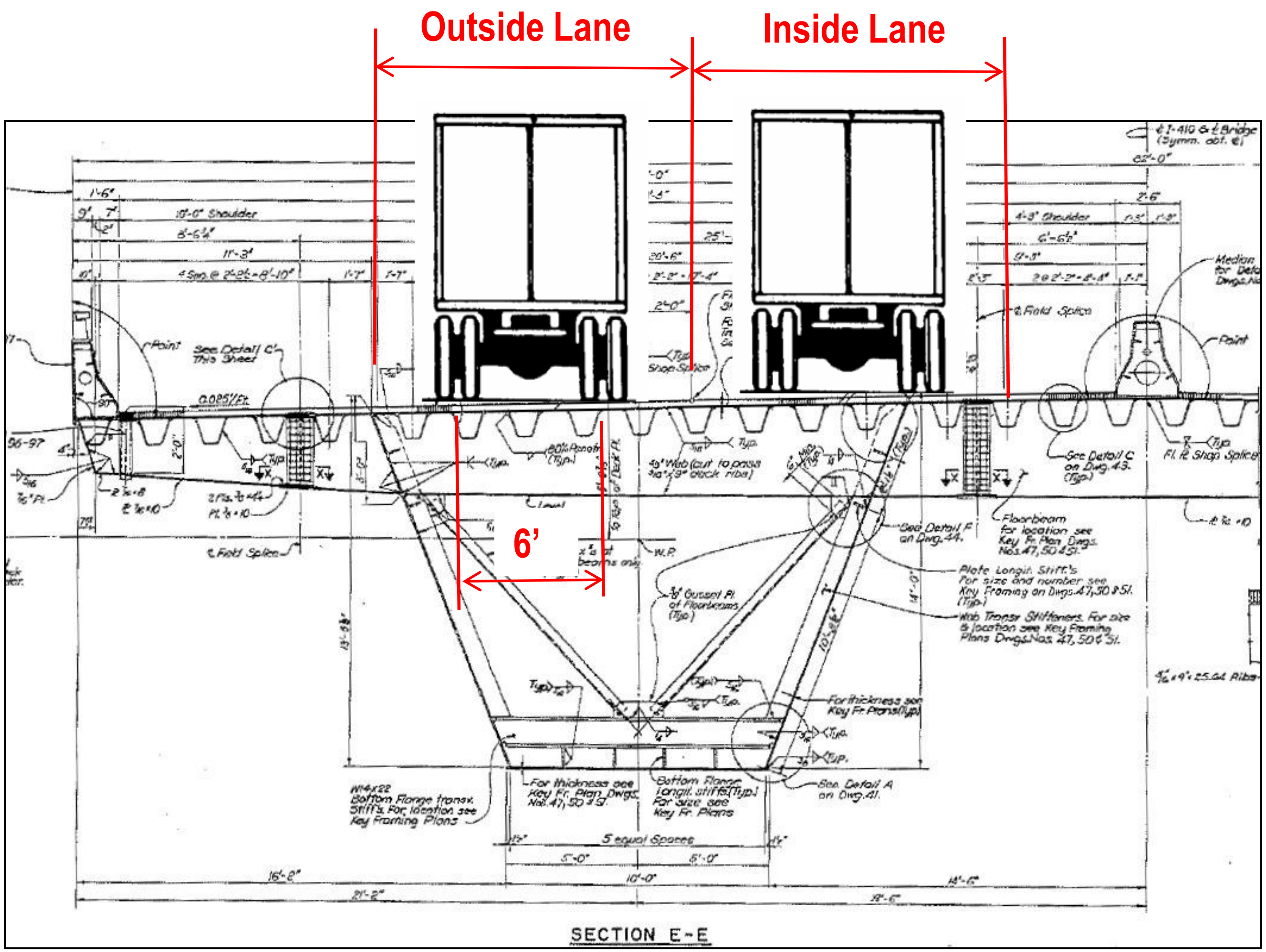
Refined mesh

Floor beam

Web of Box Girder

Deck

Fatigue Truck Loading

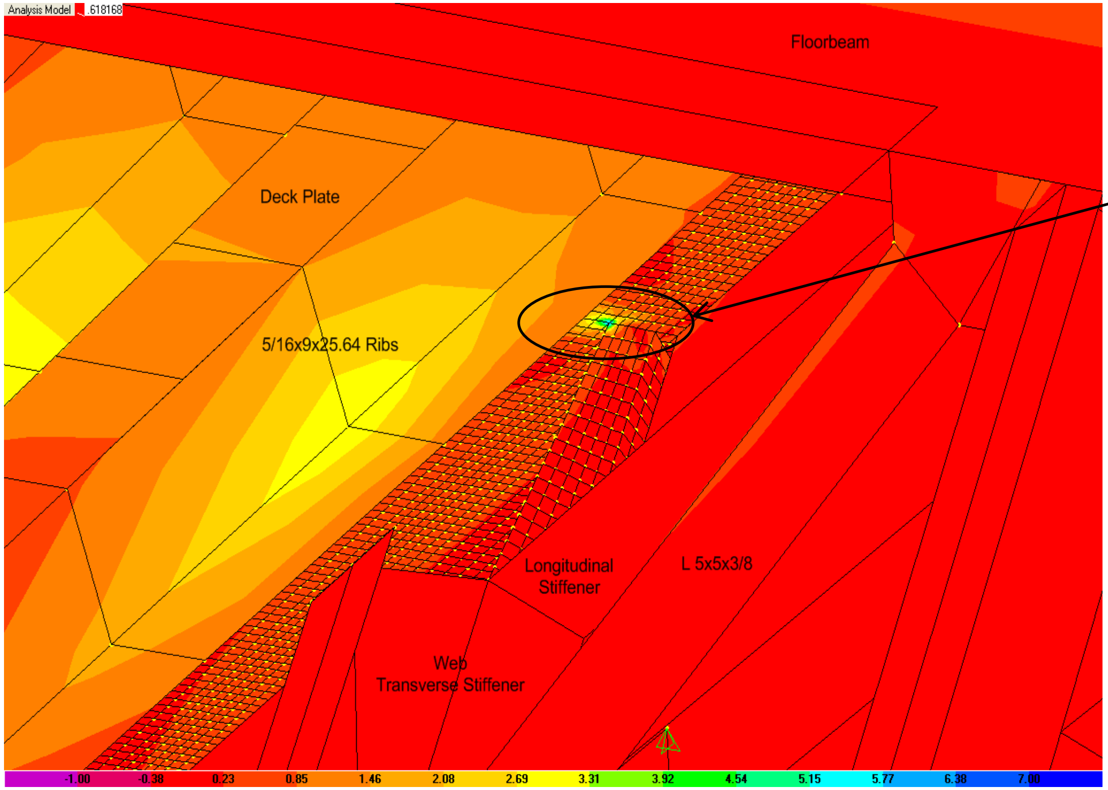


Applied Wheel Loads:

- One truck (outside lane or inside lane)
- 2 -12kips x 1.1 (impact assumed) = 13.2 kips wheels spaced at 6 feet transversely
- Applied as area load

Analytical Results: Outside Lane Loaded

- **Concentrated stress at the web transverse stiffener to the deck plate connection (outer web).**



Concentrated stress

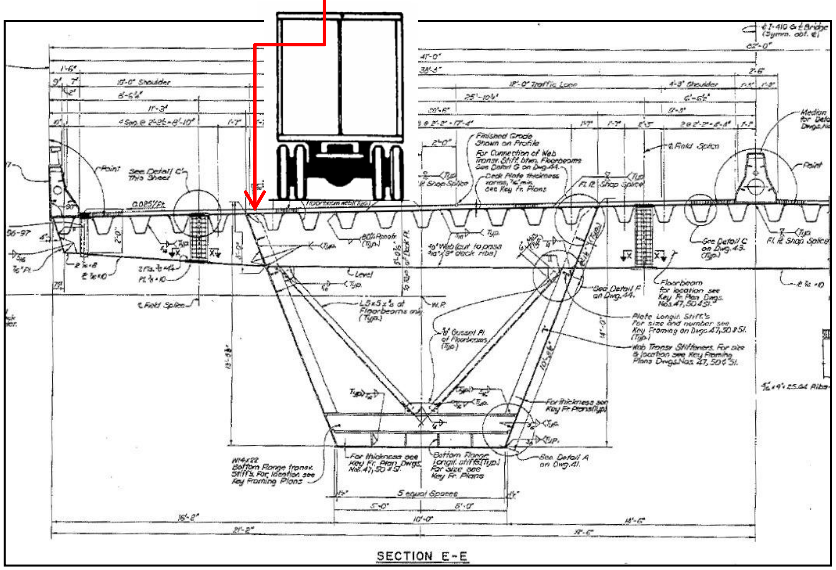
Fatigue Stress Ranges in Deck Plates

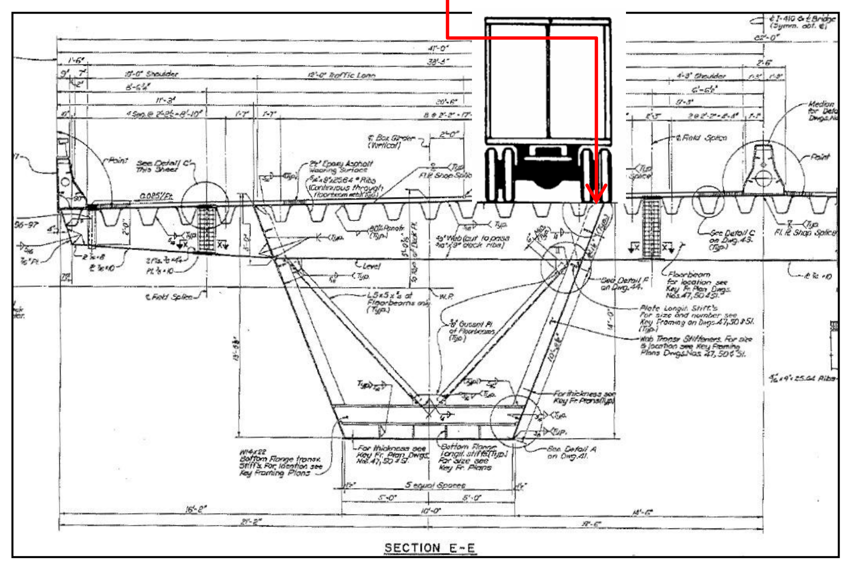
Table 1 – Fatigue Stress Ranges in Deck Plates Along Outer Web of Box Girder

Location	Outside Web	AASHTO Limiting Stress Range (Cat. C)
	(Axial, ksi)	(ksi)
At Web Stiffener	6.635	4.4
At Non Web Stiffener	0.099	4.4

Table 2 – Fatigue Stress Ranges in Deck Plates Along Inner Web of Box Girder

Location	Inner Web	AASHTO Limiting Stress Range (Cat. C)
	(Axial, ksi)	(ksi)
At Web Stiffener	1.188	4.4
At Non Web Stiffener	0.058	4.4

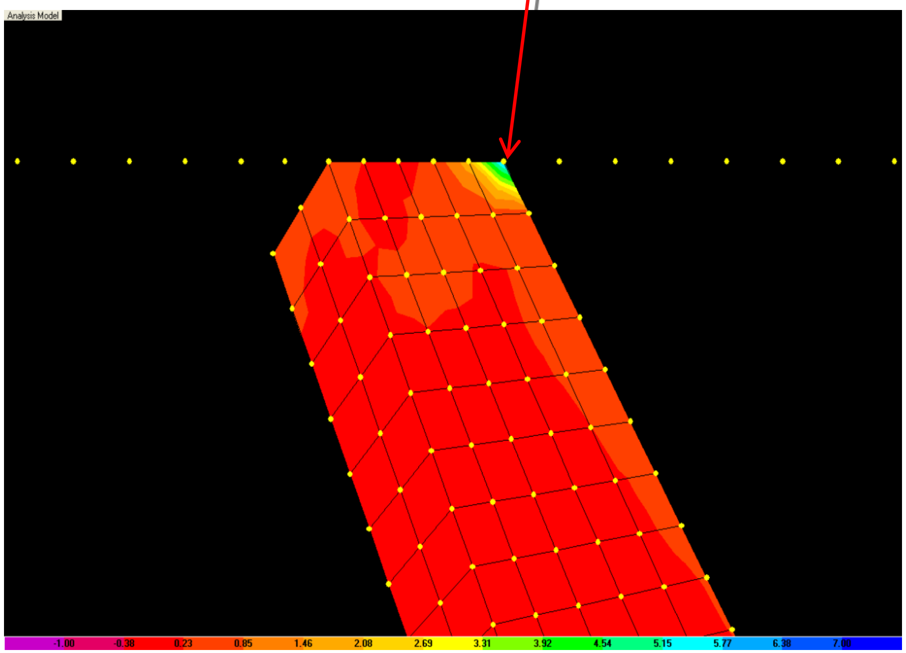




Fatigue Stress in Web Stiffeners

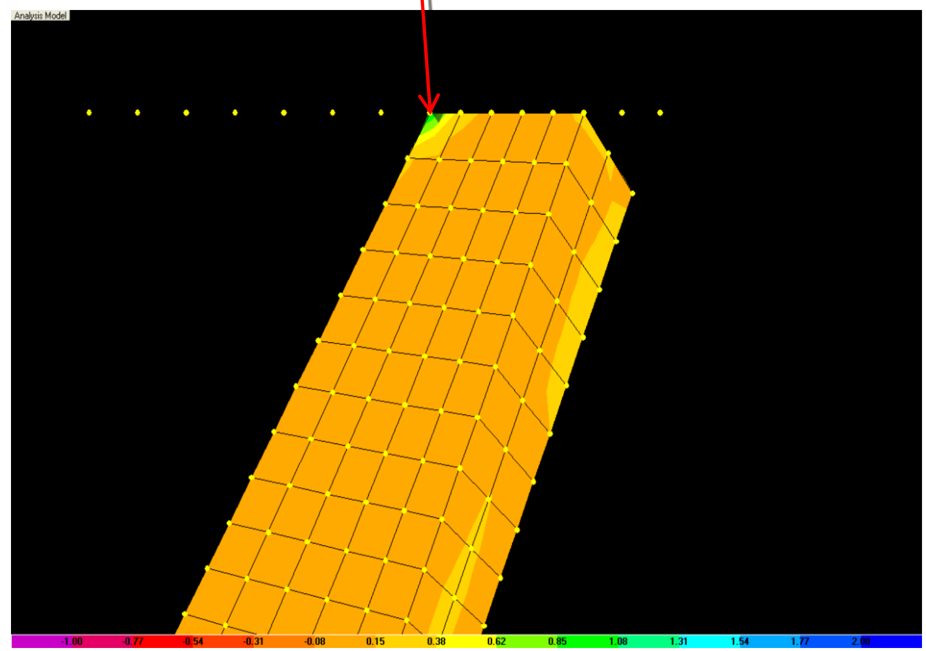
At outer Web

6.6 ksi



At inner web

1.2 ksi



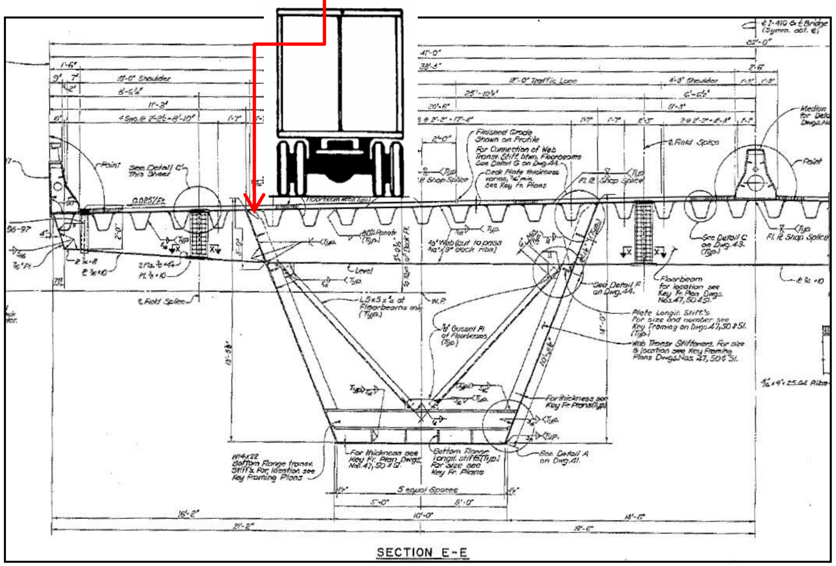
Fatigue Stress Ranges in Web Stiffeners

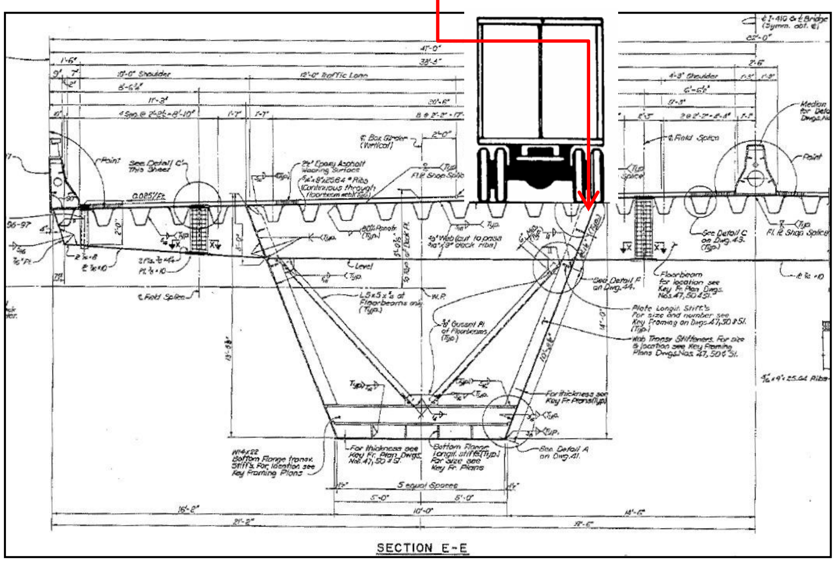
Table 3 – Fatigue Stress Ranges in Web Transverse Stiffener to Deck Connection at Outer Web

Location	Outside Web	AASHTO Limiting Stress Range (Cat. C)
	(Vertical, ksi)	(ksi)
Corner at Crack	6.635	4.4
Corner Closer to Box Girder Web	0.337	4.4

Table 4 – Fatigue Stress Ranges in Web Transverse Stiffener to Deck Connection at Inner Web

Location	Inside Web	AASHTO Limiting Stress Range (Cat. C)
	(Vertical, ksi)	(ksi)
Corner at Crack	1.188	4.4
Corner Closer to Box Girder Web	0.203	4.4





Check for Infinite Safe Fatigue Life (if fatigue is an issue)

- Factored fatigue stress range
- AASHTO Limiting stress range (Cat. C)

At outer web locations:		
9.0 ksi	**vs.**	**4.4 ksi**
At inner web locations:		
1.6 ksi	**vs.**	**4.4 ksi**

Outboard web locations will crack, 75 locations have already cracked .

Remaining Safe Fatigue Life and Mean Fatigue Life

- **Safe Fatigue Life vs. Mean Fatigue Life: Safe/Mean = 1/2**

- **Remaining Fatigue Life at outer web locations:**
  - Mean fatigue life: -8.8 years
  - Safe fatigue life: -21.3 years

  (negative means exceeded its fatigue life)

- **Remaining Fatigue Life at inner web locations:**
  - Infinite

Repair Scheme Development

- **No repair action**
  - Consider restricting traffic from the right travel lanes
  - Fatigue cracking on the inside detail would not occur for 15 years
  - Monitor detail on a more frequent basis (say every 12 months)
- **2-in diameter arrest holes in the deck plate**
- **Separation of the web transverse stiffener from the deck plate**
- **Combined repair schemes**

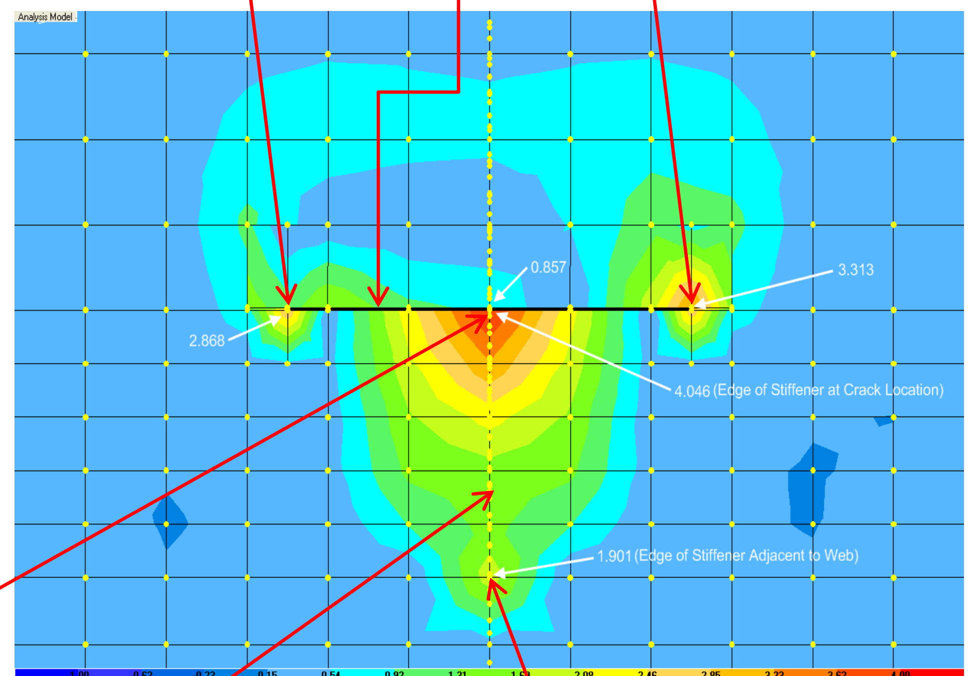
Analytical Results if No Repair Action

- A 5-in long crack modeled (typical cracking found).
- The deck stresses redistributed and decreased, but not enough.
- The stress ranges implies further crack may occur.

Crack

3.2 ksi at tip of crack

3.6 ksi at tip of crack



4.5 ksi at stiffener (crack location)

Stiffener location

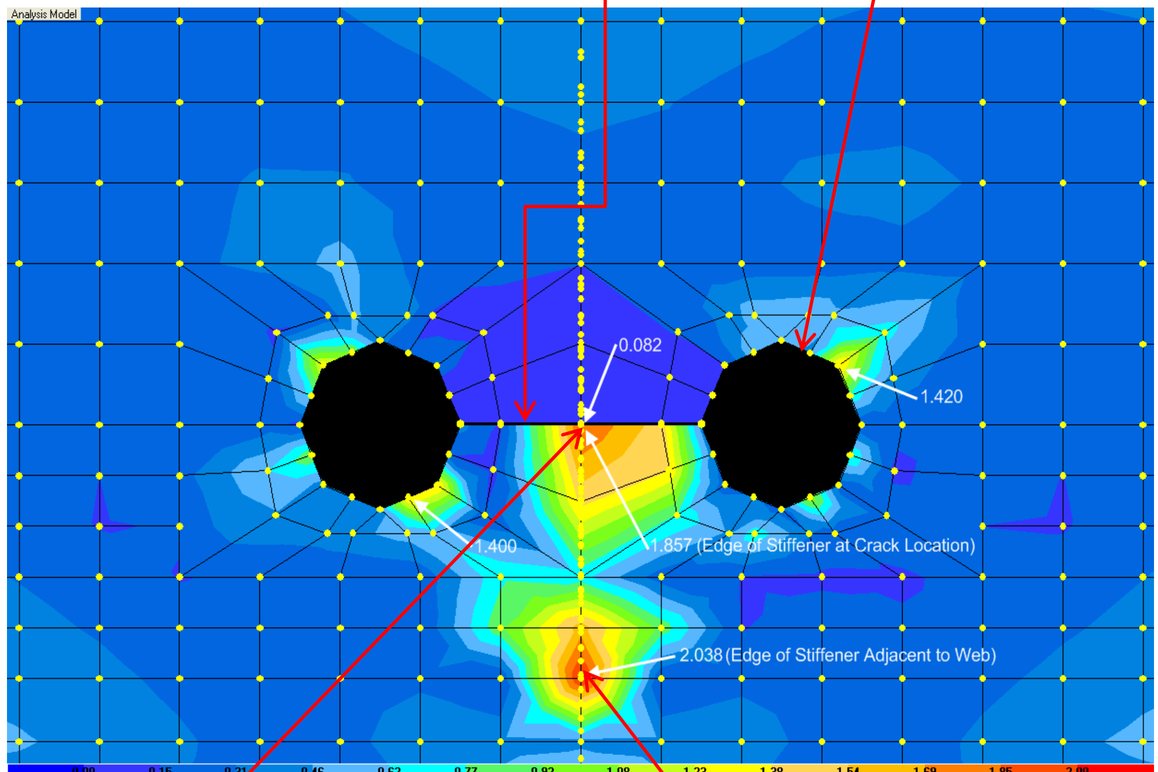
2.1 ksi at stiffener edge near web

2-in Diameter Arresting Holes

- Two 2-in diameter holes.
- The stress range at crack decreased by 54%.
- All stress ranges less than 4.4 ksi.

Crack

2" Hole (typ.)



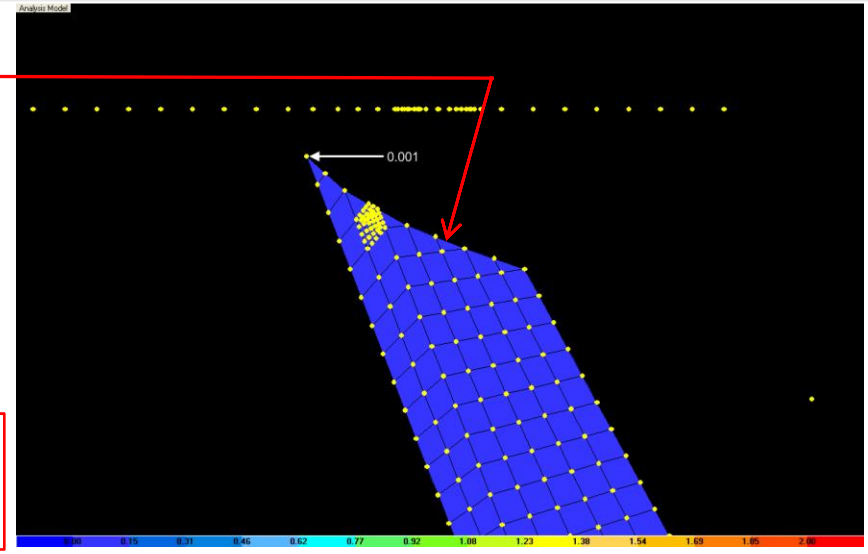
2.0 ksi at stiffener (crack location)

2.2 ksi at stiffener edge near web

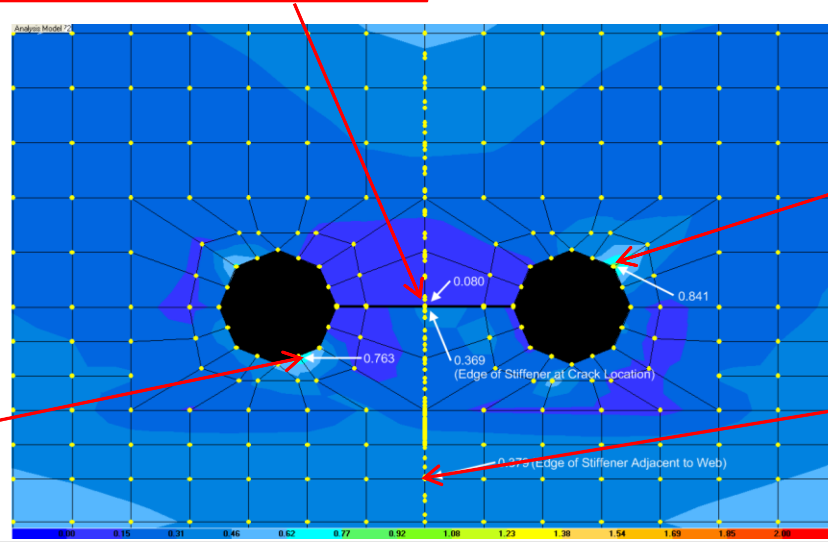
2-in Diameter Arresting Holes and Cutting Web Stiffener

- The web transverse stiffener to deck connection removed.
- The stresses in the deck significantly reduced.

7” Radius Circular Cut



0.4 ksi at stiffener (crack location)



0.9 ksi at the drilled hole

0.9 ksi at the drilled hole

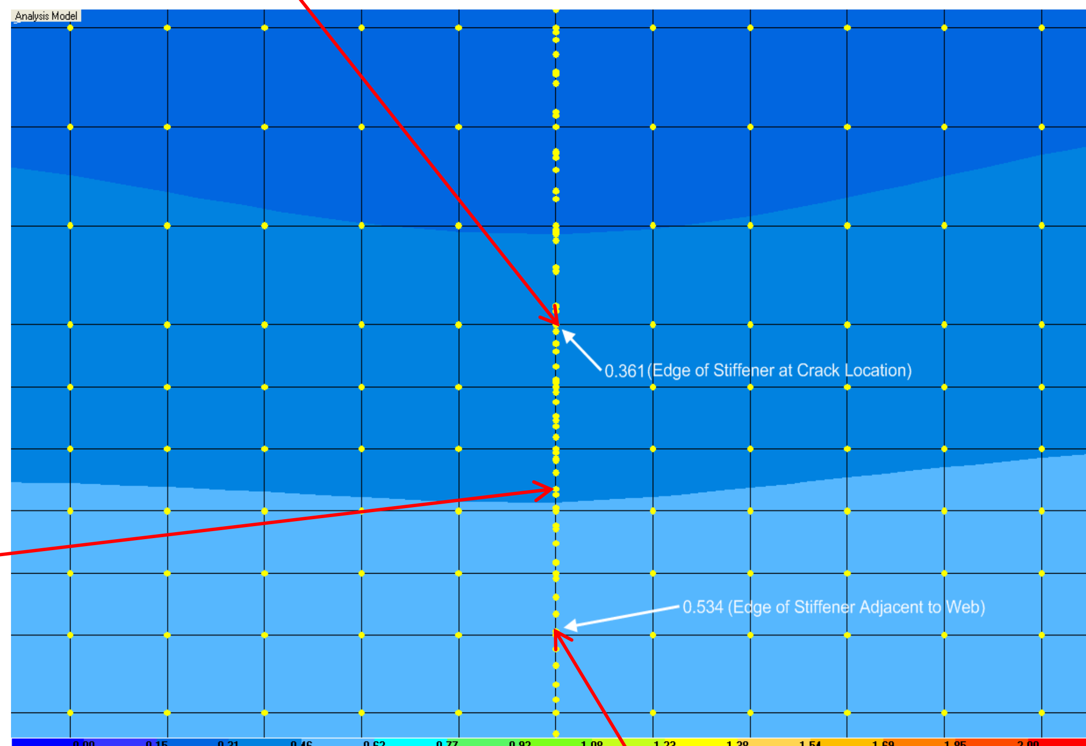
0.4 ksi at stiffener edge near web

Cutting Web Stiffener at Locations with No Cracking

- The web transverse stiffener to deck connection removed.
- The stresses in the deck significantly reduced.

0.4 ksi at stiffener edge (vs. 6.6 ksi)

Web Stiffener location

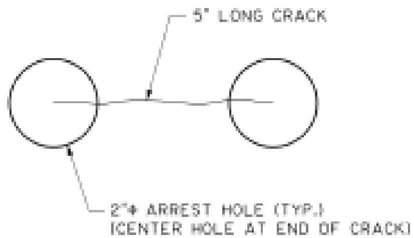


0.6 ksi at stiffener edge near web

Fatigue Stress Ranges Vs. Repair Schemes

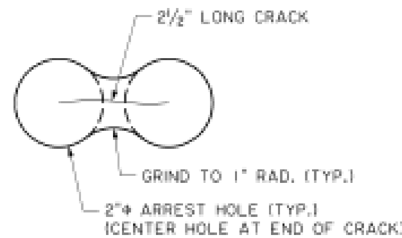
3-D Models/Repair Schemes	At Crack Initiation	Stiffener Edge Near Web	Tip of Crack/Hole	Web at Stiffener Location
	(ksi)	(ksi)	(ksi)	(ksi)
As Built Condition	6.6	0.3	N/A	0.3
5-in Crack Occurred	4.5	2.1	3.6	0.6
5-in Crack + 2-in Ø Arrest Holes	2.0	2.2	1.6	0.6
5-in Crack + 2-in Ø Arrest Holes + Cutting Stiffener	0.4	0.4	0.9	0.2
As Built Condition + Cutting Stiffener	0.4	0.6	N/A	0.3

Repair Plans: Drilled Patterns



DRILL PATTERN - 5" LONG CRACK

N.T.S.



DRILL PATTERN - 2 ½" LONG CRACK

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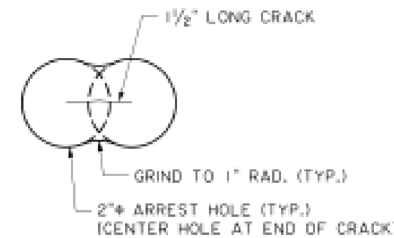
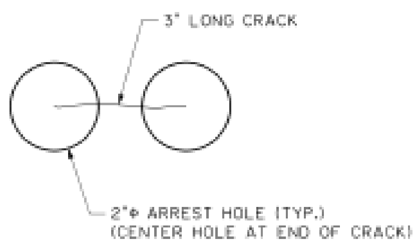


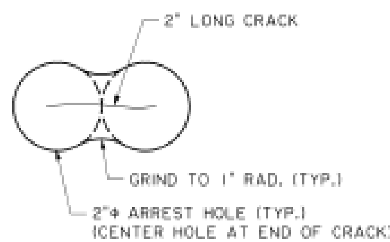
DRILL PATTERN - 1 ½" LONG CRACK

N.T.S.



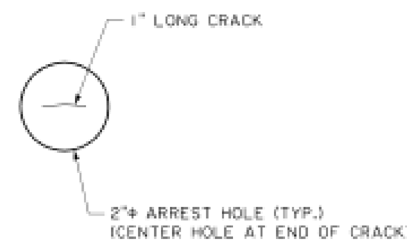
DRILL PATTERN - 3" LONG CRACK

N.T.S.



DRILL PATTERN - 2" LONG CRACK

N.T.S.



DRILL PATTERN - 1" LONG CRACK

N.T.S.

Repair Plans: Cutting Transverse Stiffeners

WORKING INSIDE THE BOX GIRDER

1. CLEAN THE AREA USING SP-3/PWB FOR 12 INCHES EACH SIDE OF THE TRANSVERSE STIFFENER.
2. ESTABLISH WP#1 AT THE END OF THE WELDS. THIS POINT IS IDENTIFIED AS THE INTERSECTION OF A TANGENT LINE AT THE ENDS OF WELD WITH THE CENTERLINE OF TRANSVERSE STIFFENER.
3. CUT THE TOP OF THE TRANSVERSE STIFFENER TO WITHIN 5/16-INCH OF THE ORTHOTROPIC STEEL PLATE AS SHOWN IN DETAIL A.
4. REMOVE THE TOP OF THE TRANSVERSE STIFFENER BY CUTTING ON A 7-INCH RADIUS FROM A POINT NEAR THE TOP OF STIFFENER WITHIN 5/15-INCH OF THE WEB TO THE EXISTING ANGLE BREAKPOINT IN THE STIFFENER.
5. REMOVE THE REMAINING PORTION OF THE TOP OF STIFFENER BY GRINDING AND BUFFING.
6. PERFORM MAGNETIC PARTICLE (MP) TESTING ON THE UNDERSIDE OF THE ORTHOTROPIC

Acknowledgement

- Owner of the Bridge: Louisiana DOT & Development
- CTL – prime consultant for design & inspection
- IBT – prime consultant for construction management
- TranSystems – subconsultant to CTL & IBT

Thank you and any questions?

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