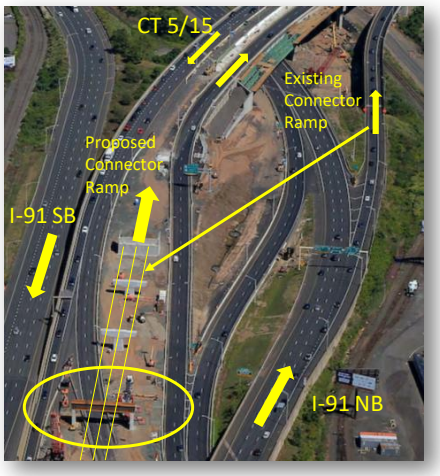
Design, Fabrication, and Construction of a Redundant Three I-Girder Straddle Beam

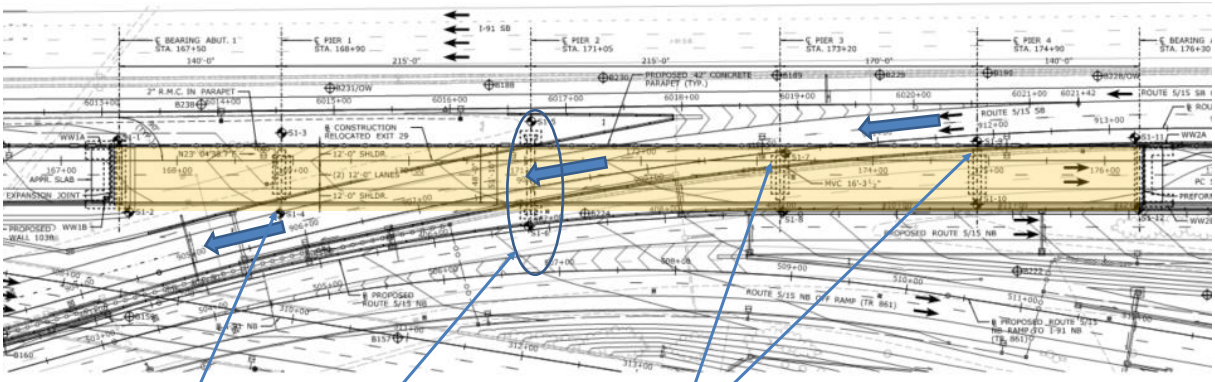
Presented by: Michael P. Culmo, CHA Consulting, Inc.
Ronnie Medlock, High Steel Structures

Project Profile

- Major Interchange Reconstruction
- New Connector Ramp:
  - I-91 North to Route 84 East
  - Eliminate narrow and steep 1 lane ramp
  - Add new 2 lane high-speed connector ramp
- Design Challenge
  - New bridge crosses CT Route 5/15 SB at a very flat angle
  - Result: Need for a straddle bent



CTDOT New Ramp Bridge



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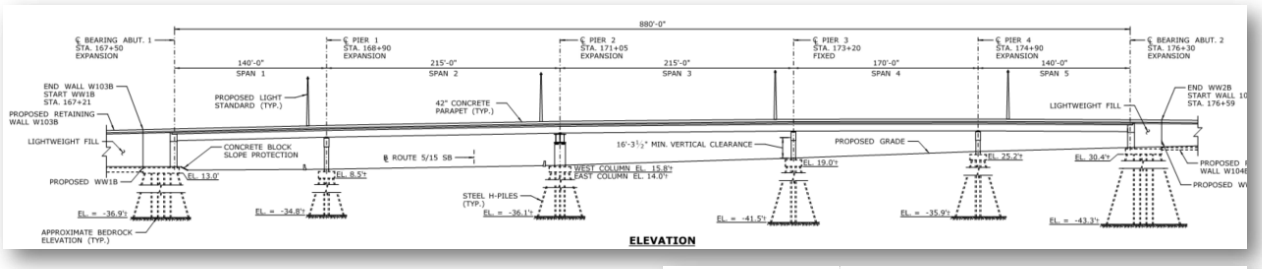
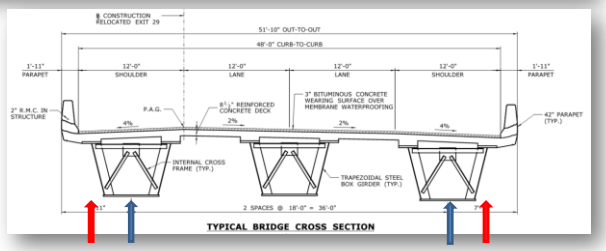
New Ramp Bridge



- 5 Span Overpass
  - 140’-215’-215’-170-140’
  - Weathering Steel Box Girders
  - Tub girders chosen
    - Favorable span/depth ratio
    - Reduces Hammer Head width by 8 feet
    - Aesthetics



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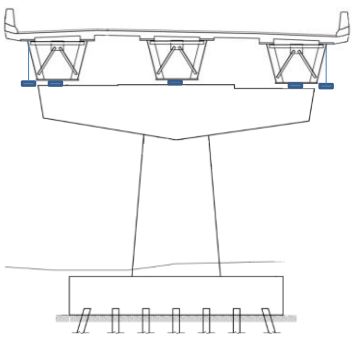
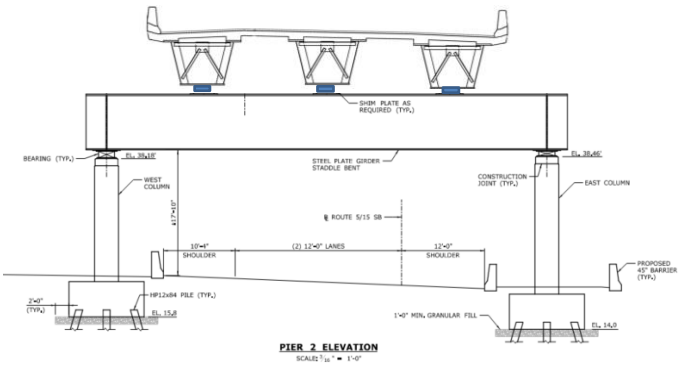
Typical Substructure Configurations





FHWA Redundant member approaches

- Internal redundancy (IRM)
  - Use of mechanically fastened built-up members to reduce overall fracture potential
  - Bolted plates and angles ➡ Lots of bolts = $$

"A steel primary member in tension, or with a tension element, that is not qualified as an LPRM but has redundancy in the cross-section such that fracture of one element will not propagate through the entire member, and is discoverable by the applicable inspection procedures."

- System Redundancy

"A steel primary member in tension, or with a tension element, that is not qualified as an LPRM but has redundancy in the bridge system, such that fracture of one cross section of the member will not cause a portion of or the entire bridge to collapse."

- Load Path Redundancy

"A steel primary member in tension, or with a tension element, that has redundancy based on the number of main supporting members between points of support, such that fracture of one cross section of one member will not cause a portion of or the entire bridge to collapse."

Source: FHWA PPT presented at 2019 AASHTO COBS Annual Meeting

FHWA Redundant member approaches

- Load Path Redundancy Members (LPRM)

  - Note: LPRMs are usually longitudinal and parallel, such as girders or trusses. Redundancy can be determined by engineering judgement or simple calculation. Primary members in common girder bridges with three or more girders are classified as LPRMs in most cases.

Source: FHWA PPT presented at 2019 AASHTO COBS Annual Meeting

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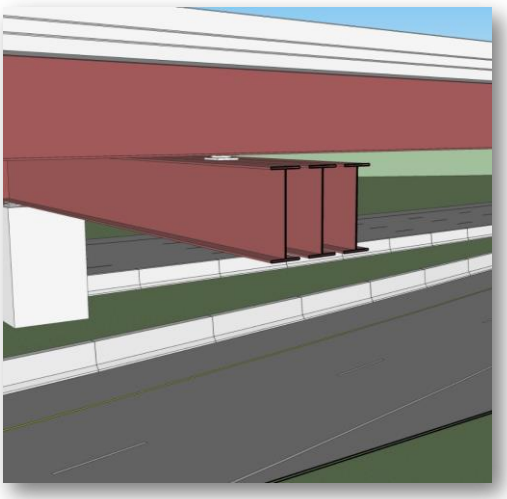
Straddle Bent Design Concept



Cutaway section through the bent

Concept:

- Replace Bolted Box Girder with triple I-Girder

Goals:

- Eliminate Non-redundant Designation
  - Load Path Redundant
- Facilitate shipping and erection
  - Break into pieces that can be assembled on site
  - Can be erected in one piece or three

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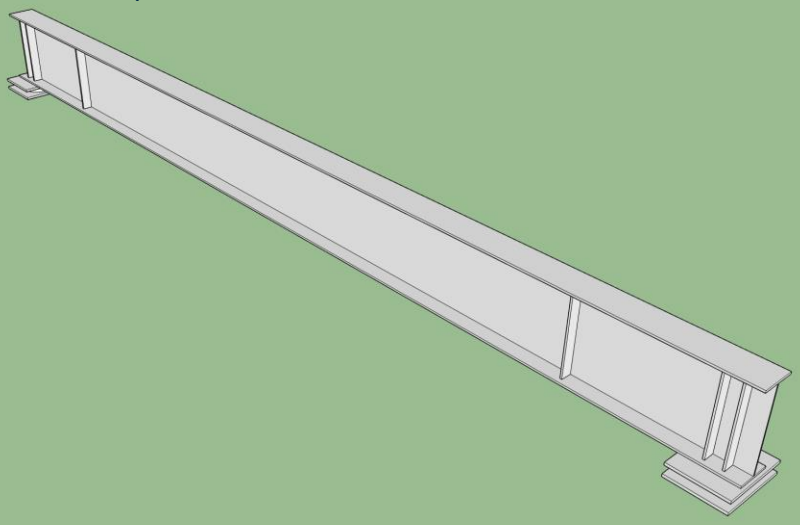
Integral Straddle Bent Concept



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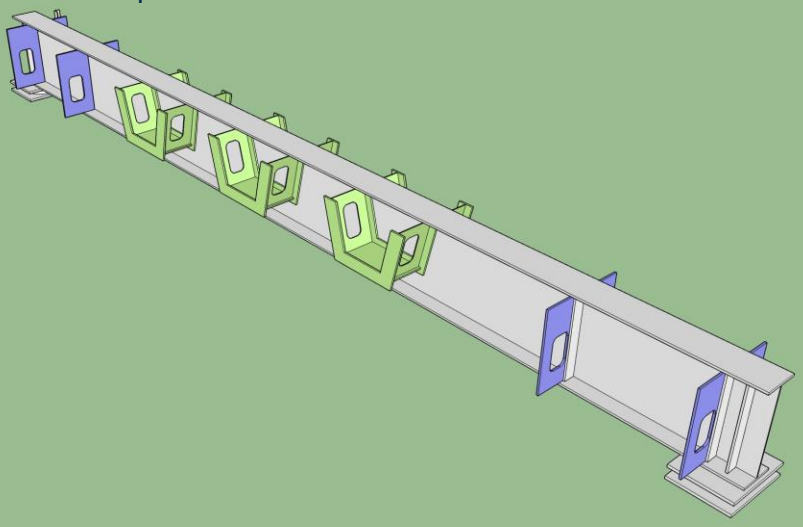
Integral Straddle Bent Concept



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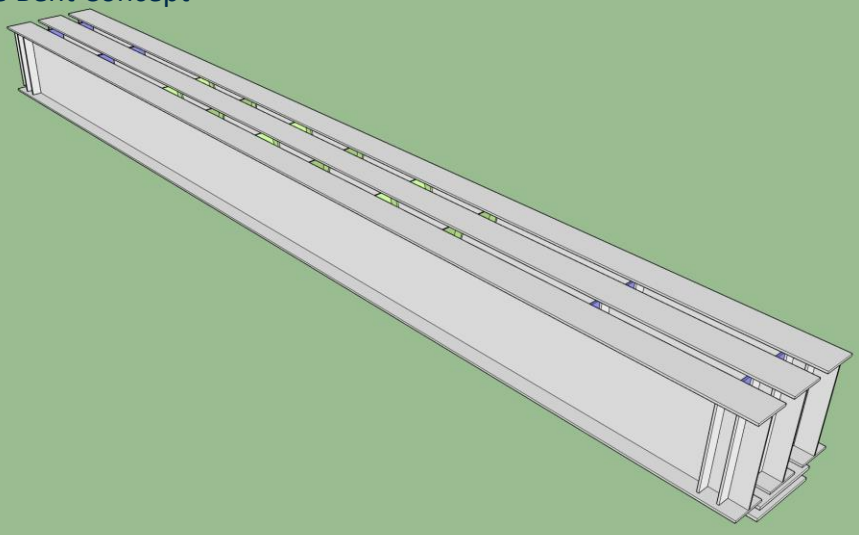
Integral Straddle Bent Concept



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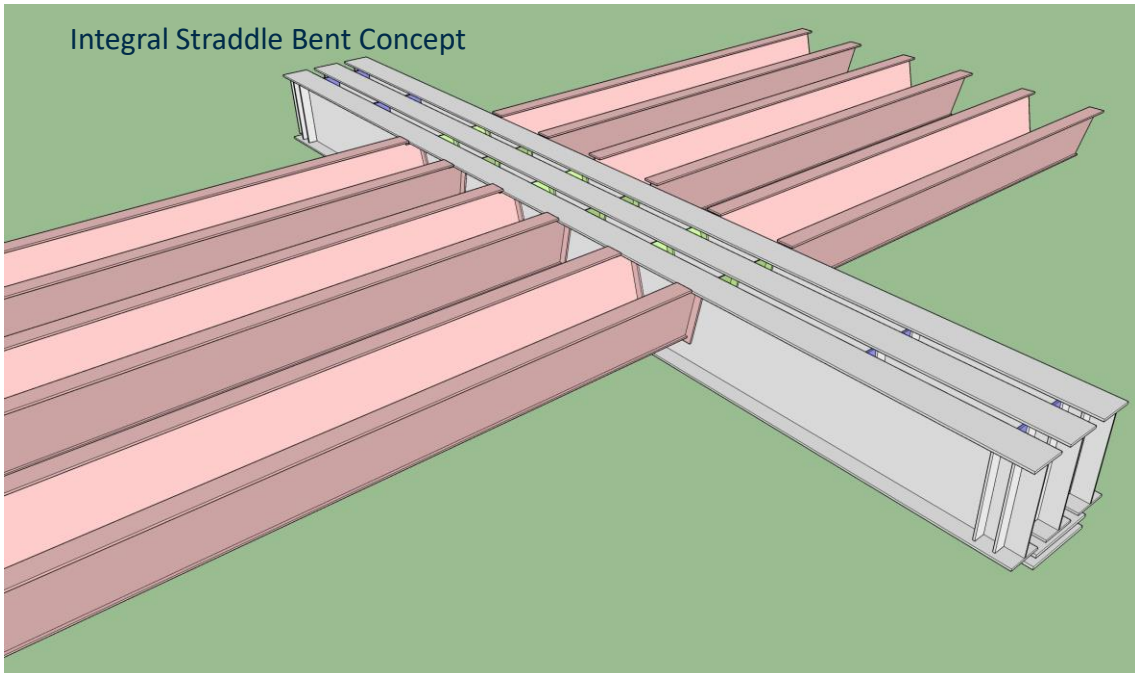
Integral Straddle Bent Concept



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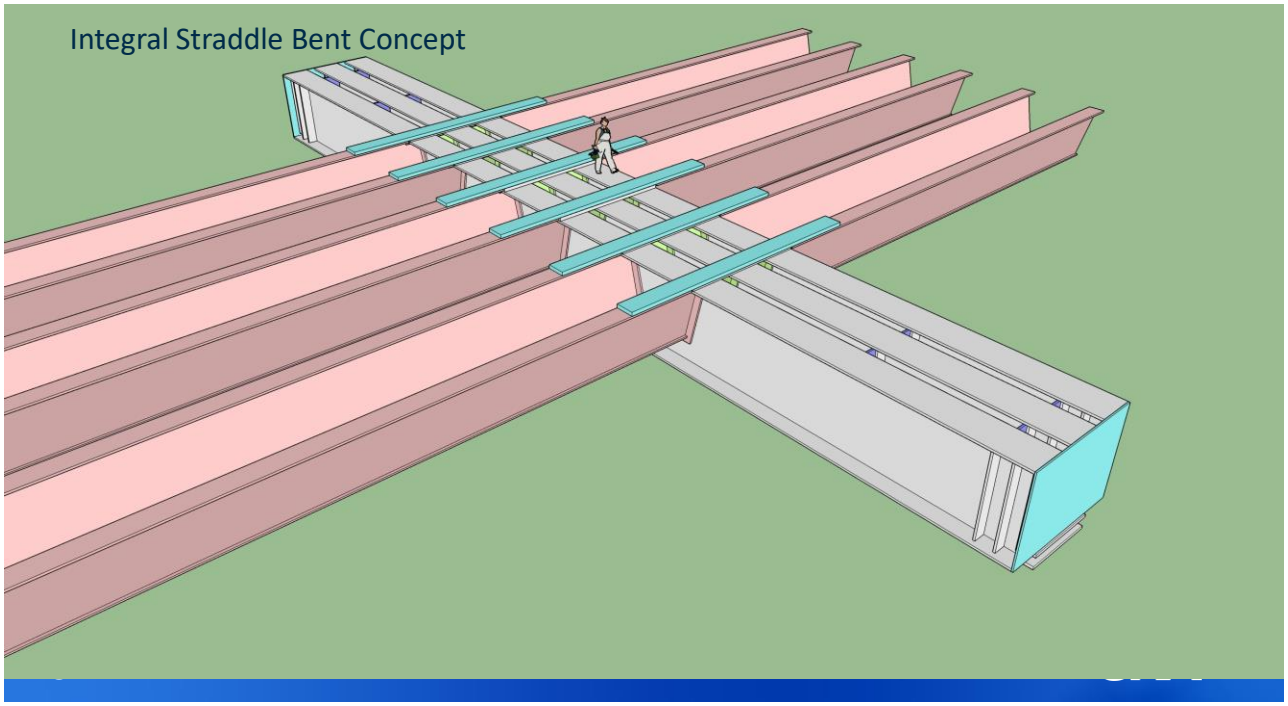
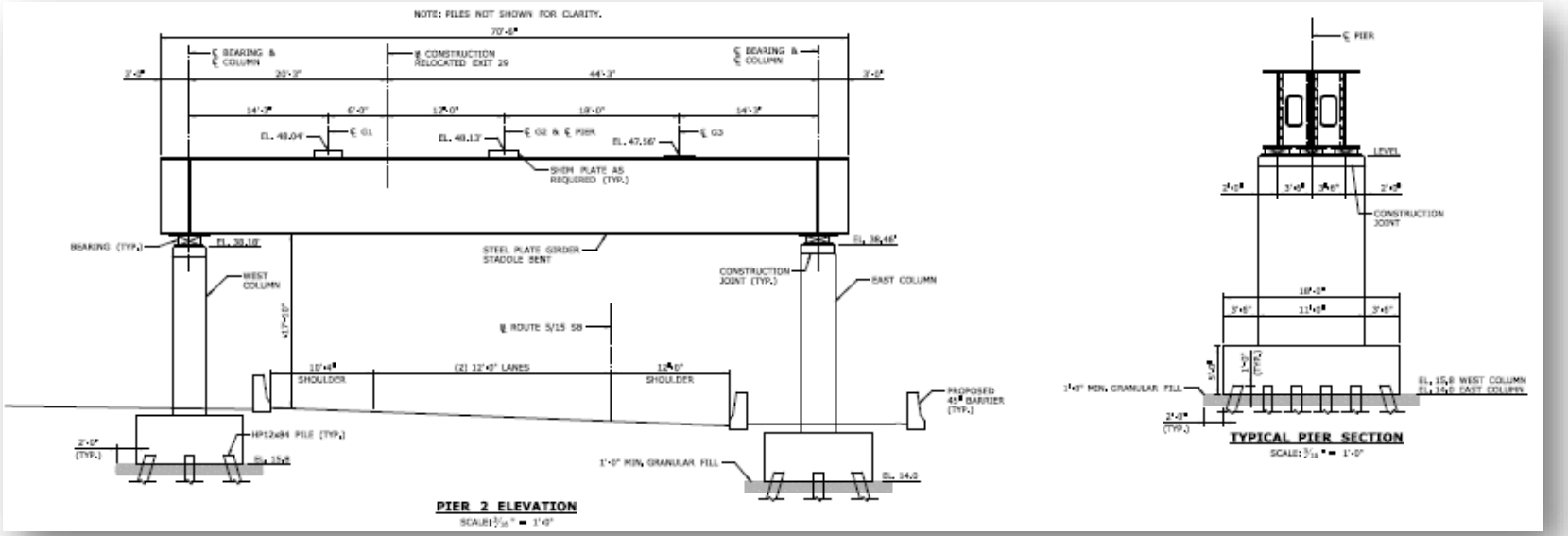

Integral Straddle Bent Concept

Innovative Three-I-Girder Straddle Bent
Fabrication Considerations



Ronnie Medlock, PE

VP – Technical Services
High Steel Structures, LLC

ABCD of NEOH
27 November 2023

NO.	REVISION	BY	CHK	DATE
3	REVISED EDGE GRINDING NOTE	EF		1-9-20
2	ADDED CLEANING AND PAINT SECTIONS.	EF	SG	11-4-19
1	CORRECTED SHOP PROCEDURE NOTE	HC	SG	10-1-19

HIGH STEEL STRUCTURES LLC
An Affiliate of High Industries Inc.

GENERAL SHOP NOTES
BRIDGE 06947, RELOCATION OF RTE. I-91 NB INTERCHANGE 29 (SITE #10)
RTE. I-91 NB STA. 167+50 TO STA. 176+30
TOWN OF HARTFORD, CONNECTICUT
STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

STATE CONT. OR REF. NO.	63-703 ℄ 159-191	FED. AID. PROJ. NO.	1063(1043)0912(136)
GENERAL CONTRACTOR	O ℄ G INDUSTRIES, INC.	HSS PROJ. MGR	JOHN FLAUD
DETAILER		MADE BY: EF	CHK'D BY: DATE: 7-27-19
HSS PROJ NUMBER	1180238D-4	DRAWING NUMBER	GN401 of GN401

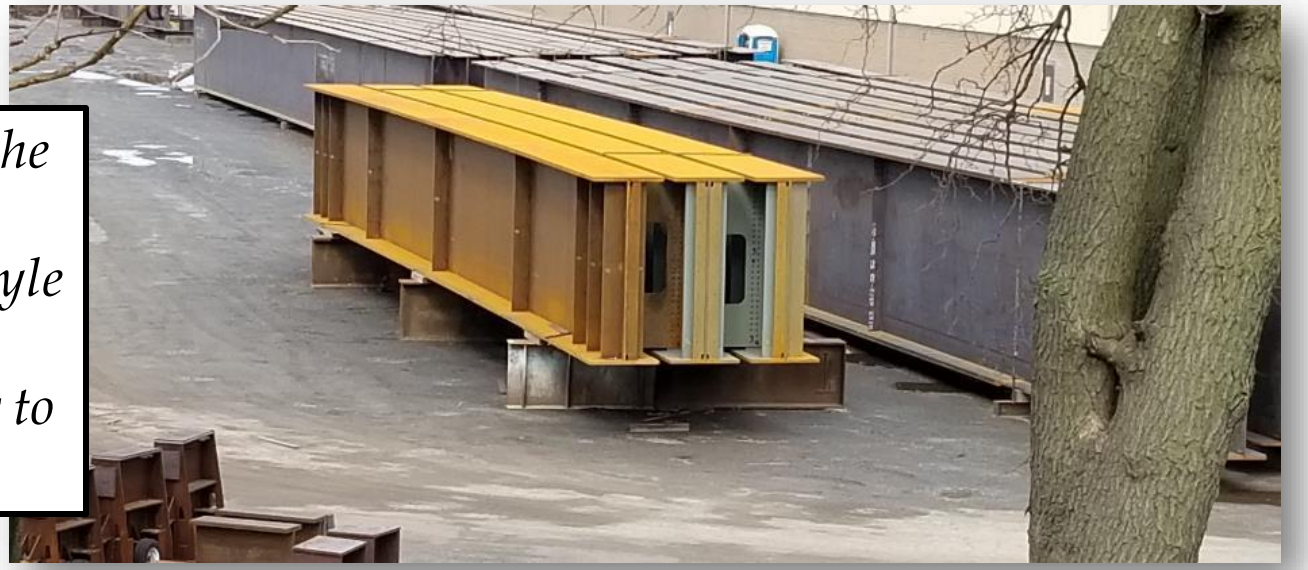
HOLES | BOLTS | COATING | CODE(S) | SCALE | CT

Straddle Bent Styles

box with CJP weld corners

box with bolted corners

~ ½ to 2/3 the cost of the other box style caps and much faster to build

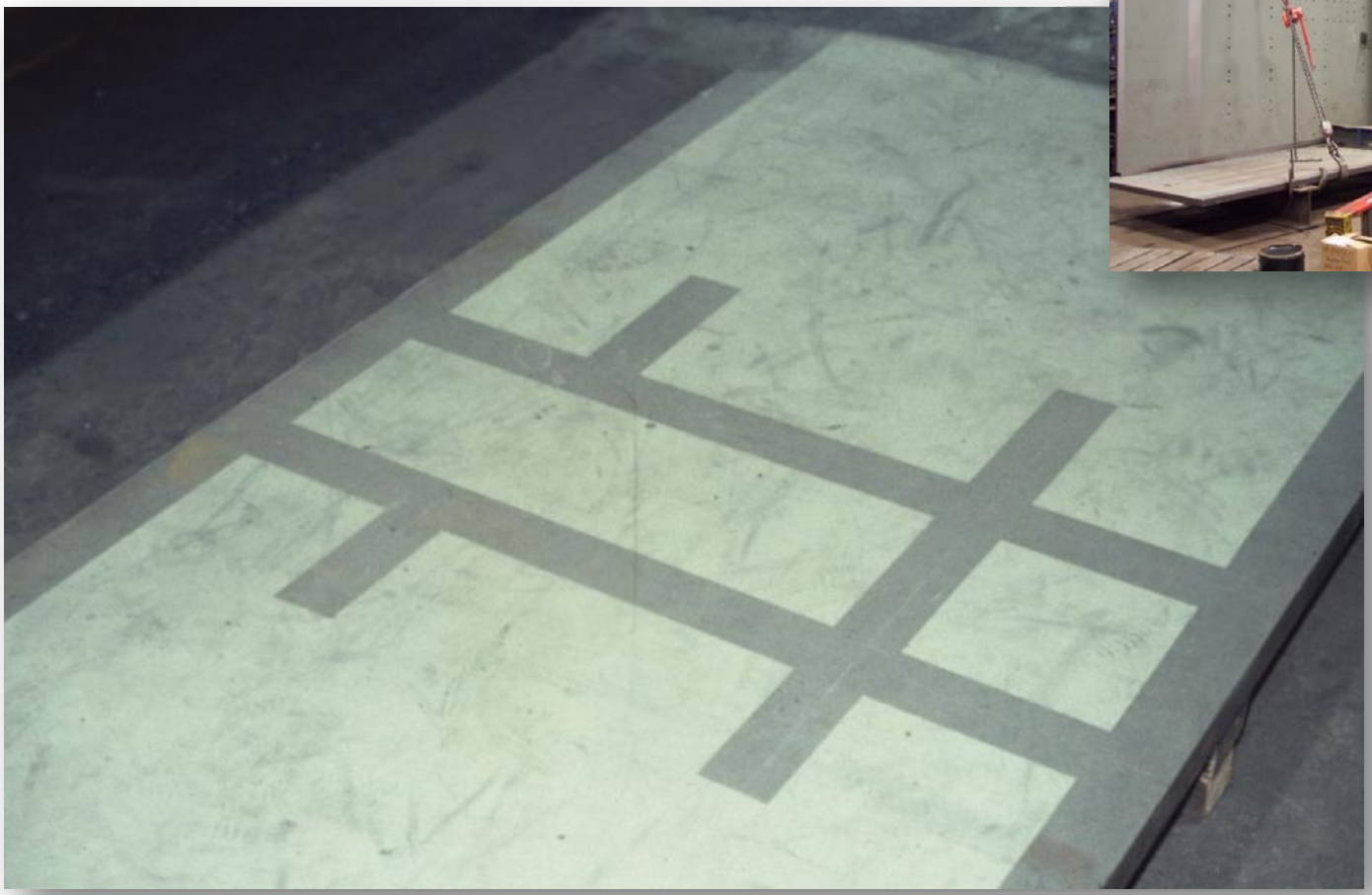


three I-girder

Box Building

- Common method is to start with a web and flange, then add internal elements, then add second web, then add second flange
- A lot of effort needed to keep the box square and fit the webs and flanges to internal elements

Three girder cap:
normal girder building versus box building



Three girder cap:

Prime coat after fabrication of components is complete

Box Building

- Two stage prime coating - if the inside of the box is painted, the webs and flanges are usually preblasted and primed before building

Box Building

- Complete joint penetration (CJP) corner groove welds require a lot of effort
- Steps:
  - Bevel the web
  - Attach backing with tack welds (inside the groove)
  - Join the webs to flange with tack weld (again, inside the groove)
  - Weld – could be one or two dozen passes
  - Test (UT)

Three girder cap:

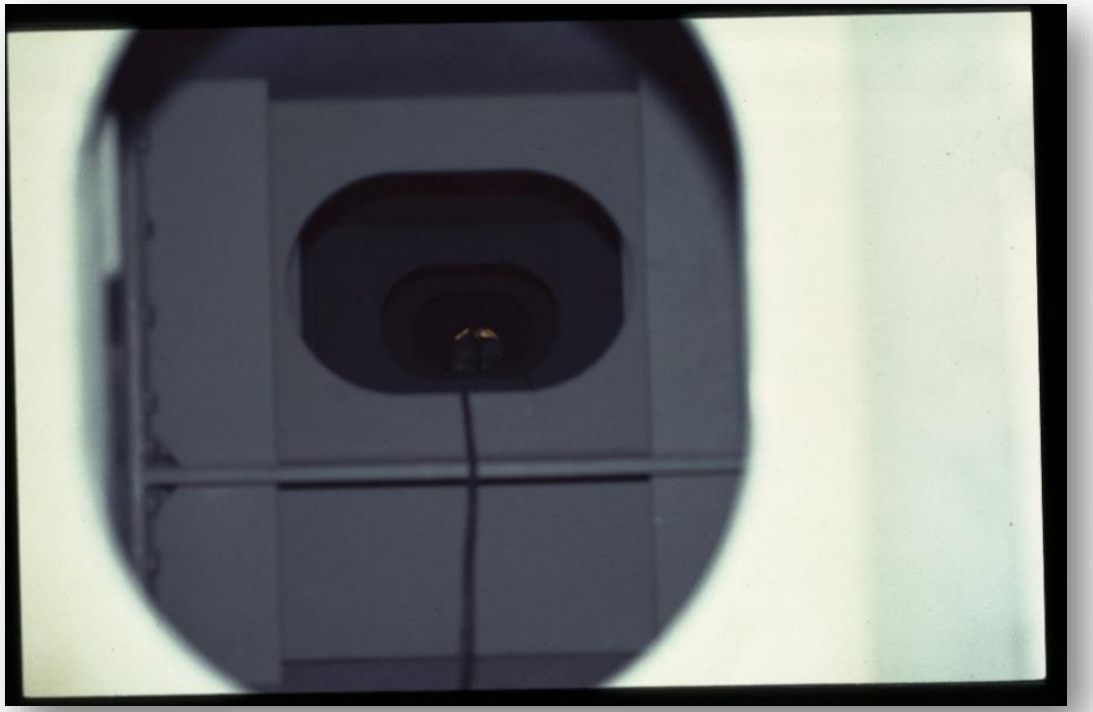
No CJP corner groove welds

Box Building

- Working inside is a safety hazard
- Two workers required for any given task

Box Building

- Working inside is challenging and increases normal effort, particularly for moving equipment and selves through the box



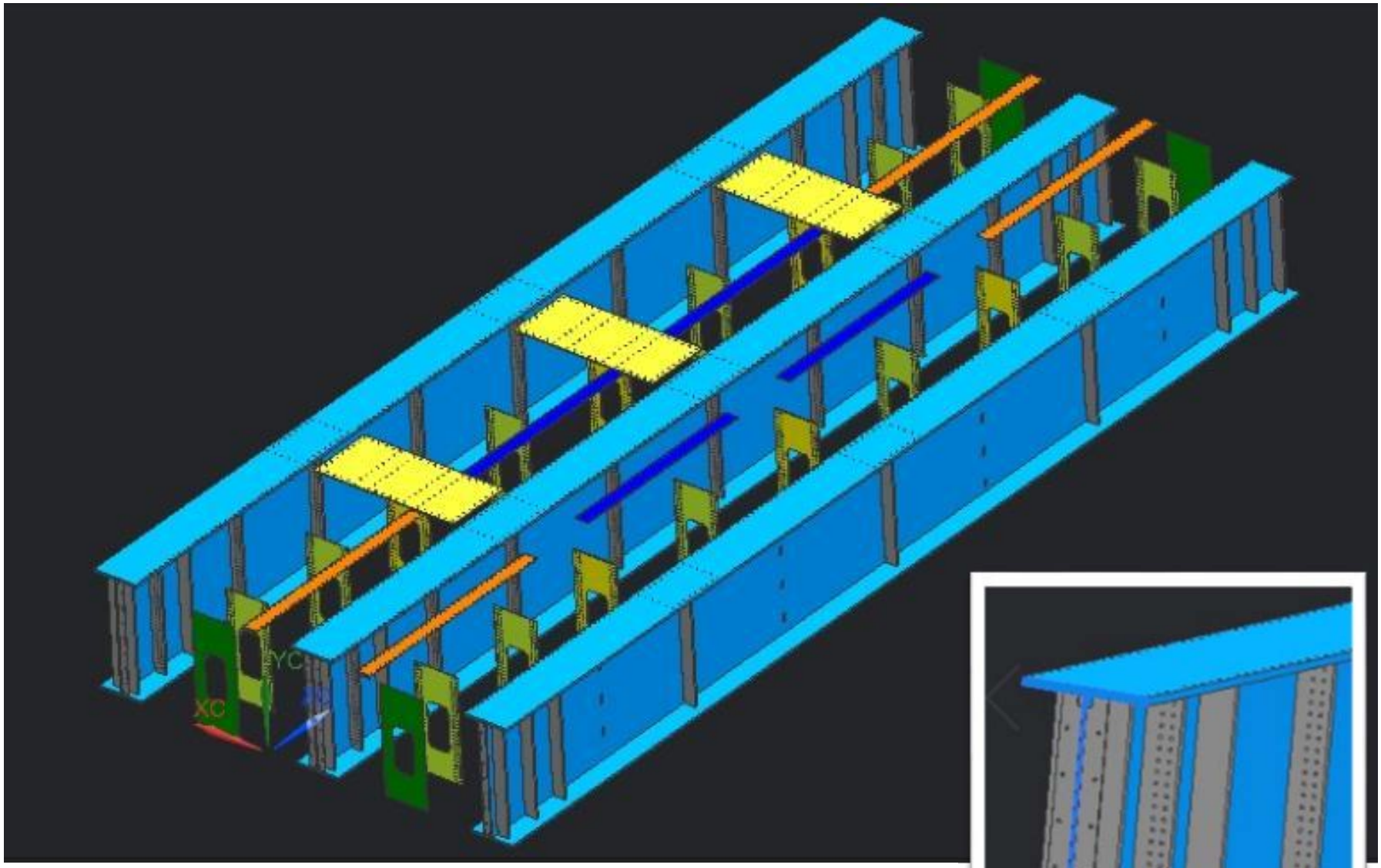
Three girder cap:

No confined space work

No dragging equipment in and out of the box

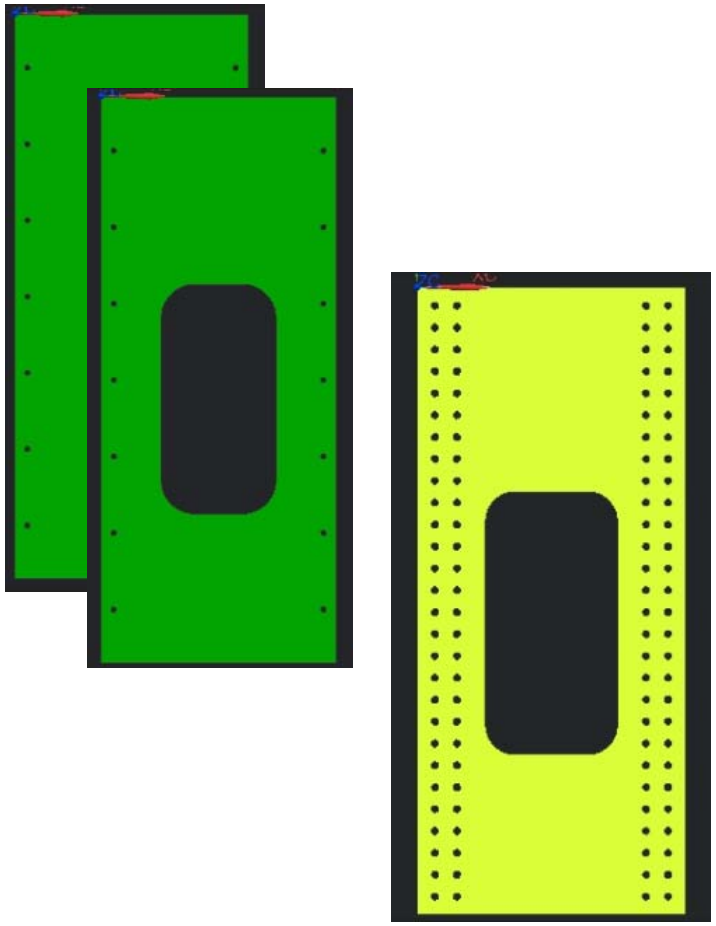
No working in the heat of the box in awkward positions

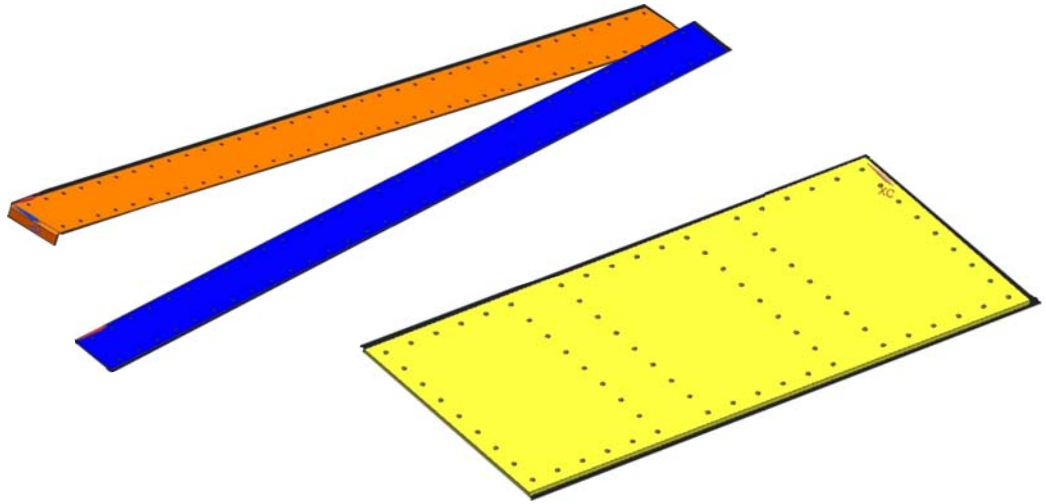
Three I-girder straddle bent (cap) building, by comparison

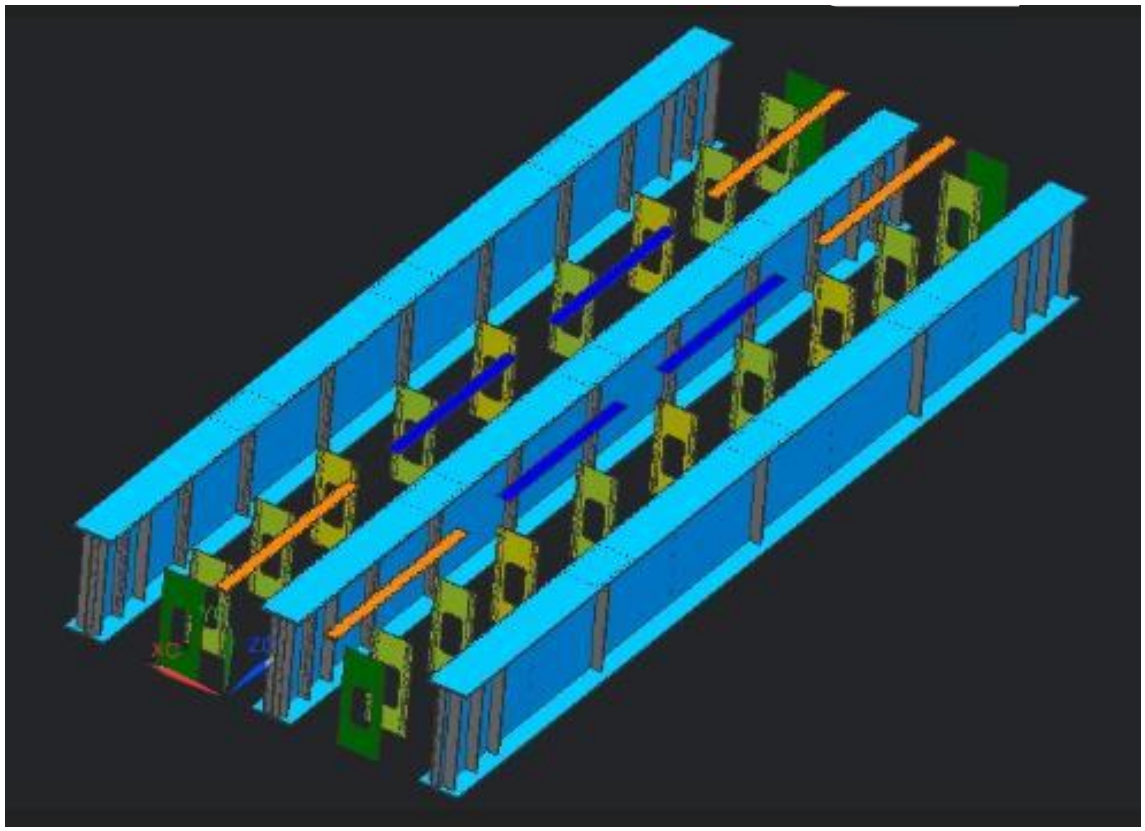


Three I-girder Cap – fabrication includes

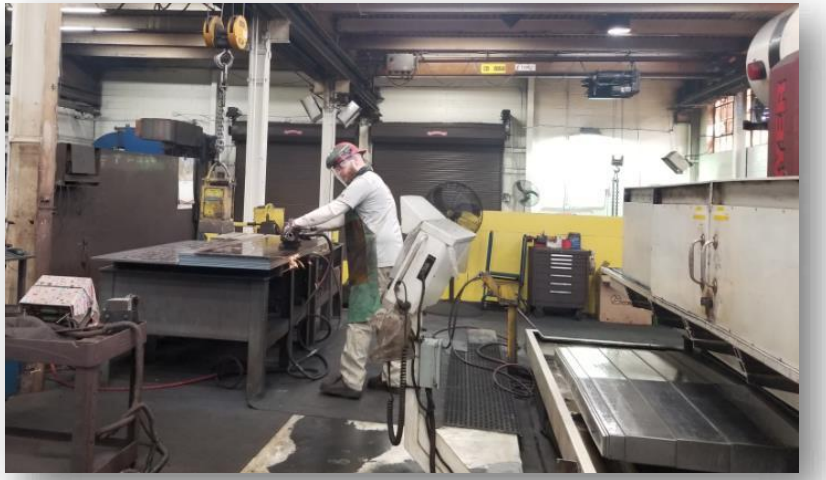
- Three I-girders
- 33 processed plates

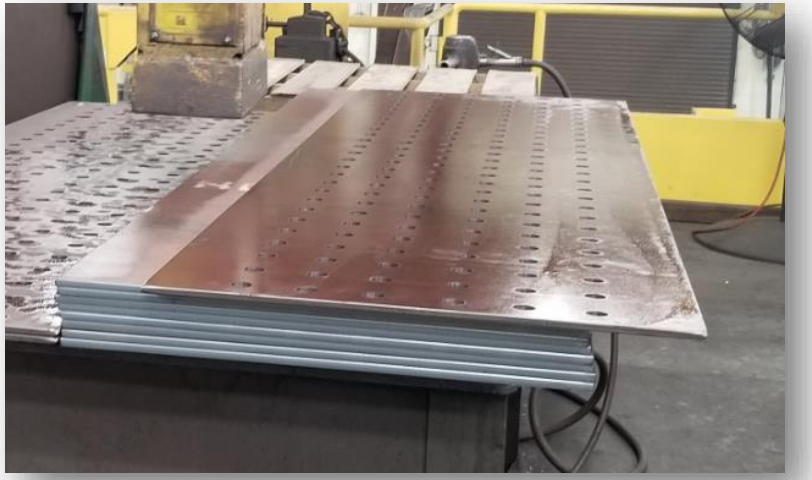






- 33 plates
  - Four end diaphragms in two styles
  - 18 internal diaphragms, one style
  - Eight stitch plates in two styles
  - Three top plates





This machine does CNC drilling

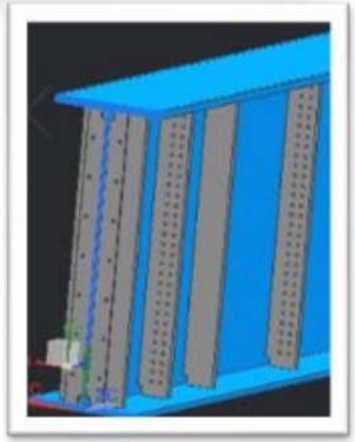
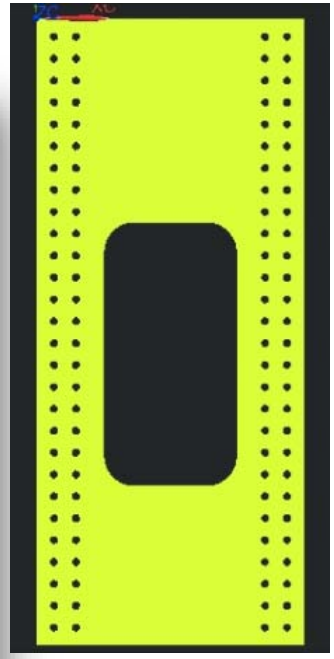


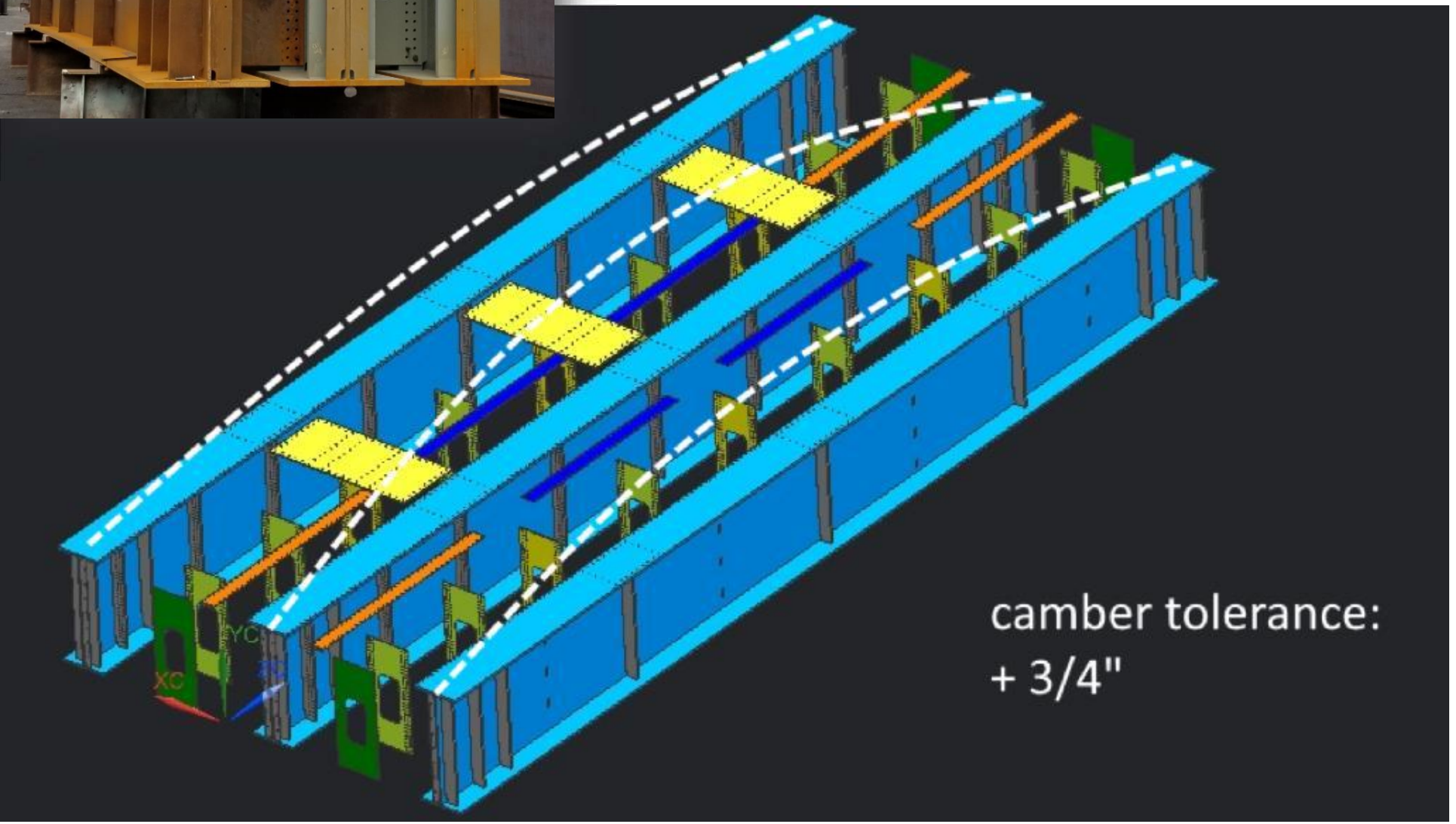
Plate Processing – 33 plates, including diaphragms, stitch plates, and top plates are programmed and then cut and drilled by CNC

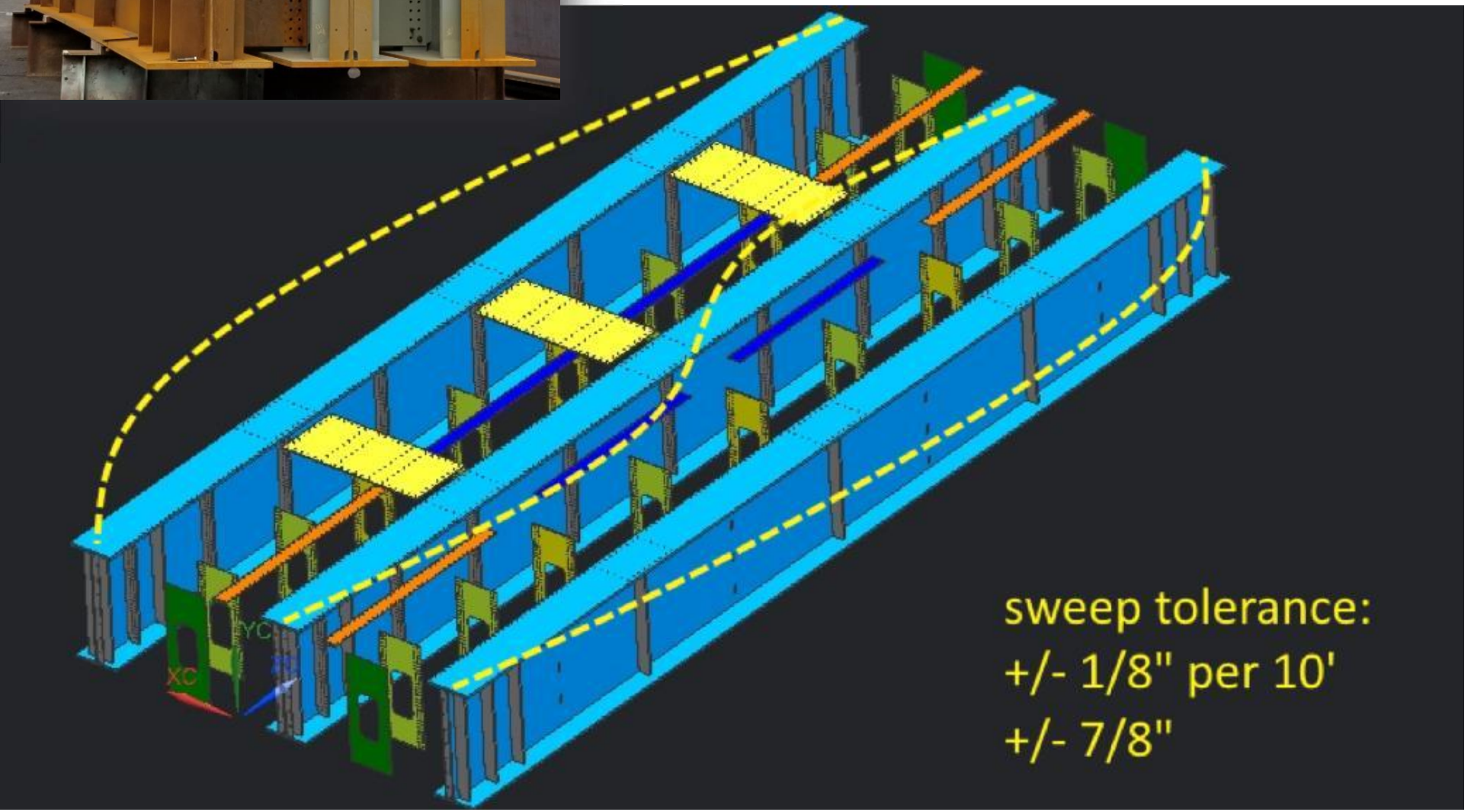
Plate processing



This machine does CNC cutting and drilling

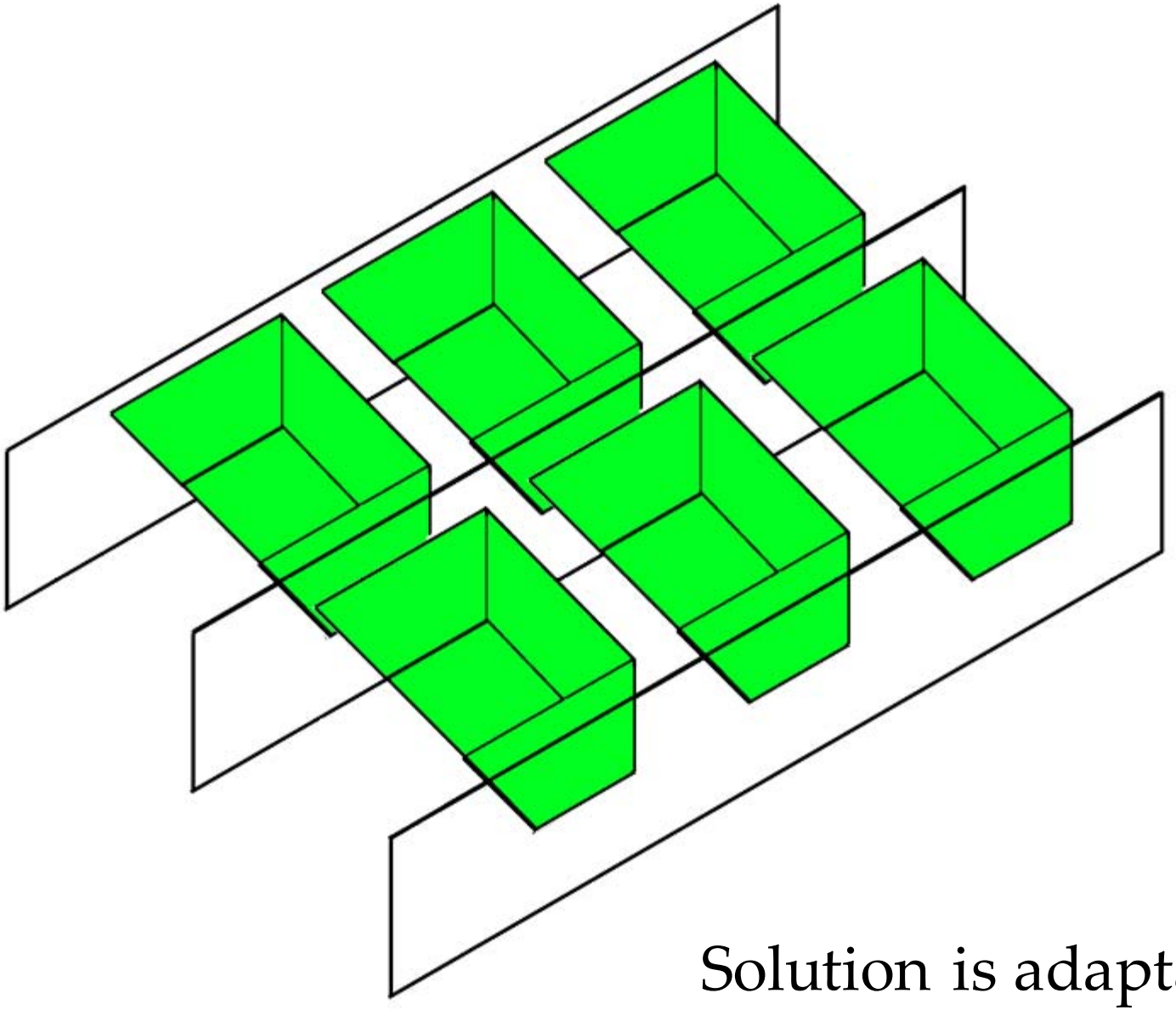
- NB: The cap assembly is not as flexible as a traditional three girder assembly


YC
XC
camber tolerance:
+ 3/4"


YC
XC
sweep tolerance:
+/- 1/8" per 10'
+/- 7/8"

Tolerances

- Normal sweep and camber tolerances insufficient
- Fabricators make their own adjustments based on the constraints they see

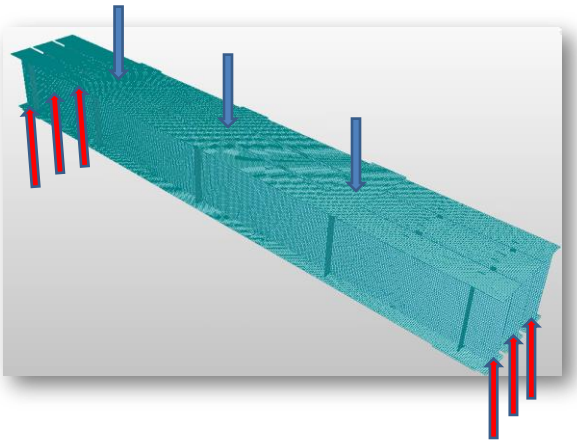


Solution is adaptable to frame-through tub superstructure

Fabrication Summary

- The three-girder cap not only helps with redundancy, but it is also economical
  - Much faster through the shop
  - About half to two-thirds the cost of a traditional box with CJPs groove weld corners or bolted corners
- It is basically made by building three girders, processing diaphragms and other plates, and bolting them together
- Ease of fabrication is highly dependent upon CNC processing
  - Connection plate bolt hole patterns must match diaphragm bolt hole patterns
  - With CNC, these parts are accurately drilled separately
  - Traditional drilling (subsize and ream, templates in assembly) negate fabrication advantages
- Girders are built to tolerances that are tighter than usual, particularly regarding sweep
  - As needed for fit-up and assembly
  - Can get there reading with tighter controls and heat correction (as needed)

Design



Analysis Approach

- 3D FEA used to model transfer of bearing loads from center girder to fascia girders
- Interaction of superstructure with straddle bent cap was modeled
- Designed prior to current AASHTO Redundancy Guide
- Conservative design used to ensure redundancy and minimize deflection

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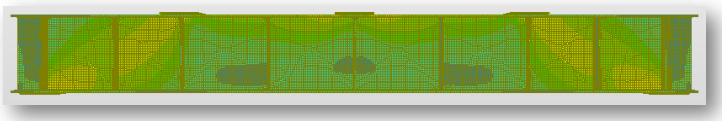
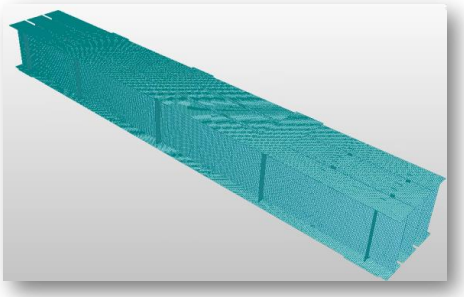
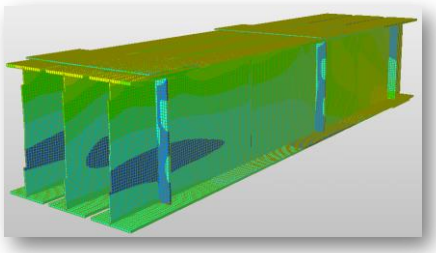
FEA Analysis



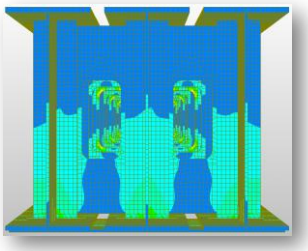
Center girder stresses (Strength I)



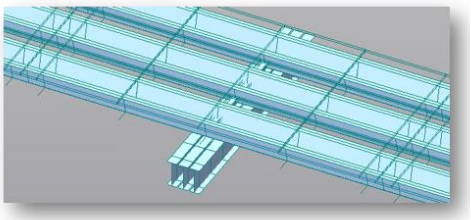
Overall Model



Section near mid span



Perspective Section Showing Stresses in Diaphragms



Grillage Model

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Efficiency and Cost Effectiveness

- Steel Sections
  - Flange areas are essentially the same as a box girder straddle bent
  - There is slightly more web area
- Fabrication
  - During design, the thought was that fabrication costs would be similar
- Transportation and Erection
  - Can be shipped in pieces to reduce weight = avoid overweight permits
  - Can be erected in pieces = potentially smaller cranes
  - Gave the contractor more flexibility

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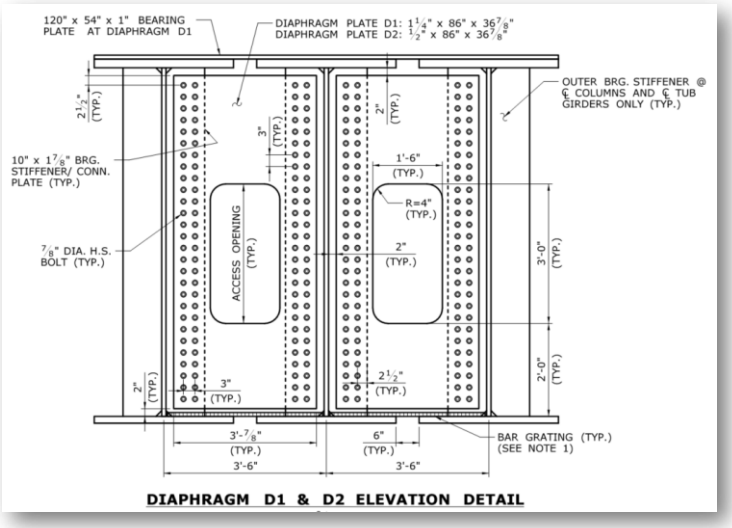
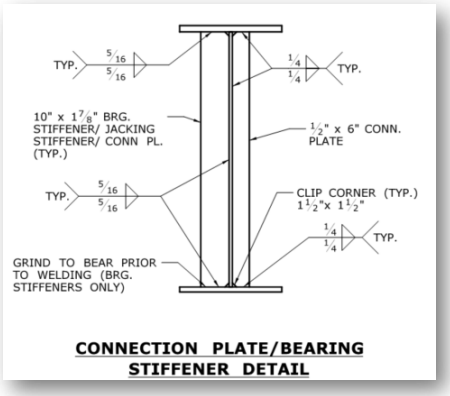
Details





Fatigue and fracture resistance of this section is very well known

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Fabrication

- Comments on Fabrication of the Triple I Girder Straddle Bent

High Streel Structures

HIGH STEEL STRUCTURES LLC
An Affiliate of High Industries Inc.

Construction

Shipping and Assembly

- Two shipped as a pair
- Third added on site

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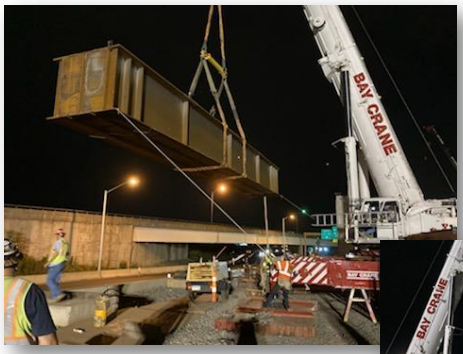
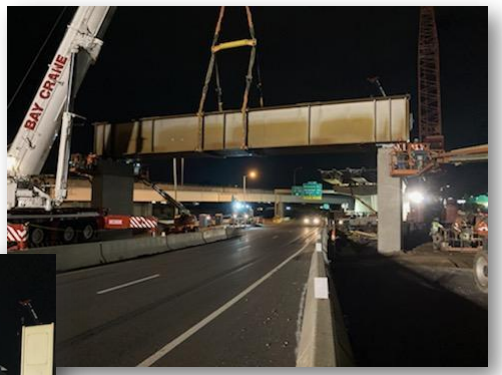
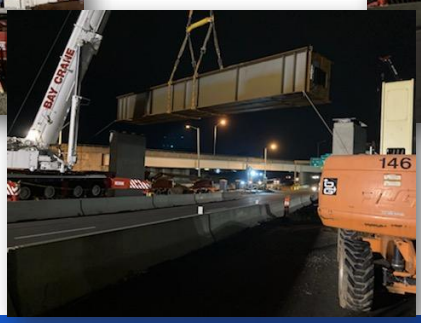
Construction







Erection

- Erected as a single unit
- Large crane was available for box girder erection the next day

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Construction

Tub Girder Erected

21

Construction

22

Construction

Second Tub Girder Erected

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Construction

Erection of all Spans Complete

24

Construction

Construction Complete

25

Construction

Construction Complete

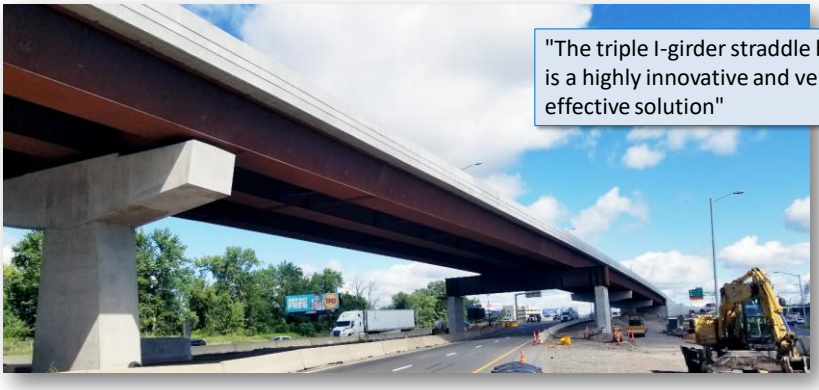
26

Construction

Construction Complete

27

Awards



AISC/NSBA Prize Bridge Awards:

- 2022 Prize Bridge Award: Medium Span Category
- 2022 Bridge of the Year

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Redundancy Design

Fracture mechanics basics

- Fracture typically follows fatigue:
  - If fatigue cracks were to occur, they grow, slowly at first.
  - At some point, the crack may become unstable and lead to a fracture.

The reality of a straddle bent cap design

- They carry a lot of dead load and a smaller portion of live load. The strength limit state typically controls the design.
- The fatigue loading specified in AASHTO LRFD BDS is a **single truck** with a lower load factor and impact factor
- Result is a very low fatigue live load stress range in straddle bent caps
- We design for infinite fatigue life. These straddle bents typically meet this easily
- Result: The risk of a fatigue crack occurring is **very** low, therefore fracture risk is essentially zero.

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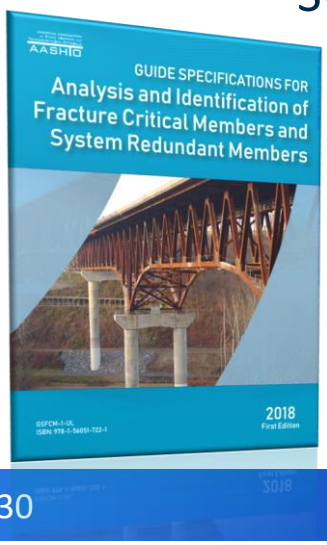
AASHTO Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members



- Provides a systematic method for determining if a member is fracture critical or system redundant
- Specifies two load combinations
- Defines “failure”

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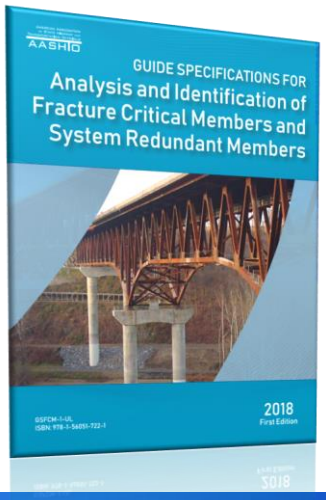
AASHTO Guide Specifications Provisions



- Load combinations

Redundancy I–Load combination relating to dead load and a point-in-time live load applied at the instant when the assumed failure of the member occurs. This load combination is intended to capture the effects of dynamic amplification during free vibration immediately following the member failure in the presence of dead load and live load.

Redundancy II–Load combination relating to the normal vehicular use of the bridge without wind after the failure of a primary member. This load combination is intended to characterize the loading scenario after the assumed fracture has occurred and the structure has reached a steady state.

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AASHTO Guide Specifications Provisions

- Load combinations

$$\gamma Q_n = (1 + DA_R)[\gamma_{DC} DC + \gamma_{DW} DW + \gamma_{LL}(LL + IM)]$$

Table 3.4-1—Load Combinations for Redundancy Evaluation for Bridges Fabricated to the AASHTO/AWS FCP

Load Combination	γ_{DC}	γ_{DW}	γ_{LL}	DA_R *	IM
Redundancy I	1.05	1.05	0.85	See Table 3.3.1-1	0.00
Redundancy II	1.05	1.05	1.30	0.00	0.15

*DA_R may be modified as specified in Article 3.3.2

Table 3.3.1-1—Dynamic Amplification Factor, DA_R

Structure Type	DA_R
Continuous twin tub bridges with individual spans less than 225 ft	0.20
All other bridge types to which these provisions apply.	0.40

Redundancy 1: $\gamma Q_n = 1.4[1.05DC + 1.05DW + 0.85LL]$

Redundancy 2: $\gamma Q_n = 1.0[1.05DC + 1.05DW + 1.30(1.15LL)]$

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Redundancy Design

- Recommended Approach
  - Option 1: Redundant by inspection, use η=1.00
    - Texas DOT uses this approach, FHWA and others have agreed
  - Option 2: Base Redundancy Factor on level of analysis
    - More conservative approach
    - Reduce risk through analysis:
    - Require analysis of the bent cap using the *AASHTO Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members.*
      - Non-linear FEA analysis
      - This guide specification was developed specifically for this purpose
    - If the analysis confirms redundancy, use η=1.00

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Conclusions

It is possible to design a straddle bent that is not fracture critical
- This design can be considered as a Load Path Redundant Member
- If there is a concern, use the *AASHTO Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members* to verify this

Integral and non-integral concepts were developed and studied
- Keep the details simple

Cost effective?
- Yes, much easier to fabricate
- Easier to ship
- Options for erection equipment

Aesthetics
- Same appearance as box girder straddle bent

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Questions?

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