Steel Design Considerations for Erection & Constructability

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Bismarck, ND

April 23, 2025

Overview

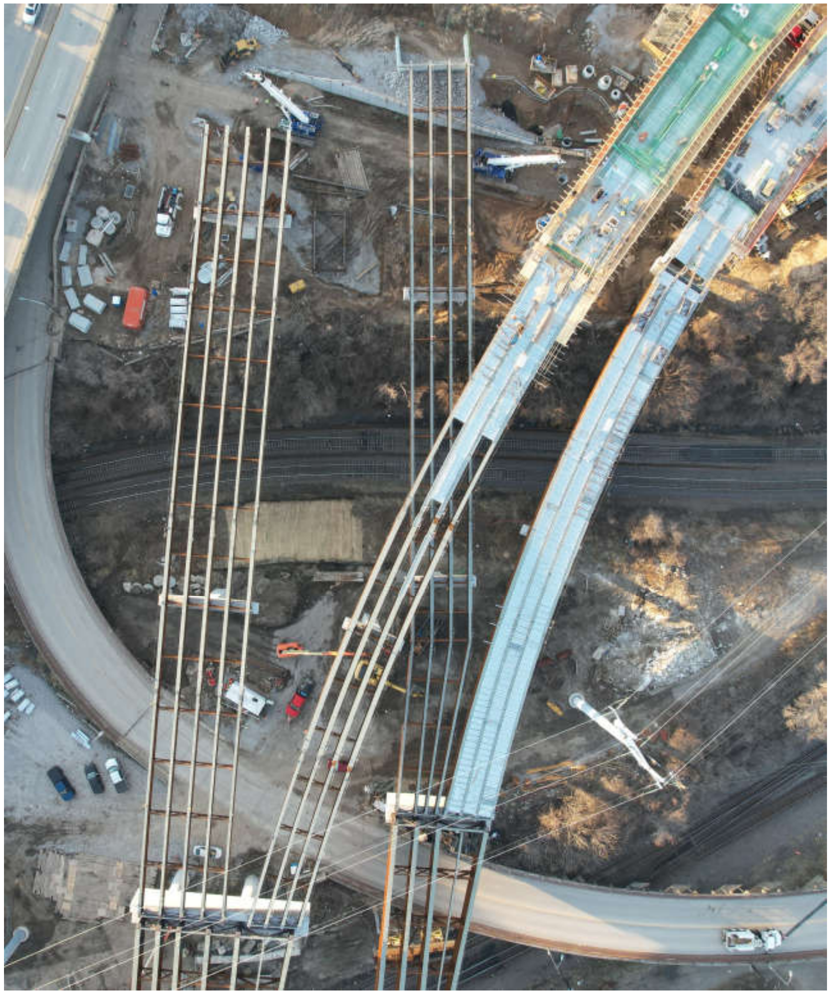
1. Erection Activities & Planning

2. Methodology & Resources

3. Role of Design Engineer

4. Designing for Constructability

5. Beyond I-Girders



US 169/I-35 Buck O'Neil Bridge

1. Erection Activities & Planning

- Fundamental Goal:

  Safely and accurately construct the bridge.

US 169/I-35 Buck O'Neil Bridge

1. Erection Activities & Planning

- Fundamental Goal:

  Safely and accurately construct the bridge

  - Stability and strength at all stages
  - No permanent distortion/distress

  - Understand and plan for site constraints
  - Prioritize repetition – simple, predictable
  - Minimize equipment and time

US 54 Champ Clark Bridge

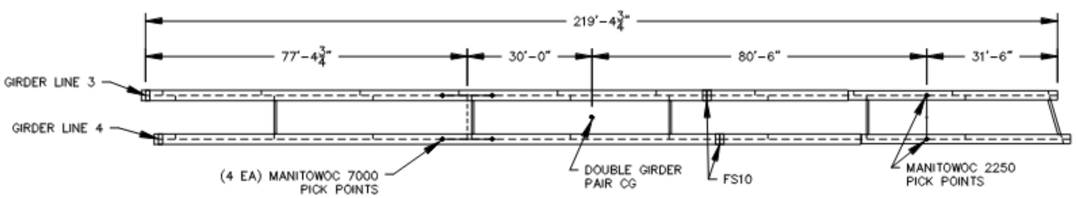
1. Erection Activities & Planning

- Site Access & Constraints
  - Storage, assembly, equipment locations
  - MOT, closure durations
  - Obstacles (over & under)

US 169/I-35 Buck O'Neil Bridge

1. Erection Activities & Planning

- Field Pieces & Assembly
  - Length, weight
  - Transportation & delivery route
  - Handling, tripping, picking
    - Local forces, stability/buckling
  - Ground/barge vs. in-air



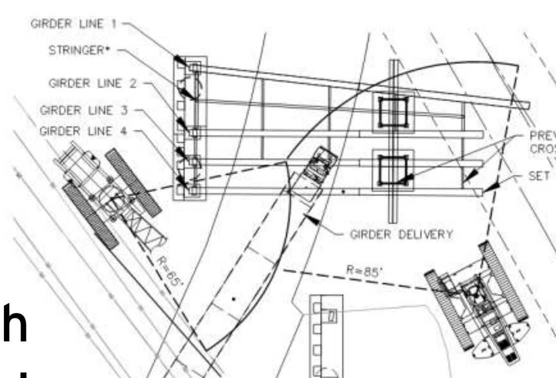
DOUBLE GIRDER PAIR PICK POINTS
(TOTAL WEIGHT 461.2 KIPS)

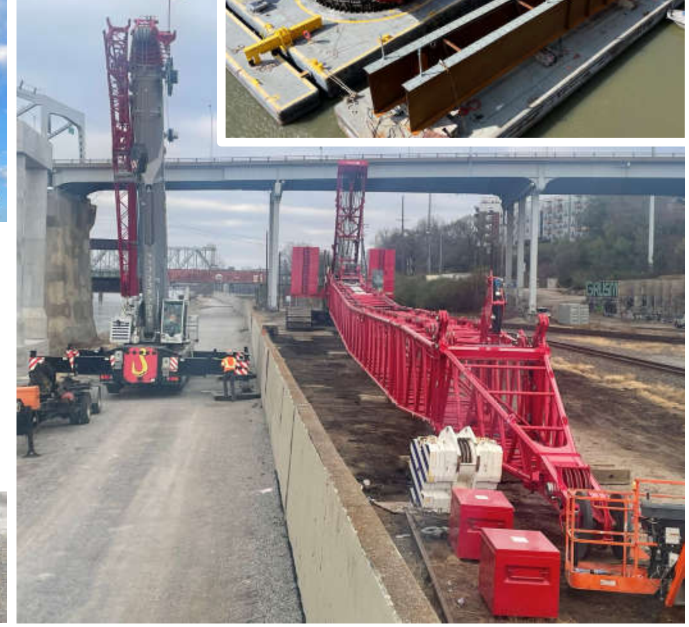
US 169/I-35 Buck O'Neil Bridge

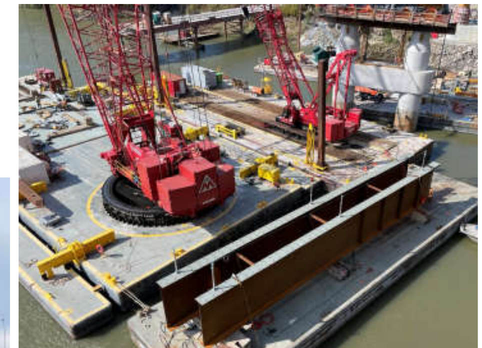
1. Erection Activities & Planning

- Crane Type, Capacity, Radius, Positioning
  - Lattice vs. telescoping; mobile/crawler/ringer
  - Spreaders, clamps, shackles, slings
  - Single or multi-crane picks
  - Static vs. walking

- Alternatives
  - Strand jack pull
  - Climbing jack push
  - Slide, SPMT, float-In
  - Incremental launch



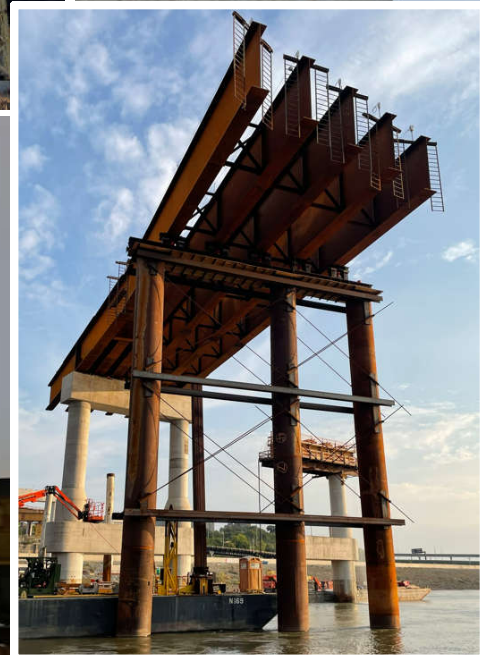




US 169/I-35 Buck O'Neil Bridge

1. Erection Activities & Planning

- Temporary Supports
  - Shoring / falsework bents
  - Pier brackets “angel wings”
  - Temp. lateral bracing
  - Longitudinal restraints

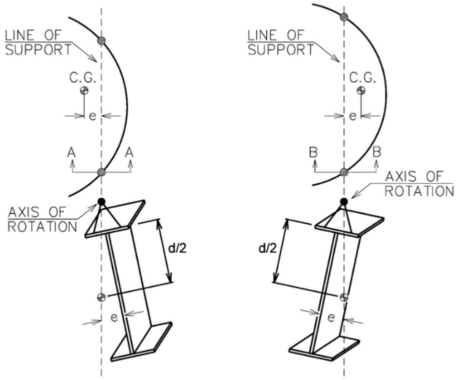


US 54 Champ Clark Bridge

US 169/I-35 Buck O’Neil Bridge

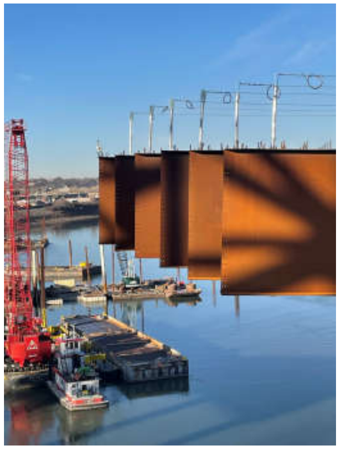
1. Erection Activities & Planning

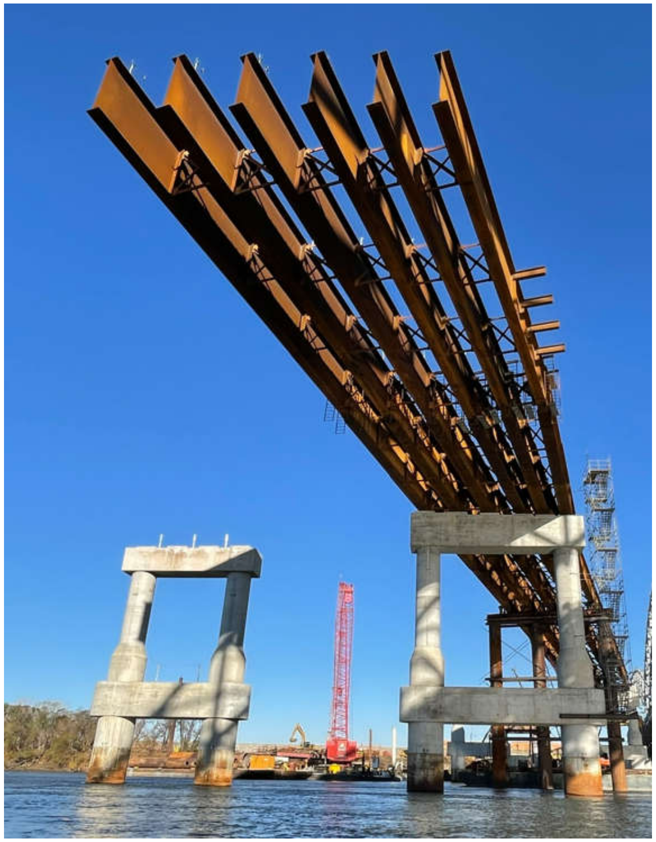
- Fit-Up
  - Vertical (Tip Deflection)
  - Longitudinal (Drop-In Segs.)
  - Warping & twist (Curve, Skew)
  - Hold & helper cranes
  - Shims, jacks



FHWA

I-235/13th St. Wichita Floodway





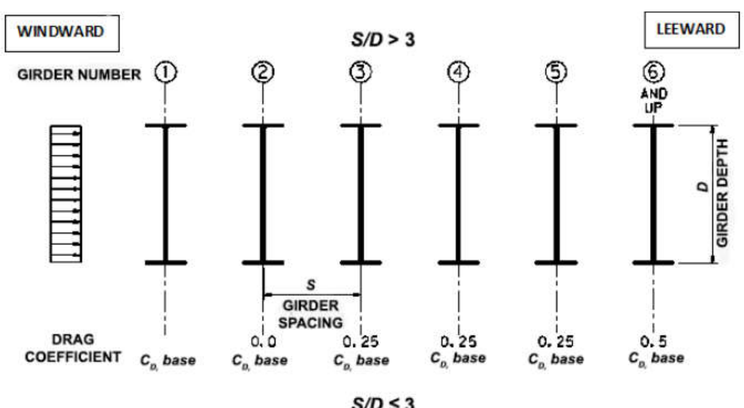
US 169/I-35 Buck O'Neil Bridge

1. Erection Activities & Planning

- Interim Configurations - Erection
  - Wind: active vs. inactive, forms present?
    - Duration, drag coeff., trailing girders
  - Member strength & stability
  - Connection adequacy, completeness
  - Cross frame install sequence

Table 4.2.1-1—Wind Speed Reduction Factor During Construction, *R*

Superstructure Construction Duration	Wind Speed Reduction Factor during Construction, *R*
0-6 weeks	0.65
6 weeks to 1 year	0.73
>1-2 years	0.75
>2-3 years	0.77
>3-7years	0.84



AASHTO

US 169/I-35 Buck O'Neil Bridge

1. Erection Activities & Planning

- Interim Configurations - Deck Placement
  - Continuous vs. skip-pour, deck joints
  - Finishing machine & temp. loads
  - Member & connection forces
  - Displacements -> camber, & fillets

	Sequence of Pours				
	Direction				
Segment	1	2	3	4	5
Pour Rate ✳	45	40	40	35	35

✳ Min. Rate of Pour Cu. Yds./Hr. (With Retarder)

The contractor shall pour and satisfactorily finish the slab pours at the rate given. Retarder shall be an approved type and retard the set of concrete to 6.0 hours.

US 169/I-35 Buck O'Neil Bridge

1. Erection Activities & Planning

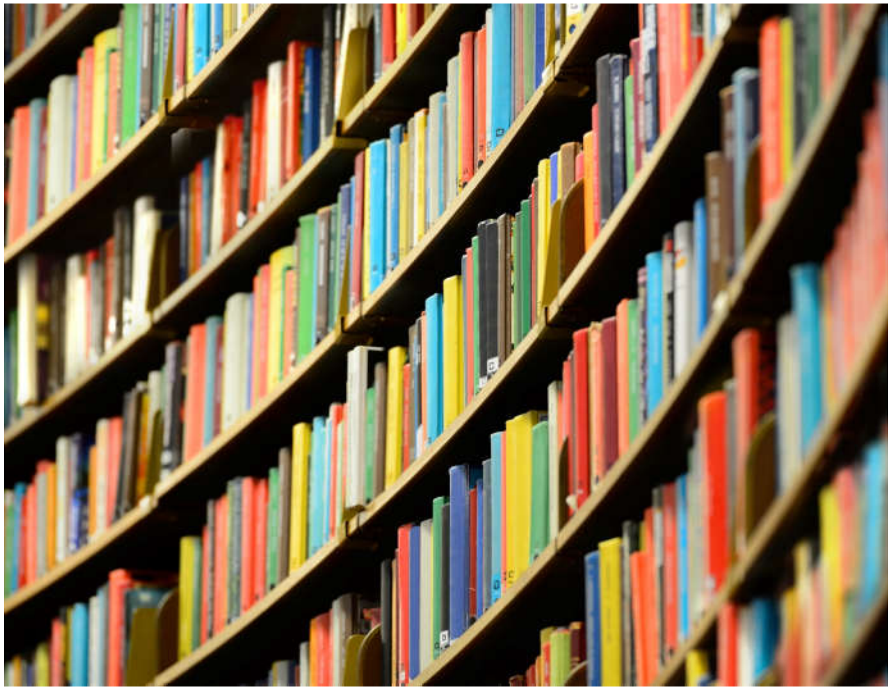
- The Erection Engineer Must:
- Analyze: All Members, All "Critical" Configurations/Stages
- Evaluate: Perm. Members & Connections
  - Typically alter sequence, load points, or brace
  - May oversize or strengthen
  - Permanent/locked-in changes affect design
- Design: Equip. & Temp. Elements
  - Lifting/cranes, matting, barge configurations
  - Shoring + foundations
  - Brackets
  - Braces
  - Restraints

I-235/13th St. Wichita Floodway (KS)

2. Methodology & Resources

2. Methodology & Resources

- Many Documents, Few Totally Comprehensive
  - Perm. vs. Temp. Conditions
  - Perm. vs. Temp. Members
  - Design vs. Evaluation
- Codes & Specs
  - Owner + Project
- Guidance Documents
- Elective Resources
  - “Engineering Judgment”



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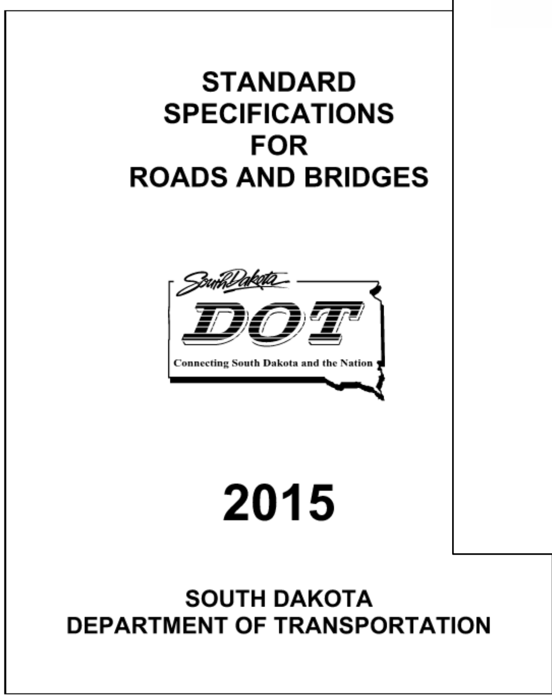

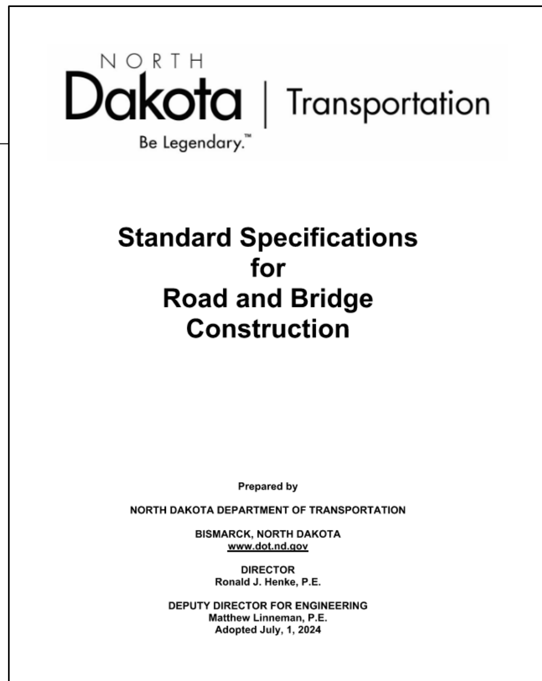

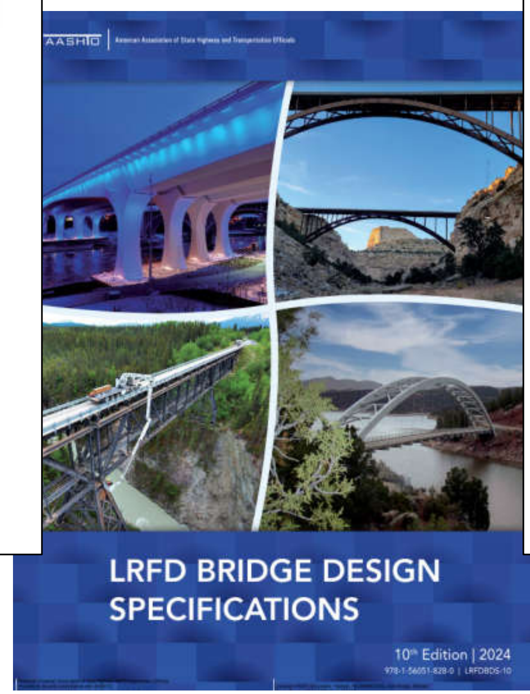

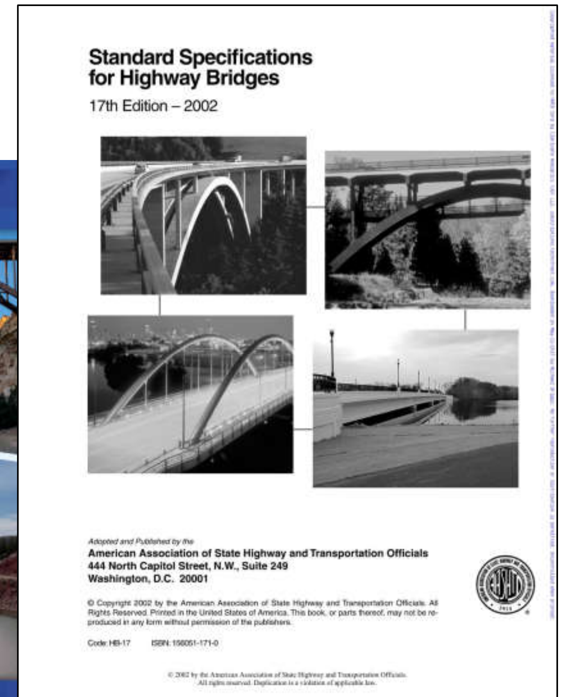

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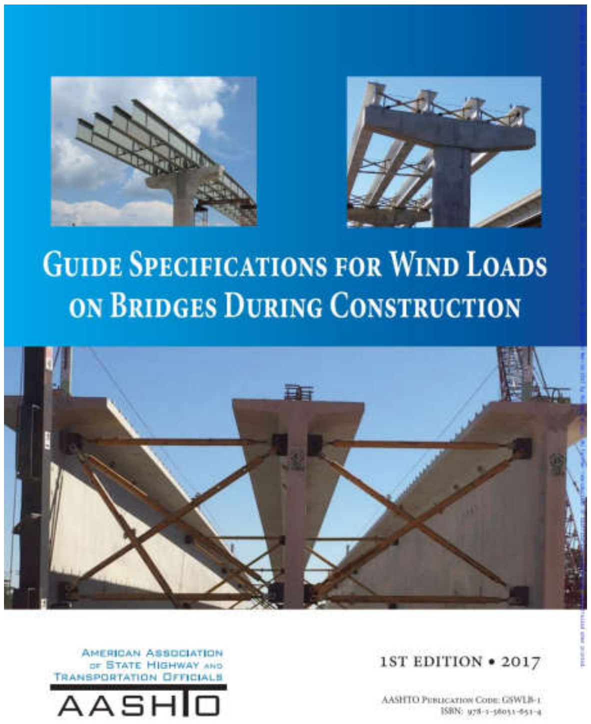

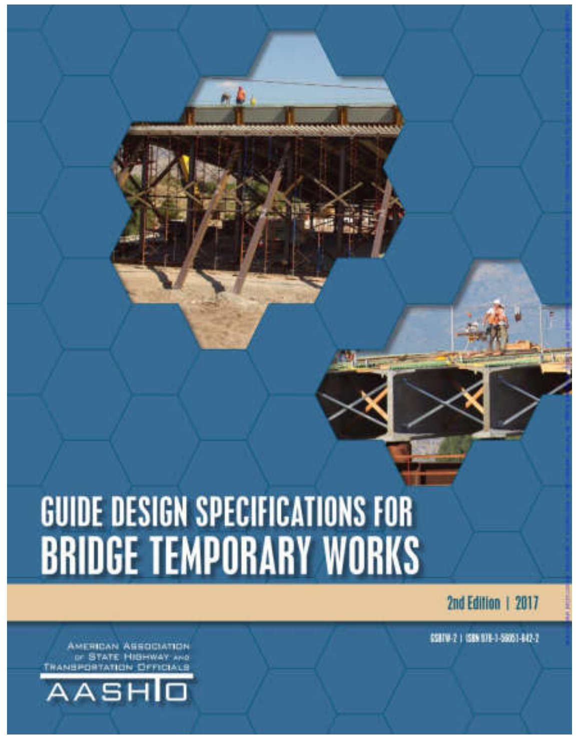

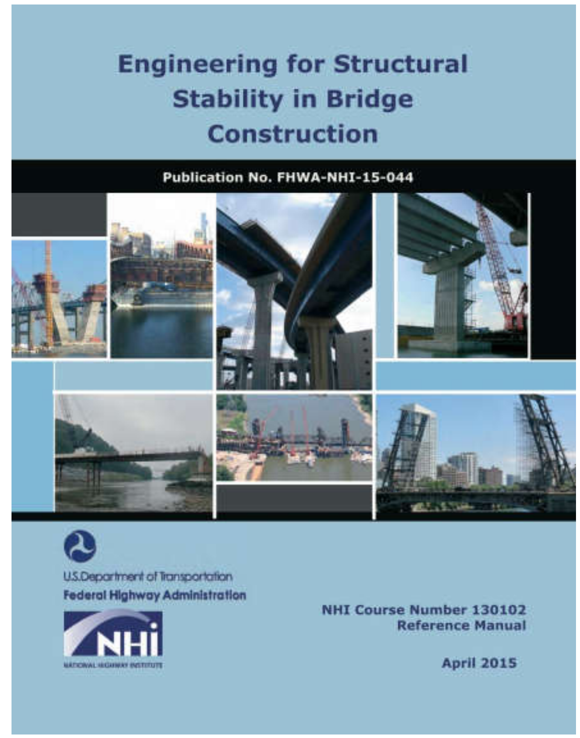

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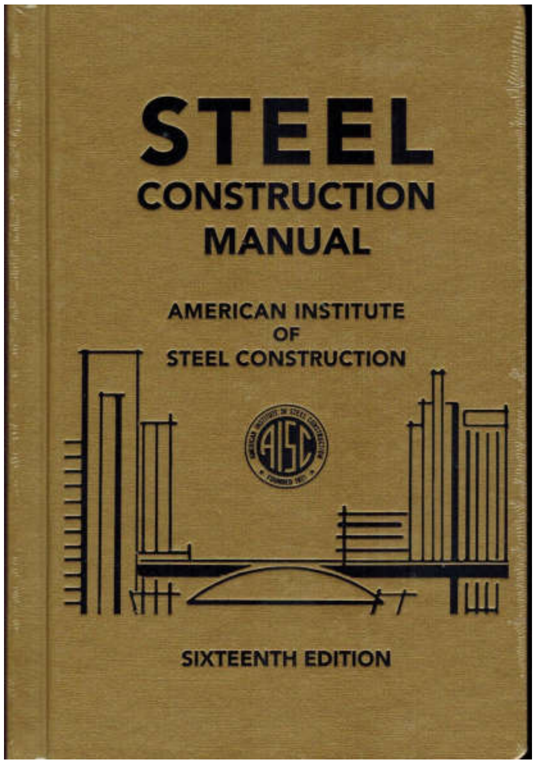

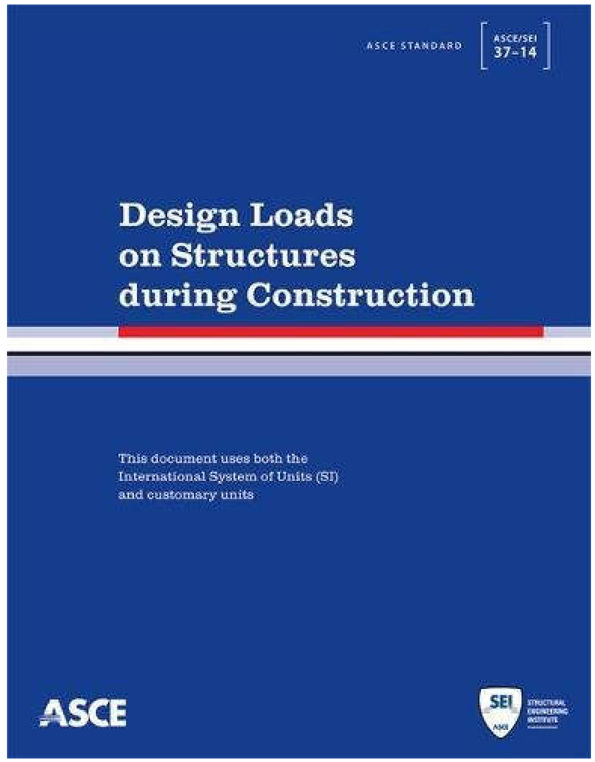

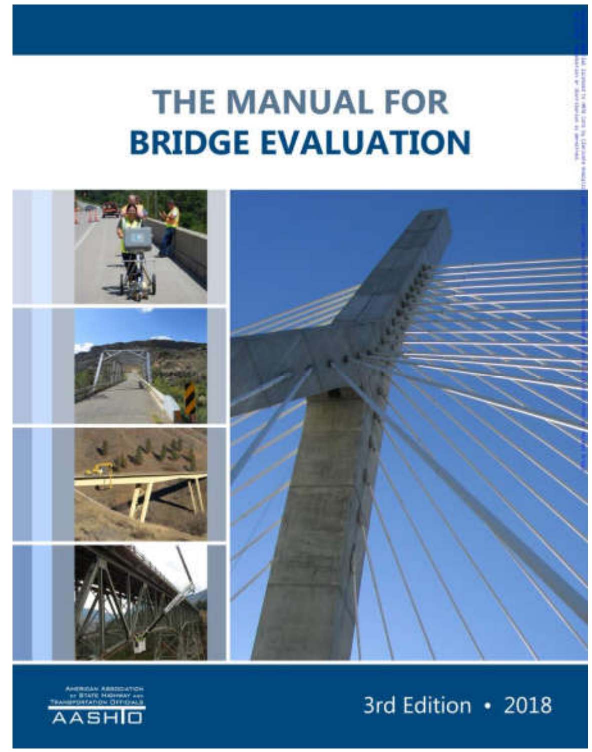

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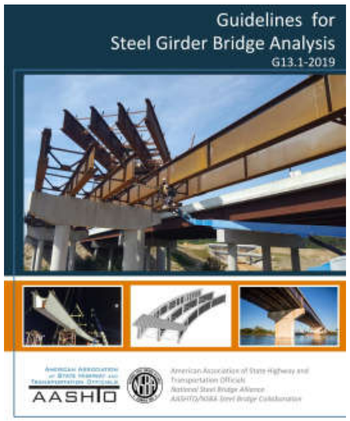

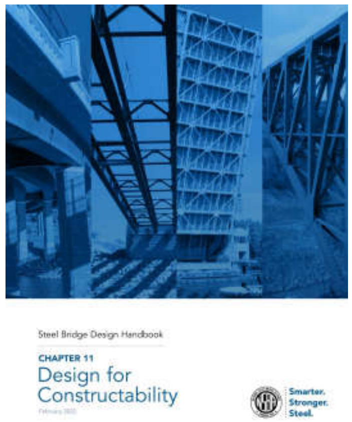

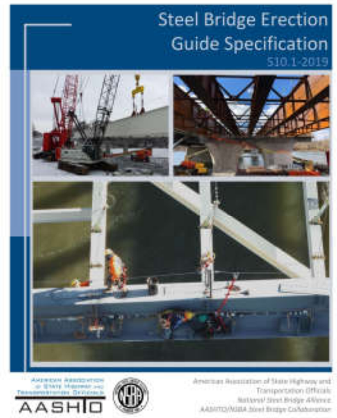

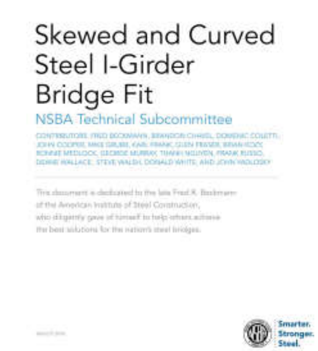

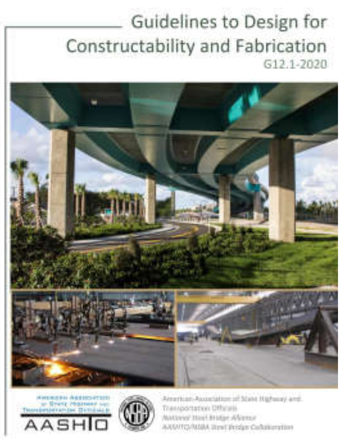

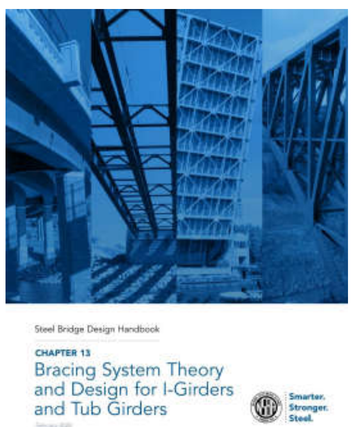

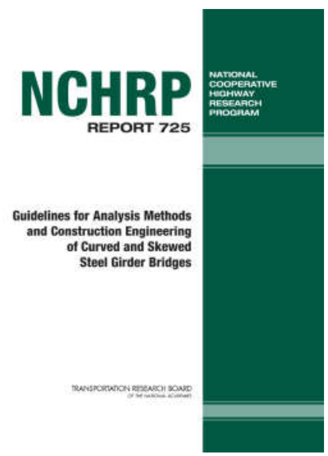

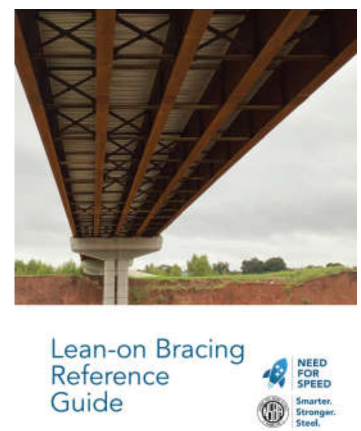

3. Role of Design Engineer

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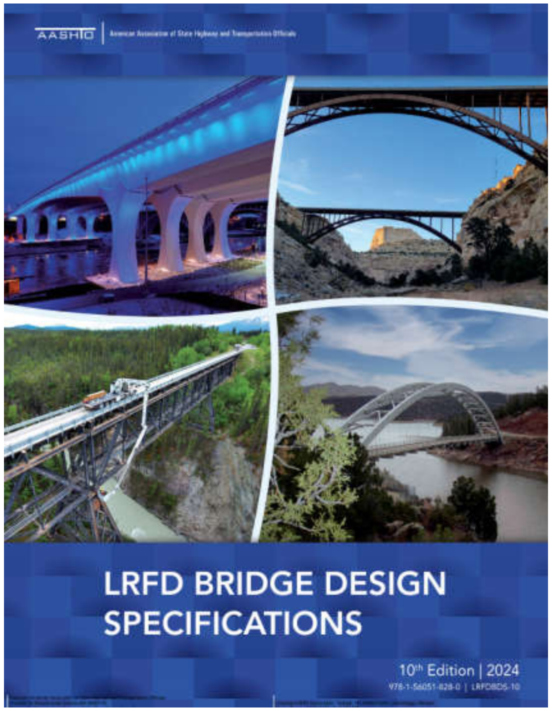
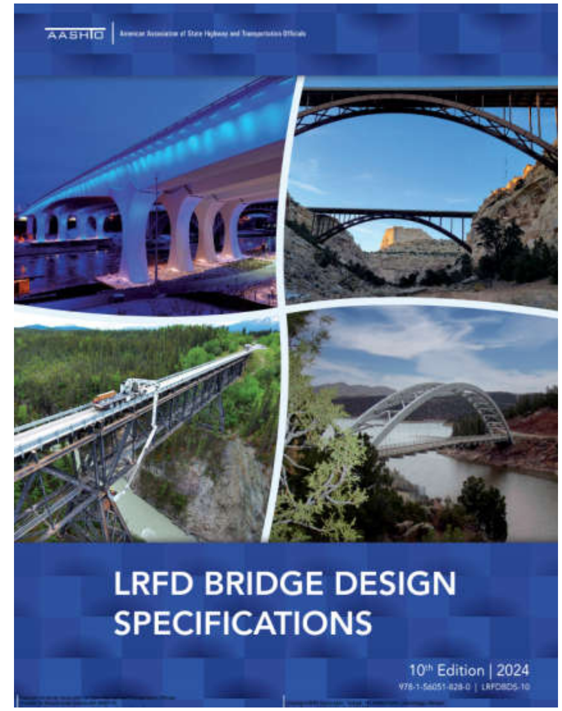


- 2.5.3 – General
  - Identify environ. conditions, site constraints
  - One feasible method incl. supports, sequence
  - Fabricate & erect without undue difficulty/distress
- 6.5.1 – Steel
  - *Shall* evaluate critical stages (2.5.3 = *should*)
  - Construction, handling, transport, erection, service life… *by designer*?
- 6.10.3 – Steel I-Sections
  - No yielding/buckling/distress/slip
  - Evaluate uplift
  - Sensitive behaviors more likely without deck

3. Role of Design Engineer

- 3.4.2 – Load Factors During Construction
  - Established by owner (explicit)
  - Lower than in-service (implicit)
  - What is a construction load? Not defined.
    - Transient or limited duration
    - LL+IM + equipment + materials

  - Steel superstructures only: 1.40*(DC+CL)



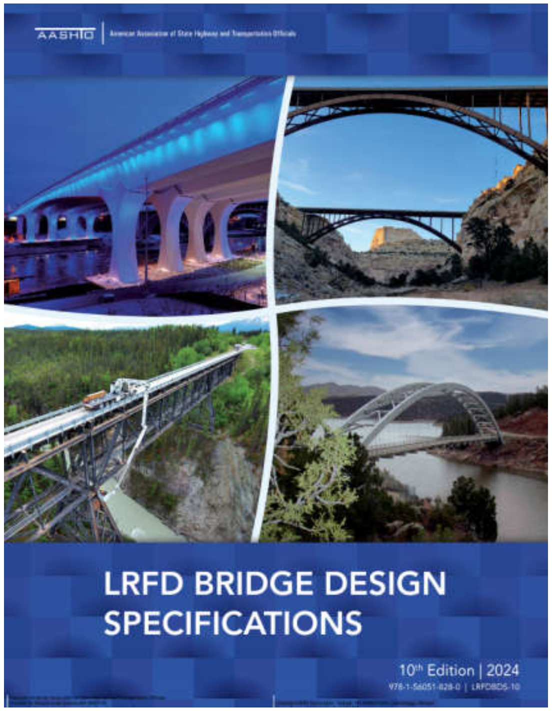
C3.4.2.1

For steel superstructures, the use of higher-strength steels, composite construction, and limit-states design approaches in which smaller factors are applied to dead load force effects than in previous service-load design approaches have generally resulted in lighter members overall.

To ensure adequate stability and strength of primary steel superstructure components during construction, an additional strength limit state load combination is specified for the investigation of loads applied to the fully erected steelwork.

3. Role of Design Engineer

- 6.7.4 – Diaphragms & Cross-Frames
  - Final configuration & critical stages
- 6.10.3.4 – Deck Placement
  - Incl. effects of temp. overhang brackets

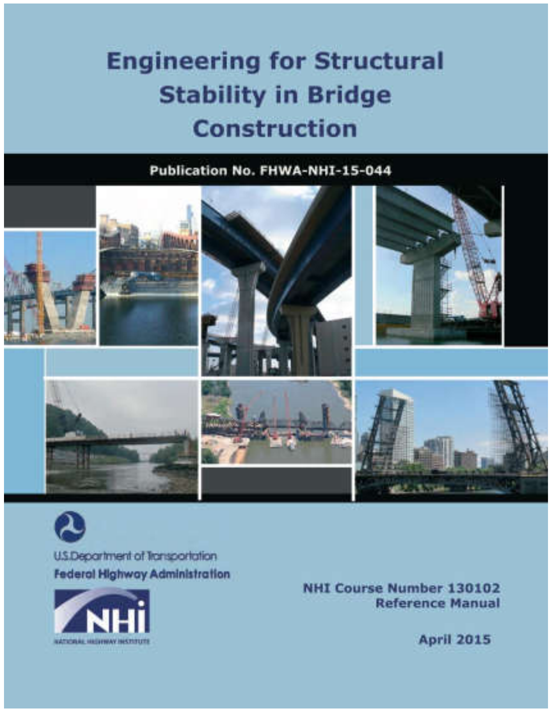


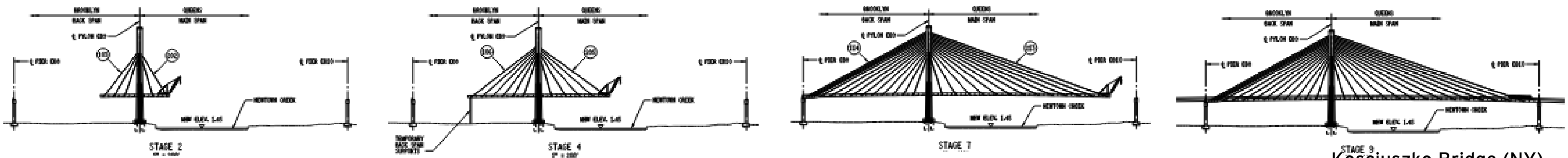
I-235/13th St. Wichita Floodway (KS)

US 169/I-35 Buck O'Neil Bridge

3. Role of Design Engineer

- Critical Stages
  - Not defined in AASHTO
  - May refer to FHWA Stability
- Conventional Structure:
  - Designer shouldn't try to specify
  - Interim steps per contractor (mostly)
- Unusual/Exotic Structure:
  - Designer must fully design for stages of suggested feasible sequence





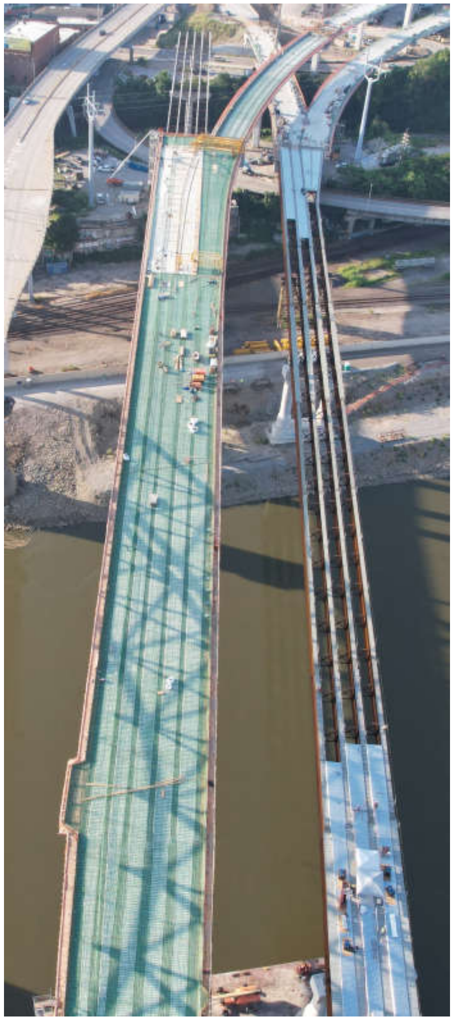
Kosciuszko Bridge (NY)

3. Role of Design Engineer

- Critical Stages = Basis of Design Loadings
  - Estimate temp. durations, formwork, constr. loads
  - Specify in plans

- Basic Stages
  1. Fully-erected steel on permanent supports
  2. Final in-service config. and loadings

- Supplemental Stages
  3. Wind A = bare steel (trailing girder drag, girder height)
  4. Wind B = deck forms in place (drag, girder+form height)
  5. Plan placing sequence (continuous, skip, joints)
  6. Plan cross frame fit condition (if req'd.)



US 169/I-35 Buck O'Neil Bridge

3. Role of Design Engineer

- Constructability
  - Recognize & accommodate site constraints
  - Anticipate preferences, economy
  - Member proportions, reserve capacity
  - Final $1 material saved may cost $3 to build
  - Talk to the industry – this room!
  - Learn from your last project

US 169/I-35 Buck O'Neil Bridge

4. Designing for Constructability

4. Designing for Constructability

- Leverage Advantages (of Steel)

4. Designing for Constructability

- Leverage Advantages – Lightweight*
  - Minimize equipment needs
  - Avoid site obstacles
  - Facilitate ABC

(*relatively)

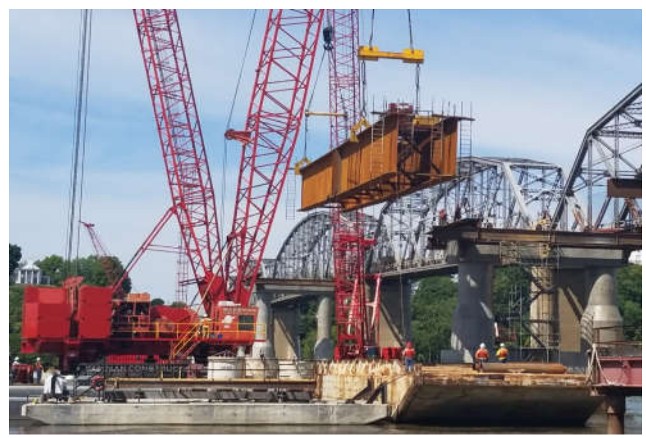
FARM Bridge Program - DeLong's

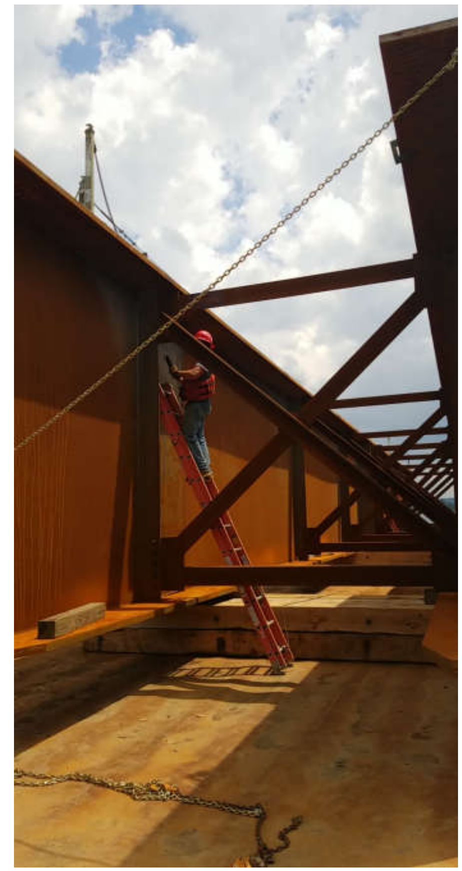
US 169/I-35 Buck O'Neil Bridge

4. Designing for Constructability

- Leverage Advantages – Field Pieces
  - Optional field splices
  - Ground/barge assembly
    - Girder pairs, two segment, quad picks

US 169/I-35 Buck O'Neil Bridge

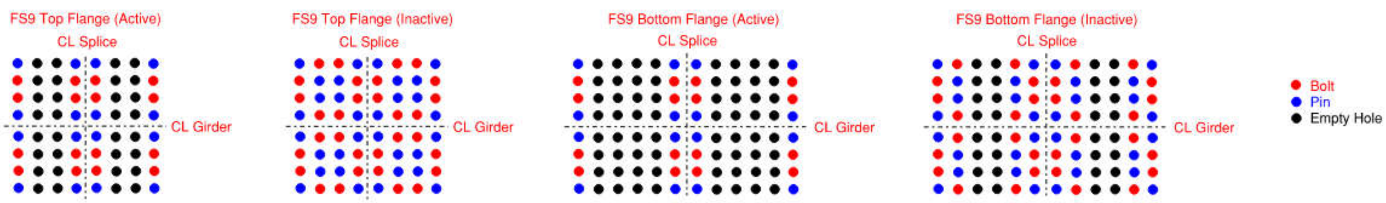


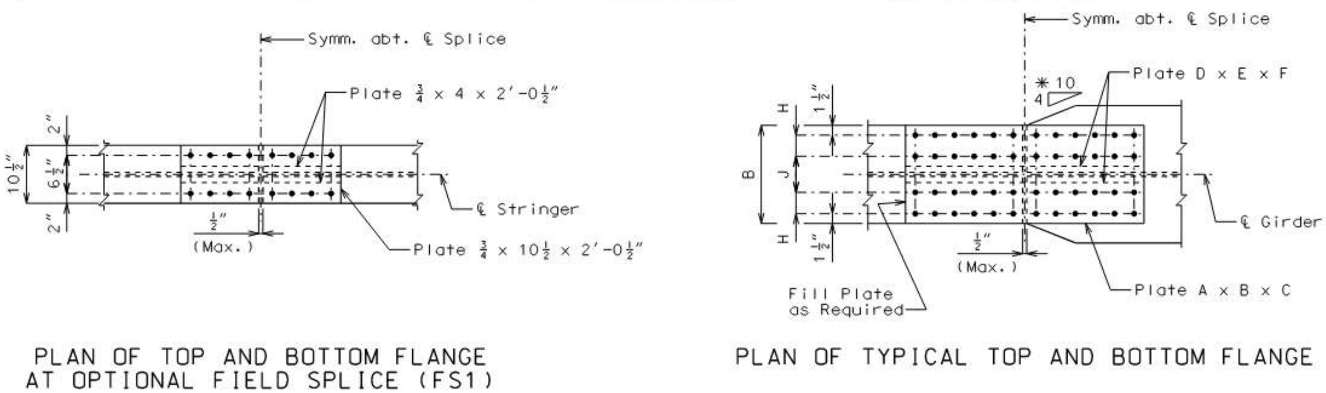


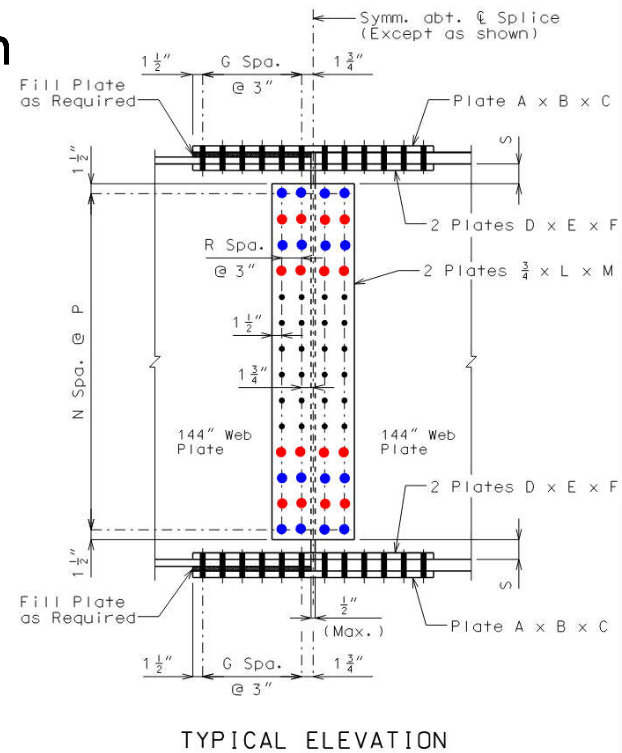
US 54 Champ Clark Bridge

4. Designing for Constructability

- Leverage Advantages – Field Assembly
  - Interim bolting can be based on required strength
  - Allows release of workpiece, crane moves to next

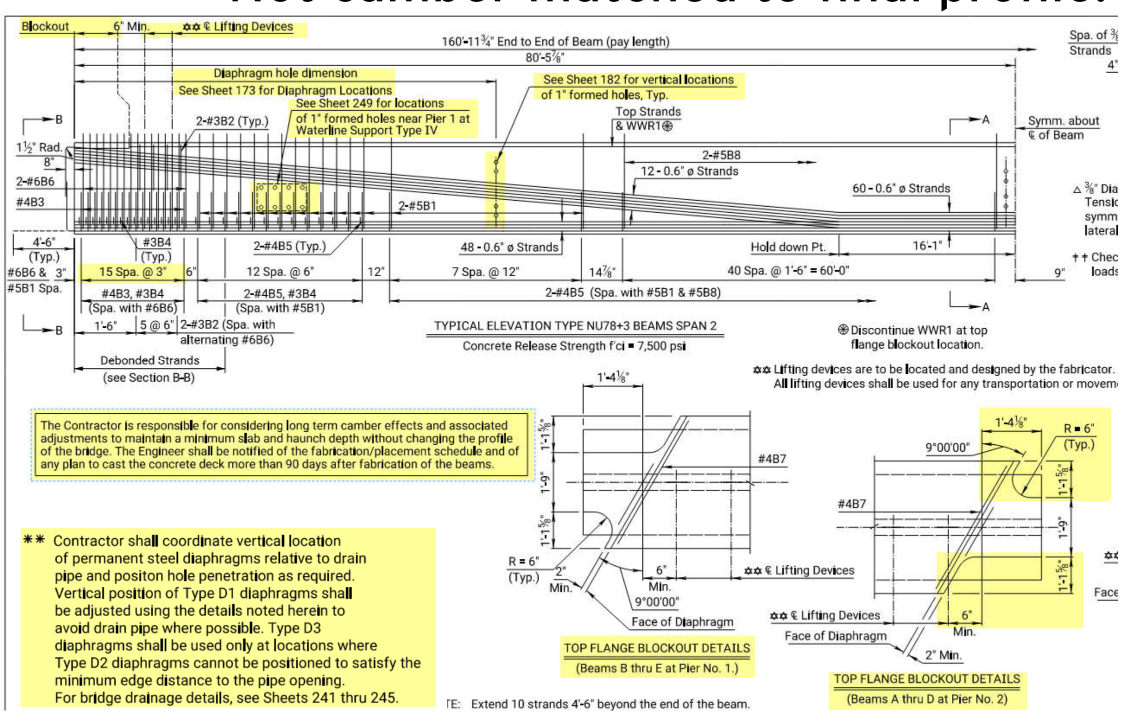


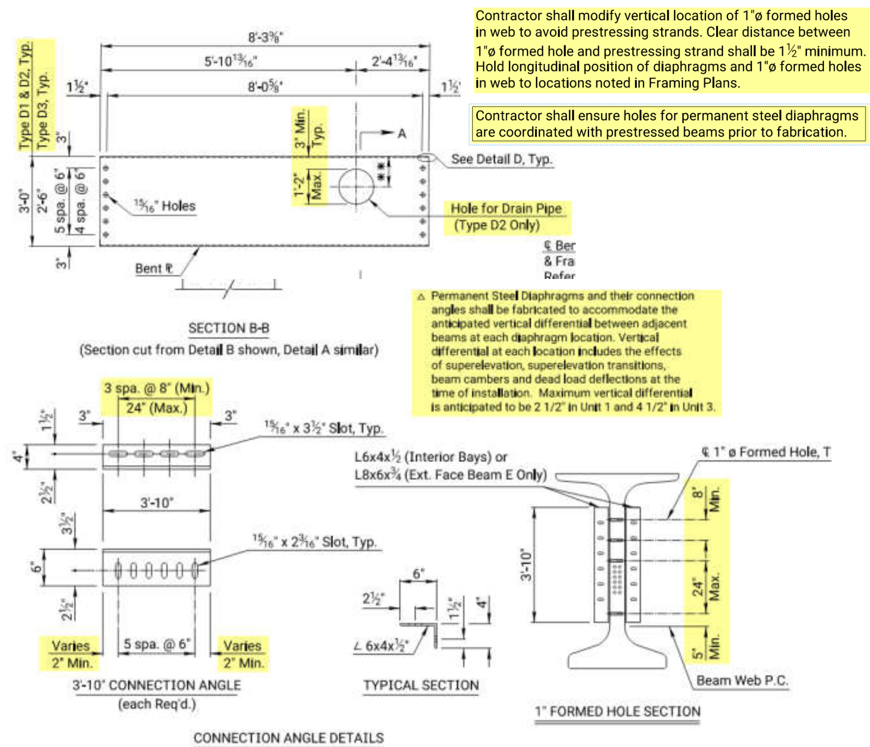




4. Designing for Constructability

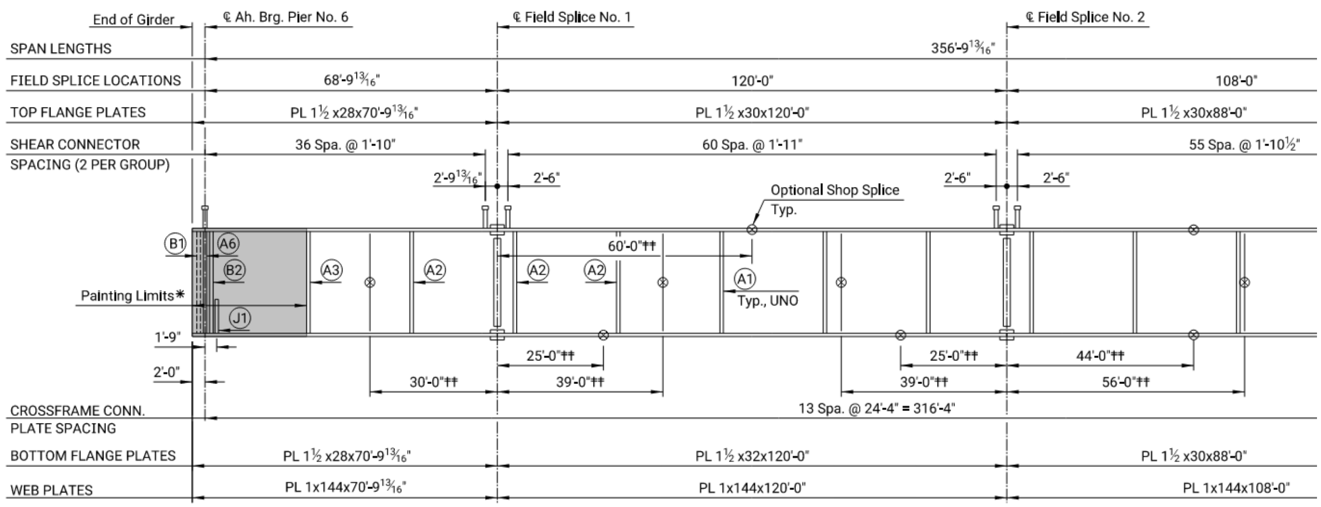
- Leverage Advantages – Custom-Built Geometry
  - Not camber matched to final profile:

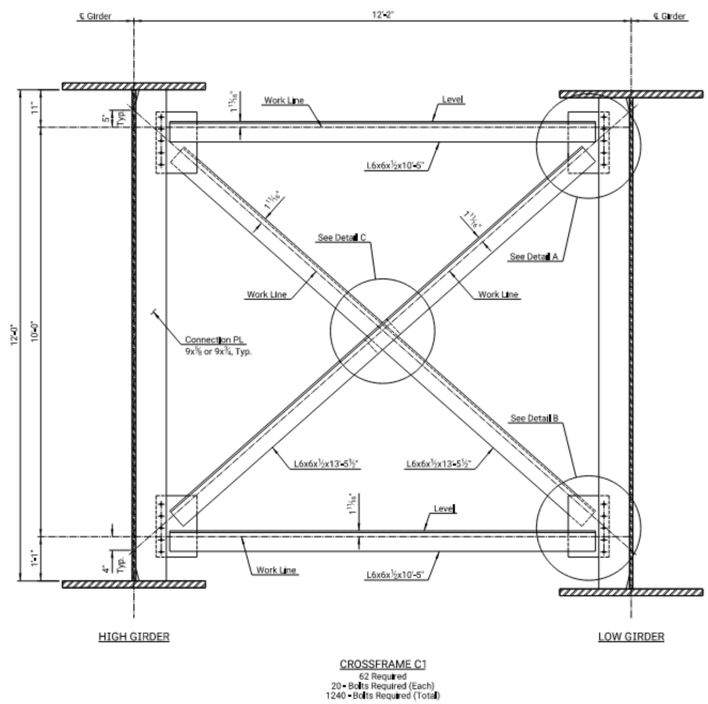




4. Designing for Constructability

- Leverage Advantages – Custom-Built Geometry
  - Camber matched to final profile:
  - Single detailer/fabricator
  - "Standard practice"





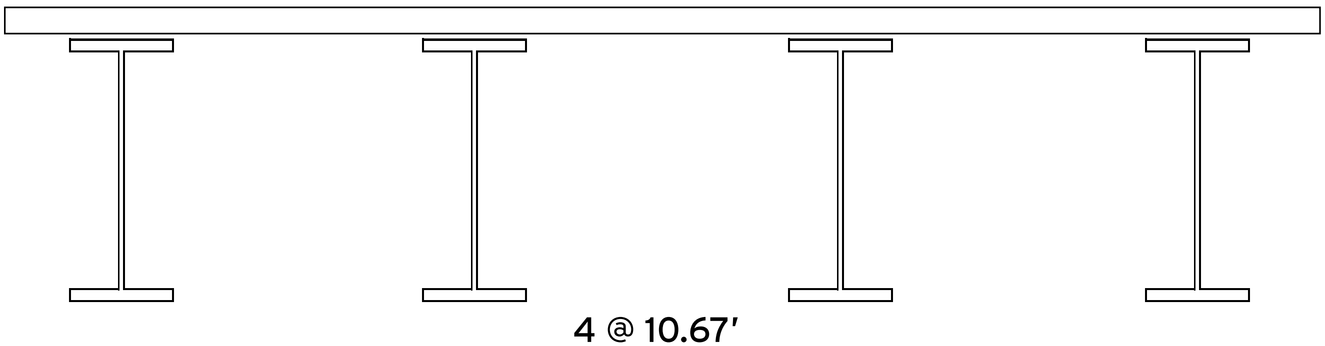
4. Designing for Constructability

- Material Optimization

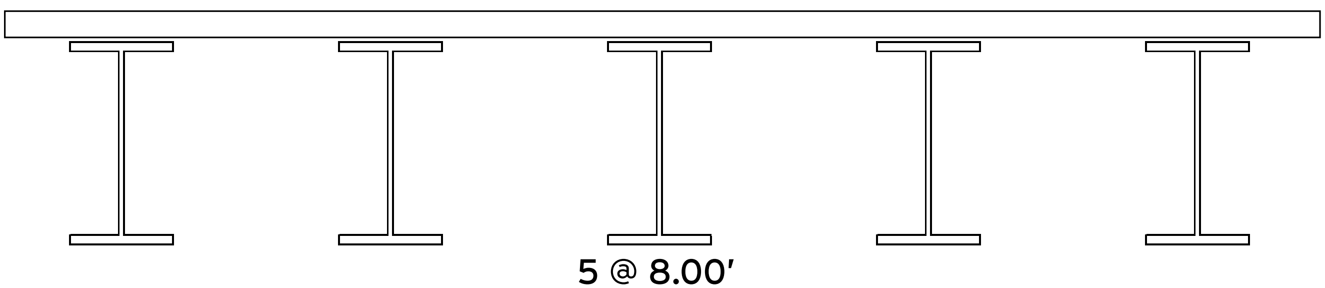
4. Designing for Constructability

- Material Optimization is Good, Right?

Alt. A



Alt. B



4. Designing for Constructability

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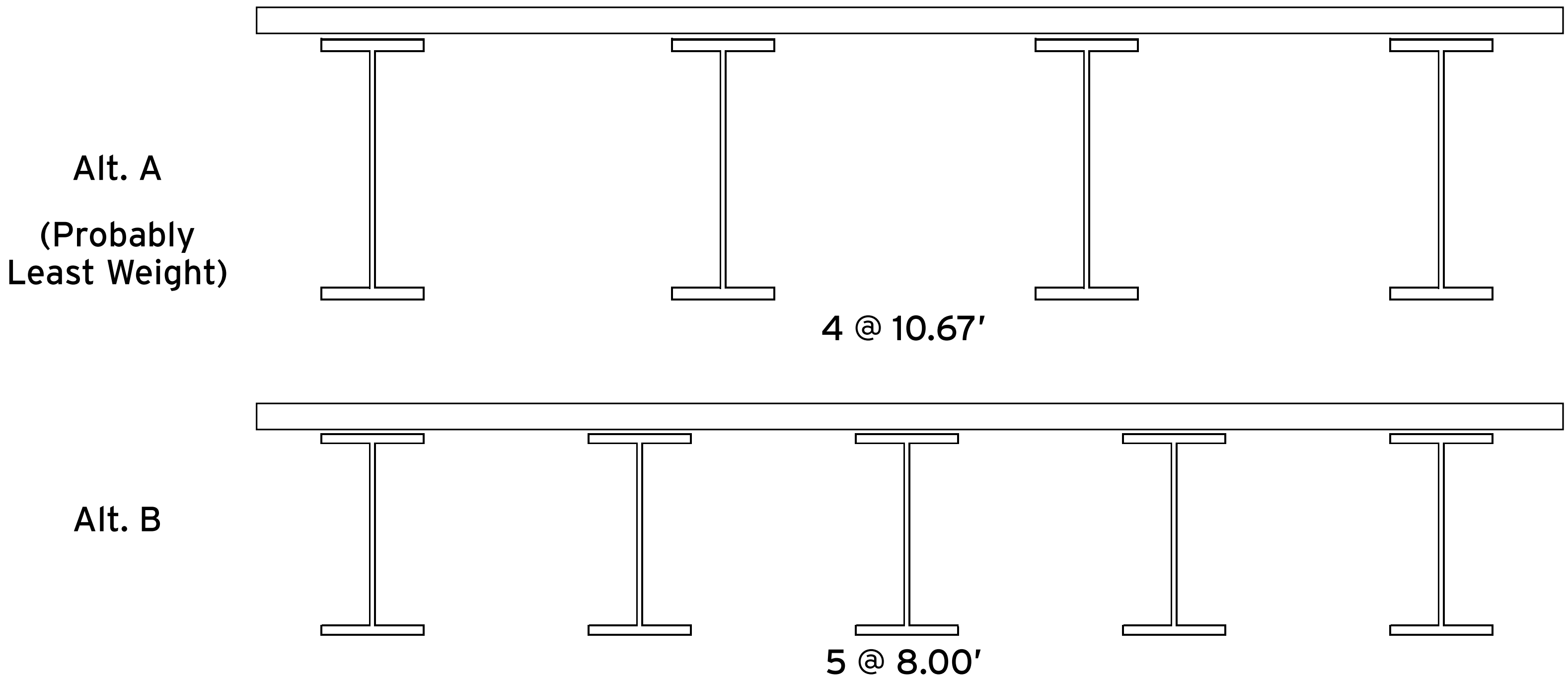
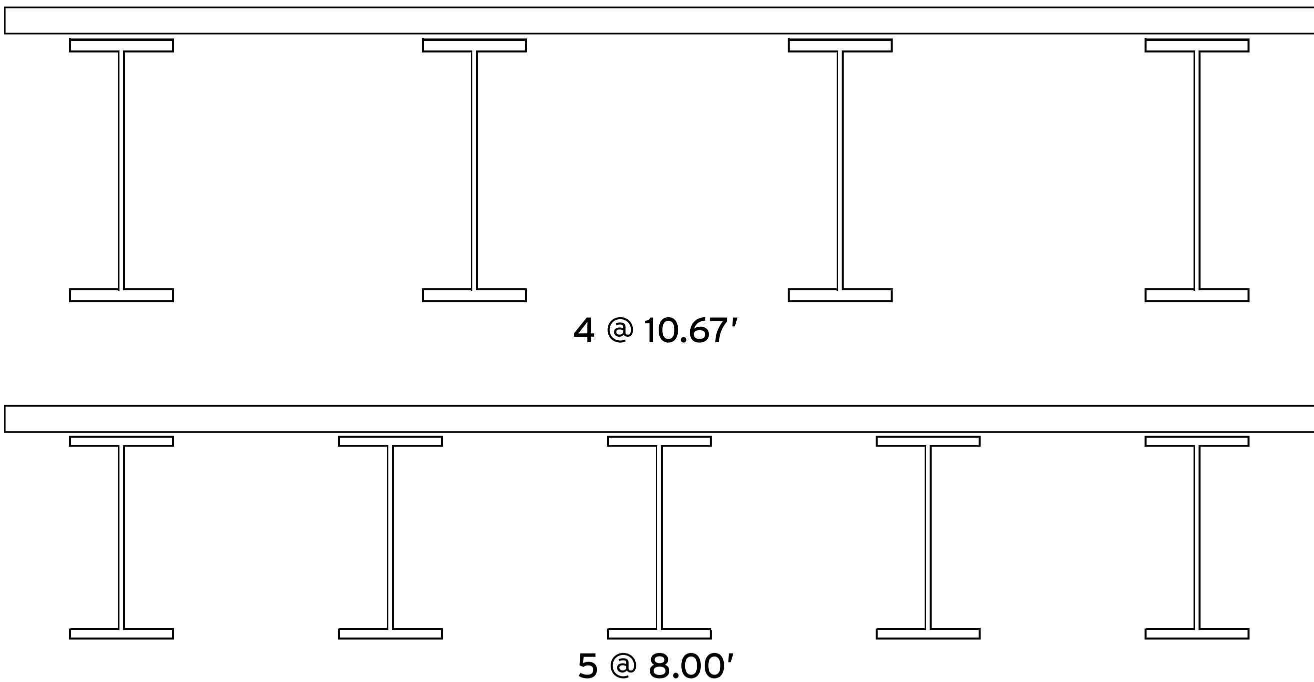


4. Designing for Constructability

- Material Optimization is Good, Right?

Alt. A

(Probably Least Weight)



Roadway Costs

Fewer Field Pieces

Fewer Cross Frames

Heavier Field Pieces

Heavier Cross Frames

More Deck Rebar

Alt. B

More Flexibility (Fabricator, Field)

Thinner, Smaller (Cheaper) Plates

More Pieces/Assembly

Easier Future Rehab

4. Designing for Constructability

- Material Optimization

- Avoid Extremes
  - expectations,
  - procedures,
  - skills,
  - equipment,
  - understanding of risk,

  - primarily honed on experience with common member proportions

At the edge of the map:

There Be Dragons

4. Designing for Constructability

- Material Optimization

- Paradigm Shift: Labor Cost >> Material Cost
  - Make pieces less complicated
    - Less flange plate transitions, thicker web

  - Easier/Faster/Cheaper to Fabricate = to Erect also?
    - More reserve capacity, less need for temporary support
    - More consistent members, more repeatable work

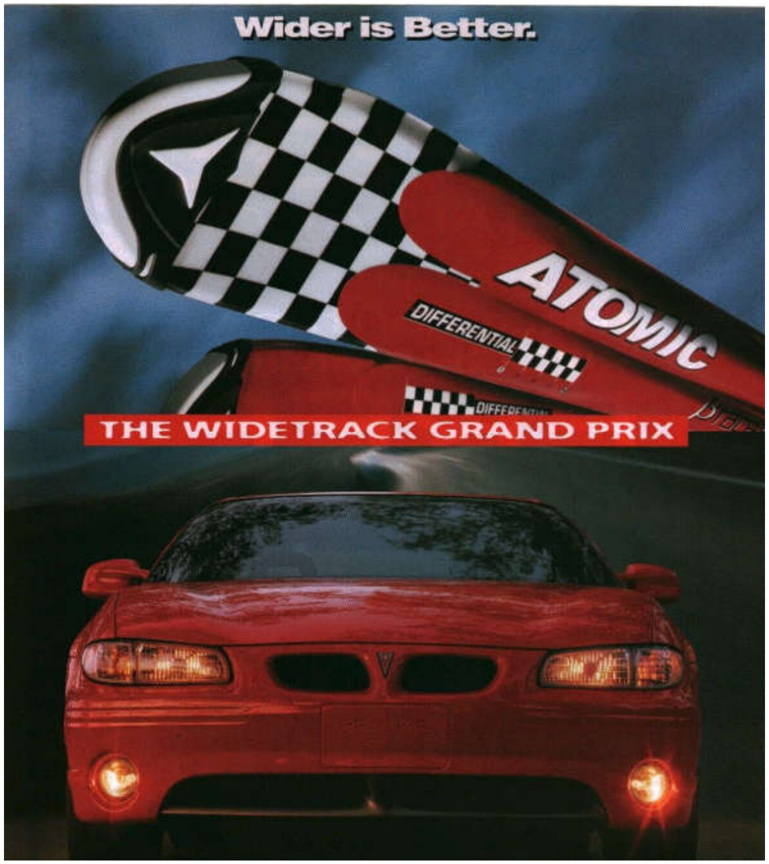
4. Designing for Constructability

- Wide Flanges

4. Designing for Constructability

- Wide Flanges
  - are better flanges

- Lateral Bending Performance ⬆



Some Old Magazine

4. Designing for Constructability

- Wide Flanges – Shipping

130 ft

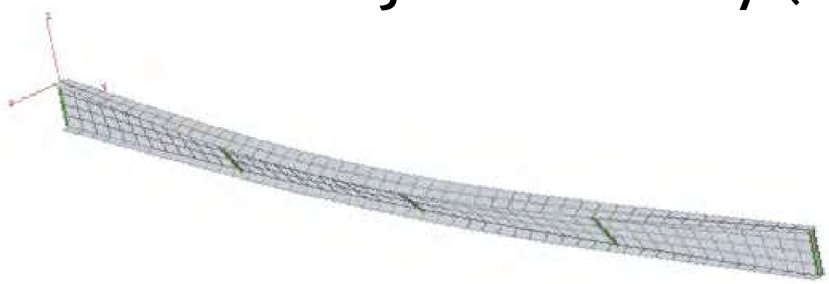
(48")

(30")

US 169/I-35 Buck O'Neil Bridge

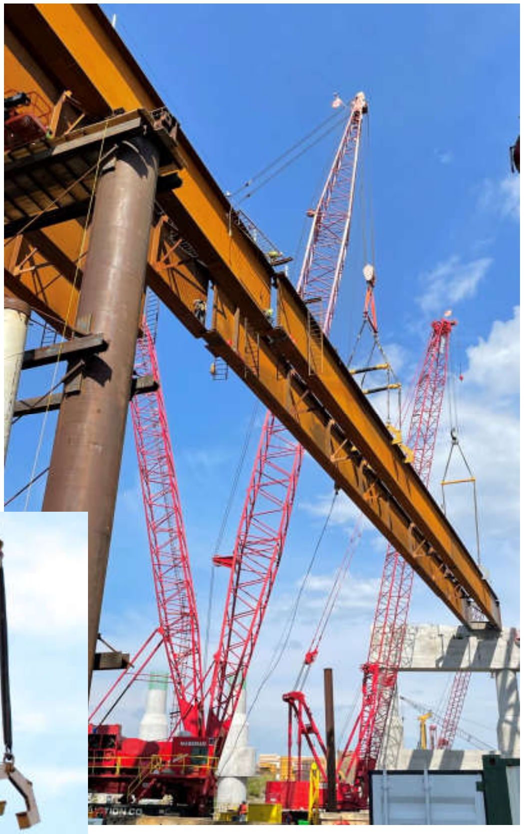
4. Designing for Constructability

- Wide Flanges – Stability (Picking/Handling)



FHWA

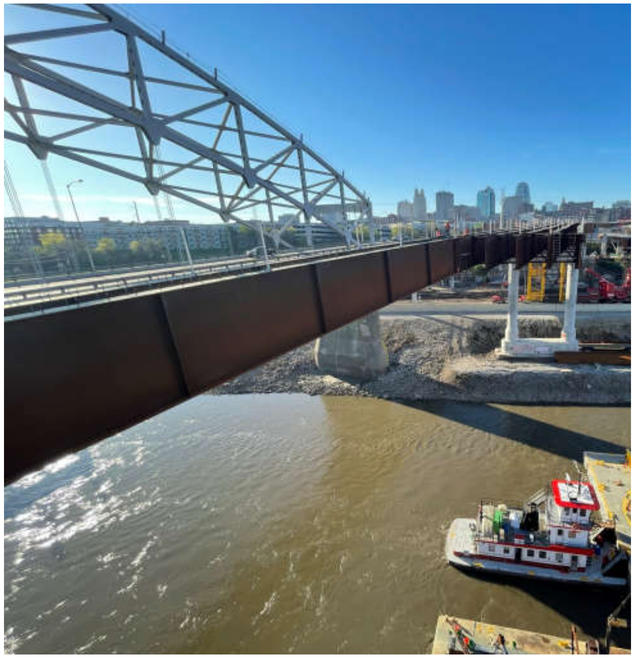
US 54 Champ Clark Bridge



US 169/I-35 Buck O'Neil Bridge

4. Designing for Constructability

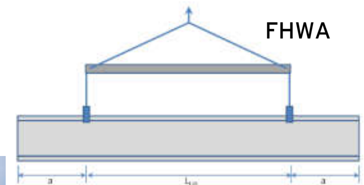
- Wide Flanges – Stability (In-Place)
  - Initial piece
  - Cantilever
  - Drop-in



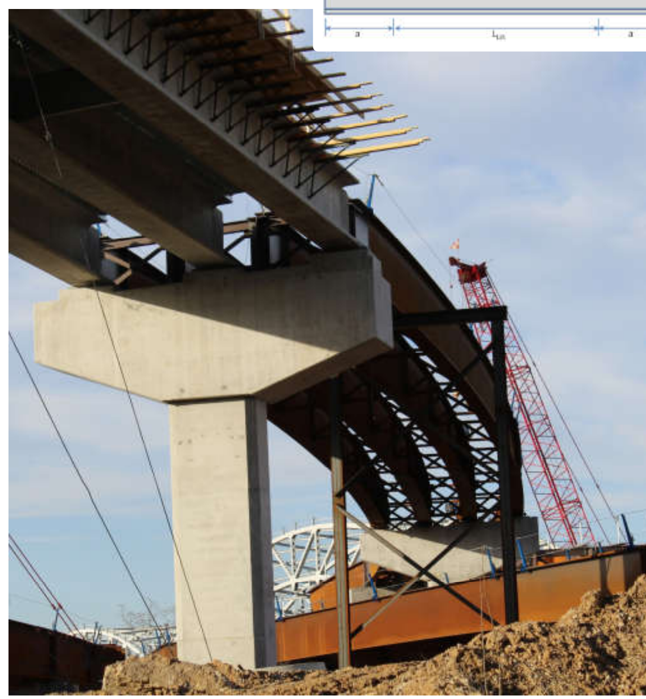
US 169/I-35 Buck O'Neil Bridge

4. Designing for Constructability

- Wide Flanges – Stress (Curvature)



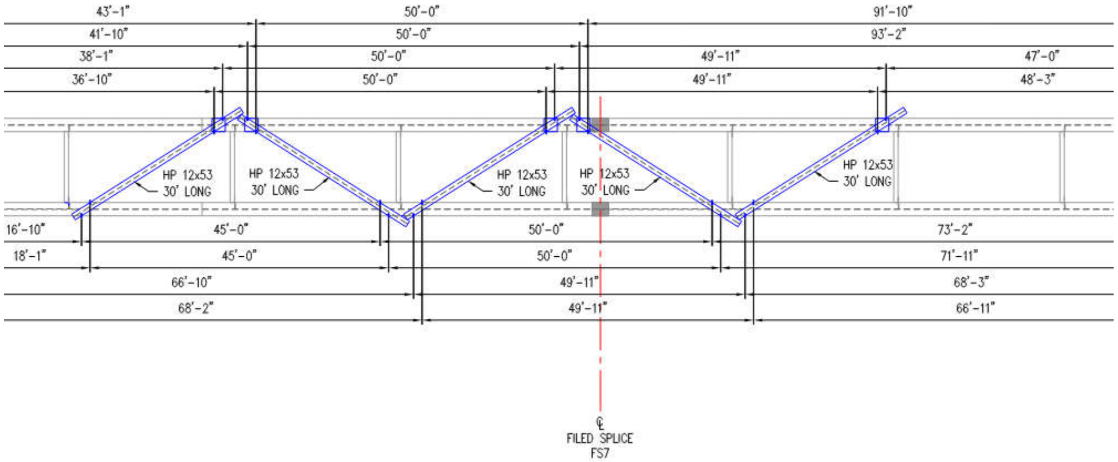
I-235/13th St. Wichita Floodway (KS)



US 169/I-35 Buck O'Neil Bridge

4. Designing for Constructability

- Wide Flanges – Stress (Wind)
  - Reduce or eliminate need for
    - Permanent lateral bracing
    - Temporary stiffening trusses



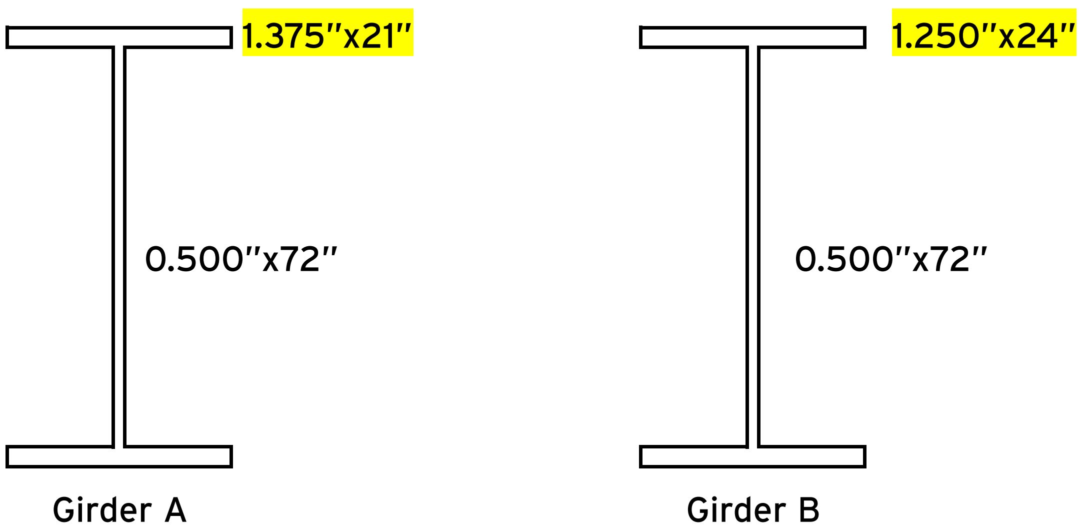
PLAN VIEW SPAN 3-4 - TEMPORARY LATERAL BRACING


US 54 Champ Clark Bridge


US 169/I-35 Buck O'Neil Bridge

4. Designing for Constructability

- Wide Flanges – A Tale of Two Girders
  - Flange thickness -> flange width



Girder B / A

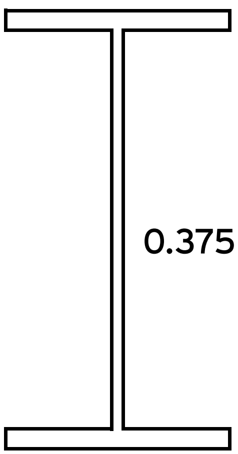
Weight: +2%

Strong Axis: +3%

Weak Axis: +36%

4. Designing for Constructability

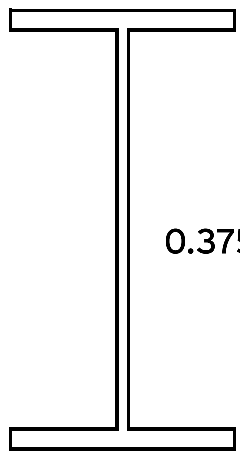
- Wide Flanges – A Tale of Two Girders
  - Let's go further!



1.125"x21"

0.375"x54"

Girder Y



1.000"x24"

0.375"x54"

Girder Z

Girder Z / Y

Weight: +1%

Strong Axis: -11% (FLB)

Weak Axis: +33%

4. Designing for Constructability

- Wide Flanges – How Wide is Too Wide?
  - Flange local buckling
  - Fabrication impacts
  - Stiffener width
  - Formwork

Local Buckling Capacity Ratio, F_{nc}/F_{yc}

F_{yc} = 50 ksi; F_{yr} = 35 ksi; R_b = 1.00 --; I_{pf} = 9.15 --

F_w = 50 ksi; E = 29,000 ksi; R_h = 1.00 --; I_{rf} = 16.12 --

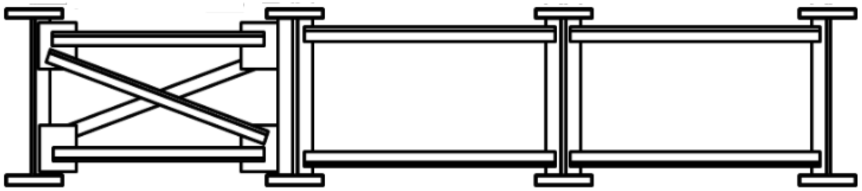
Flange Thickness (in.) \ Width (in.)	12	15	18	21	24	27	30	33	36	39	42	45	48
0.750	1.00	0.96	0.88	0.79	0.71	0.62	0.53	0.45	0.36	0.27	0.19	0.10	0.02
0.875	1.00	1.00	0.95	0.88	0.80	0.73	0.66	0.58	0.51	0.43	0.36	0.29	0.21
1.000	1.00	1.00	1.00	0.94	0.88	0.81	0.75	0.68	0.62	0.55	0.49	0.43	0.36
1.125	1.00	1.00	1.00	0.99	0.93	0.88	0.82	0.76	0.71	0.65	0.59	0.53	0.48
1.250	1.00	1.00	1.00	1.00	0.98	0.93	0.88	0.83	0.77	0.72	0.67	0.62	0.57
1.375	1.00	1.00	1.00	1.00	1.00	0.97	0.92	0.88	0.83	0.78	0.74	0.69	0.64
1.500	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.92	0.88	0.83	0.79	0.75	0.71
1.750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95	0.91	0.88	0.84	0.80
2.000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.94	0.91	0.88
2.250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.93
2.500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98
2.750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3.000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

4. Designing for Constructability

- Cross Frames

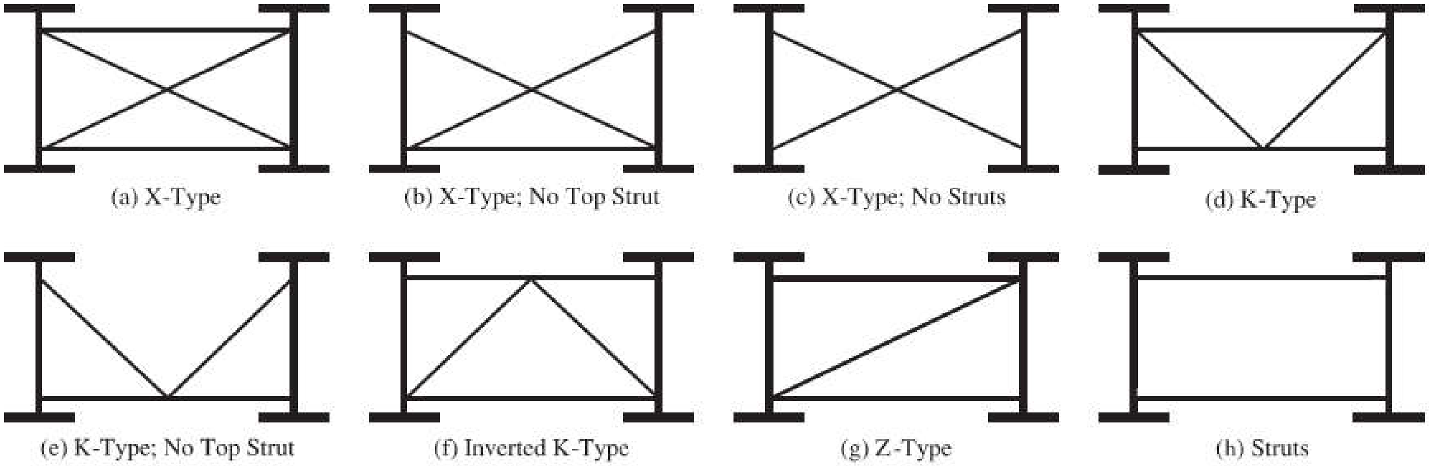
4. Designing for Constructability

- Cross Frames - Type
  - Configuration, bay aspect
  - Spacing, orientation
  - Installation sequence



FHWA

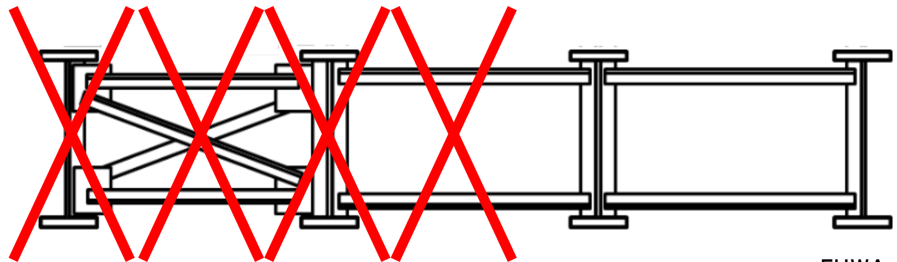
Internal bracing (XFs) rely on stiffness of adjacent girder.



NCHRP 962

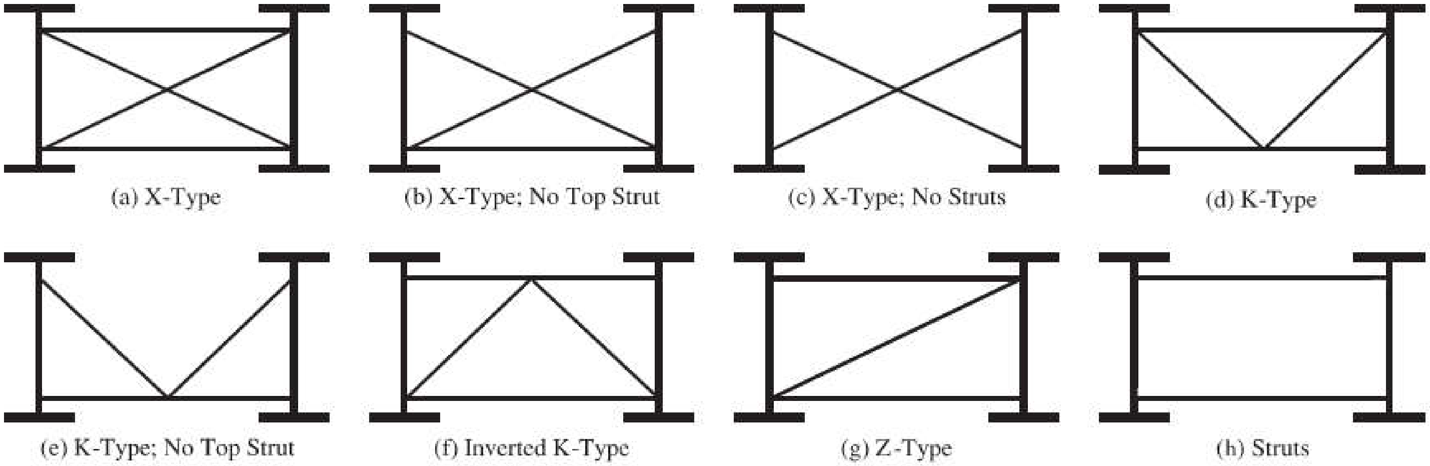
4. Designing for Constructability

- Cross Frames - Effectiveness
  - When missing neighbors?
  - When missing deck?



FHWA

FHWA



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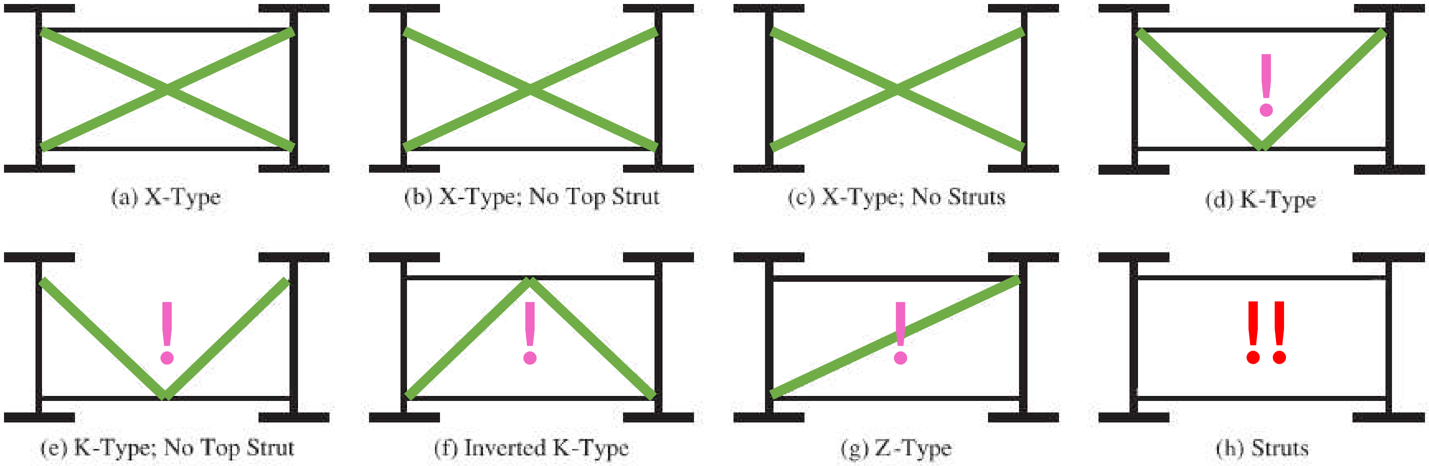
4. Designing for Constructability

- Cross Frames - Diagonals
  - Vertical brace (XF shear)
  - V or Z = 50% of X
  - Lean-on = 0%

US 169/I-35 Buck O'Neil Bridge



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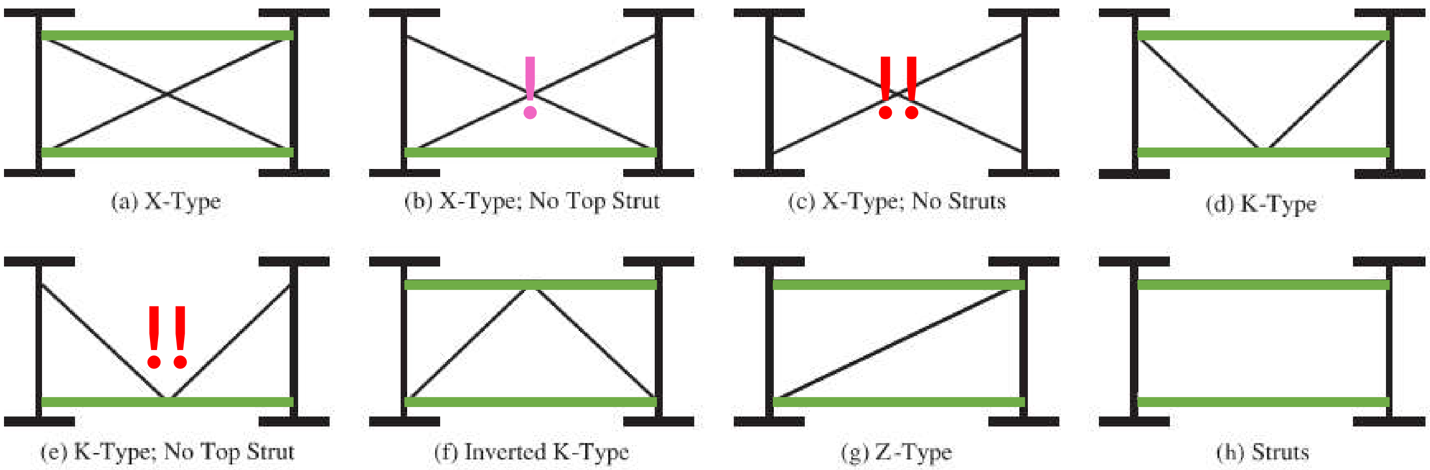
4. Designing for Constructability

- Cross Frames - Chords
  - Lateral brace (XF moment)
  - 1 strut <= 50%?
  - No struts ~= 0%



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5. Beyond I-Girders

5. Beyond I-Girders

- Unusual/Exotic Structures
  - "Design" erection sequence
    - Contractor confirms/refines
    - Erection Manual = standard

P-954 Flyover (Bahrain)

SH 278 Kosciuszko Bridge (NY)

Broadway Bridge (AR)

5. Beyond I-Girders

- Unusual/Exotic Structures
  - Alternative Lifting/Placing
    - Float-in/SPMT
    - Lateral slide

BNSF 0047 66.4 (WA)

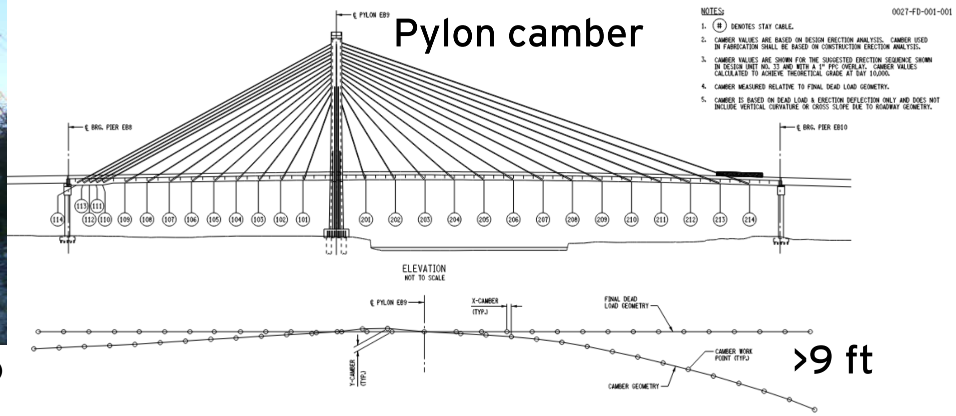
P-954 Flyover (Bahrain)

Broadway St. Bridge (AR)

5. Beyond I-Girders

- Unusual/Exotic Structures
  - Geometry control – project spec tolerances
  - Camber: x, y, z, rotation

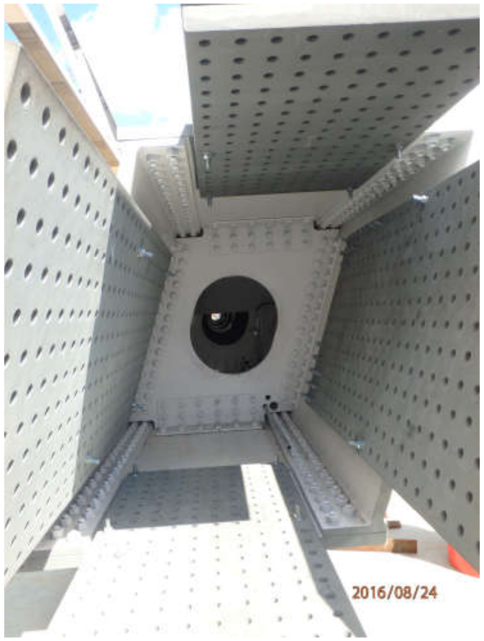
US 26 over Snake R. (WY)



Y-CAMBER FOR EDGE GIRDER (FT.)

CAMBER WORK POINT	℄ BRG.	114	113	112	111	110	109	108	107	106	105	104	103	102	101	℄ PLYON EB9	201	202	203	204	205	206	207	208	209	210	211	212	213	214	℄ BRG.
NORTH EDGE GIRDER	-1.84	-1.73	-1.63	-1.53	-1.43	-1.36	-1.13	-0.92	-0.70	-0.49	-0.30	-0.14	-0.03	0.04	0.06	0.00	-0.11	-0.26	-0.47	-0.75	-1.12	-1.57	-2.10	-2.68	-3.31	-3.98	-4.69	-5.45	-6.26	-7.15	-8.21
SOUTH EDGE GIRDER	-2.00	-1.87	-1.74	-1.62	-1.51	-1.41	-1.12	-0.86	-0.62	-0.41	-0.23	-0.10	0.00	0.06	0.06	0.00	-0.11	-0.28	-0.52	-0.84	-1.25	-1.74	-2.31	-2.95	-3.64	-4.38	-5.17	-6.02	-6.94	-7.93	-9.11

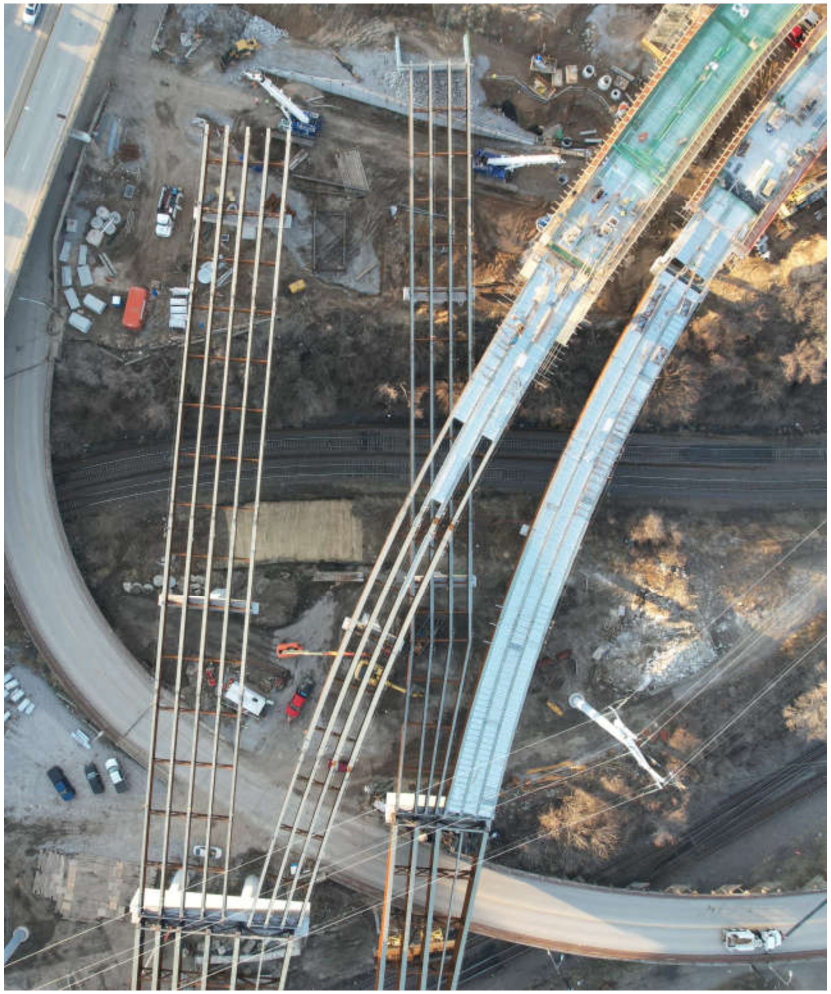
SH 278 Kosciuszko Bridge (NY)



Broadway St. Bridge (AR)

Recap

1. Erection Activities & Planning
2. Methodology & Resources
3. Role of Design Engineer
4. Designing for Constructability
5. Beyond I-Girders



US 169/I-35 Buck O'Neil Bridge

Questions