Cross Frame Design for Curved and Skewed Bridges

Using AASHTO LRFD, 8th Edition

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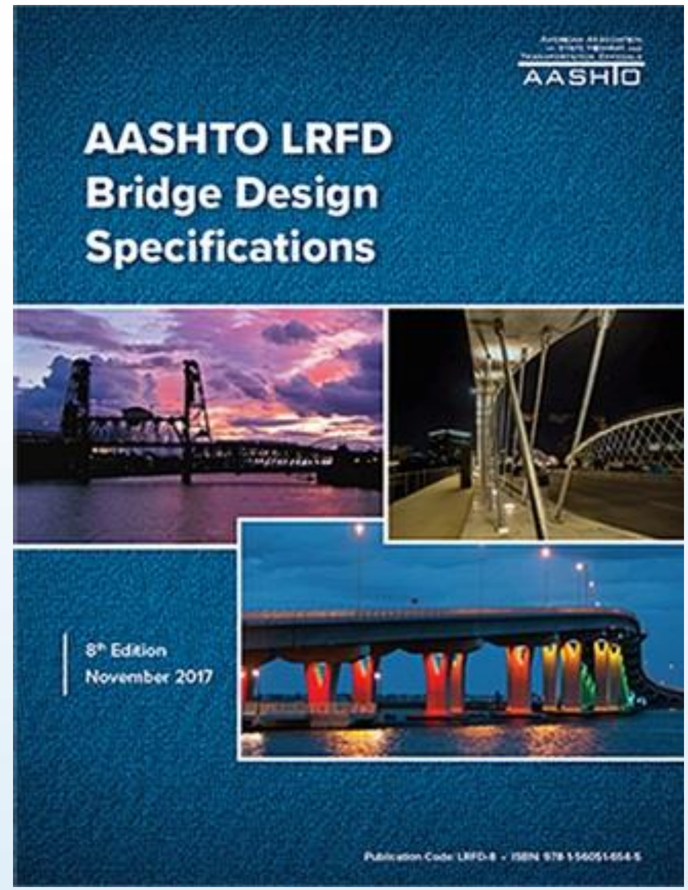
Cross frames in the 8th Edition

- Recent code changes have a significant effect on cross frame design for beam and girder bridges
- Allowable fatigue range for welded connections has been greatly reduced

In this presentation:

- Discussion of cross frame design and analysis methods
- Demonstrate the effect of the code changes on design calculations
- Discussion of how the reduction in fatigue capacity affects analysis methods and design details

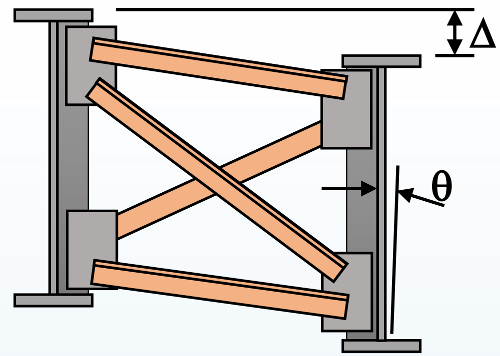


Cross frame design

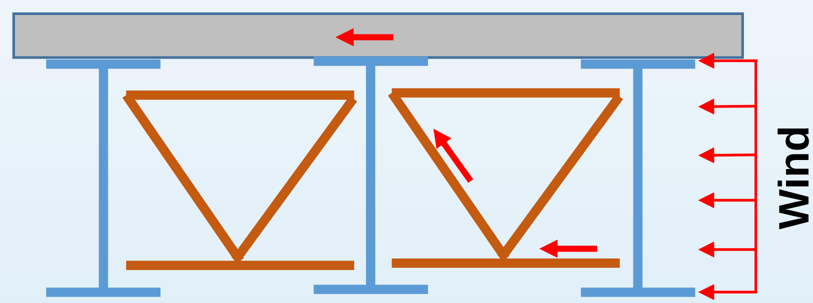
What functions do cross frames serve?

- Provide geometric control during erection and deck placement
- Transfer wind loads from the girders to the deck, and from the deck to the bearings
- Brace the compression flange
- Participate in the distribution of dead load and live load

Geometric Control:



Wind Load Transfer:

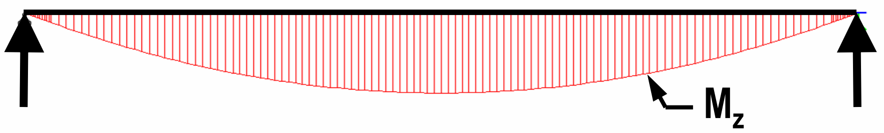


Cross frame design

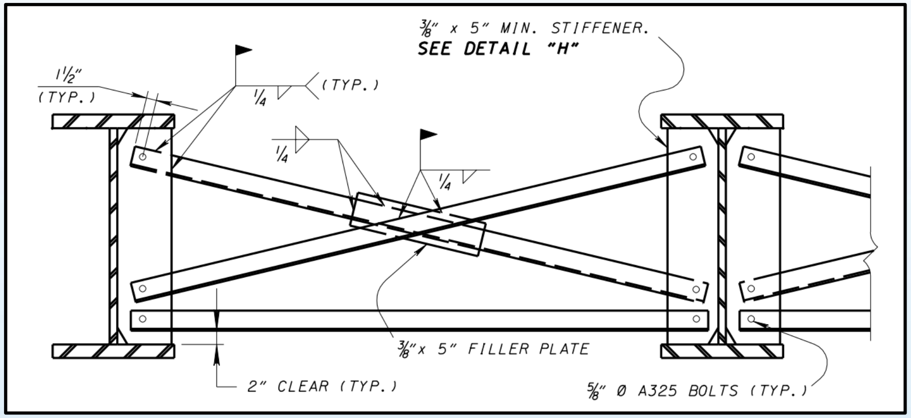
Straight, non-skewed bridges:

- Often designed using line-girder models, cross frame forces are not explicitly calculated (secondary members)
- Details are often taken from standard designs (such as GSD-1-96)
- AASHTO LRFD 6.7.1.1: at a minimum, cross frames must be designed to transfer wind load, and must meet member slenderness requirements.

Line Girder Model:



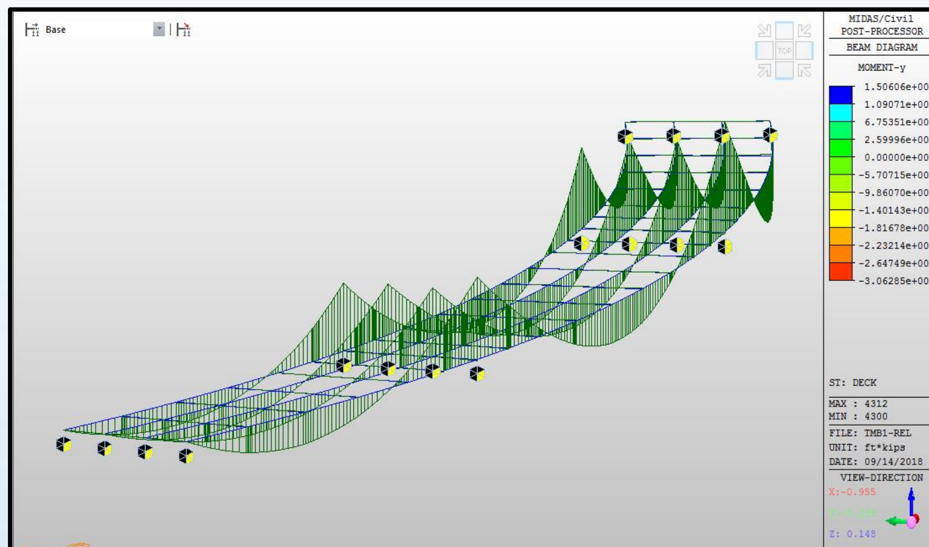
GSD-1-96:



Cross frame design

Curved Bridges:

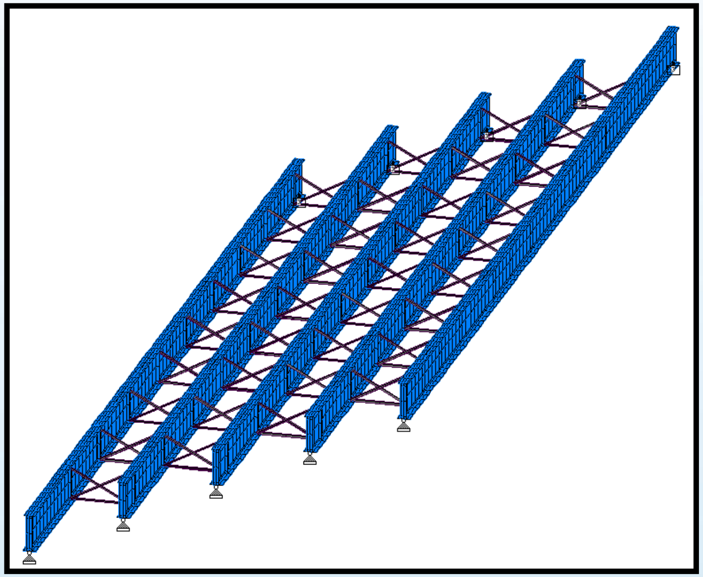
- Cross frames are required to maintain stability in curved girder structures.
- Cross frames must be included in the design model. A two-dimensional grid model is required, at a minimum.
- As cross frames are included in the model, they are also subject to fatigue loading.



Cross frame design

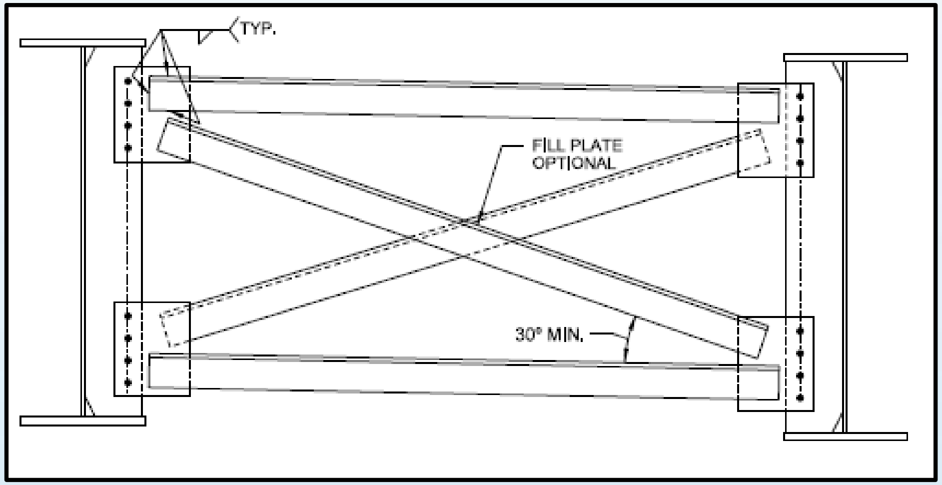
Skewed Bridges:

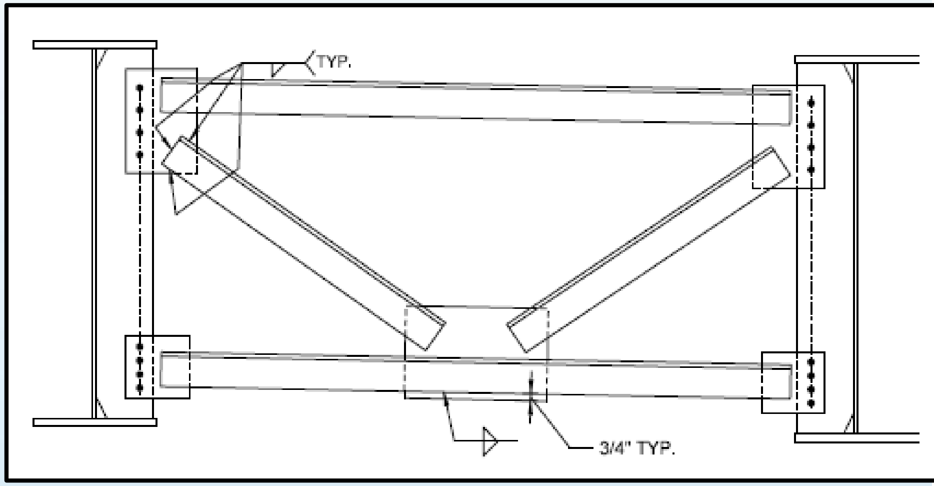
- Skewed framing produces differential deflection between adjacent girders.
- Cross frames form secondary loads paths for dead and live load.
- When skew effects are significant, they should be included in the structural model. Guidance is provided on the ODOT website.
- When included in the structural model, cross frames are subject to fatigue loading.



Preferred cross frame details

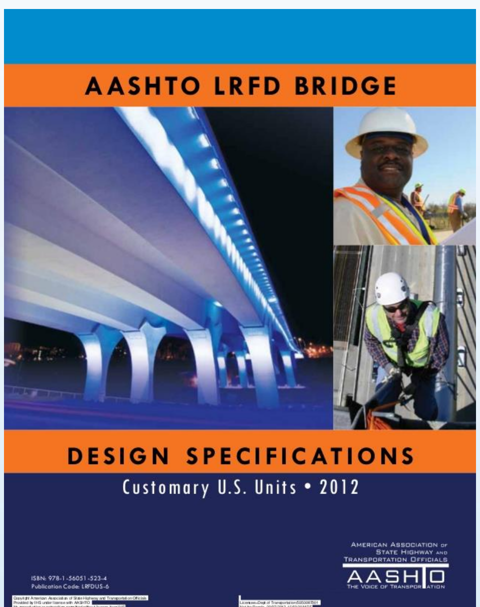
- Cross frame details are discussed in the ***AASHTO-NSBA Guidelines to Design for Constructability***
- NSBA recommends the use of one-piece, shop welded assemblies over "knock-down" cross frames.
- Shop assemblies provide better geometric control, require less shop and field handling.
- For complex geometry, there are less pieces to keep track of and less chance for errors during fabrication and erection.

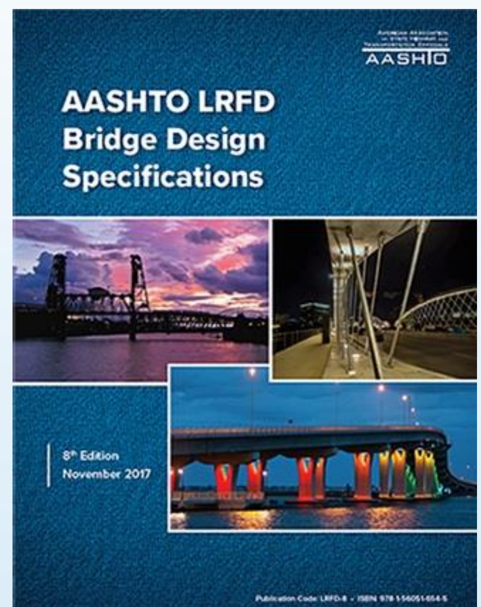




Code Changes

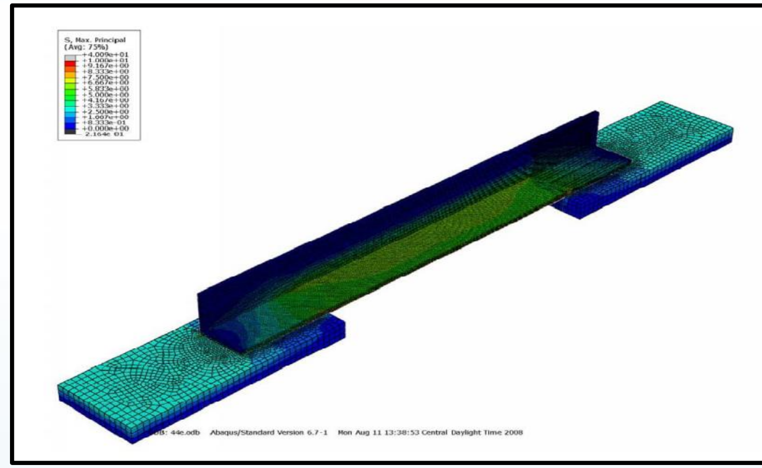
- AASHTO 7th Edition, 2016 Interims changed the fatigue category for fillet welded angles and T-sections from E to E'.
- Effective member area of angles and T-sections must be reduced to account for partially welded attachment.
- AASHTO 8th Edition (2017) increased the load factors for fatigue load combinations.

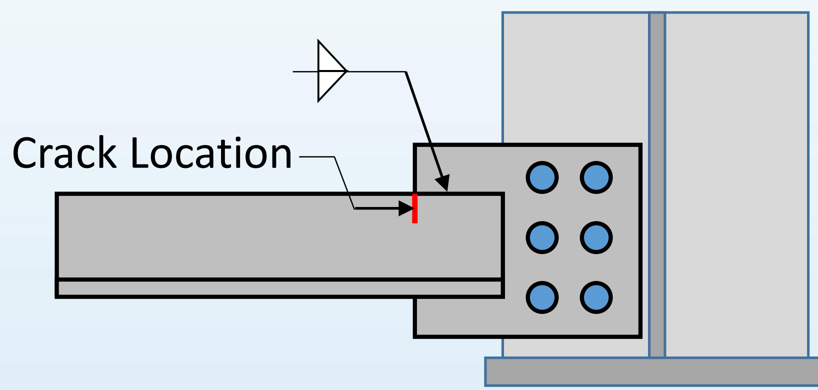




Code Changes

- Fatigue requirements for welded tee-sections and angles are based on research at UT Austin by McDonald and Frank (2009)
- Cracks form at unstiffened edges at welded connections
- As member force is concentrated at the welded leg at the connection, a reduced effective area (A_e) can be calculated
- 2016 Interims upgraded this detail from an E to an E'





Code Changes

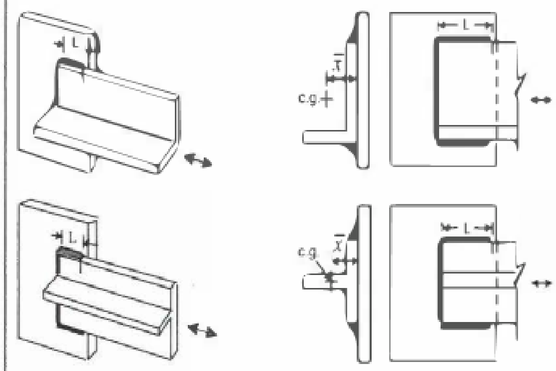
7.2 Base metal in angle or tee section members connected to a gusset or connection plate by longitudinal fillet welds along both sides of the connected element of the member cross-section, and with or without backside welds. The fatigue stress range shall be calculated on the effective net area of the member, $A_e = UA_g$, in which $U = (1 - \bar{x}/L)$ and where A_g is the gross area of the member. $\bar{x}$ is the distance from the centroid of the member to the surface of the gusset or connection plate and L is the maximum length of the longitudinal welds. The effect of the moment due to the eccentricities in the connection shall be ignored in computing the stress range (McDonald and Frank, 2009).	E′	3.9×10^8	2.6	Toe of fillet welds in connected element	

Table 6.6.1.2.5-3—Constant-Amplitude Fatigue Thresholds

Detail Category	Threshold (ksi)
A	24.0
B	16.0
B′	12.0
C	10.0
C′	12.0
D	7.0
E	4.5
E′	2.6
ASTM F3125, Grades A325 and F1852 Bolts in Axial Tension	31.0
ASTM F3125, Grades A490 and F2280 Bolts in Axial Tension	38.0

Code Changes

- Increased load factors are based on research by Kulicki et al. (2014)
- New factors calculated based on statistical analysis of current truck traffic
- Report recommended FAT I /FAT II factors of 0.8 and 2.0.
- Code value were set to 0.8 and 1.75 (formerly 0.75 and 1.50).

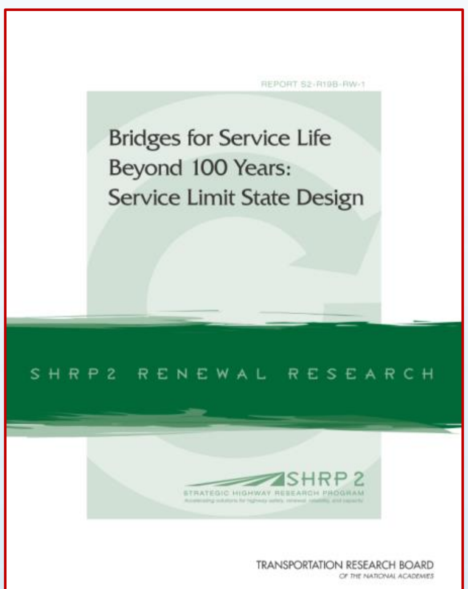
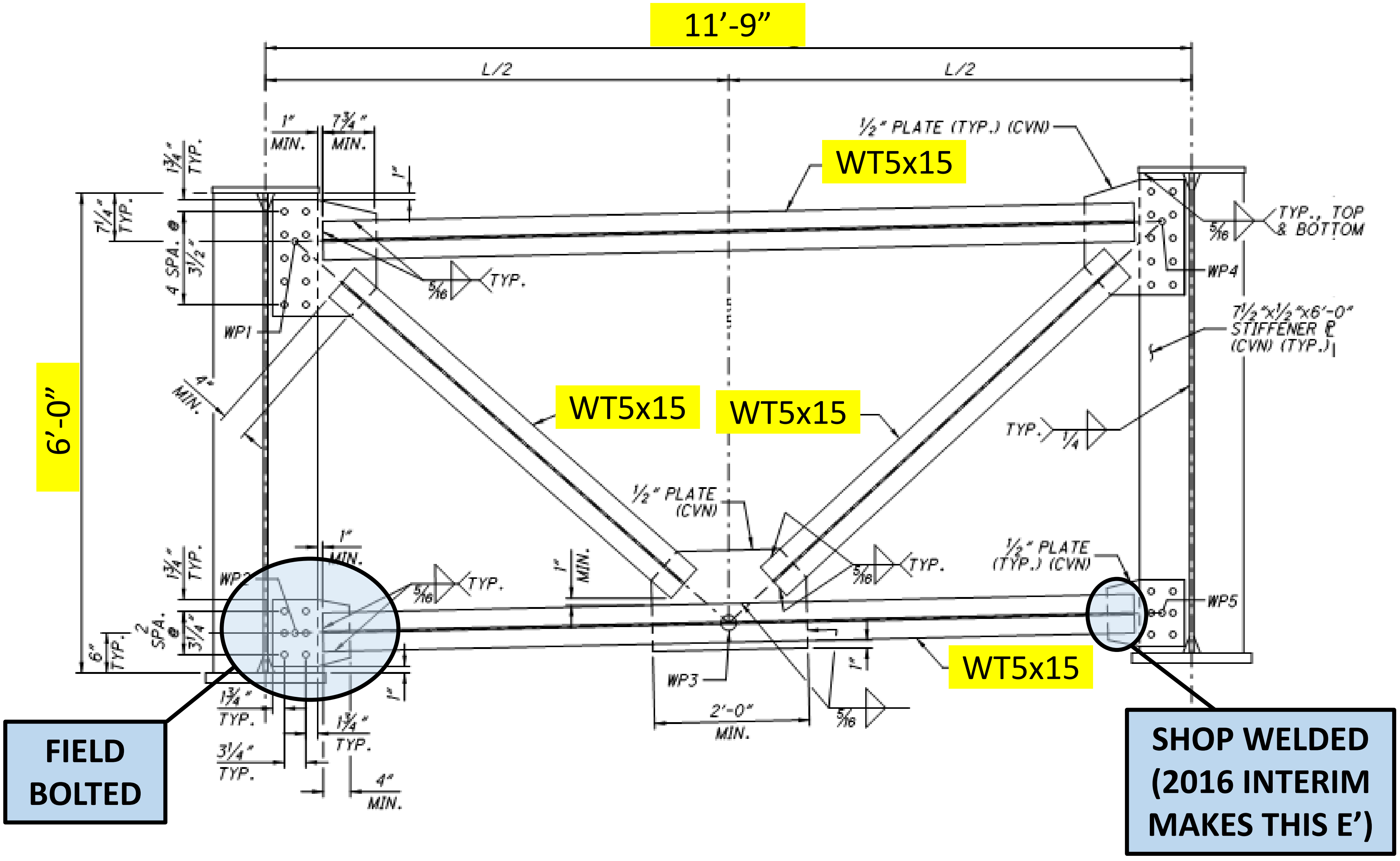


Table 3.4.1-1—Load Combinations and Load Factors

Load Combination Limit State	*DC DD DW EH EV ES EL PS CR SH*	*LL IM CE BR PL LS*	*WA*	*WS*	*WL*	*FR*	*TU*
Fatigue I— *LL*, *IM* & *CE* only	—	1.75	—	—	—	—	—
Fatigue II— *LL*, *IM* & *CE* only	—	0.80	—	—	—	—	—

Typical Cross frame – Pre 2016 Interim:



Sample Calculation – Shear Lag

WT5x15 A_g = **4.42 in^2**

$\bar{x}$ = **1.10 in**

L = 5.00 in (weld length)

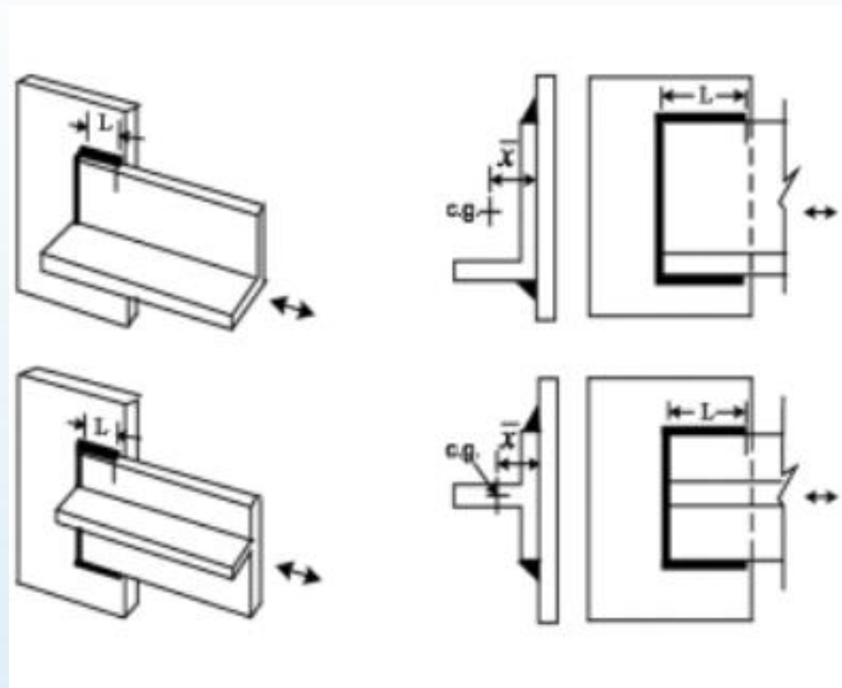
<u>*Per Table 6.6.1.2.3-1, Detail 7.2:*</u>

$U = (1 - \bar{x}/L)$

$U = (1 - 1.1/5) = 0.78$

$A_e = Ua_g$

$A_e = (4.42)(0.78) =$ **3.44 in^2**



Sample Calculation – Fatigue Threshold

WT5x15 $A_g = 4.42\ in^2$ $A_e = 3.44\ in^2$

Before 7th Edition 2016 Interim Revisions:

Category E, FAT I fatigue threshold= 4.5 ksi (table 6.6.1.2.5-3)

Factored force range = 4.5 ksi x 3.44 in² = 15.48 kips

Service force range = 15.48 kips/1.5 load fact. = ***10.32 kips***

Current Criteria (AASHTO 8th Edition):

Category E', FAT I stress range = 2.6 ksi (table 6.6.1.2.5-3)

Factored force range = 2.6 ksi x 3.44 in² = 8.94 kips

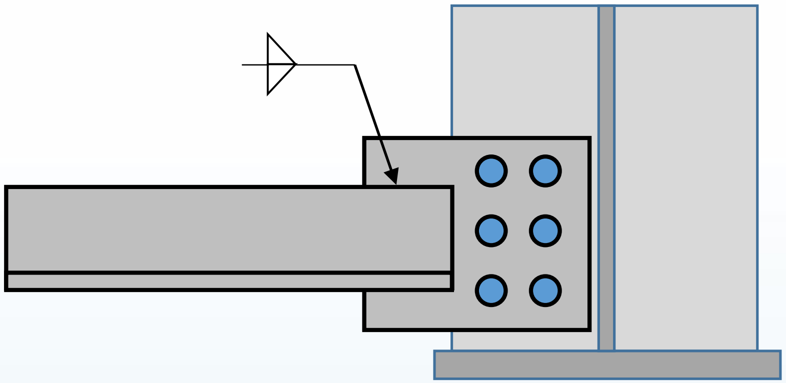
Service force range = 8.94 kips/1.75 load fact. = ***5.10 kips***

50% Reduction

WT5x15 => WT5x34

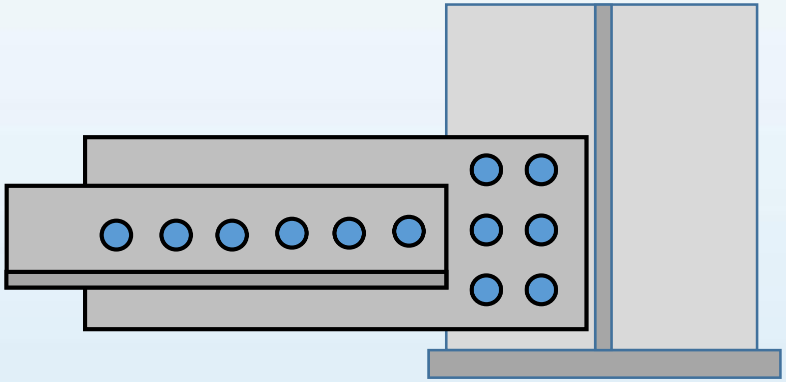
Impact of changes

- Larger cross frame members (50%+ increase in member area)
- Designers considering replacing welded connections with bolts
- Designers considering the use of non-standard member types (channels)



Problems:

- Bolted connections for small members carrying large forces are difficult to detail and fabricate
- Shear lag is still an issue
- Cost of complex/unusual details may outweigh material savings



Impact of changes

Recommendations:

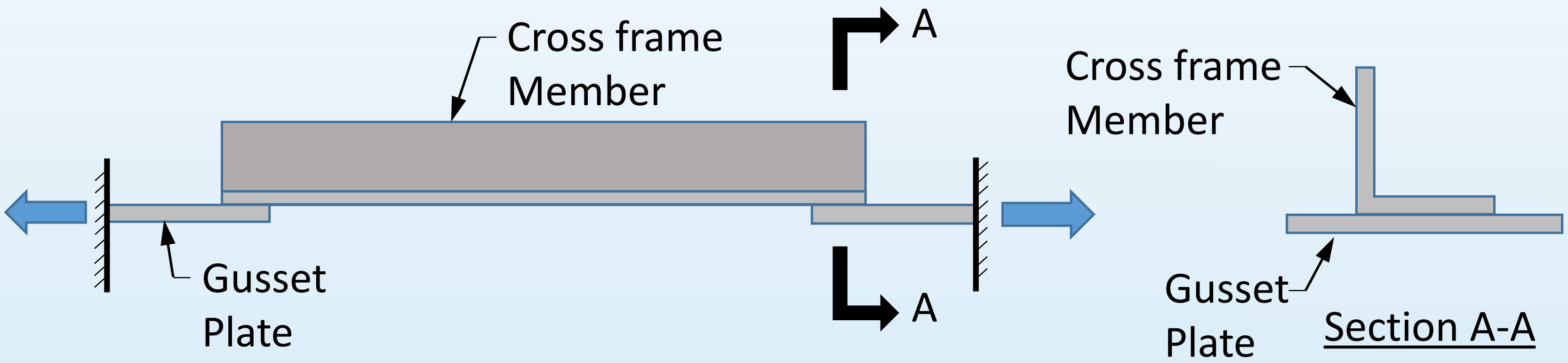
- Bolted connections are not necessarily “better” due to lower fatigue category
- Common welded connections are still preferable to fabricators

Considerations during design:

- ***Code Provisions*** - take advantage of provisions that allow reductions in fatigue load
- ***Framing Arrangements*** - use arrangements that minimize cross frame forces
- ***Refined Modeling*** -use analysis methods that minimize demand on cross frames

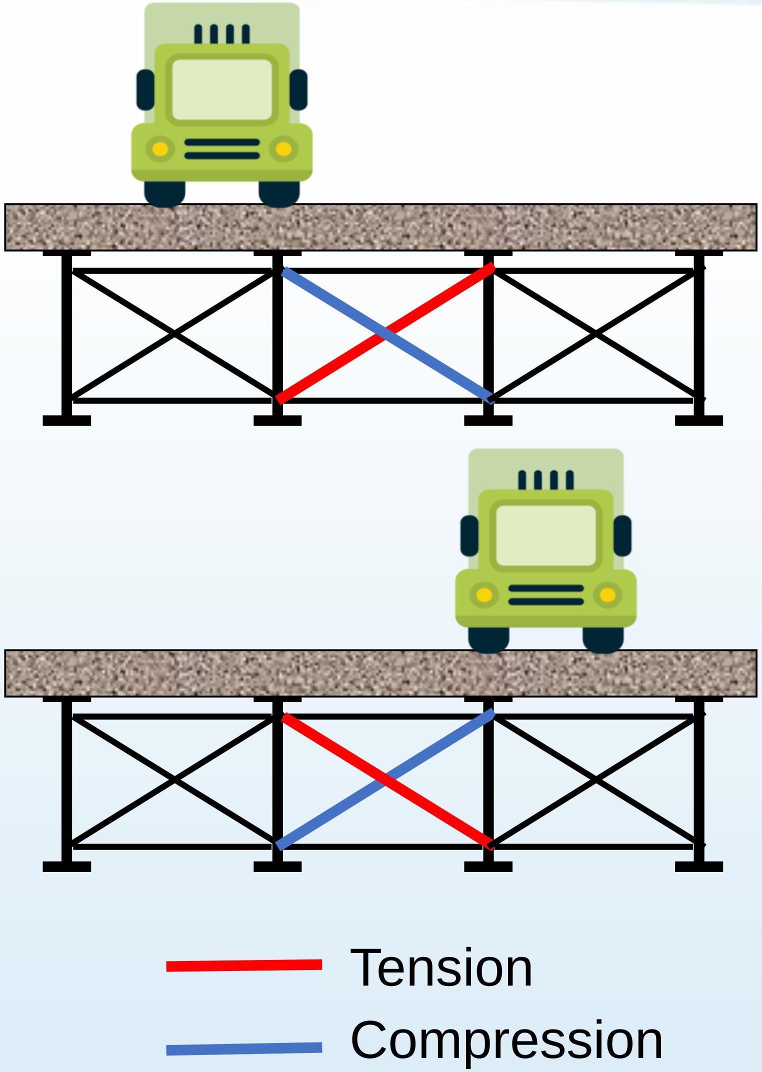
Code Provisions

- 4.6.3.3.4 – "The influence of end connection eccentricities shall be considered in the calculation of equivalent axial stiffness of single-angle and flange-connected tee-section cross-frame members"
- C4.6.3.3.4 – "In lieu of a more accurate analysis, $(AE)_{eq}$ … may be taken as 0.65 AE.
- Reduced stiffness in the structural model results in lower member forces.
- Can be difficult to implement using standard design software.



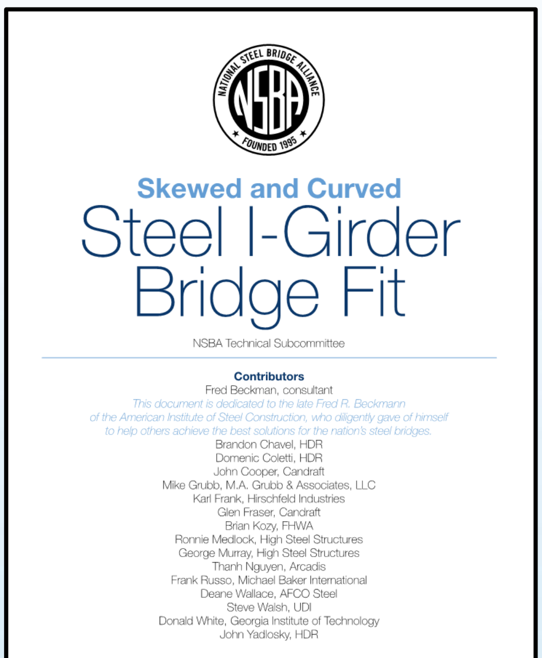
Code Provisions

- C6.6.1.2.1 – Maximum fatigue stresses in cross frames can be determined “with the truck confined to one critical transverse position per each longitudinal position throughout the length of the bridge”.
- This means that fatigue stress is calculated using only a single transverse lane position.
- Standard grid design software is generally not considering this. This requires isolating loading from individual lanes in the analysis.



Framing Arrangements

- Cross frames can form an alternative load path for primary forces
- This effect can be reduced if considered in the framing arrangement
- Some discussion of this in AASHTO 6.7.4.2.
- Detailed discussion in NSBA "Steel I-Girder Bridge Fit" document.



Skewed and Curved
Steel I-Girder Bridge Fit

NSBA Technical Subcommittee

Contributors

Fred Beckman, consultant

This document is dedicated to the late Fred R. Beckmann of the American Institute of Steel Construction, who diligently gave of himself to help others achieve the best solutions for the nation's steel bridges.

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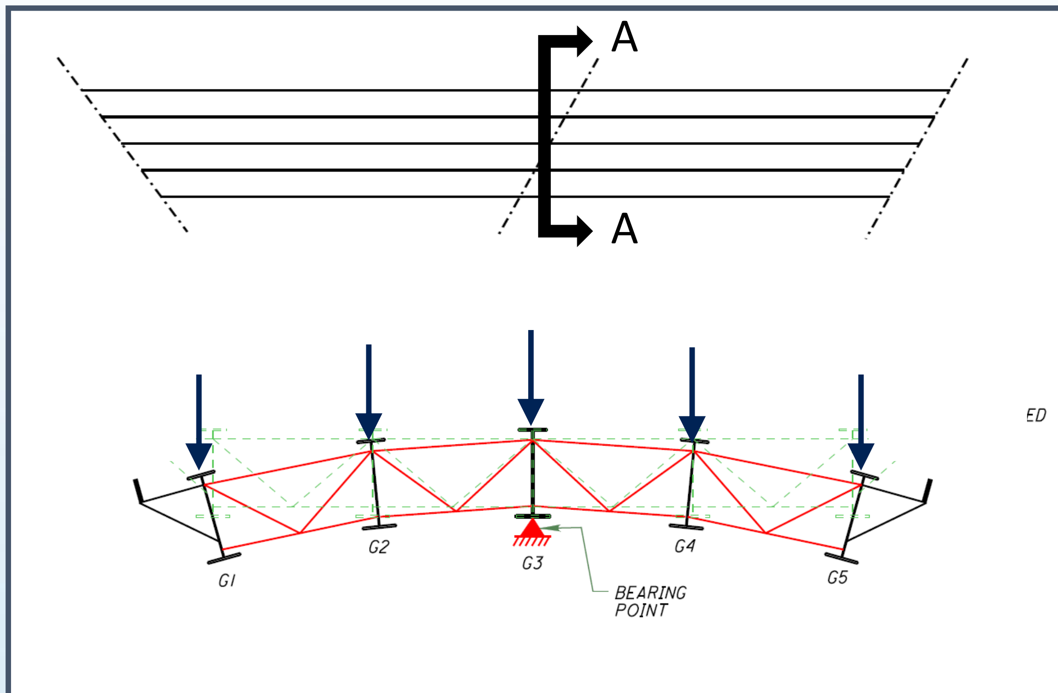
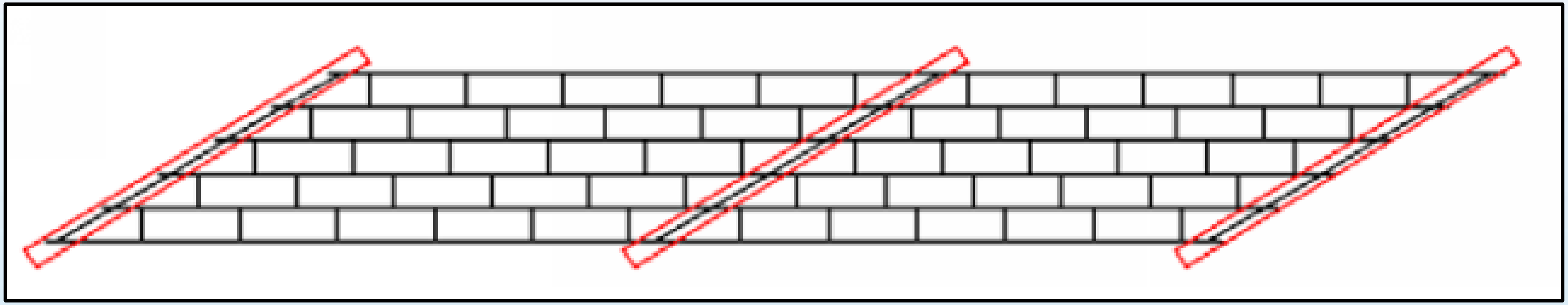


Framing Arrangements

Parallel Skew Bridges:

- Placing intermediate cross frames in continuous lines across the structure can create stiff transverse load paths, producing high cross frame forces.
- Placing intermediate cross frames in discontinuous (staggered) lines reduces transverse stiffness and cross frame forces.
- This arrangement increases girder flange lateral bending, and this effect should be accounted for in design.
- Place cross frames at skewed supports on the skew. Do not frame continuous transverse lines into supports.



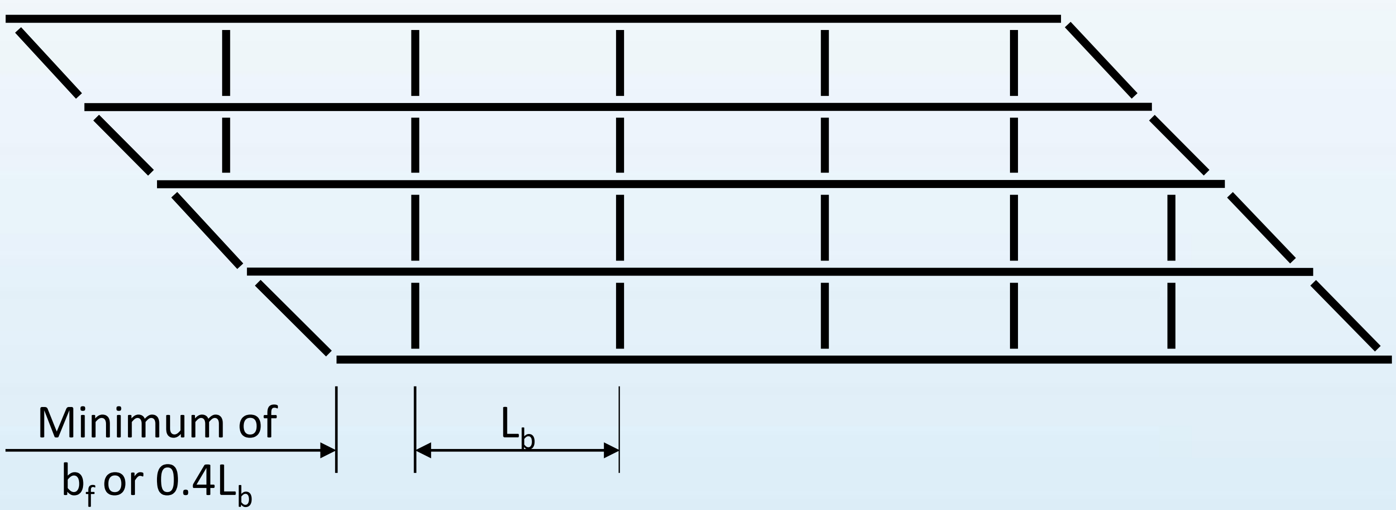
Framing Arrangements

Skewed Bearing Lines:

- AASHTO LRFD C6.7.4.2 – For skews > 20º, the first intermediate cross frame placed normal to the girders should be offset from the support by a minimum of:

= $4b_f$ (b_f = flange width)

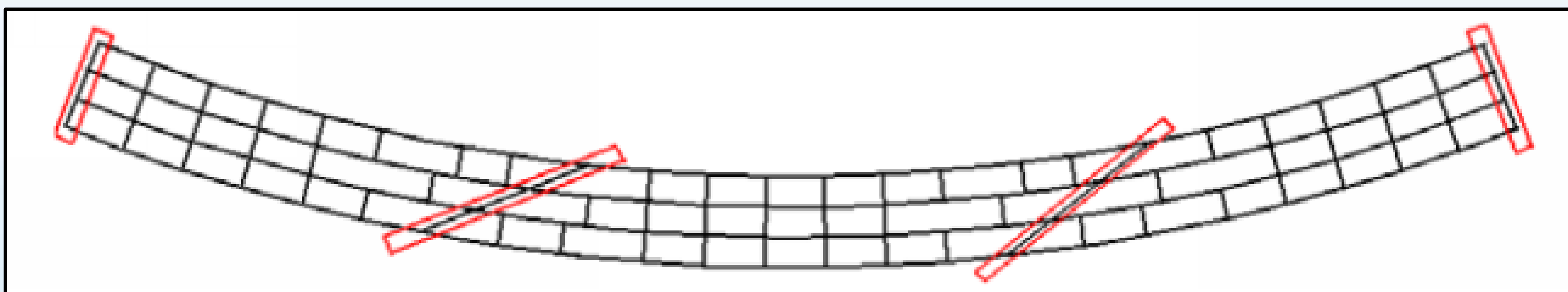
= $0.4\ L_b$ (L_b = unbraced length between cross frames)



Framing Arrangements

Curved and Skewed Bridges:

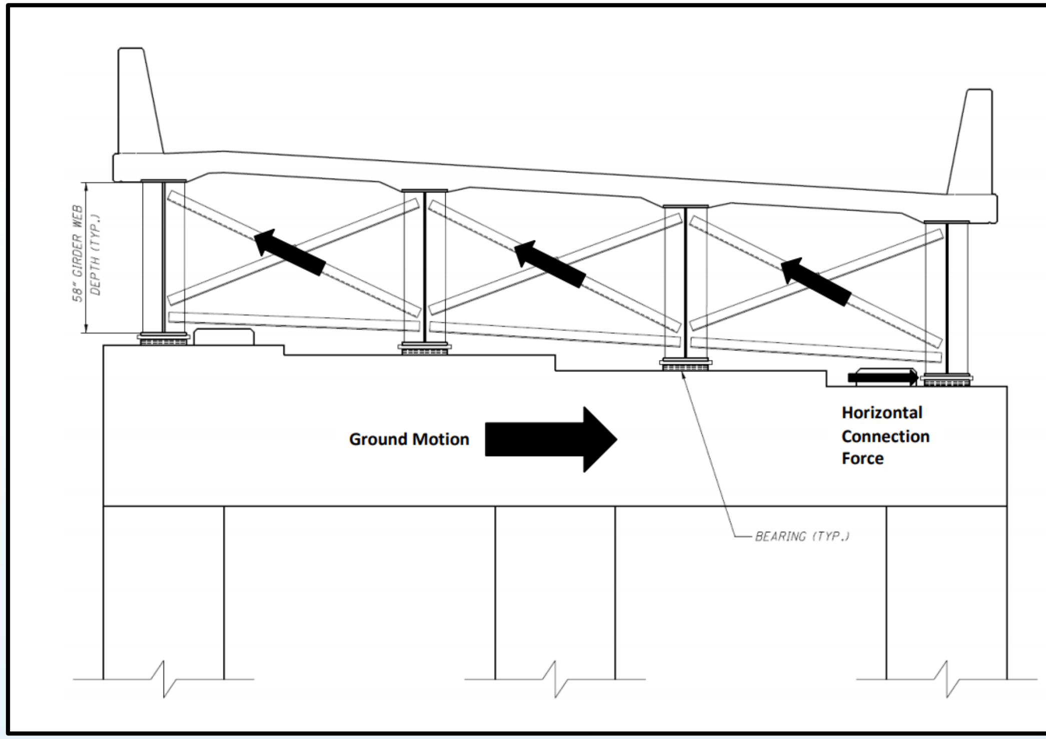
- Continuous cross frame lines are generally required near midspan to develop the torsional stiffness of the superstructure.
- Use discontinuous (staggered) lines near the supports.
- Place cross frames at skewed supports on the skew. Do not frame continuous transverse lines into supports.



Framing Arrangements

ODOT Seismic Provisions:

- ODOT BDM 301.4.4.1.b requires that cross frames be provided to create a direct load path from the deck to the horizontal connection force at the substructures.
- Keep cross frame lines at the skewed supports on the skew.



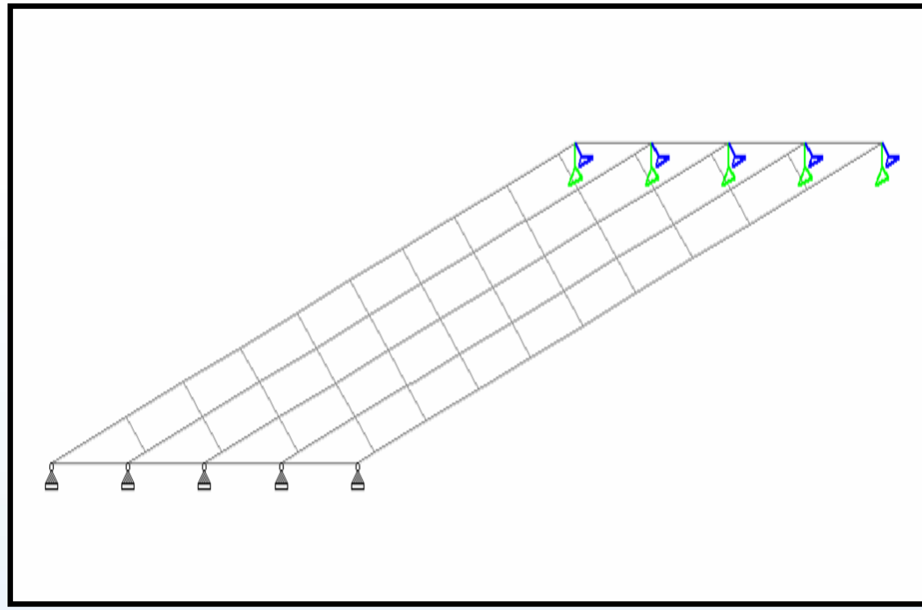
Refined Modeling

- Most commonly used analysis software uses either line girder analysis or 2-D grid analysis methods.
- Line girder analysis determines live load distribution using calculated distribution factors. Cross frame forces are not calculated.
- 2D grid analysis generally includes the girders (using both non-composite and composite section properties) and the cross frames.
- The longitudinal stiffness of the deck is included in the girder properties. The lateral stiffness of the deck is not considered in the model.
- Neglecting the lateral stiffness of the deck generally results in an over-estimation of the portion of the live load carried by the cross frames.

Refined Modeling

Conventional Grid Model:
(MDX, Descus, LEAP Bridge)

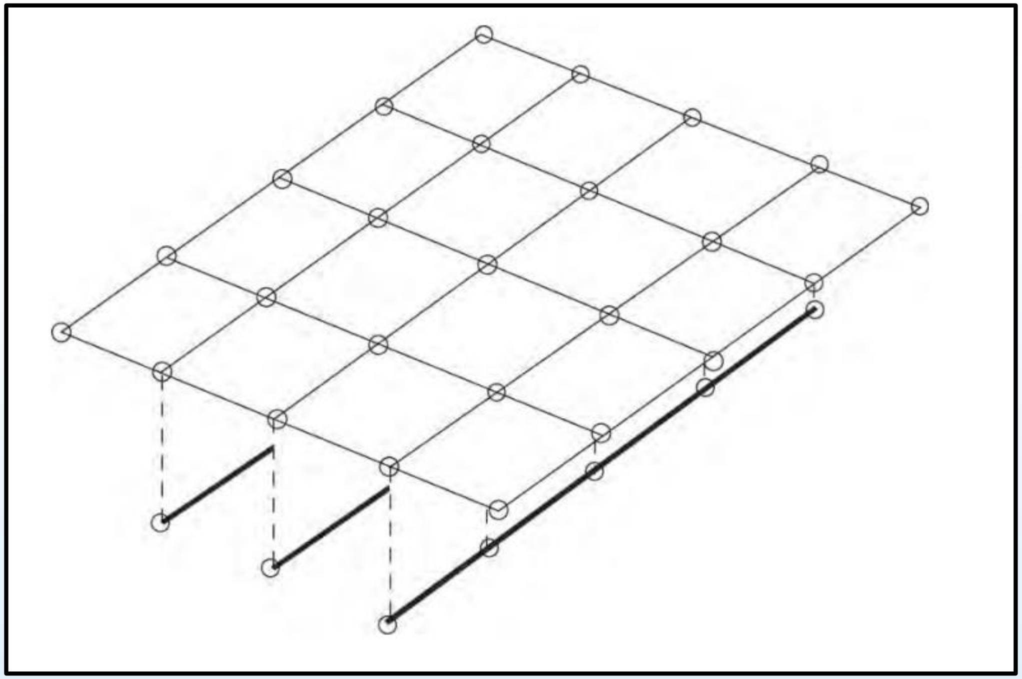
- Minimum level of analysis for curved and highly skewed structures
- Cross frames behavior is approximated using equivalent beam elements
- Warping stiffness of the beams is generally neglected
- Transverse stiffness of the deck is generally neglected



Refined Modeling

Plate and eccentric beam model:

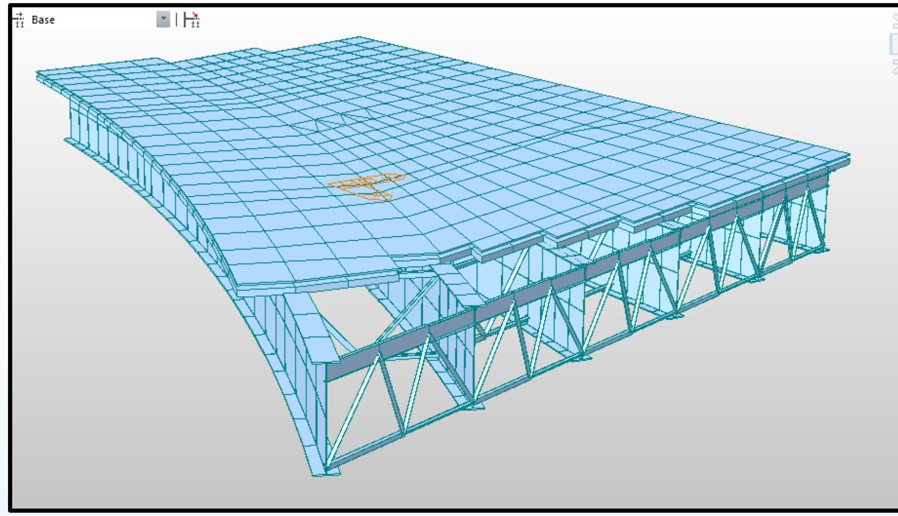
- Alternative to conventional gird analysis
- Uses beam elements to model the girders and cross frames, and plate elements to model the bridge deck
- Produces a coupling effect between the deck and cross frames, reduces the overall demand on the cross frames.

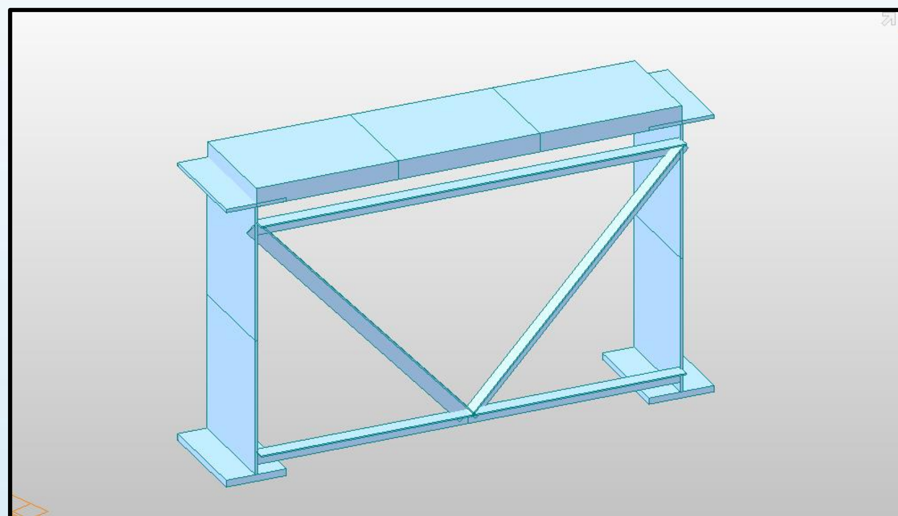


Refined Modeling

3D FEM Model:

- Higher level of modeling
- Use plate elements for the girder web, beam or plate elements for the flanges, truss elements for the cross frame members, plate elements for the deck.
- More accurately reflects the behavior of the structure.
- Generally predicts lower live load forces in the cross frames

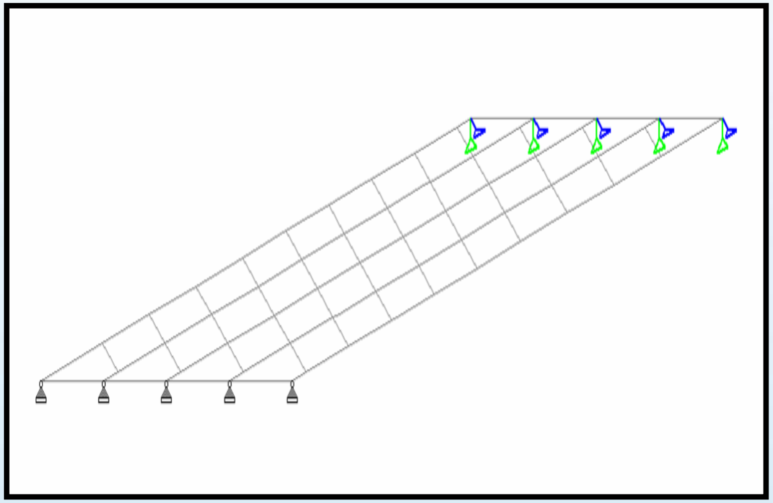


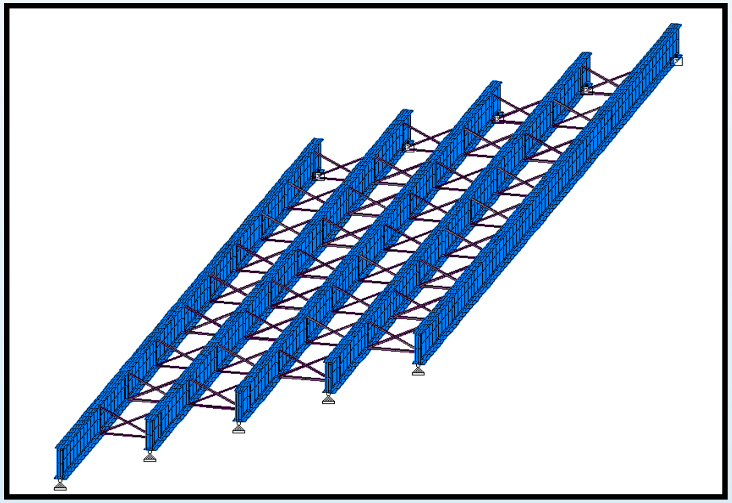


Refined Modeling

Modeling Recommendations:

- Follow detailed recommendations for appropriate model types provided in *Guidelines for Steel Girder Bridge Analysis (AASHTO/NSBA TG 13)*
- For standard curved or skewed structures, use of a conventional grid model is generally adequate.
- Where cross frame fatigue forces control the design, use of a refined model for live load conditions should be considered. Including the transverse stiffness of the deck serves to reduce cross frame demand.

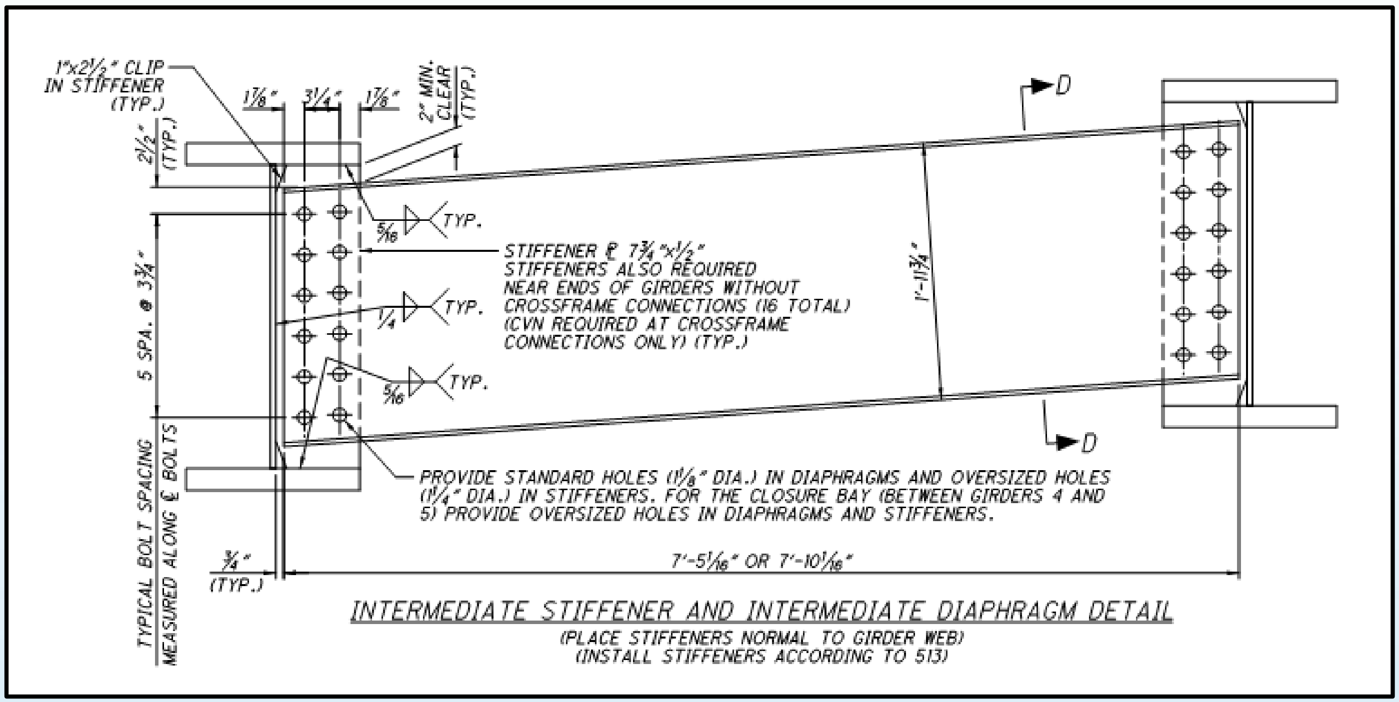




Alternative Details

Plate / Channel Diaphragms

- Using bolted channel or bent plate diaphragms is an alternative for shorter spans.
- Requires only field bolting and eliminates the E' detail



Reference Publications

Guidelines for Steel Girder Bridge Analysis (AASHTO/NSBA TG 13)

- Discussion of behavior of skewed and curved bridges
- Analysis recommendations and guidance

Skewed and Curved Steel I-Girder Bridge Fit (NSBA)

- Discussion of fit-up conditions for steel framing
- Recommended framing configurations

FHWA Steel Bridge Design Handbook

- Design examples, including cross frames (AASHTO LRFD 7th Ed.)

=> All available for free download

Forthcoming Publications & Research

- ***AASHTO/NSBA Taskgroup 11 - Guidelines for the Design of Cross Frame Members –*** Updated guidance document on cross frame design, including sample calculations.

- ***NCHRP 12-113 – Propose Modification to AASHTO Cross-Frame Analysis and Design –*** Ongoing research project (University of Texas) to evaluate and propose changes to the current specifications.

Questions?

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