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ERRATA for *G12.1, Guidelines to Design for Constructability,* 2016 Edition

December 2016

Dear Customer:

Recently, we were made aware of some technical revisions that need to be applied to the *Guidelines to Design for Constructability,* 2016 Edition.

Please scroll down to see the full erratum.

In the event that you need to download this file again, please download from AASHTO's online bookstore at:

http://downloads.transportation.org/NSBAGDC-3-Errata.pdf

Then, please replace the existing pages with the corrected pages to ensure that your edition is both accurate and current.

AASHTO staff sincerely apologizes for any inconvenience to our readers.

Summary of Errata Changes for NSBAGDC-3, December 2016

Page	Existing Text	Corrected Text
5	**1.4.2 Wide Flange Beam Length Availability** Structural shape sections of various sizes are produced domestically. Refer to the American Institute of Steel Construction (AISC) website for specific section availability: http://www.aisc.org/steel/searchForm.aspx?id=2044	**1.4.2 Wide Flange Beam Length Availability** Structural shape sections of various sizes are produced domestically. Refer to the American Institute of Steel Construction (AISC) website for specific section availability: https://www.aisc.org/steelavailability/
13	**1.6.1 Fit and Differential Deflections** When choosing a fit condition for a steel I-girder bridge, consider: • Differential deflections at each cross frame • Span length • Radius (for curved bridges) • The need for lateral rotational capacity of the bearings	**1.6.1 Fit and Differential Deflections** When choosing a fit condition for a steel I-girder bridge, consider: • Differential deflections at each cross frame • Span length • Radius (for curved bridges) • The need for lateral rotational capacity of the bearings • Owner preferences and local practices
14	**1.6.2 Deflection due to Phased Construction** …Provide a deck placement sequence diagram in the contract plans.	**1.6.2 Deflection due to Phased Construction** …Provide a deck placement sequence diagram in the contract plans. Ensure that the deflections shown in the contract plans and used for camber calculations account for the effect of phasing.
26	**C2.1.4** … The use of field welds to connect primary members (girders) or secondary members (diaphragms) introduces the potential for misalignment and loss of dimensional control. For instance, when diaphragms are shop welded, the dimensional accuracy can be verified and mistakes minimized.	**C2.1.4** … The use of field welds to connect primary members ~~(girders)~~ or secondary members ~~(diaphragms)~~ introduces the potential for misalignment and loss of dimensional control. For instance, when diaphragms are shop welded, the dimensional accuracy can be verified and mistakes minimized.

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29	**C2.2.1.2.4** Field splices in straight or curved box girders are typically assembled completely prior to shipping to the job site. The connections have traditionally been drilled or reamed while assembled, but may be drilled CNC without full assembly if the fabricator provides the engineer with a geometry control plan.	**C2.2.1.2.4** Field splices in straight or curved box girders are typically assembled completely prior to shipping to the job site. The connections have traditionally been drilled or reamed while assembled, but may be drilled by CNC without full assembly if the fabricator provides the engineer with a geometry control plan.
33	**C2.2.5** … All girder loads require permits and some jobs require the fabricator to do a route survey to determine how the product will be delivered to the job site. Due to the extreme length, width, height, or weight of some girder loads, police escorts may be required to transport the load to the job site.	**C2.2.5** …All girder loads require permits and some jobs require the fabricator to do a route survey to determine how the product will be delivered to the job site. Due to the extreme length, width, height, or weight of some girder loads, police escorts may be required to transport the load to the job site. Permit load requirements vary from state to state.
36	**2.2.6.5 Reducing Demand on Cross Frames in Straight I-Girder Bridges** …In moderately to severely skewed bridges, significant transverse stiffness in the structural steel framing can lead to high cross frame forces. The anticipated publication of the final research report for National Cooperative Highway Research Program (NCHRP) Research Project 20-07 Task 355 includes many suggestions for reducing the stiffness of these transverse load paths, leading to greatly reduced cross frame forces, and fewer, lighter cross frames, without significantly compromising the strength of the girders.	**2.2.6.5 Reducing Demand on Cross Frames in Straight I-Girder Bridges** …In moderately to severely skewed bridges, significant transverse stiffness in the structural steel framing can lead to high cross frame forces. The ~~anticipated publication of~~ the final research report for National Cooperative Highway Research Program (NCHRP) Research Project 20-07 Task 355 includes many suggestions for reducing the stiffness of these transverse load paths, leading to greatly reduced cross frame forces, and fewer, lighter cross frames, without significantly compromising the strength of the girders.

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37	**C2.2.6.5** … In order to develop a lean-on bracing system configuration, the erection sequence of the steel girders must be determined. The designer is strongly encouraged to consult with local contractors and erectors to form a solid assumption about how the bridge will be built. This ensures that the appropriate number of cross frames is placed between the first girder segments lifted, which are usually the most critical stage of girder erection. For guidance on developing a lean-on bracing framing configuration and understanding the distribution of forces across the bridge in a cross frame system with lean-on bracing refer to the 2012 FHWA Bridge Design Handbook; Volume 13, Bracing System Design.	**C2.2.6.5** … In order to develop a lean-on bracing system configuration, the erection sequence of the steel girders must be determined. The designer is strongly encouraged to consult with local contractors and erectors to form a solid assumption about how the bridge will be built. This ensures that the appropriate number of cross frames is placed between the first girder segments lifted, which are usually the most critical stage of girder erection. For guidance on developing a lean-on bracing framing configuration and understanding the distribution of forces across the bridge in a cross frame system with lean-on bracing refer to the 2012 FHWA Bridge Design Handbook; Volume 13, Bracing System Design. The designer must state the assumed erection sequence used for the lean on bracing system design in the contract plans.

Table 1.4.1.B: Plate Length Availability
ASTM A709 Grade HPS 70W (all dimensions in inches)

Plate Thickness	Plate Width				
	72	84	96	108	120
½	580	580	580	580	580
¾	580	580	580	580	580
1	580	580	580	580	580
1½	580	580	580	580	580
2	580	580	580	580	580
2½	600	600	600	600	600
3	600	600	600	600	600
3½	600	600	600	600	600
4	600	600	600	600	600

Notes: Widths and thicknesses are grouped for convenience. Other widths and thicknesses are available in similar lengths. Interpolate between adjacent values for other size plates. Material in the shaded area is currently available from three domestic rolling mills.

1.4.2 Wide Flange Beam Length Availability

Structural shape sections of various sizes are produced domestically.

Refer to the American Institute of Steel Construction (AISC) website for specific section availability:

https://www.aisc.org/steelavailability/

C1.4.2

Examples of common rolled beam bridge sections are shown in Table 1.4.2.A below. Longer lengths may be available, depending on the producer.

1.6—DIFFERENTIAL DEFLECTIONS

1.6.1 Fit and Differential Deflections

When choosing a fit condition for a steel I-girder bridge, consider:

- Differential deflections at each cross frame
- Span length
- Radius (for curved bridges)
- The need for lateral rotational capacity of the bearings
- Owner preferences and local practices

For recommendations on what fit condition is appropriate for a given bridge, see the document "Skewed and Curved Steel I-Girder Bridge Fit," published by NSBA on August, 20, 2014.

In practice historically, contractors or fabricators have made the fit choice when not specified by the designer in the contract plans, but considering the influence the fit condition can have on member loads (as well as constructability), it is prudent for the designer to make this decision, as is currently required by the AASHTO *LRFD Bridge Design Specifications* (AASHTO).

C1.6.1

In an I-girder bridge, "fit" refers to how the cross frames are detailed and fabricated to fit to the girders. They may be:

- Detailed to fit when all dead loads are applied ("total dead load fit," TDLF, or "final fit");
- Detailed to fit at erection ("steel dead load fit," SDLF, or "erected fit");
- Detailed to fit in the no-load condition ("no-load fit," NLF, or "fully-cambered fit"); or,
- Detailed to fit at some other condition in between.

The girders and cross frames may actually fit at more than one or all of these conditions. The distinction here is not whether or not the bridge components actually fit in these conditions, rather it is how the bridge is detailed to fit.

The detailed fit condition can influence:

- The ability to construct the bridge. For example, choosing TDLF for a sharply curved bridge can make the bridge unconstructable; and
- Internal loads associated with the fit condition.

"Differential deflections" refer to the difference in girder deflection at either end of each cross frame. When differential deflections exist (as they must on skewed and curved bridges), cross frames tend to deflect a different amount on either end. Since the cross frames are very stiff, they cannot easily distort to accommodate these differential deflections, so the result for most bridges is that the girders twist.

For bridges detailed to TDLF, there will be layover (twist) at erection, but generally the girders will come back to plumb under total dead load. Conversely, on a skewed bridge detailed to steel dead load fit, girders will be plumb at erection but will experience some final layover under total dead load. For this reason, the fit condition is sometimes referred to as the plumb condition. However, it is not recommended to refer to fit in this way because it confuses the issue—particularly when the "plumb" discussion is extended to curved girders in which layover and plumb do not work the same way.

The document referenced in the recommendation provides more explanation about these choices and phenomena. For more in-depth discussion of these issues, a more detailed version of the skewed and curved steel I-girder bridge fit document is expected to be published by NSBA in the near future. See the commentary on Section 2.2.6.5 for the full reference.

1.6.2 Deflection due to Phased Construction

Consider using single member top and bottom struts; omission of the cross frames or diaphragms between units; or use field-drilled holes, slotted holes, or field-welded connections where phased construction would cause significant differential deflection in the bay between previous and new construction (phase 1 versus phase 2, existing versus widening, etc.). Note that for curved girders, AASHTO does not allow slotted or oversize holes.

Provide a deck placement sequence diagram in the contract plans. Ensure that the deflections shown in the contract plans and used for camber calculations account for the effect of phasing.

C1.6.2

If phased construction is required, the differential deflection between units due to the application of dead loads at different times can be significant. There are many ways to address this in the design and detailing of cross frames between the adjacent units.

The use of independent single member top and bottom struts without diagonals (also known as "lean-on" bracing) with a single bolt in each end is one simple and effective possible way to address this situation when the differential deflections are not too significant. Using this type of detailing provides some bracing for the girder compression flange while still allowing for differential deflection between adjacent units built at different times. Care should be taken to ensure that deflections are not so great that the deflected orientation of the brace is so far out of plane from the girder compression flange that is cannot continue to function as a brace.

Another approach that may be effective in cases where differential deflections are small is the use of slotted holes for the connections on one side of the cross frames in the bay between the adjacent units. In this situation the cross frame is installed with fully-tightened bolts in the connections to one girder, but with snug-tight bolts in slotted holes in the connections to conformance with the welding procedures and specifications. A properly performed weld is acceptable whether it is performed in the shop or in the field.

- Retrofits to existing structures
- Stay-in-place (SIP) deck formwork (in compression areas)
- Large sections that are impractical to ship by available means
- Cross frame connections between staged construction

Considerations to be made when specifying field welding include:

1) Local availability of experienced, qualified welders and welding inspectors.

In geographic areas where field welds are extensively used, experienced, qualified welders will be more readily available than other areas. While most welders can be qualified, it is also necessary to employ welders, who through experience, have proven they are capable of producing welds that consistently meet the acceptance criteria of the applicable welding code.

2) Means to establish and maintain fit-up and dimensional control of the connection or assemblage.

The use of field welds to connect primary members or secondary members introduces the potential for misalignment and loss of dimensional control. For instance, when diaphragms are shop welded, the dimensional accuracy can be verified and mistakes minimized.

3) Sensitivity of welding to environmental factors such as cold, wind, rain, snow, structure vibration or deflection, etc.

Ambient temperatures influence the amount of heating required to maintain appropriate pre-heat, interpass and post-heat temperatures. Maintaining temperature can be a challenge in cold environments. Enclosures may be required to prevent wind from removing shielding gases.

4) Means to provide safe and stable access for welder to all parts of the weld

A stable, well-positioned platform allows the welder to focus on the weld. Access to both sides of the weld must be considered if required. When space is limited, a mock-up may be appropriate to ensure there is sufficient room for the welder to perform the weld safely. Confined spaces with elevated temperatures and shielding gases for the welding process may present safety issues that need to be addressed.

fall protection required. The assembly can be made with the webs either vertical or horizontal. Either method will yield similar results if executed properly.

2.2.1.2.4 Position of Assembly for Box Girders

Members may be rotated to use more convenient work lines or planes from the beginning to end of each assembly, or use a chord line from beginning to end of each continuous span unit. Shop drawing details must accurately show all dimensions and elevations to assemble the members properly for drilling or reaming.

C2.2.1.2.4

Field splices in straight or curved box girders are typically assembled completely prior to shipping to the job site. The connections have traditionally been drilled or reamed while assembled, but may be drilled by CNC without full assembly if the fabricator provides the engineer with a geometry control plan.

To minimize blocking and the elevation of the assembly, the girders can be rotated to eliminate grade and cross-slope.

2.2.1.3 Full Shop Assembly of Steel Girder Structures

Full or partial shop assembly including transverse elements should only be required by contract for appropriate cases, including: structures that are very rigid (e.g., bascule and through-girder railroad bridges); structures with small radii or complex geometry; and where girders terminate at load-carrying diaphragms or other girders. Allowing the fabricator to use alternate schemes that will ensure proper final fit without assembly should be considered to expedite fabrication and reduce cost.

C2.2.1.3

Shop assembly of a single girder line (line assembly) for the purpose of drilling or reaming girder splice connections or for confirming the accuracy of pre-drilled connections is common. Inclusion of transverse elements (cross frames, etc.) in assembly (full shop assembly) is not common and is expensive and time-consuming. Therefore, if the owner intends to require full shop assembly, this requirement should be clearly indicated in the contract documents. Extra emphasis is placed on "clearly indicated" because full shop assembly is unusual and can have a big impact on cost and schedule. It is important to make sure this requirement is clear. When full shop assembly is required, no load fit is typical.

Curved girders usually have sufficient transverse and vertical flexibility to allow relatively small horizontal and vertical displacements for installation of cross-frames in the field without prior shop assembly. Heavy, deep, or rigid members will not be as flexible and may require shop assembly if the radius is tight. Important issues include longitudinal accuracy and how the members are supported during erection.

Either method is effective when executed properly, and may be employed based upon the structure requirements.

AASHTO specifications allow the use of both heat curving and cut curving procedures, with restrictions on the use of heat curving. See AASHTO *LRFD Bridge Construction Specifications*, Article 11.4.12 for additional guidance.

2.2.5 Girder Field Section Length

Use piece lengths that can be shipped by truck and allow the fabricator to add or move splices to optimize delivery. Girders can readily be shipped in lengths up to 120'. Depending on route and site constraints, pieces over 150' and even approaching 175' can be delivered.

Curved girders may require additional field splices due to the curvature of the girders and the location of the girder on the shipping equipment.

C2.2.5

The equipment used to transport longer girders adds significantly to the length of the truck, up to 30′ more. This will, in turn increase the amount of room that is required to make turns to deliver the girder to the job site.

All girder loads require permits and some jobs require the fabricator to do a route survey to determine how the product will be delivered to the job site. Due to the extreme length, width, height, or weight of some girder loads, police escorts may be required to transport the load to the job site. Permit load requirements vary from state to state.

Curved girders add a different set of issues. Because the girder is curved, it must be balanced on the shipping equipment. This causes the width of the load to be more than the mid-ordinate of the girder alone.

2.2.6 Cross Frames and Diaphragms

2.2.6.1 Intermediate Cross Frames or Diaphragms for I-Girder Bridges

Use cross frame types shown in Figure 2.2.6.1A or Figure 2.2.6.1.B. The fabricator should be permitted to use parallelogram as well as rectangular configurations to keep connection plates identical. If the angle of the diagonals in an X-type frame would be less than 30°, use the K-frame, otherwise use the X-Frame. The Z-frame shown in Figure 2.2.6.1.C may be an acceptable option for girders more than 42 inches deep, and the bent plate diaphragm, or a rolled channel section as in Figure 2.2.6.1.D is a good option for girders less than 48″ deep.

C2.2.6.1

Cross frame types vary considerably both within and between states. AASHTO/NSBA Steel Bridge Collaboration G1.4, *Guidelines for Design Details*, should be adopted whenever possible. The following recommendations cover the more common applications.

Fabricators prefer single-angle (or when necessary, single-member, such as a WT shape) bracing. Double angles are expensive to fabricate, and painting the backs of the angles is difficult to accomplish Fabricators prefer cross frames such as the K-frame or Z-frame that can be welded from one side only. However, where connections are subject to salt spray, they should be sealed by welding on both sides. Configuration of cross frames should allow as many identical frames as possible. Differences in elevations should be accounted for in the cross frames, not the connection plates. Configuring cross frames as parallelograms instead of rectangles can increase the number of identical connection plates.

Eliminating the top chord of K-frames is not recommended because it has low stiffness at the middle of the cross frame due to lack of depth. Also, it is preferred that X-frames have a top chord as well.

For single member diaphragms, using a W shape is less expensive than an MC shape even though the flanges must be coped. However, the W section is more difficult to paint. Other options are bent plates or plate girders.

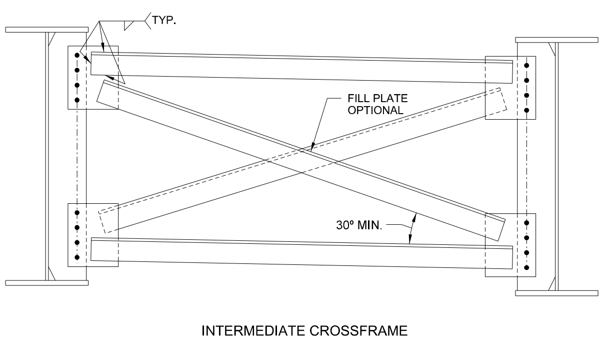

Figure 2.2.6.1.A

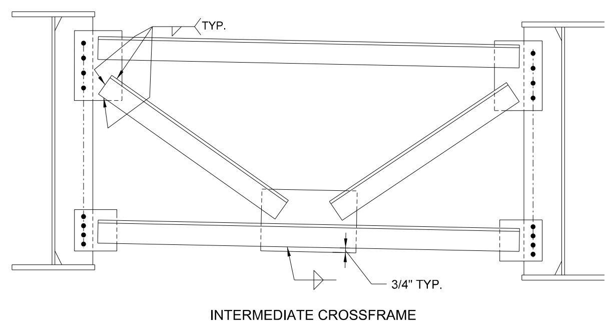

Figure 2.2.6.1.B

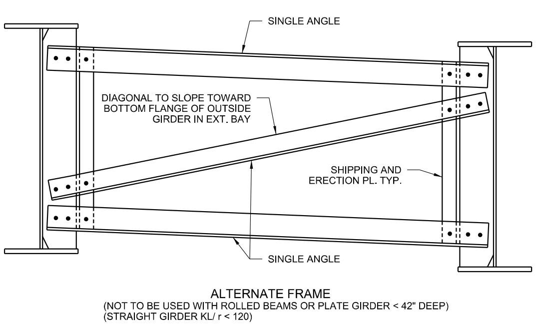

Figure 2.2.6.1.C

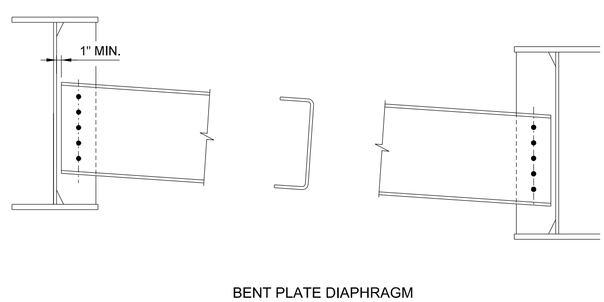

Figure 2.2.6.1.D

2.2.6.2 Intermediate Cross Frames or Diaphragms for Rolled Beam Bridges

Several options are acceptable for intermediate cross frame or diaphragm types for rolled beam bridges:

- AASHTO/NSBA Steel Bridge Collaboration G1.4, *Guidelines for Design Details.*
- Rolled beam or channel with connection angles shop welded or bolted to diaphragm. Field connection bolted to beam web.
- Bent plates with a depth of ½ the beam depth. See Figure 2.2.6.1.D.

C2.2.6.2

End angles attached to rolled-beam or channel diaphragms for field bolting to stringers can eliminate intermediate connection plates.

If the stringer is painted, welding plates is a better alternative than bolting a connection angle.

2.2.6.3 End Cross Frames for I-Girder Bridges

For I-girder bridges, use end cross frame types shown in Figure 2.2.6.3.A and Figure 2.2.6.3.B.

C2.2.6.3

An "inverted K-type" frame is preferred as end cross frame types. The end cross frame shown in Figure 2.2.6.3.A requires more gusset plates and welding than the cross frame shown in Figure 2.2.6.3.B. Also, the end cross frame shown in Figure 2.2.6.3.A has welding on the front and back, requiring the frame to be flipped over to complete the welds. Therefore, the end cross frame shown in Figure 2.2.6.3.B may be preferable. However, if bent gusset plates are used due to a skewed condition, then the end cross frame shown in Figure 2.2.6.3.A is preferred because the channel would be skewed to the connection plate and could not be bolted directly to it.

Some owners prefer to have studs on the top of the top chord channel to make it composite with the deck.

End cross frames and their attachments may need to be designed for future jacking. Plate girder end diaphragms can be considered for this purpose, as well as a useful option for severely skewed end diaphragms, where the width-to-height ratio is high.

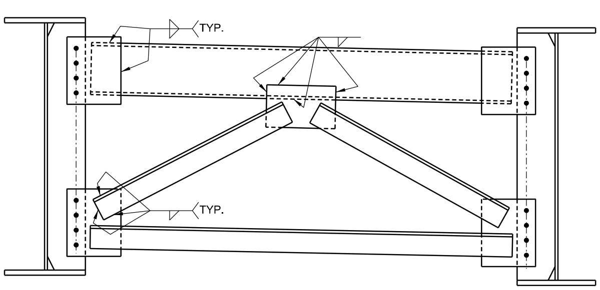

Figure 2.2.6.3.A

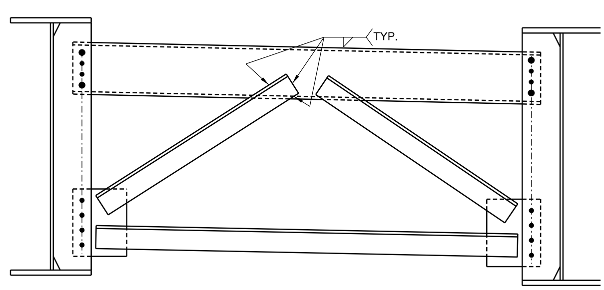

Figure 2.2.6.3.B

2.2.6.4 Gusset Plates

Cross frame gusset plates should not have clipped corners.

C2.2.6.4

Clipping the corners of the gusset plates is an aesthetic cut to make the plate look better. The clipped corner is not needed for structural stability, constructability (welding access), or improved cross frame performance. Additionally, specifying gusset plates with clipped corners will increase the cost of fabrication.

2.2.6.5 Reducing Demand on Cross Frames in Straight I-Girder Bridges

There are many ways to improve economy of cross frames in bridges with straight steel I-girders. Depending on the situation, these techniques can significantly reduce loads in cross frames and/or allow for smaller member sizes or fewer cross frames or cross frame members. Select techniques are listed here, including the use of lean-on bracing concepts and suggestions for economical staggered framing patterns.

In moderately to severely skewed bridges, significant transverse stiffness in the structural steel framing can lead to high cross frame forces. The final research report for National Cooperative Highway Research Program (NCHRP) Research Project 20-07 Task 355 includes many suggestions for reducing the stiffness of these transverse load paths, leading to greatly reduced cross frame forces, and fewer, lighter cross frames, without significantly compromising the strength of the girders.

Utilizing lean-on bracing concepts allows several girders to be braced across the width of the bridge by a single cross frame. Girders that lean on the cross frame brace require top and bottom struts to control girder twist (Helwig, et. al, 2012). Figure 2.2.6.5 depicts a lean-on bracing system, where in a given bracing line, 4 girders can lean on a single cross frame brace.

C2.2.6.5

See Section 4.4 of the final research report for NCHRP Research Project 20-07 Task 355 (White, et. al.). The recommendations in this research report are also summarized and presented in *Skewed and Curved Steel I-Girder Bridge Fit* (NSBA, 2016) which can be found on the NSBA website.

A key component of a steel I-girder bridge is the bracing system. Braces at intermediate locations along the girder length provide overall stability of the girders and increase the stiffness and strength of the system during construction and in service. Intermediate braces usually consist of cross frames or diaphragms.

Cross frames represent a costly structural component, are often difficult to install due to fit-up problems, and also can attract significant live load forces which lead to fatigue problems. Minimizing the number of cross frames on the bridge can lead to better overall bridge behavior as well as reduced fabrication, erection, and maintenance costs (Helwig, et. al, 2012). The lean-on bracing concept minimizes the number of cross frames and improves the structural efficiency of the system. However, note that lean-on bracing cannot be used for curved girder bridges, where all the cross-frames need to be able to carry shear, and therefore, need diagonals.

In order to develop a lean-on bracing system configuration, the erection sequence of the steel girders must be determined. The designer is strongly encouraged to consult with local contractors and erectors to form a solid assumption about how the bridge will be built. This ensures that the appropriate number of cross frames is placed between the first girder segments lifted, which are usually the most critical stage of girder erection. For guidance on developing a lean-on bracing framing configuration and understanding the distribution of forces across the bridge in a cross frame system with lean-on bracing refer to the 2012 FHWA Bridge Design Handbook; Volume 13, Bracing System Design. The designer must state the assumed erection sequence used for the lean-on bracing system design in the contract plans.

The total stiffness of the lean-on bracing system is a function of the cross frame stiffness, the cross-sectional stiffness, as well as the in-plane stiffness of the girder. The stiffness at each line of bracing across the width of the bridge should be checked. Formulations and design assumptions from TxDOT research project 0-1772 (Helwig, et. al., 2003) can be used to maintain the general torsional bracing requirements for I-girders.

REFERENCES:

Helwig, T.A., Wang, L. (2003). *Cross Frame and Diaphragm Behavior for Steel Bridges with Skewed Supports,* TxDOT Research Report 0-1772-1, University of Texas at Austin.

Helwig, T.A., Yura, J.A. (2012). *Steel Bridge Design Handbook: Bracing System Design,* Federal Highway Administration, Washington, DC.

NCHRP (2015). "Guidelines for Reliable Fit-Up of Steel I-Girder Bridges," Final Report, NCHRP 20-07/Task 355, Transportation Research Board, National Research Council, Washington, DC.

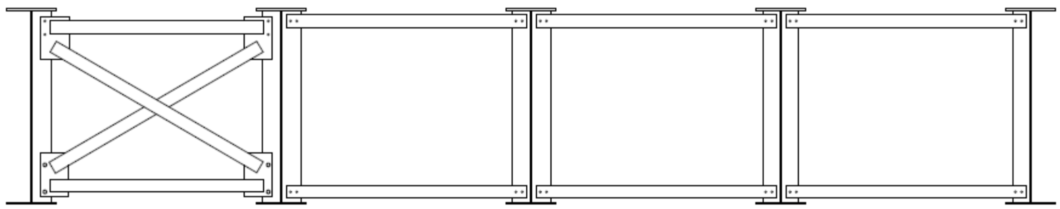

Figure 2.2.6.5 Lean-on Cross Frame Bracing

2.3—LONGITUDINAL FIELD WEB SPLICES IN DEEP GIRDERS

For longitudinal field-bolted web splices in girders too deep to ship, use sub-flanges in the web splice design.

C2.3

Where deep girders are required, their depth may preclude shipping them in one piece. Longitudinal field-welded or field-bolted web splices are then required. Two possibilities for design of field-bolted splice include:

- Using a sub-flange on the top of the bottom section and on the bottom of the top section.
- Using conventional side plates, similar to a typical web splice (See Figure 2.3).

Both options are viable, but sub-flanges provide a stiffer section for shipping and are easier to fit-up in the field. Another approach is to provide both details in the design and allow the contractor to pick his preferred option.