AASHTO 9th Edition Updates & A Look-Ahead to the 10th Edition (LRFD BDS Section 6)

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Significant Updates Appearing in the 9th Edition LRFD BDS

- Revisions to the L/85 Guideline
- Improvements to the Web Load-shedding Factor, R_b, for Longitudinally Stiffened Girders
- Revisions to the Fatigue Detail Table 6.6.1.2.3-1
- Revisions to the Flexural Design Provisions for Tees & Double Angles
- Revisions to the Design Provisions for Variable Web Depth Members
- New Design Provisions for Noncomposite Box-Section Members

Revisions to the L/85 Guideline

- Description of Specification Revisions:
  - Moves the L/85 guideline from Article C6.10.3.4.1 (Deck Placement) to Article C6.10.2.2 (Girder Flange Proportioning).
  - Guideline intended to ensure that individual field sections are more stable and easier to handle during lifting, erection, and shipping.
  - Guideline should be used in conjunction with the flange proportioning limits in Article 6.10.2.2 to establish a minimum top-flange width for each unspliced girder field section.
  - Terms in the guideline are redefined as follows (Eq. C6.10.2.2-1):

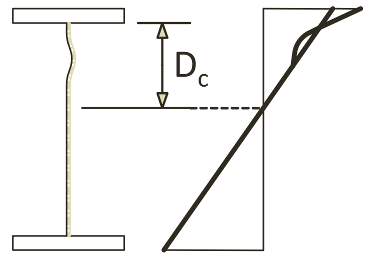
$$b_{tfs} \geq \frac{L_{fs}}{85}$$

  - The guideline is only to be applied to individual unspliced girder field sections for design.

Improvements to R_b for Longitudinally Stiffened Girders

- Description of Specification Revisions:
  - Improvements to the web load-shedding factor, R_b, for longitudinally stiffened steel girders.
  - Based on research by Lakshmi Subramanian and Don White at Georgia Tech – supported by AISI, AASHTO, FHWA, GDOT, and the MBMA.

Improvements to R_b for Longitudinally Stiffened Girders



- Maximum major-axis bending resistance:
  - Compression flange $F_{nc} = R_b R_h F_{yc}$
- R_b = 1 when
  - Section is composite in positive flexure, and $D/t_w \leq 150$
  - One or more longitudinal stiffeners are provided, and:

$$\frac{D}{t_w} \leq 0.95\sqrt{\frac{Ek}{F_{yc}}}$$

  - $2D_c/t_w \leq \lambda_{rw}$, where $\lambda_{rw} = 5.7\sqrt{E/F_{yc}}$ (i.e., web is nonslender)
- Otherwise: $R_b = 1.0 - \frac{a_{wc}}{1200 + 300a_{wc}}\left(\frac{2D_c}{t_w} - \lambda_{rw}\right) \leq 1.0$

Improvements to R_b for Longitudinally Stiffened Girders

- … when the web satisfies $2D_c / t_w \leq \lambda_{rw}$, $R_b = 1.0$
- Otherwise: in lieu of a strain-compatibility analysis considering the web effective widths, for longitudinally-stiffened sections in which one or more continuous longitudinal stiffeners are provided that satisfy $d_s / D_c < 0.76$:

$$R_b = 1.07 - 0.12\frac{D_c}{D} - \frac{a_{wc}}{1200 + 300a_{wc}}\left[\frac{D}{t_w} - \lambda_{rwD}\right] \leq 1.0$$

- For all other cases:

$$a_{wc} = \frac{2D_c t_w}{b_{fc} t_{fc}}$$

$$R_b = 1.0 - \frac{a_{wc}}{1200 + 300a_{wc}}\left(\frac{2D_c}{t_w} - \lambda_{rw}\right) \leq 1.0$$

Improvements to R_b for Longitudinally Stiffened Girders

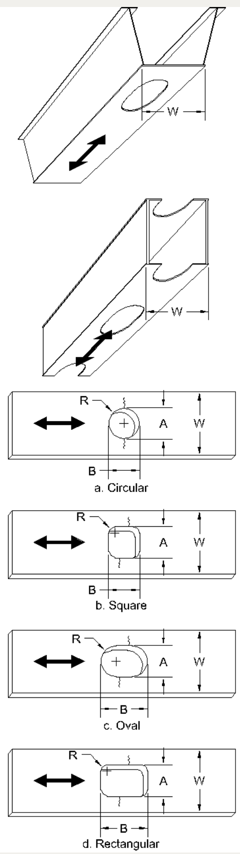
- … when the web satisfies $2D_c / t_w \le \lambda_{rw}$, R_b = 1.0

$$4.6\sqrt{\frac{E}{F_{yc}}} \le \lambda_{rw} = \left(3.1 + \frac{5.0}{a_{wc}}\right)\sqrt{\frac{E}{F_{yc}}} \le 5.7\sqrt{\frac{E}{F_{yc}}}$$

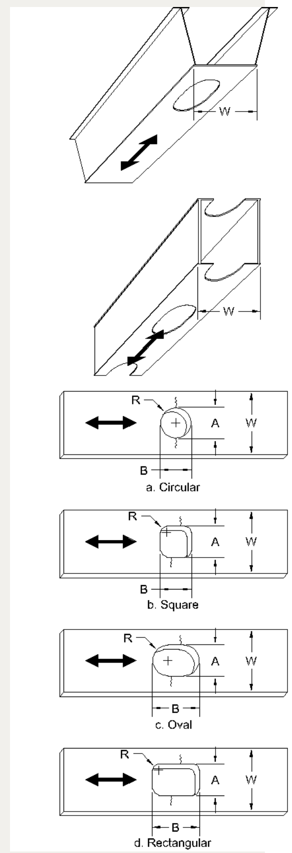
$$a_{wc} = \frac{2D_c t_w}{b_{fc} t_{fc}}$$

F_{yc} (ksi)	$\lambda_{rw} = 4.6\sqrt{\frac{E}{F_{yc}}}$	$\lambda_{rw} = 5.7\sqrt{\frac{E}{F_{yc}}}$
36.0	130	162
50.0	111	137
70.0	94	116
90.0	82	102
100.0	78	97

Revisions to the Fatigue Detail Table 6.6.1.2.3-1

1.6 Base metal at the net section of manholes or hand holes made to the requirements of AASHTO/AWS D1.5, in which the width of the hole is at least 0.30 times the width of the plate (A ≥ 0.30W) (Bonachera Martin and Connor, 2017). The geometry of the hole shall be: a. circular; or b. square with corners filleted at a radius at least 0.10 times the width of the plate (R ≥ 0.10W); or c. oval (B > A), elongated parallel to the primary stress range; or	C	44 x 10^8	10	In the net section originating at the side of the hole	

Revisions to the Fatigue Detail Table 6.6.1.2.3-1

d. rectangular ($B > A$), elongated parallel to the primary stress range, with corners filleted at a radius at least 0.10 times the width of the plate ($R \geq 0.10W$). All holes shall be centered on the plate under consideration, and all stresses shall be computed on the net section. (Note: Condition 1.5 shall apply for all holes in cross-sections in which other smaller open holes or holes with nonpretensioned fasteners are located anywhere within the net section of the larger hole, and minimum edge distance requirements specified in Article 6.13.2.6.6 are satisfied for the smaller holes.)	C	44×10^8	10	In the net section originating at the side of the hole	

Revisions to the Flexural Design Provisions for Tees & Double Angles

Description of Specification Revisions:

- Revisions are made to Articles 6.12.2.2.4 and C6.12.2.2.4 for determining the flexural resistance of tees and double angles loaded in the plane of symmetry in order to bring the provisions up-to-date with the latest provisions in AISC (2016).

  - Prior editions of the AISC Specification did not distinguish between tees and double angles and as a result, there were instances when double angles would appear to have less strength than two single angles. This concern is now addressed by providing separate provisions for tees and double angles.
  - In those cases where double angles should have the same strength as two single angles, the revised provisions make use of the equations for single angles, as applicable, given in Section F10 of AISC (2016).

Revisions to the Flexural Design Provisions for Tees & Double Angles

- In addition, a new linear transition equation from M_p to M_y is introduced for the limit state of lateral-torsional buckling when the stem of the member is in tension; that is, when the flange is subject to compression. Previous specifications transitioned abruptly from the full plastic moment to the elastic buckling range.

For ~~lateral torsional buckling~~ tee stems and double angle web legs subject to tension, the nominal flexural resistance based on lateral-torsional buckling shall be taken as:

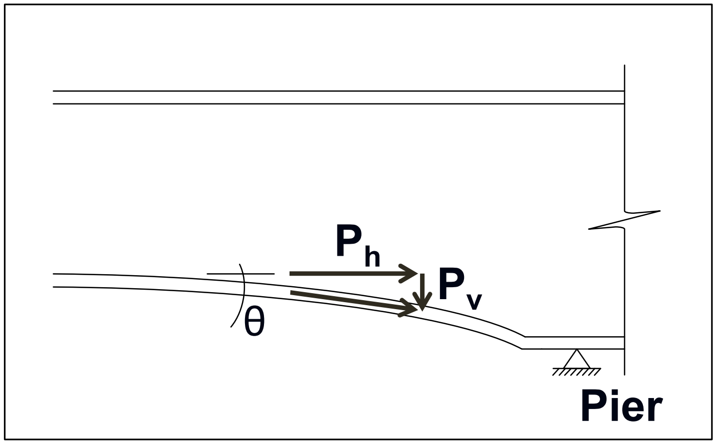
- If $L_b \leq L_p$, then lateral-torsional buckling shall not apply.
- If $L_p < L_b \leq L_r$, then:

$$M_n = M_p - \left(M_p - M_y\right)\left(\frac{L_b - L_p}{L_r - L_p}\right) \quad (6.12.2.2.4c\text{-}1)$$

- If $L_b > L_r$, then:

$$M_n = M_{cr} \quad (6.12.2.2.4c\text{-}2)$$

Revisions to the Design Provisions for Variable Web Depth Members



Horizontal component of force in flange:

$$P_h = M \frac{A_f}{S_x}$$

Normal stress in inclined flange:

$$f_n = \frac{P_h}{A_f \cos\theta}$$

Vertical component of force in flange:

$$P_v = P_h \tan\theta$$

Revisions to the Design Provisions for Variable Web Depth Members

- A provision in Article 6.10.1.4 on Variable Web Depth Members has been revised as follows:

6.10.1.4—Variable Web Depth Members

At points where the bottom flange becomes horizontal, ~~the transfer of the vertical component of the flange force back into the web shall be considered.~~ full- or partial-depth transverse stiffening of the web shall be provided, unless the provisions of Article D6.5.2 are satisfied for the factored vertical component of the inclined flange force using a length of bearing *N* equal to zero.

Revisions to the Design Provisions for Variable Web Depth Members

D6.5.2—Web Local Yielding

Webs subject to compressive or tensile concentrated loads shall satisfy:

$$R_u \leq \phi_b R_n \qquad \text{(D6.5.2-1)}$$

in which:

R_n = nominal resistance to the concentrated loading (kip)

- For interior-pier reactions and for concentrated loads applied at a distance from the end of the member that is greater than d:

$$R_n = \left(5k + N\right) F_{yw} t_w \qquad \text{(D6.5.2-2)}$$

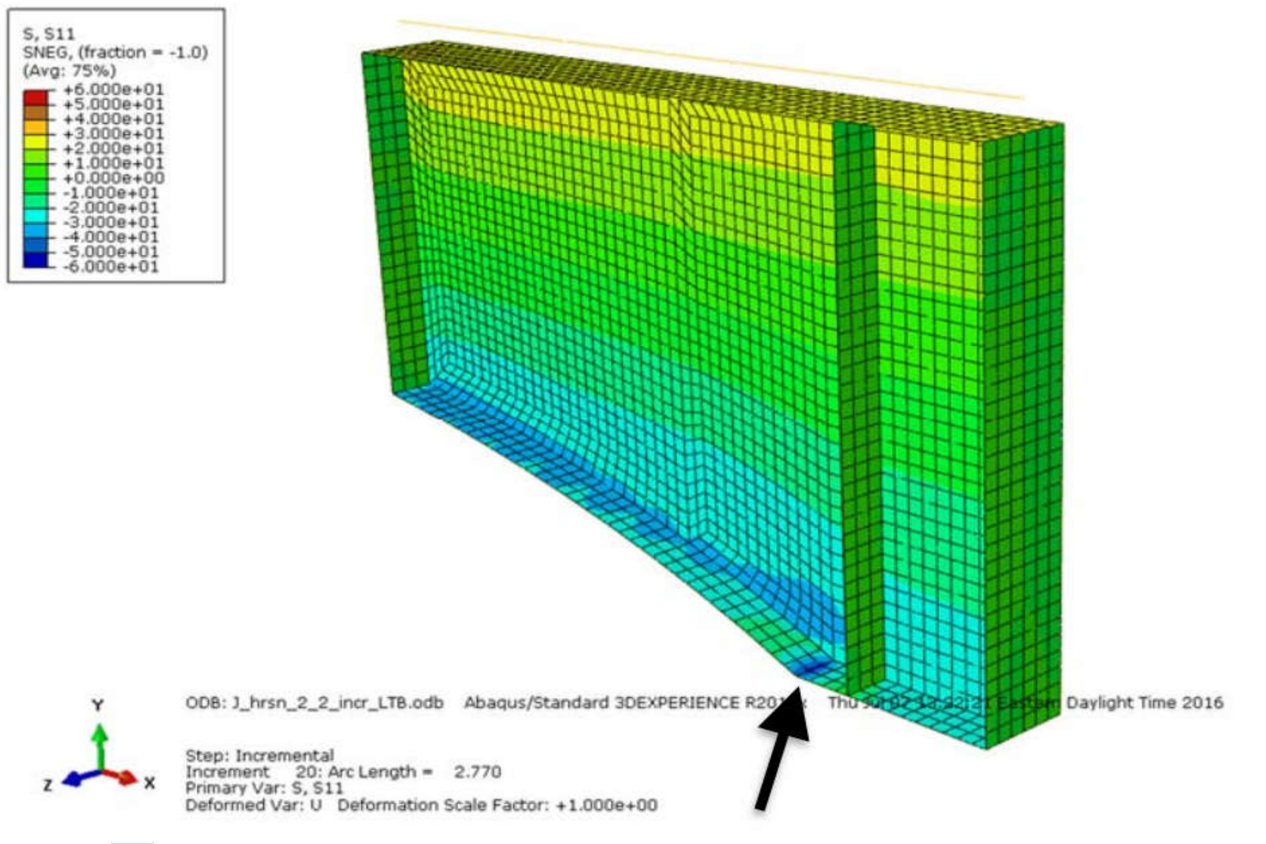
- Otherwise:

$$R_n = \left(2.5k + N\right) F_{yw} t_w \qquad \text{(D6.5.2-3)}$$

where:

ϕ_b = resistance factor for bearing specified in Article 6.5.4.2
d = depth of the steel section (in.)
k = distance from the outer face of the flange resisting the concentrated load or bearing reaction to the web toe of the fillet (in.)
N = length of bearing (in.). N shall be greater than or equal to k at end bearing locations.
R_u = factored concentrated load or bearing reaction (kip)

Revisions to the Design Provisions for Variable Web Depth Members



New Design Provisions for Noncomposite Box-Section Members

- Description of Specification Revisions:
  - Implementation of a more general and consistent approach for the LRFD design of unstiffened and stiffened compression elements in all noncomposite box sections (i.e., box sections utilized in trusses, arches, frames, straddle beams, etc.) subject to uniform stress (compression) or nonuniform stress (e.g. compression plus bending or compression plus bending plus shear and/or torsion, etc.)
  - Based on research conducted under FHWA IDIQ Task Order 5011 managed by HDR Engineering
  - Project Team:
    - Don White, Georgia Tech (Technical PI)
    - Ajinkya Lokhande, Georgia Tech
    - John Yadlosky, HDR Engineering
    - Charles King, COWI
    - Mike Grubb, M.A. Grubb & Associates
    - Tony Ream, HDR Engineering
    - Frank Russo, Michael Baker International, LLC

New Design Provisions for Noncomposite Box-Section Members

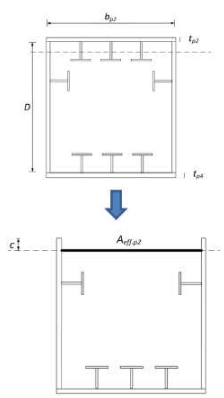
- Benefits:
  - Unstiffened and longitudinally stiffened noncomposite *rectangular* box-section members
  - Built-up welded boxes, bolted boxes, and square and rectangular HSS
  - Singly- and doubly-symmetric rectangular sections
  - Homogeneous and hybrid sections
  - All ranges of web and flange plate slenderness
  - Use of an effective compression flange width in determining cross-section properties for boxes with noncompact and slender compression flanges (rely on post-buckling resistance)
  - No theoretical shear buckling or plate local buckling permitted at the fatigue and service limit states, and for constructibility
  - Use of a web plastification factor for sections having noncompact or compact webs (allows flexural resistances > M_{ye})

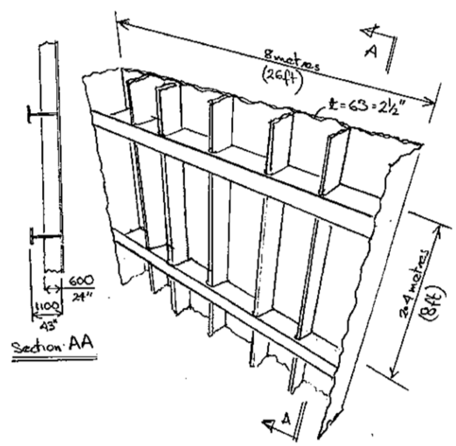
New Design Provisions for Noncomposite Box-Section Members

- Benefits (cont.):
  - No need to check elastic LTB; accuracy with respect to the limit state of inelastic LTB is significantly improved
  - More efficient b/t limits for solid web arches
  - Eliminates reliance on LFD Truss Guide Specifications
  - Handles interaction of all force effects, including torsion
  - Provides improved provisions for longitudinally stiffened flanges (new Appendix E6):
    - Provide same set of equations for any number of stiffeners, transversely stiffened or not
    - Take advantage of longitudinal stiffener, transverse stiffener and stiffened plate contributions to compression capacity
    - Allows designer to easily determine from equation components if longitudinally and/or transverse stiffening is effective
  - Obtain more accurate and sufficient ratings for existing structures outside the slenderness limits of the current Specifications, or with inadequate stiffeners

New Design Provisions for Noncomposite Box-Section Members

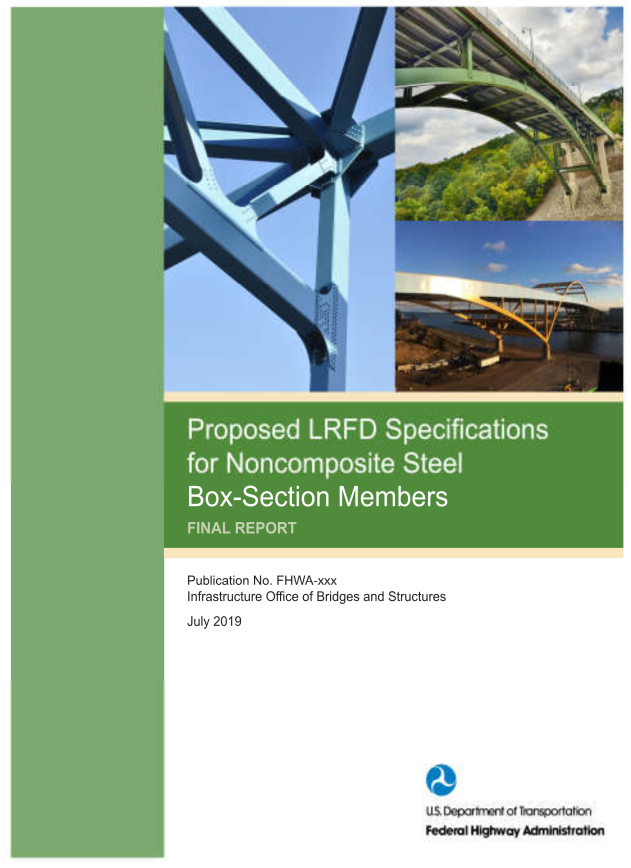
- Benefits (cont.):
  - Stiffened slender boxes have the potential to reduce weight for large structures, such as steel tower legs for cable stayed bridges
  - Specifications are more streamlined and user-friendly
  - Similar, but better prediction results relative to current AASHTO & AISC, where the current AISC & AASHTO are actually applicable … and similar, but better, predictions compared to Eurocode, BS5400 (pre Eurocode), and Wolchuk & Mayrbaurl (1980)

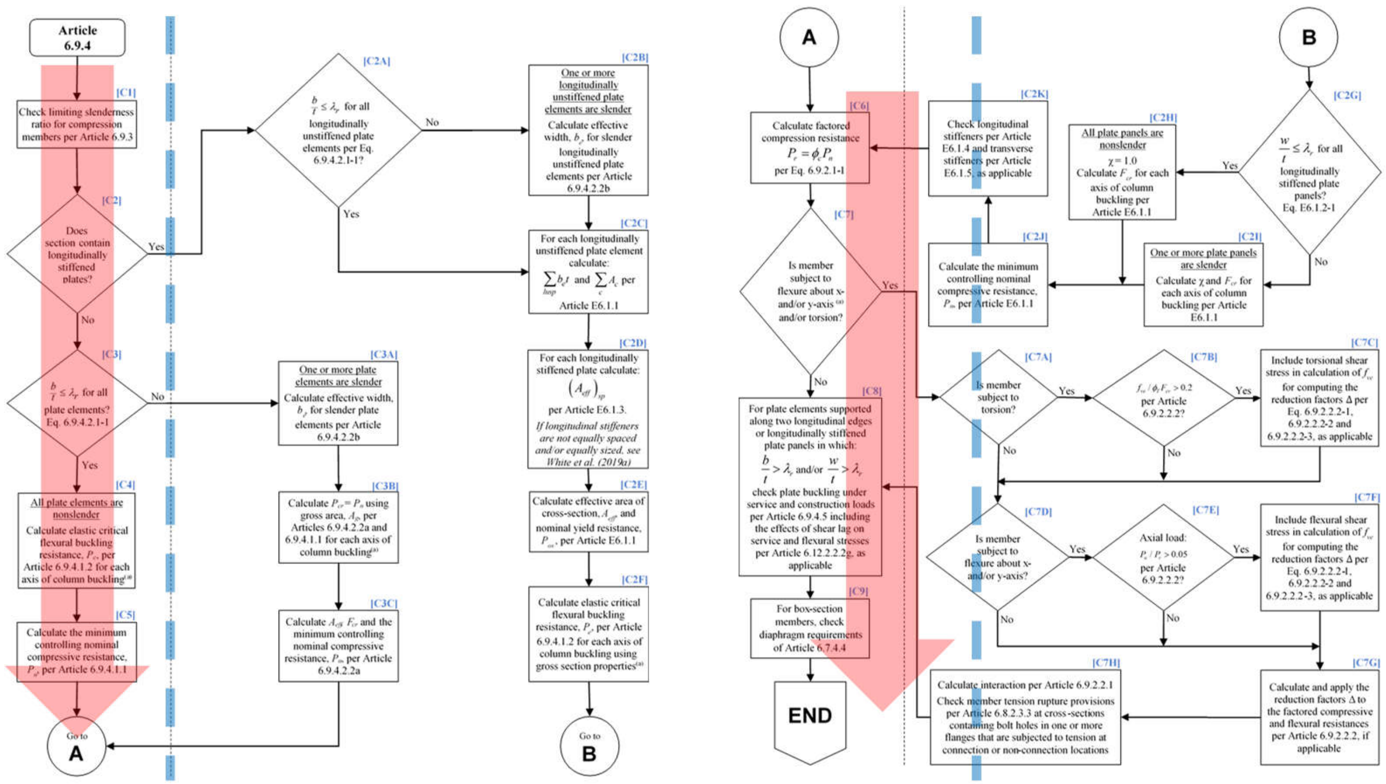




New Design Provisions for Noncomposite Box-Section Members

- **"Proposed LRFD Specifications for Noncomposite Steel Box-Section Members"**
  - FHWA-HIF-19-063 | July 2019
  - (NCHRP 20-07/415)
- **Expanded Commentary**
- **Additional provisions for specialized situations**
- **3 Examples:**
  - Longitudinally Unstiffened Truss End Post
  - Longitudinally Stiffened/Slender Tie Girder
  - Longitudinally Stiffener Arch Rib
- **2 Flowcharts coordinated with Examples**
  - Compression & Flexural Resistance




Article 6.9.4
[C1] Check limiting slenderness ratio for compression members per Article 6.9.3
[C2] Does section contain longitudinally stiffened plates?
Yes
No
[C2A] $\frac{b}{t} \le \lambda_r$ for all longitudinally unstiffened plate elements per Eq. 6.9.4.2.1-1?
No
Yes
[C2B] One or more longitudinally unstiffened plate elements are slender
Calculate effective width, b_e for slender longitudinally unstiffened plate elements per Article 6.9.4.2.2b
[C2C] For each longitudinally unstiffened plate element calculate: $\sum_{lsep} b_e t$ and $\sum_c A_c$ per Article E6.1.1
[C2D] For each longitudinally stiffened plate calculate: $(A_{eff})_{sp}$ per Article E6.1.3.
If longitudinal stiffeners are not equally spaced and/or equally sized, see White et al. (2019a)
[C2E] Calculate effective area of cross-section, A_{eff}, and nominal yield resistance, P_{os}, per Article E6.1.1
[C2F] Calculate elastic critical flexural buckling resistance, P_e, per Article 6.9.4.1.2 for each axis of column buckling using gross section properties(a)
Go to B
[C3] $\frac{b}{t} \le \lambda_r$ for all plate elements? Eq. 6.9.4.2.1-1
No
Yes
[C3A] One or more plate elements are slender
Calculate effective width, b_e for slender plate elements per Article 6.9.4.2.2b
[C3B] Calculate $P_{cr} = P_n$ using gross area, A_g, per Articles 6.9.4.2.2a and 6.9.4.1.1 for each axis of column buckling(a)
[C3C] Calculate A_{eff}, F_{cr} and the minimum controlling nominal compressive resistance, P_{ns}, per Article 6.9.4.2.2a
[C4] All plate elements are nonslender
Calculate elastic critical flexural buckling resistance, P_e, per Article 6.9.4.1.2 for each axis of column buckling(a)
[C5] Calculate the minimum controlling nominal compressive resistance, P_n, per Article 6.9.4.1.1
Go to A
A
[C6] Calculate factored compression resistance $P_r = \phi_c P_n$ per Eq. 6.9.2.1-1
[C7] Is member subject to flexure about x- and/or y-axis (a) and/or torsion?
Yes
No
[C8] For plate elements supported along two longitudinal edges or longitudinally stiffened plate panels in which: $\frac{b}{t} > \lambda_r$ and/or $\frac{w}{t} > \lambda_r$ check plate buckling under service and construction loads per Article 6.9.4.5 including the effects of shear lag on service and flexural stresses per Article 6.12.2.2.2g, as applicable
[C9] For box-section members, check diaphragm requirements of Article 6.7.4.4
END
B
[C2G] $\frac{w}{t} \le \lambda_r$ for all longitudinally stiffened plate panels? Eq. E6.1.2-1
Yes
No
[C2H] All plate panels are nonslender
χ = 1.0
Calculate F_{cr} for each axis of column buckling per Article E6.1.1
[C2I] One or more plate panels are slender
Calculate χ and F_{cr} for each axis of column buckling per Article E6.1.1
[C2J] Calculate the minimum controlling nominal compressive resistance, P_{ns}, per Article E6.1.1
[C2K] Check longitudinal stiffeners per Article E6.1.4 and transverse stiffeners per Article E6.1.5, as applicable
[C7A] Is member subject to torsion?
Yes
No
[C7B] $f_{ve} / \phi_v F_{cv} > 0.2$ per Article 6.9.2.2.2?
Yes
No
[C7C] Include torsional shear stress in calculation of f_{ve} for computing the reduction factors Δ per Eq. 6.9.2.2.2-1, 6.9.2.2.2-2 and 6.9.2.2.2-3, as applicable
[C7D] Is member subject to flexure about x- and/or y-axis?
Yes
No
[C7E] Axial load: $P_u / P_r > 0.05$ per Article 6.9.2.2.2?
Yes
No
[C7F] Include flexural shear stress in calculation of f_{ve} for computing the reduction factors Δ per Eq. 6.9.2.2.2-1, 6.9.2.2.2-2 and 6.9.2.2.2-3, as applicable
[C7G] Calculate and apply the reduction factors Δ to the factored compressive and flexural resistances per Article 6.9.2.2.2, if applicable
[C7H] Calculate interaction per Article 6.9.2.2.1
Check member tension rupture provisions per Article 6.8.2.3.3 at cross-sections containing bolt holes in one or more flanges that are subjected to tension at connection or non-connection locations

Look-Ahead to the AASHTO LRFD 10th Edition BDS (2023)

T-14 Ballot Items Rolled Over from the 2020 to the 2021 CBS Meeting

- Revisions to the provisions for determining the flexural resistance of I- or H-shaped members and channels subject to flexure about their weak axis in order to bring the provisions up-to-date with the latest provisions given in the AISC Specification
- Introduction of a creep reduction factor, K_c, of 0.80 in the determination of the nominal slip resistance of a galvanized faying surface (Class C) or a duplex coated faying surface utilizing a coating producing a higher slip coefficient over a galvanized subsurface
- Revisions to the AASHTO IRM Guide Specification to incorporate angle-only and two-channel axially loaded tension members, along with some necessary revisions & updates to the design examples

Revisions to Shear Stud Design Provisions

- Deleted all reference to channel shear connectors.
- Reduced the minimum center-to-center pitch of studs from 6*d* to 4*d*.
- Added a pitch correction to account for shear lag across clustered studs.
- Revised the equation for the nominal shear resistance, Q_n, of a stud shear connector at the strength limit state (somewhat more conservative).
- Changed the slope of the fatigue resistance curve for studs in the finite-life region from -3.00 to -5.00. Maintained the constant amplitude threshold, $(\Delta F)_{TH}$, at 7.0 ksi.
- Revised the fatigue detail Table 6.6.1.2.3-1 as follows:
  - Changed the exponent in the general equation for the finite-life fatigue resistance from 1/3 to 1/*m*, and added the "growth constant", *m*, to Table 6.6.1.2.3-1 for all fatigue details.
  - Added the fatigue resistance data for studs and high-strength bolts to Table 6.6.1.2.3-1. Streamlined Article 6.10.10.2.
  - Added the values of the 75-year $(ADTT)_{SL}$ equivalent to infinite life for each detail to Table 6.6.1.2.3-1, and eliminated Tables 6.6.1.2.3-2, 6.6.1.2.5-1, and 6.6.1.2.5-3.
  - Changed Table 6.6.1.2.3-1 from portrait to landscape format.

Revisions from NCHRP Project 12-113

"Proposed Modifications to AASHTO Cross-Frame Analysis and Design"

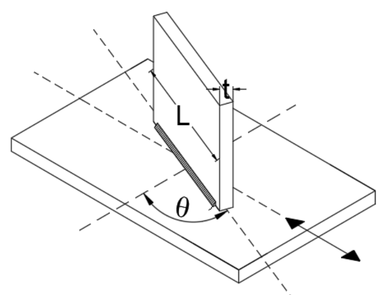
- Revisions to improve the prediction of fatigue force ranges in cross-frame members:
  - Specific fatigue truck loading requirements for refined analyses to better predict the fatigue force ranges in cross-frame members.
  - Multiply Fatigue I and Fatigue II load factors by 0.65 for cross-frames.
- Revisions to the *R* factor in Section 4 to better reflect the flexibility of cross-frame member end connections in composite bridge systems in the analysis.
- Addition of minimum stability bracing strength and stiffness requirements for cross-frame and diaphragm members in I-girder bridges (similar to the requirements in AISC Appendix Article 6.3.2).
- Recommendations to improve the prediction of cross-frame forces in 2D grid models, and the prediction in general of cross-frame forces in heavily skewed and/or curved bridges.

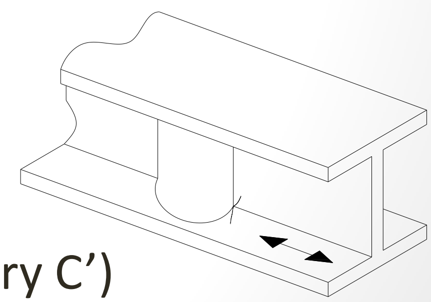
Fatigue of Obliquely Oriented Welded Attachments & Introduction of Half-Round Bearing Stiffeners

- <u>Table 6.6.1.2.3-1, Articles C6.10.8.2.3 & 6.10.11.2:</u>

➢ Fatigue characterization of obliquely oriented welded attachments

- New Condition 7.3: fatigue categories transitioning between C' and E are proposed as a function of the skew angle, θ (for attachments longer than 4 inches and less than 1-inch thick attached by groove or fillet welds)





➢ Introduction & fatigue characterization of half-round bearing stiffeners (New Condition 4.2: Category C')

Revisions Related to the Classification of FCMs, SRMs, & IRMs

- Provisions will be added to the AASHTO *Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members* to allow classification of new continuous twin tub-girder systems as System Redundant Members (SRMs) w/o performing an in-depth FEA.
- New definitions for an Internally Redundant Member (IRM), Internal Redundancy, Load-path Redundancy, and Structural Redundancy will be added to the AASHTO BDS.
- The existing definitions of a Fracture Critical Member (FCM) and System Redundant Member (SRM) in the AASHTO BDS will be revised – all definitions supplied by the FHWA.
- Commentary language will be added to the AASHTO BDS recognizing the AASHTO *Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members* and the AASHTO *Guide Specifications for Internal Redundancy of Mechanically-fastened Built-Up Steel Members.*

Other Revisions

- Eq 6.11.2.2-3 shall only apply to built-up tub section members:

$$t_f \geq 1.1 t_w \qquad (6.11.2.2\text{-}3)$$

- Revisions to Article 6.8.2.2 and 6.13.5.2 – re: further “clean-up” of Table 6.8.2.2-1 (shear lag factor, U, for tension members)
- Revisions to Various Articles – re: minimum thickness of steel and miscellaneous connection design issues
- Addition to Article C6.6.1.2.4 summarizing the conditions associated with susceptibility to constraint-induced fracture at welded details along with a brief discussion of intersecting welds

Potential Future Revisions (2022)?

- Potential improvements in the prediction of the lateral-torsional buckling (LTB) resistance of certain nonprismatic unbraced lengths, including unbraced lengths in variable web-depth members.
- Potential replacement of the current equation for the moment-gradient modifier, C_b, with the AISC quarter-point formula:

$$C_b = \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C}$$

- Potential incorporation of ASTM F3148 (torque and angle) high-strength bolts (allow for single-sided installation)
- Potential clarification of slip-critical vs. bearing type classification of connections for bracing members
- Primary and secondary member designations for cross-frame/diaphragm members in composite box-girder bridges
- Potential revisions to Article 6.11 on composite box sections in flexure

Questions?