AASHTO Design and Material Specification Changes
LRFD BDS Section 6, Various Articles

Karl H. Frank
Consultant
NSBA
Bolts
ASTM Specifications
High Strength Bolts

• New Specification Combines 4 Specifications into 1 for both buildings and bridges-F3125
  – A325 Standard Hex Bolt
  – F1852 (A325 Tension Control)
  – A490 Standard Hex Bolt
  – F2280 (A490 Tension Control)
  – + Metric

• The old names become Grades
F3125 Significant Changes

• Grade A325 - $F_u = 120$ ksi for all diameters (results in an increase in shear capacity for bolts $\geq 1$ in.)

• Annex A1 - Table gives permitted coatings and over tapping required for nuts
  – No hot dip or mechanical galvanizing of Grade A490 bolts
  – F1136 and F2833 Zinc/Aluminum Allowed on all Grades A325 and A490

• Rotational Capacity Test in Appendix A2
  – Reduced requirements for A490 bolts
  – Recommend Specifying Lubricated Nuts for Black A490 Bolts
AASHTO LRFD Changes

- Bolt Shear Strength
- Slip Critical Categories
- Standard Hole Sizes
- Girder Field Splice Design
Shear Strength
6.13.2.7

- **Initial Length Reduction**
  - Changed from 0.8 to 0.9
  - Long Joint from 50 to 38 in.

- **Bolts with threads in the shear plane:** (web bolts)
  - $R_n = \phi 0.45 A_b F_u$ (*old value 0.38*)

- **Bolts with threads excluded from the shear plane:**
  - $R_n = \phi 0.56 A_b F_u$ (*old value 0.48*)

- The nominal shear resistance of a bolt in lap tension connections greater than 38 in. in length shall be taken as 0.83 times the values above (0.9x0.83=0.75).
Unequal Bolt Shear In Long Joints

Bolt Shear
Joint Length Shear Strength Reductions

Design Strength/ Single Bolt Capacity

One Bolt
Connection Length

38 50 in.

0.90
0.80
0.75
0.64

Old Design Spec.

length
Bolt Shear Strength
Connection Length <= 38 in.

Threads Not Excluded from Shear Plane
“N” Bolt

Shear Strength:
0.9 \times 0.62 \times F_u \times 0.8 A_{bolt}
0.45 \times F_u \times A_{bolt}

\Phi_s = 0.80

Threads Excluded from Shear Plane
“X” Bolt

Shear Strength:
0.9 \times 0.62 \times F_u \times A_{bolt}
0.56 \times F_u \times A_{bolt}
Slip Capacity = \( R_n = K_h \ K_s \ N_s \ P_t \)

\( K_h = \) Hole Factor
\( = 1 \) (normal size holes)
\( K_s = \) Surface Condition Slip Coefficient
\( = 0.5 \) (blasted or Zinc Rich)
\( N_s = \) Number of Slip Planes per Bolt

\( \Phi_s = 1.0 \)
(Art.6.13.2.2)

Bolt Installed Tension

\( P_t = 0.70 \times \text{Tensile Strength} \)

\( = 0.70 \times A_{\text{tensile}} \times F_u \)

Note Installed Tension Increased for A325 Bolts > 1 in..
### AASHTO High Strength Bolt Single Shear Design Capacity

#### Equations

- \( \phi_{bb} = 0.8 \)
- \( \phi_s = 0.8 \)
- \( K_s = 0.5 \)
- \( K_h = 1 \)

<table>
<thead>
<tr>
<th>Diameter (in.)</th>
<th>0.625</th>
<th>0.75</th>
<th>0.875</th>
<th>1</th>
<th>1.125</th>
<th>1.25</th>
<th>1.375</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_b ) (in²)</td>
<td>0.307</td>
<td>0.442</td>
<td>0.601</td>
<td>0.785</td>
<td>0.994</td>
<td>1.227</td>
<td>1.485</td>
</tr>
</tbody>
</table>

#### A325 Bolt

<table>
<thead>
<tr>
<th>( F_{ub} ) (ksi)</th>
<th>120</th>
<th>120</th>
<th>120</th>
<th>120</th>
<th>120</th>
<th>120</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{ub} A_b ) (kip)</td>
<td>36.8</td>
<td>53.0</td>
<td>72.2</td>
<td>94.2</td>
<td>119.3</td>
<td>147.3</td>
<td>178.2</td>
</tr>
<tr>
<td>( P_t ) (kip)</td>
<td>19</td>
<td>28</td>
<td>39</td>
<td>51</td>
<td>56</td>
<td>71</td>
<td>85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>( \phi_s R_n ) (kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A325F</td>
<td>9.5 14.0 19.5 25.5 28.0 35.5 42.5</td>
</tr>
<tr>
<td>A325N</td>
<td>13.3 19.1 26.0 33.9 42.9 53.0 64.1</td>
</tr>
<tr>
<td>A325X</td>
<td>16.5 23.8 32.3 42.2 53.4 66.0 79.8</td>
</tr>
</tbody>
</table>

#### A490 Bolt

<table>
<thead>
<tr>
<th>( F_{ub} ) (ksi)</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{ub} A_b ) (kip)</td>
<td>46.0</td>
<td>66.3</td>
<td>90.2</td>
<td>117.8</td>
<td>149.1</td>
<td>184.1</td>
<td>222.7</td>
</tr>
<tr>
<td>( P_t ) (kip)</td>
<td>24</td>
<td>35</td>
<td>49</td>
<td>64</td>
<td>80</td>
<td>102</td>
<td>121</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>( \phi_s R_n ) (kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A490F</td>
<td>12.0 17.5 24.5 32.0 40.0 51.0 60.5</td>
</tr>
<tr>
<td>A490N</td>
<td>16.6 23.9 32.6 42.4 53.7 66.3 80.2</td>
</tr>
<tr>
<td>A490X</td>
<td>20.6 29.7 40.4 52.8 66.8 82.5 99.8</td>
</tr>
</tbody>
</table>
# Slip Critical Connections

<table>
<thead>
<tr>
<th>Class</th>
<th>Typical Surface</th>
<th>Slip Coefficient</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Old Specification</td>
<td>New Specification</td>
</tr>
<tr>
<td>A</td>
<td>Mill Scale</td>
<td>0.33</td>
<td>0.30</td>
</tr>
<tr>
<td>B</td>
<td>Zinc Rich Paint and Blasted</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>C</td>
<td>Galvanized</td>
<td>0.33</td>
<td>0.30*</td>
</tr>
<tr>
<td>D</td>
<td>Organic Zinc Rich</td>
<td>-</td>
<td>0.45</td>
</tr>
</tbody>
</table>

*Do **not** wire brush the surface

Required tension for A325 > 1 in. diameter increased

KHF
Post Slip Examination of Zinc Rich Paint Specimen
Areas for Unqualified Paints

1. Area Outside of Shaded Area may have Unqualified Paints.
2. Edges of Plates Not Participating in Developing Slip Resistance.
3. Therefore Do Not Have to Be in Contact.
Footnote on Bolting

• New Hole Size
  – 1 inch and greater: Standard hole = diameter of fastener +1/8 in.

• Miss drilled holes- fill with fully tensioned high strength bolt (Category B fatigue strength)

• New electric wrenches can be programmed for required turn of the nut
New Connection Design Criteria and Methods

- Remove applicability of the 75 percent and average rules in Article 6.13.1 to the design of bolted and welded splices for flexural members.

- 75 percent rules are applicable to connections and splices for primary members subject to axial tension or compression only.

- Clarify application of rules to primary members subjected to force effects acting in multiple directions due to combined loading.
Bolted Field Splices of Flexural Members

- Revised general article on design of bolted splices for flexural members implementing new simplified bolted splice design procedure

- Removal of check for slip of bolts during erection of steel

- The purpose is implementation of simplified design procedure and more economical field splice designs.
Expensive and Slow to Erect Field Splice

Field Splice
92 bolts in each web
32 bolts each flange
Total 312 bolts
936 holes

Bolts: 312x$20 = $6,240
Labor: 312x10 min = 52 field hours each splice
The Problem: Tub Girder Splice

Field Splice
36 each top flange
80 bolts in each web
85 bolts bottom flange
634 bolts
1,902 holes

Bolts: 634x$20 = $12,680
Labor: 634x10 min = 106 field hours each splice
Splice Design Procedure

1. Design Flange Connection to Develop the Smaller Design Yield Resistance of the Connected Flanges

Design Yield Resistance: \[ P_{fy} = F_{yf} A_e \]

\[
A_e = \left( \frac{\phi_u F_u}{\phi_y F_{yf}} \right) A_n \leq A_g
\]

2. Design Web Connection to Develop the Smaller Factored Shear Resistance of the Connected Webs

\[ V_r = \phi_v V_n \]

Two Rows of bolts minimum on each side of splice.
Positive Flange Moment Capacity Check
Bottom Flange in Tension

\[
P_{fy} = F_{fy} A_e
\]

\[
A = D + \frac{t_{ft}}{2} + t_{haunch} + \frac{t_s}{2}
\]

Moment Capacity:
\(P_{fy}\) for the Bottom Flange x Moment Arm to Mid-Depth of Deck
\[= (F_{fy} x A_e) x A\]
Negative Flange Moment and Non Composite Capacity Check
Ignore Tensile Contribution of Deck Reinforcement

Moment Capacity:
Smallest Value of $P_{fy} \times \text{Distance Between Flange Centroids}$

$$= (F_{yf} \times A_e) \times A$$
If Moment From Flanges is Not Sufficient to Resist Factored Design Moment

Calculate Additional Resisting Moment to be Provided by the Web

Applied Web Moment = Factored Moment – Moment Resistance of the Flange

= Factored Design Moment – (P_fy x A)

Resisting Web moment = H_w x A_w = (horizontal web bolt force x moment arm)

Yields Horizontal Web Force H_w:

\[
H_w = \frac{\text{Factored Design Moment} - P_{fy} \times A}{A_w} = \frac{\text{Web Moment}}{A_w}
\]
Calculation of Horizontal Web Force
Composite Section in Positive Bending

Resultant Web Horizontal Force:

\[ H_w = \frac{\text{Web Moment}}{A_w} \]
Calculation of Horizontal Web Force
Composite Section in Negative Bending or Non-Composite Section

\[
\text{Web Moment} = \frac{H_w}{2} \left(\frac{D}{2}\right)
\]

Resultant Web Horizontal Force:

\[
H_w = \frac{\text{Web Moment}}{D/4}
\]
Web Splice Force = Vector Resultant from Moment and Shear

\[ R = \sqrt{(V_r)^2 + (H_w)^2} = \sqrt{(\phi_v V_n)^2 + (H_w)^2} \]

- **Number Bolts Required** = \( R / \text{Bolt Shear Capacity} \)
- **Minimum of Two Rows each side of splice**
- **Normally Maximum Spacing and 2 Row Requirement Controls Web Bolts**
- **Assume Threads in the Shear Plane!**

\( H_w \) = Horizontal Force in Web To Resist Design Moment
\( V_r \) = Vertical Force in Web = Factored Shear Resistance of the Web
### Design Comparison

<table>
<thead>
<tr>
<th>Girder Depth in.</th>
<th>Number of Bolts Required</th>
<th>Design Method</th>
<th>Top Flange</th>
<th>Web</th>
<th>Bottom Flange</th>
<th>Difference Old-New</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>72</td>
<td></td>
<td>Old</td>
<td>12</td>
<td>36</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New</td>
<td>16</td>
<td>22</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>111</td>
<td></td>
<td>Old</td>
<td>16</td>
<td>84</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New</td>
<td>24</td>
<td>70</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>80 Tub Girder</td>
<td></td>
<td>Old</td>
<td>16</td>
<td>34</td>
<td>54</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New</td>
<td>20</td>
<td>28</td>
<td>59</td>
<td></td>
</tr>
</tbody>
</table>
Validation Finite Element Analysis

“Simplified Design of Bolted Splice Connections for Steel Girders” – Frank, Ocel, and Grubb

204 Web Bolts

100 Web Bolts
FEA Model Description

- Shell element models in Abaqus
- Adapted fastener models from NCHRP 12-84
- Five loading scenarios
  - Pure positive moment
  - Pure negative moment *
  - High shear (as little moment as possible) *
  - Proportion design positive moment/shear
  - Proportional design negative moment/shear *

*= deck not present
Results – High Shear

![Graph showing Left Support Reaction (kip) vs. Left Support Displacement (inches) for Current Method and Proposed Method. The graph highlights Step 26 and V_u.](image)

- **Current Method**
- **Proposed Method**
Results – High Shear
Von Mises Stresses @ Step 26

“Simplified Design of Bolted Splice Connections for Steel Girders” – Frank, Ocel, and Grubb
Results – High Shear
Bolt Shear Forces @ Step 26

“Simplified Design of Bolted Splice Connections for Steel Girders” – Frank, Ocel, and Grubb
Results – Prop Neg Mom & Shear

![Graph showing the comparison between the current method and the proposed method for Left Support Reaction (kip) vs. Left Support Displacement (inches).](image)

- **Current Method**
- **Proposed Method**

V_u
Results – Prop Neg Mom & Shear

Von Mises Stresses @ $V_u$

CURRENT

PROPOSED
Results – Prop Neg Mom & Shear

Bolt Shear Forces @ $V_u$
Anticipated Effect on Bridges:

- Application of the new proposed design provisions for bolted field splices will typically result in a few more bolts in the flange splices and significantly fewer bolts in the web splices than under the current design provisions.

- The overall simplification in the design procedure should result in easier interpretation of the provisions, faster and more efficient design of field splices, and more consistent and cost-effective designs.

- Clarifications to the application of the 75 percent and average rules to the design of connections and splices in primary members at the strength limit state subject to combined force effects should also be beneficial to designers.
Bolted Field Splices Document

www.steelbridges.org/nsbas splice
## Design Tools – Splice Spreadsheet

### NSBA Bolted Splice Designer - Plate Girder

**Web Calculations**

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Noncomposite Dead Load (DC1)</th>
<th>Superimposed Composite Dead Load (DC2)</th>
<th>Future Wearing Surface (DW)</th>
<th>Positive Live Load plus Impact (LL+1)</th>
<th>Negative Live Load plus Impact (LL−1)</th>
<th>Deck Casting</th>
<th>Factored Shear (kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Casting</td>
<td>-82.00</td>
<td>-12.00</td>
<td>-11.00</td>
<td>19.00</td>
<td>-112.00</td>
<td>-82.00</td>
<td>-114.00</td>
</tr>
<tr>
<td>Service II - Positive</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.30</td>
<td>0.00</td>
<td>1.40</td>
<td>60.30</td>
</tr>
<tr>
<td>Service II - Negative</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.30</td>
<td>0.00</td>
<td>0.00</td>
<td>-250.60</td>
</tr>
</tbody>
</table>

### Bolt Factored Shear Resistance

<table>
<thead>
<tr>
<th>Location</th>
<th>Bolt Type</th>
<th>Bolt Area (sq-in)</th>
<th>K_a</th>
<th>( \phi )</th>
<th>F_s (ksi)</th>
<th>P_t (kip)</th>
<th>R_s - Single Shear (kip)</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web</td>
<td>A325 - Included</td>
<td>0.6013</td>
<td>Standard</td>
<td>0.60</td>
<td>120</td>
<td>39.00</td>
<td>25.96</td>
<td></td>
</tr>
</tbody>
</table>

### Bolt Nominal Slip Resistance

<table>
<thead>
<tr>
<th>Faying Surface Class (K_s)</th>
<th>Hole Size Factor (K_h)</th>
<th>P_s (kip)</th>
<th>Slip Capacity - Double (kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1.00</td>
<td>39.00</td>
<td>39.00</td>
</tr>
</tbody>
</table>

### Flange Design Results

<table>
<thead>
<tr>
<th>Flange Moment Resistance Check Results</th>
<th>( H_s ) (kip)</th>
<th>Controlling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>DNA</td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td>DNA</td>
<td></td>
</tr>
</tbody>
</table>
NSBA Splice Spreadsheet

• NSBA Splice Spreadsheet
  – Plate Girder Bolted Splice Design Tool.
  – Subscribe to NSBA Newsletter for up-to-date information.

www.steelbridges.org/nsbassplice
NSBA Splice Spreadsheet - Download
NSBA Splice Spreadsheet - Download

**LRFD SIMON**
Simon is a line-girder analysis software that can be used to analyze straight and low skew plate girder and tub girder bridges. Simon is perfect for those bridge projects that don’t require a 3D finite model and where hand calculations would be too involved.

CONTINUE

**NSBA SPLICE**
NSBA Splice takes the time consuming task of designing and checking a bolted splice connection and rewrites the process as a simple input and output form. NSBA Splice allows the designer to quickly analyze various bolted splice connections to determine the most efficient bolt quantity and configuration.

CONTINUE

**IRM EVALUATOR**
The IRM Evaluator automates much of the process for evaluation of built-up members for internal redundancy. The IRM Evaluator follows provisions of the new AASHTO Guide Specifications for Internal Redundancy of Mechanically-Fastened Built-up Steel Members evaluating internal redundancy and establishing a special inspection interval.

CONTINUE

For questions regarding Design Resources, please send an email to nsbasimon@steelbridges.org.
NSBA Splice Spreadsheet - Download

UPDAtED: NSBA Splice

NSBA Splice takes the time consuming task of designing and checking a bolted splice connection and rewrites the process with a simple input page and output form. NSBA Splice can be incorporated as a design tool on plate bridges allowing the designer to quickly analyze various bolted splice connections to determine the most efficient configuration. Based upon the updated AASHTO LRFD 8th Edition, Splice allows the user to easily vary effects of bolt spacing, bolt size, strength and connection dimensions on the overall splice design.

Splice is presented in an easy to understand Microsoft Excel spreadsheet format allowing users with Microsoft Excel 2010 or later to access and utilize. Included in the download is the design example as well as two completed examples. The examples are the inputs and solutions for Examples 1 and 2 presented in 'Bolted Field Splices for Steel Bridge Flasural Members'.

The current version of NSBA Splice (v3.05) was released on August 2, 2019 (Release Notes).

[Diagram of asplice connection with labels: Fill Plate, Top Flange Splice Plates, Bottom Flange Splice Plates]

Download NSBA Splice
Result of Changes to Field Splice Design

• Reduced Design Effort and Cost, Lower Connection Costs, & Faster Erection
A New Day- Another Bridge