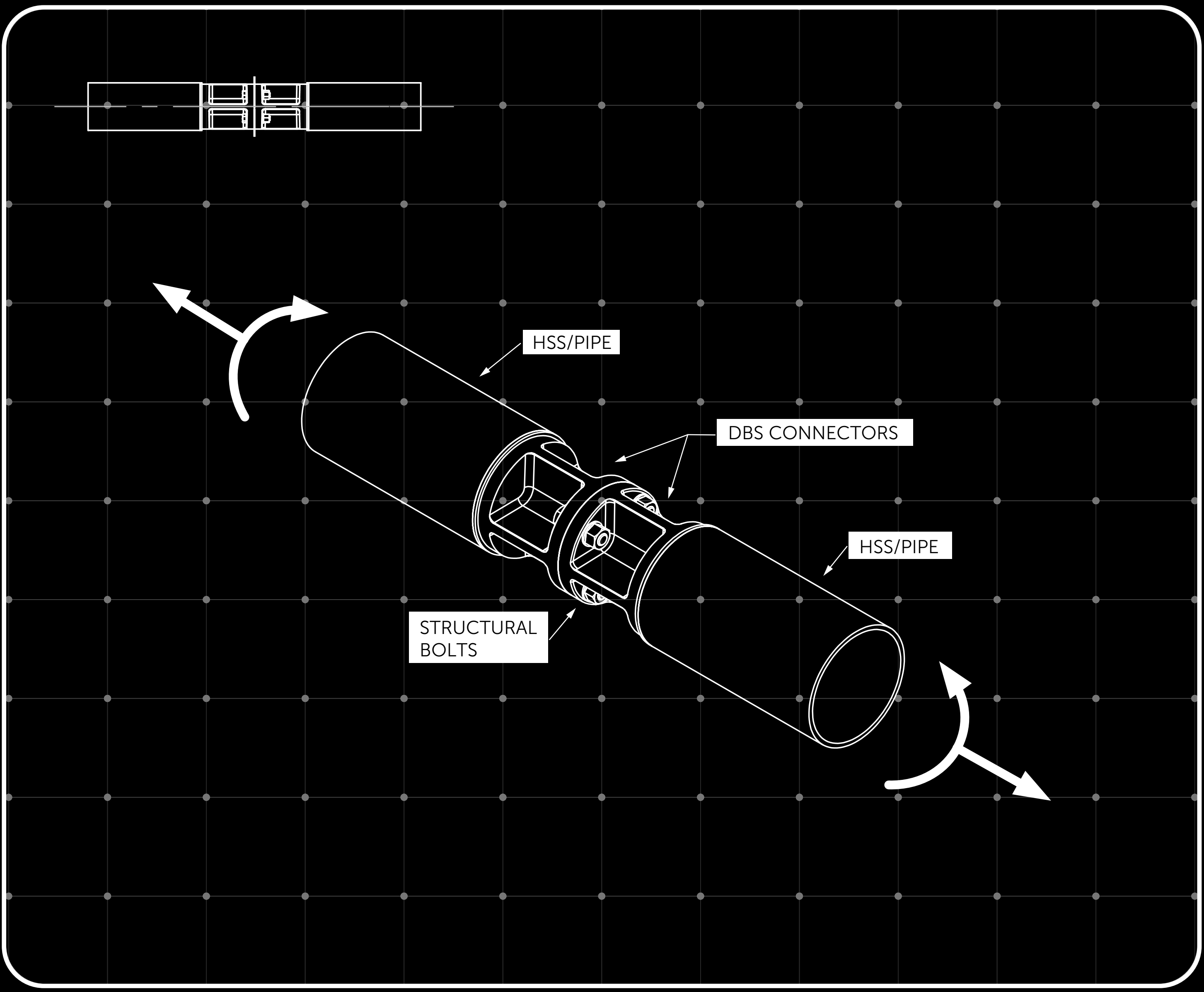
CASTCONNEX®



Diablo Bolted Splice™ (DBS) User Guide for Combined Loading

ANSI/AISC 360-22

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Introduction

CAST CONNEX Diablo™ Bolted Splices (DBS) are cast steel connectors that enable field bolted splices in circular hollow structural section or pipe members (hollow structural sections and pipe will both be referred to as HSS in this document).

The factored strength or allowable strength of a splice in an HSS member that is made with two DBS connectors is the lesser of the factored strength or allowable strength of:

1. The HSS member,
2. The welded joints between the HSS members and the DBS connectors,
3. The bolted joint between the adjoining DBS connectors, or
4. The DBS connectors themselves.

This document provides information relative to the factored strength or allowable strength of the bolted joint between adjoining DBS connectors (item 3 in the list above), as limited by the factored strength or allowable strength of the DBS connectors themselves (item 4 in the list above).

For brevity, going forward in this document the term "strength" will refer to either factored strength (LRFD) or allowable strength (ASD).

Background

DBS connectors create fixed structural connections between adjoining HSS members (though it should be noted that the torsional stiffness of a DBS splice is likely to be less than that of the adjoining HSS members). Accordingly, DBSs may be subject to six components of force depending on the structural framing configuration and applied loading: axial force, horizontal and vertical shear force, horizontal and vertical bending moment, and torsion (Figure 1). While assuming connection fixity for DBS splices can be a reasonable structural analysis assumption, a more detailed evaluation of DBS splice stiffness may be necessary to accurately account for its impact on both structural deformations and forces, depending on the application.

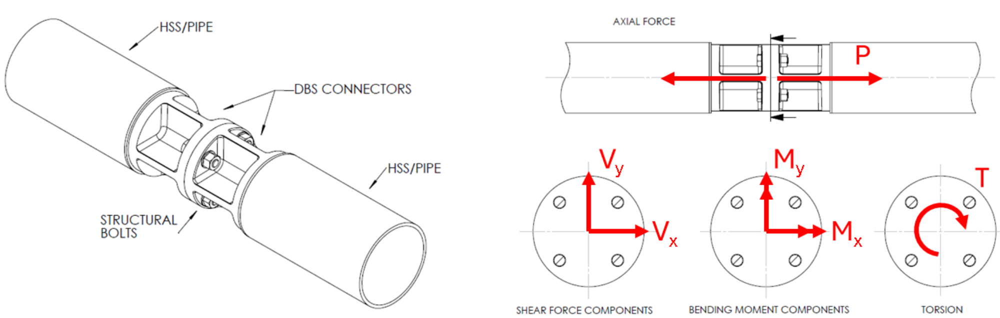


Figure 1: Forces and Moments on Typical DBS Connection

As outlined in AISC 360, the affects of all six force components must be considered when determining the strength of a bolted end plate connection. Thus, the strength of the bolted joint between two DBS connectors is governed by the *combined* effect of the forces acting at the joint.

Computation of the strength of a splice made with DBSs under combined loading must take into consideration many factors, including: the bolt type (Group 120 or Group 150 bolts), bending axis orientation ("strong", "weak", or off-axis), and code approach (LRFD or ASD). These calculations must appropriately consider limit states for bolt tension strength, DBS-to-DBS bearing stress, and DBS sectional strength. Note that the DBS connectors have been proportioned such that end plate yielding does not govern the strength of the splice.

To aid in the design process and ease the burden of performing such multi-variable calculations, Cast Connex has prepared *DBS Strength Envelope Plots* which present pre-calculated code-based strength values under a range of possible loading conditions. The strength values presented in this report only apply to Cast Connex DBS connectors and do not apply to conventionally fabricated connections. This report is intended for use only as a guide; the engineer of record must assume responsibility for all connections and confirm all calculations.

DBS Strength Envelope Plots

Overview

The *DBS Strength Envelope Plots* are interaction curves which communicate the flexural strength of the DBS connections at various axial force values. The axial force ranges from the full tensile strength of the connection, which is the factored tension strength of the bolt group, to the full compressive strength of the connection, which is the factored cross-sectional strength of the DBS steel section. In between this range of axial forces, the strength of the DBS connection may be governed by bolt tension strength (high axial tension + bending moment), DBS-to-DBS bearing strength (low tension or compressive axial force + high bending moment), or DBS steel sectional strength (high axial compression + bending moment).

For each P+M point on the plots, iterative computation was utilized to determine the location of the bolt group neutral axis assuming an elastic stress distribution (refer to AISC steel construction part 7 "Case I" approach for bolted end plate connection analysis considering the neutral axis not at the center of gravity), solving for the force in each bolt and the maximum bearing stress at the interface between the connectors. Figure 2 shows schematic example calculation results for some of the critical points in the P+M envelope. The images show the bolt forces and compressive stress profile in the connection bearing region. It should be noted that, as a conservative assumption, the effective area assumed in compression was taken as the DBS cross-section projected onto the end-plate, rather than eight times the connection element thickness as permitted by the AISC steel construction manual page 7-11.

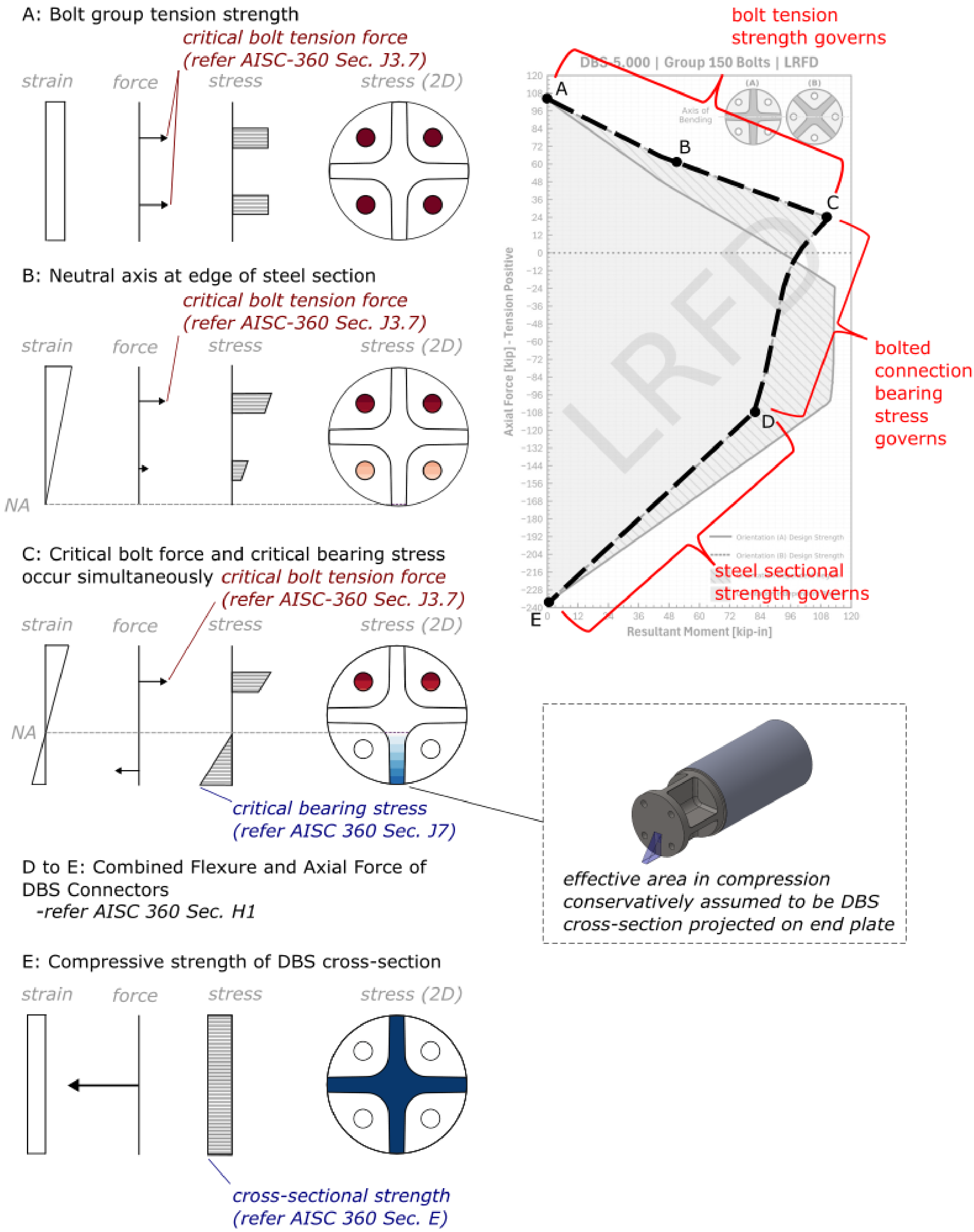


Figure 2: Strength Envelope Plots Sectional Analysis

Consideration of biaxial bending

Biaxial bending (combined bending in both the x-direction and y-direction) can be considered by first computing the resultant bending moment, M_r, and direction, θ, as shown in the image below. M_r and the corresponding axial force can then be plotted and confirmed on the appropriate *DBS Strength Envelope Plot.*

Each *DBS Strength Envelope Plot* presents two curves: one for each of the primary bending axes associated with the DBS steel section and bolt group (referred to as orientation (A) and orientation (B)). The simplest and most conservative approach for consideration of biaxial bending is to plot the point that represents the resultant moment and the axial load to confirm that the load case is within *both* the (A) and (B) curves, within the shaded gray "orientation independent region". If this is the case, then the strength of the DBS connection is confirmed regardless of the resultant moment angle.

If the point that represents the resultant moment and the axial load falls *between* the (A) and (B) curves, within the hatched "orientation dependent regions", then the bending direction θ must be confirmed to align with the appropriate orientation (A) or (B), noting that the governing orientation ("strong" versus "weak" axis) may depend on the magnitude and direction of the applied axial force. For θ *between* axis (A) and (B), more detailed calculations may be required to confirm the connection's strength for a point that represents a resultant moment and axial force that lies within the hatched "orientation dependent regions".

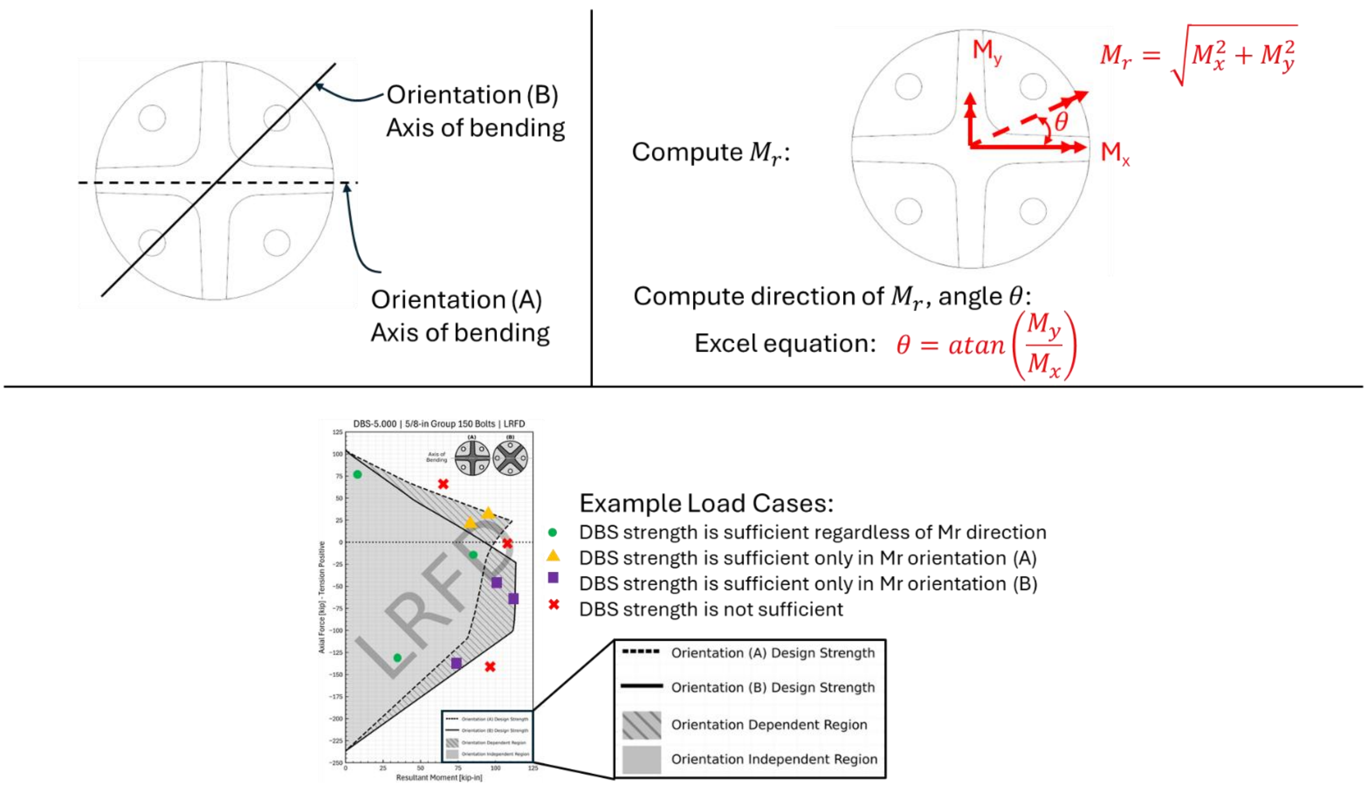


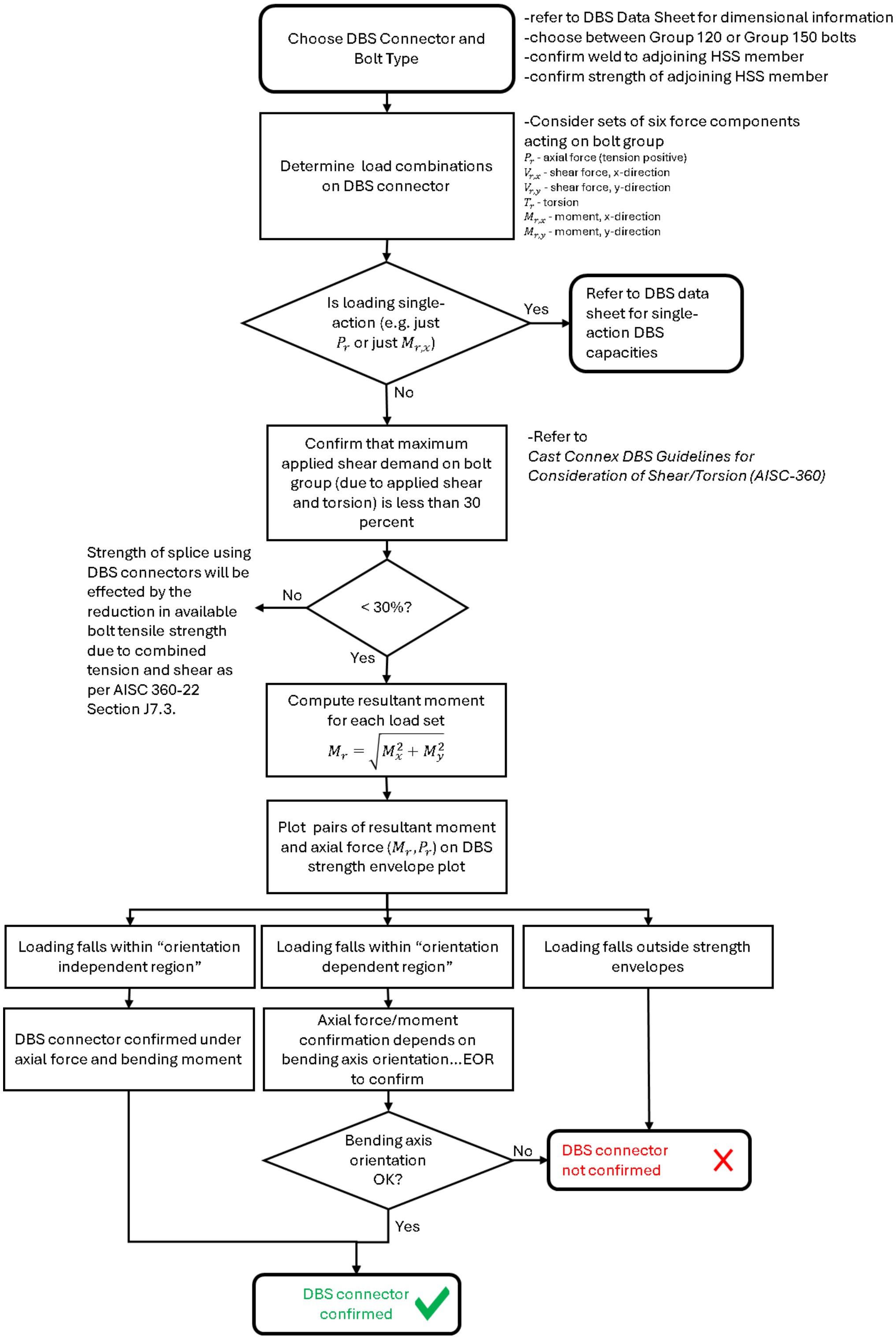
Figure 3: Example Confirmation of Load Sets

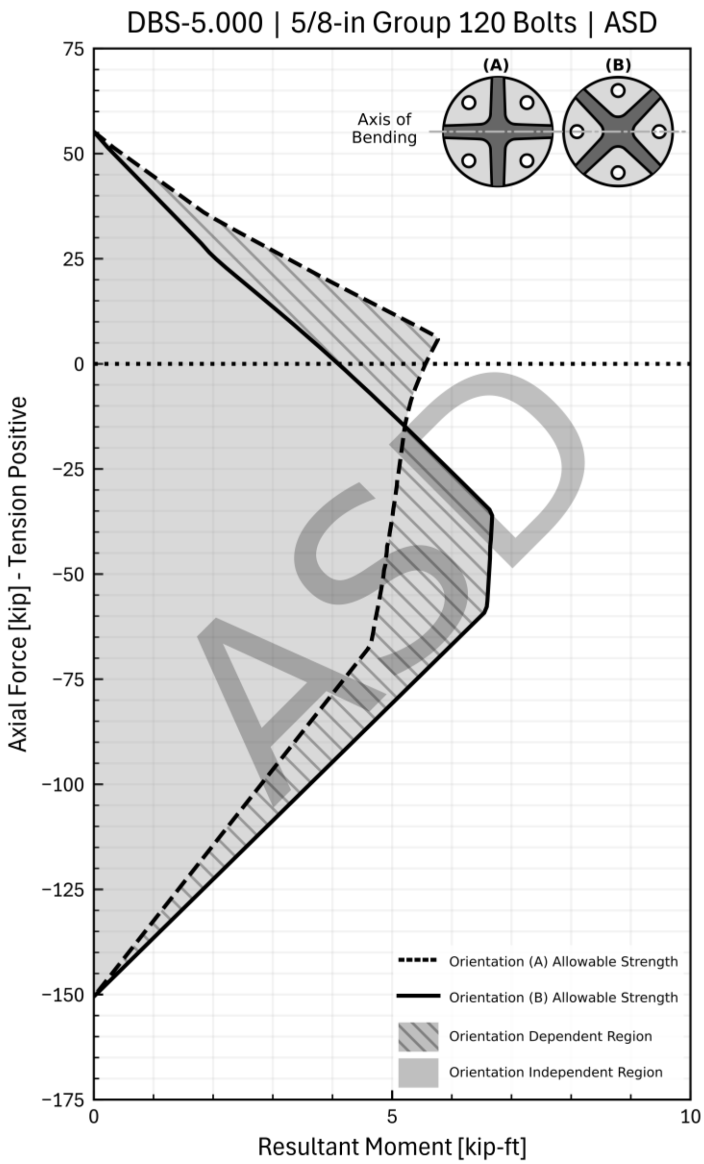
Consideration of shear/torsion

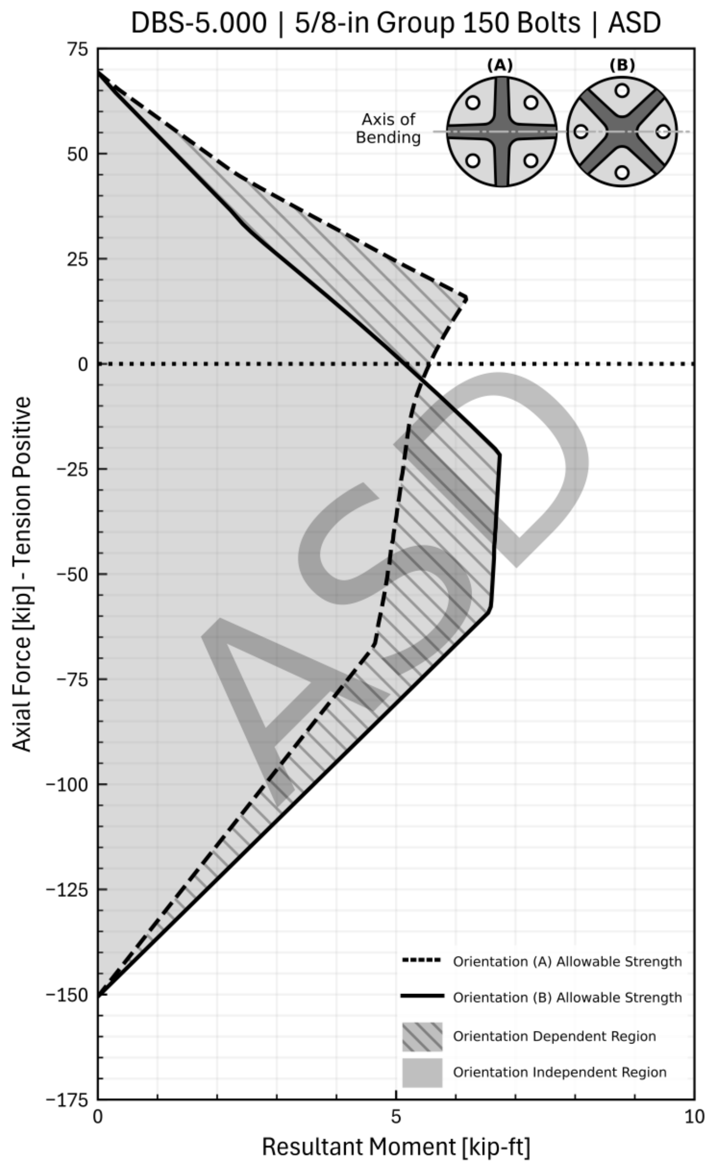
No reduction in bolt tensile strength due to combined tension and shear has been incorporated into the *DBS Strength Envelope Plots*. As per the user note in AISC 360-22 Section J3.8, the interaction between bolt shear and bolt tension need not be considered when the required shear stress is less than or equal to 30% of the available shear stress. Thus, the plots are only valid for maximum bolt shear stress utilization up to 30%. While it is expected that this range of shear utilization will cover most applications of the DBS connectors, the shear utilization of the bolt group should be confirmed to be less than 0.3 when using the *DBS Strength Envelope Plots*. Under applied shear, the shear demand can be calculated simply as the applied shear divided by the number of bolts. In cases where there is an applied torsion in addition to applied shear, the effects of combined shear and torsion should be considered. Additional guidelines on how to confirm the bolt shear stress utilization can be found in Appendix A of this document.

The following flow chart is provided to aid in the use of the *DBS Strength Envelope Plots*.

DBS Design Confirmation Flow Chart

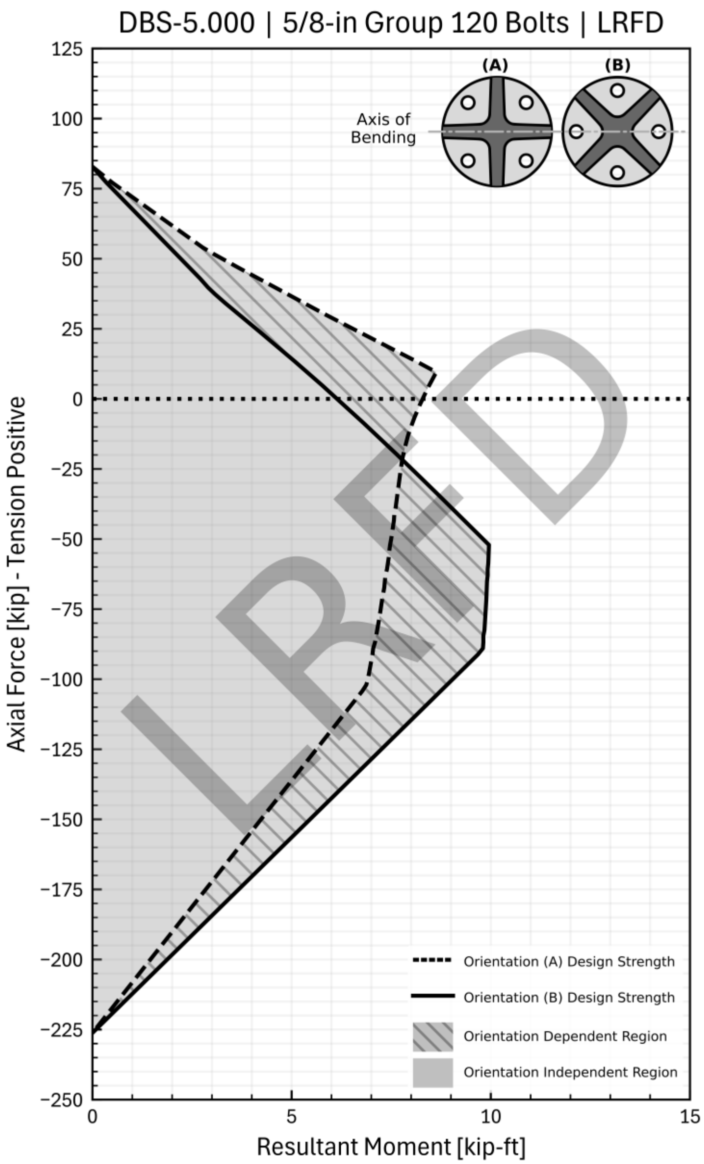


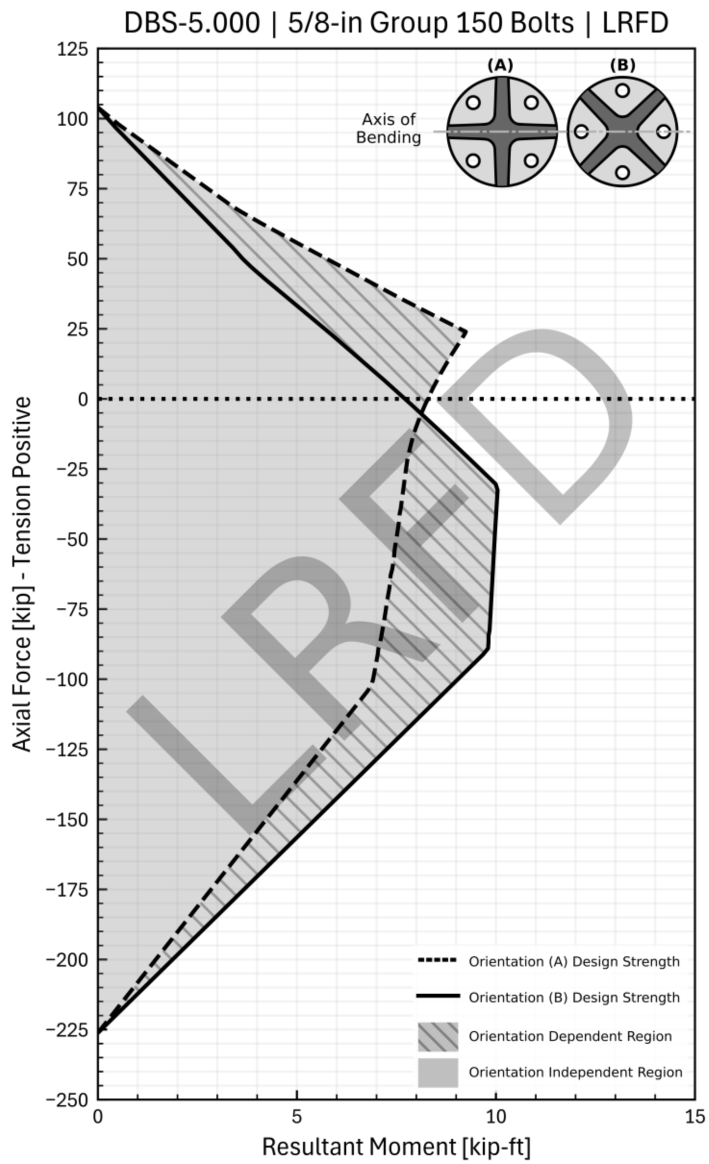




Notes:

- The allowable strength of the DBS connector is the minimum of (a) the strength shown in the above plots, (b) the allowable strength of the HSS-to-connector welded connection, and (c) the allowable strength of the connecting HSS member.
- Plots indicate allowable strength of the DBS connector considering minimum of bolt tensile strength, bearing stress between adjoining connectors and sectional strength (refer to AISC 360-22 J3.7, J7 and H1.1).
- Plots assume the required bolt group shear strength (due to applied shear and torsion) is less than or equal to30% of the corresponding design shear strength as per AISC 360-22 J3.8 User Note.
- Plots are valid for ASD load combinations.
- Load cases shall be evaluated separately.
- The Engineer of Record (EOR) shall verify the orientation of the DBS in the orientation dependent regions.
- Resultant Moment: $M_r = \sqrt{M_x^2 + M_y^2}$





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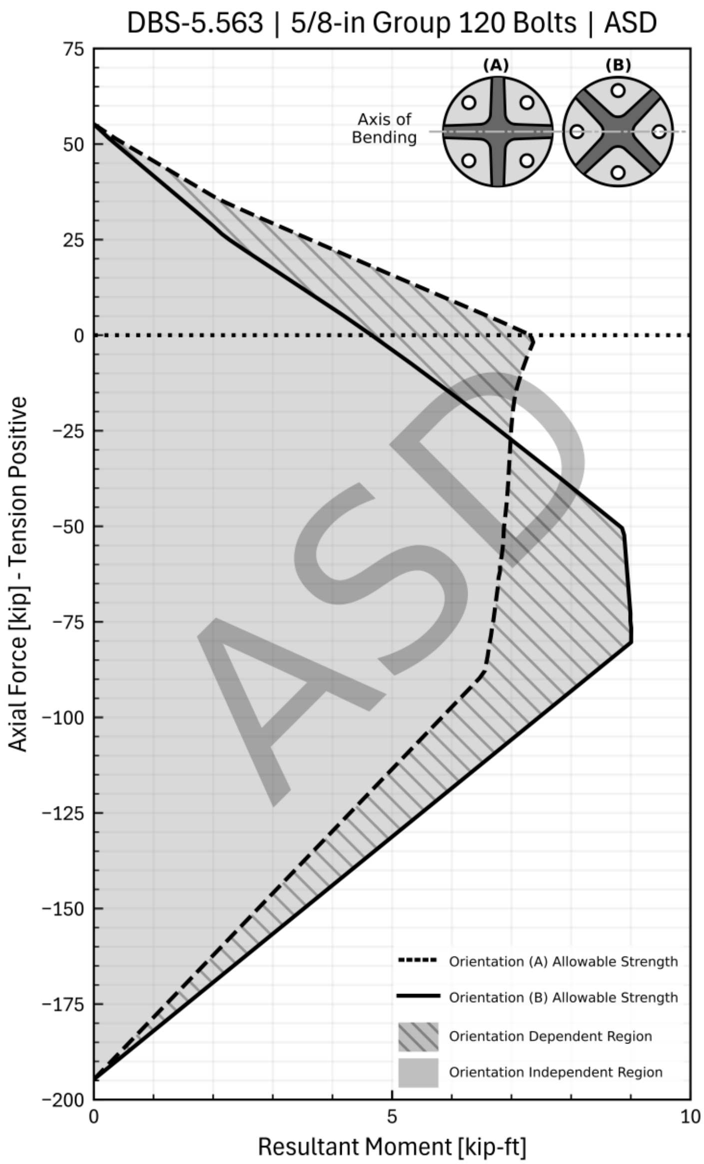

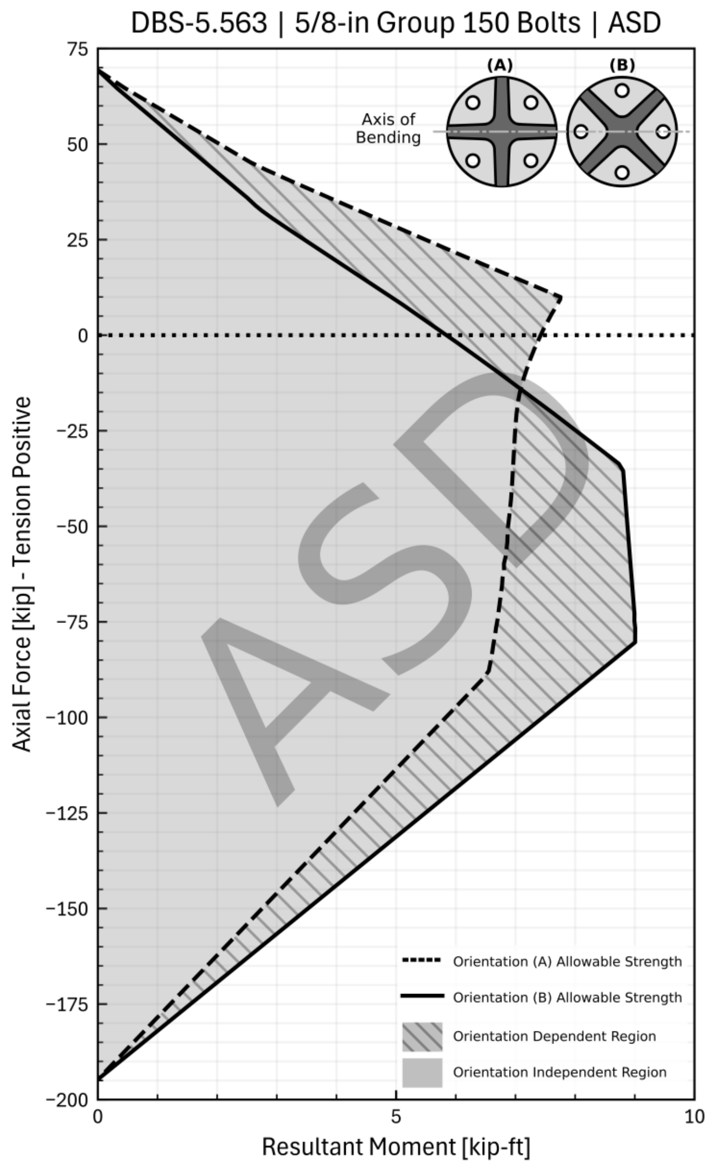

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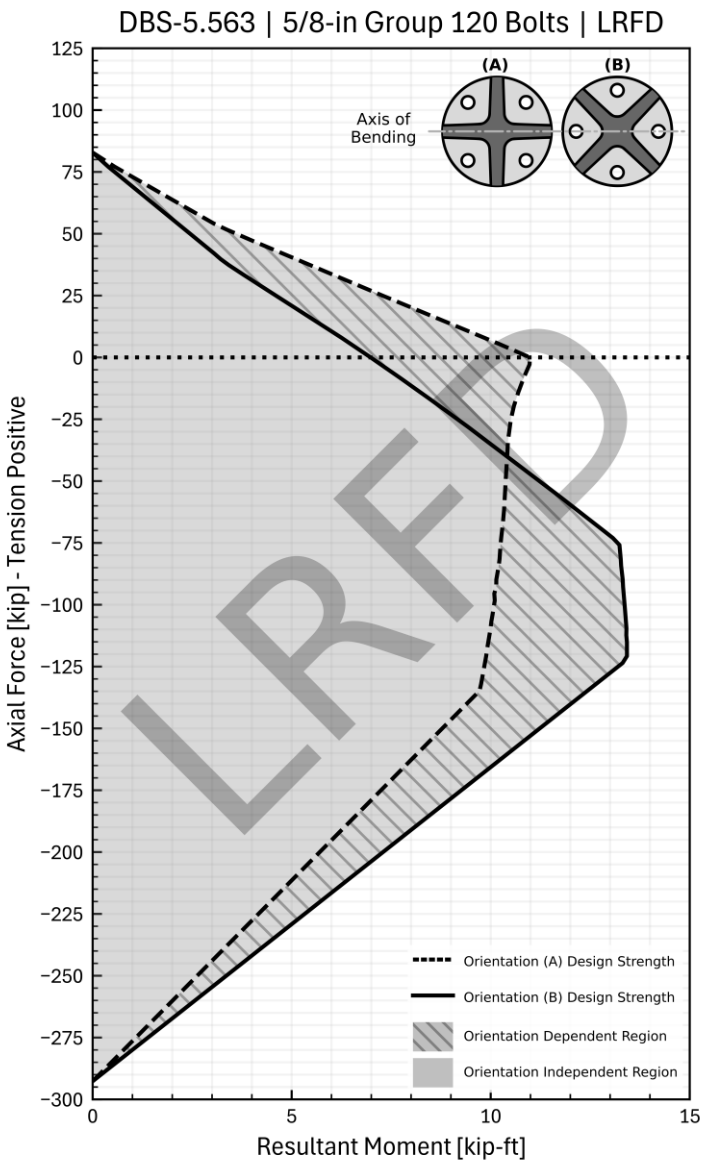

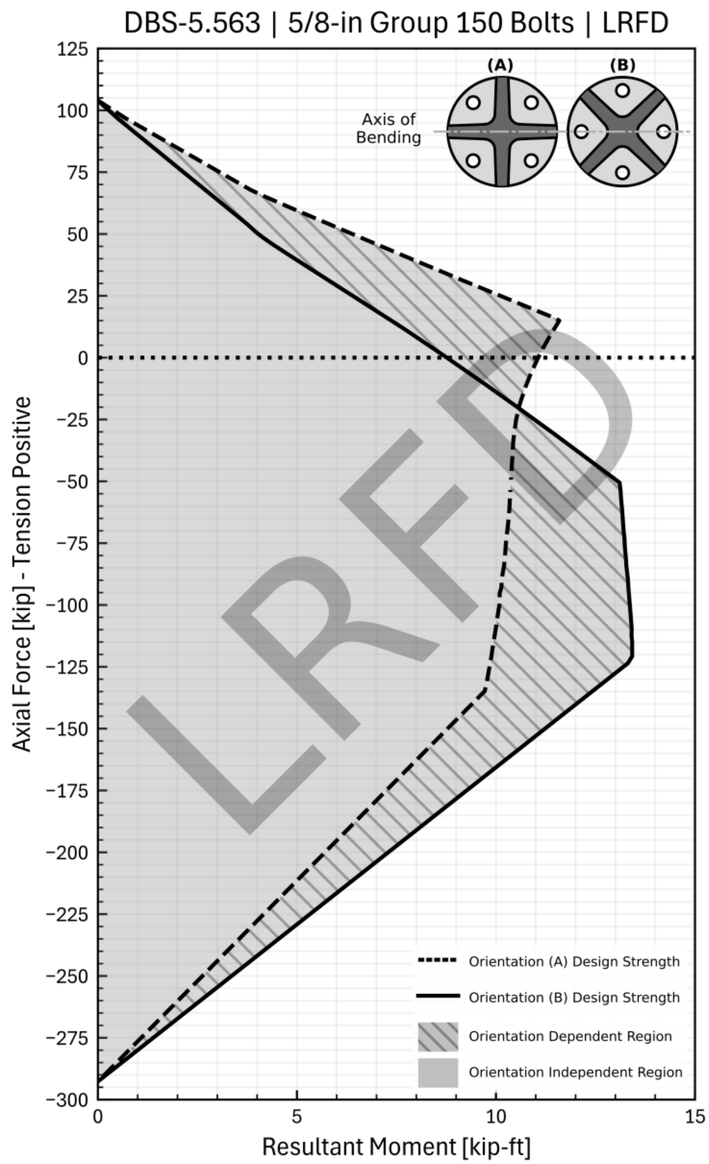

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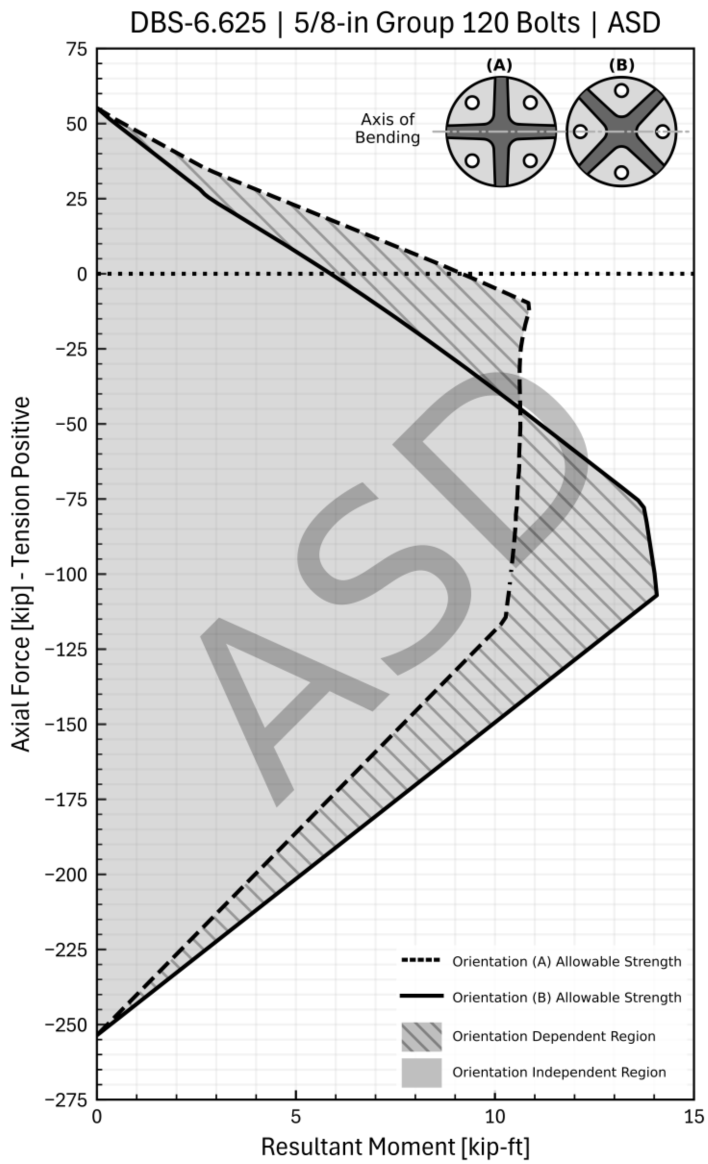

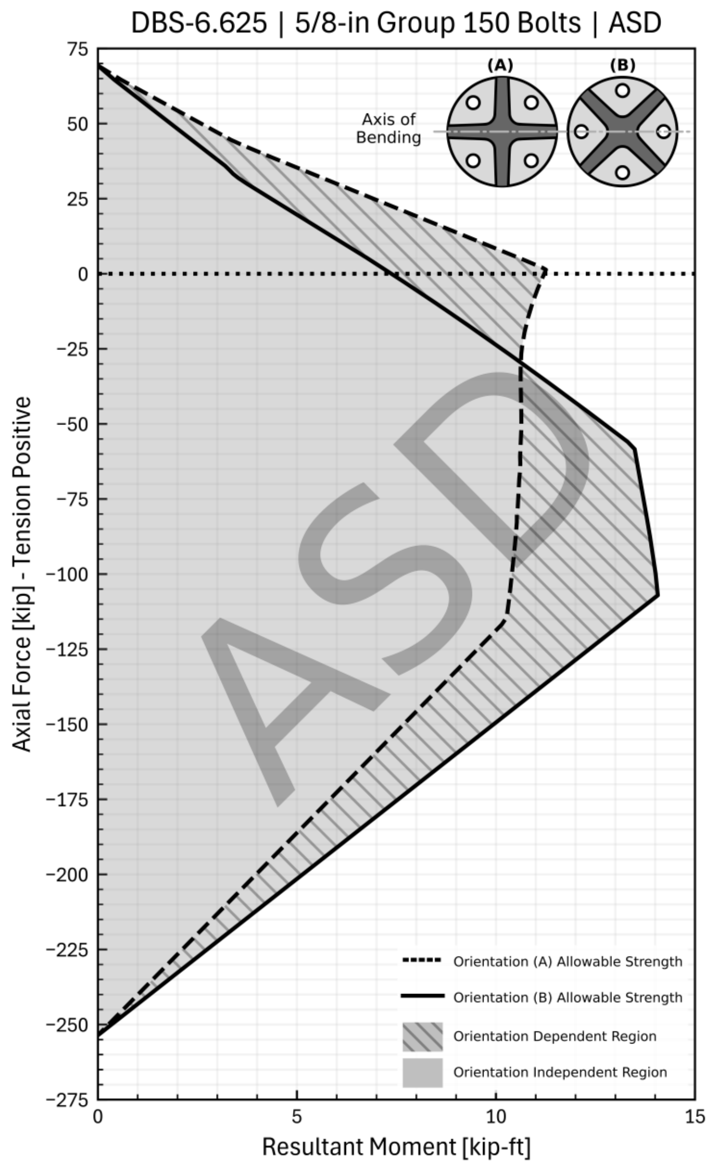

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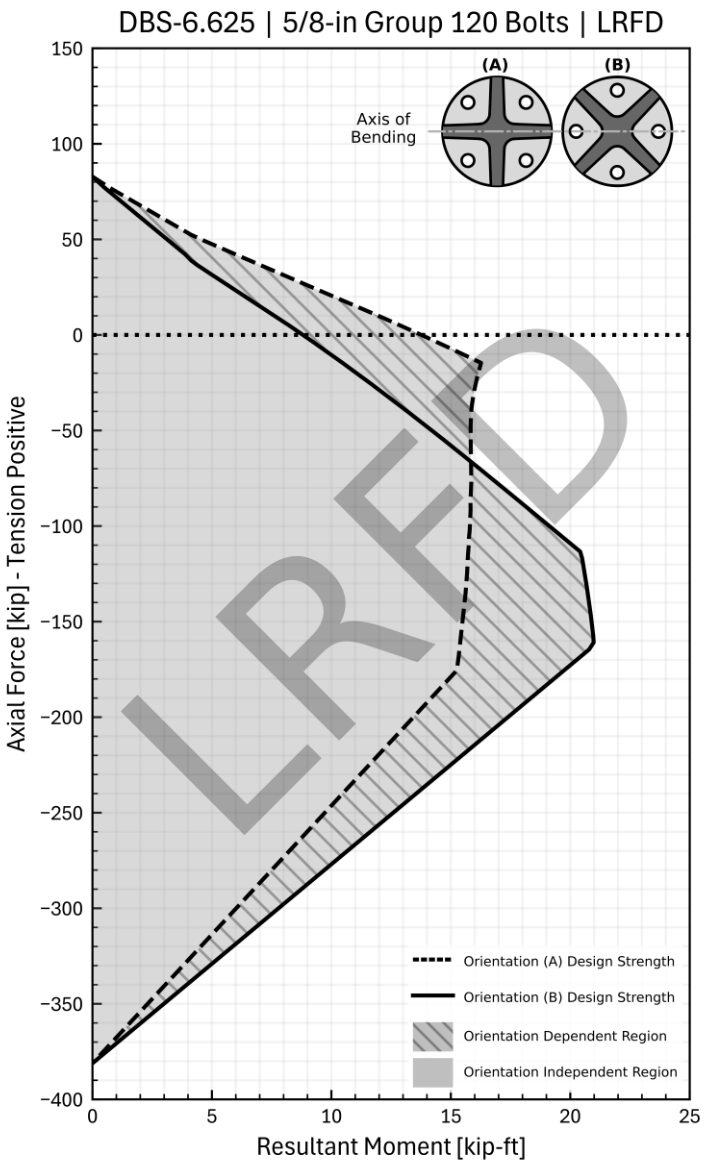

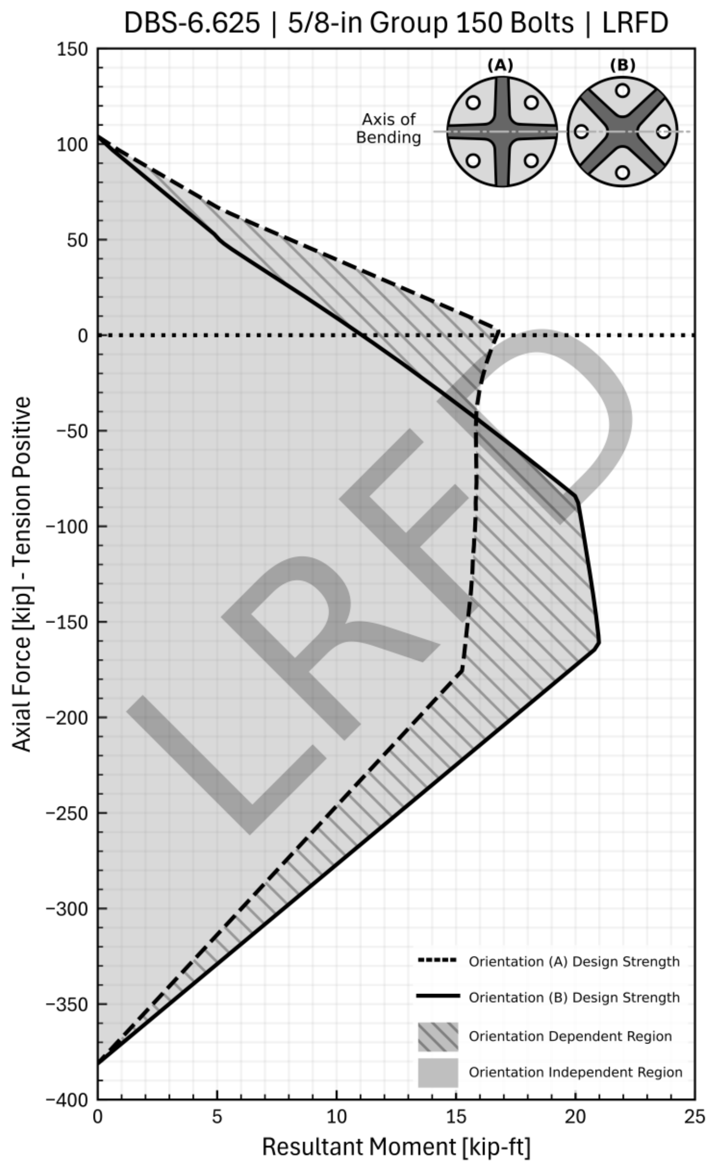

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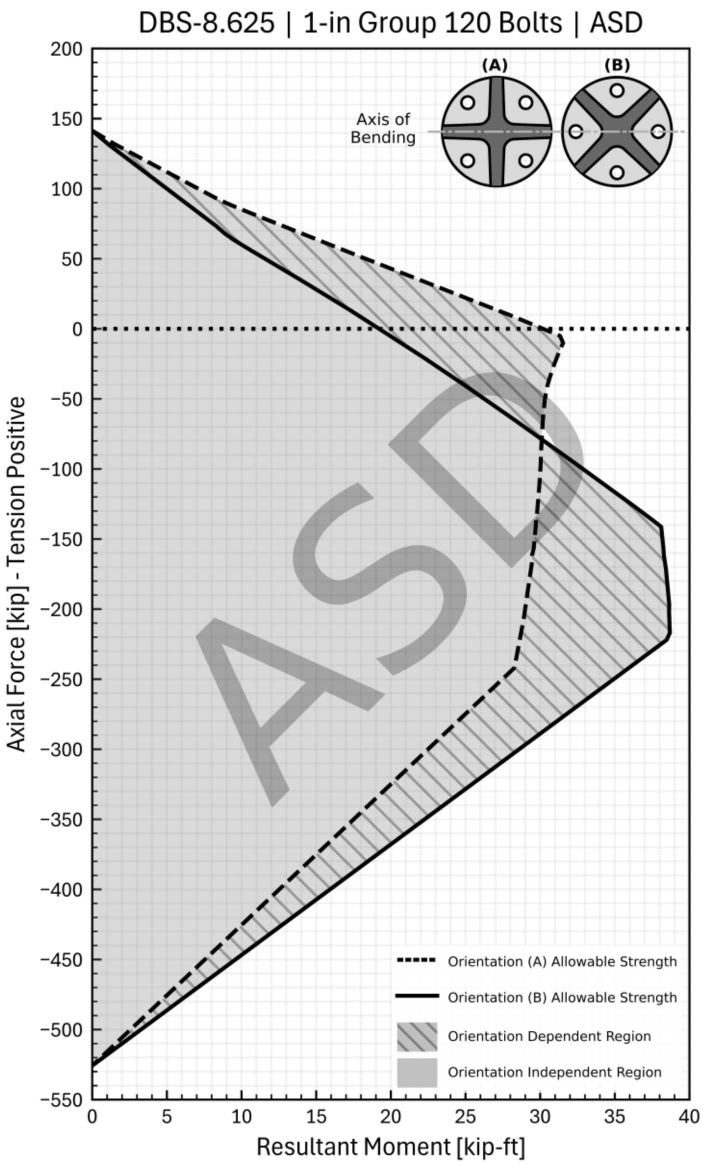

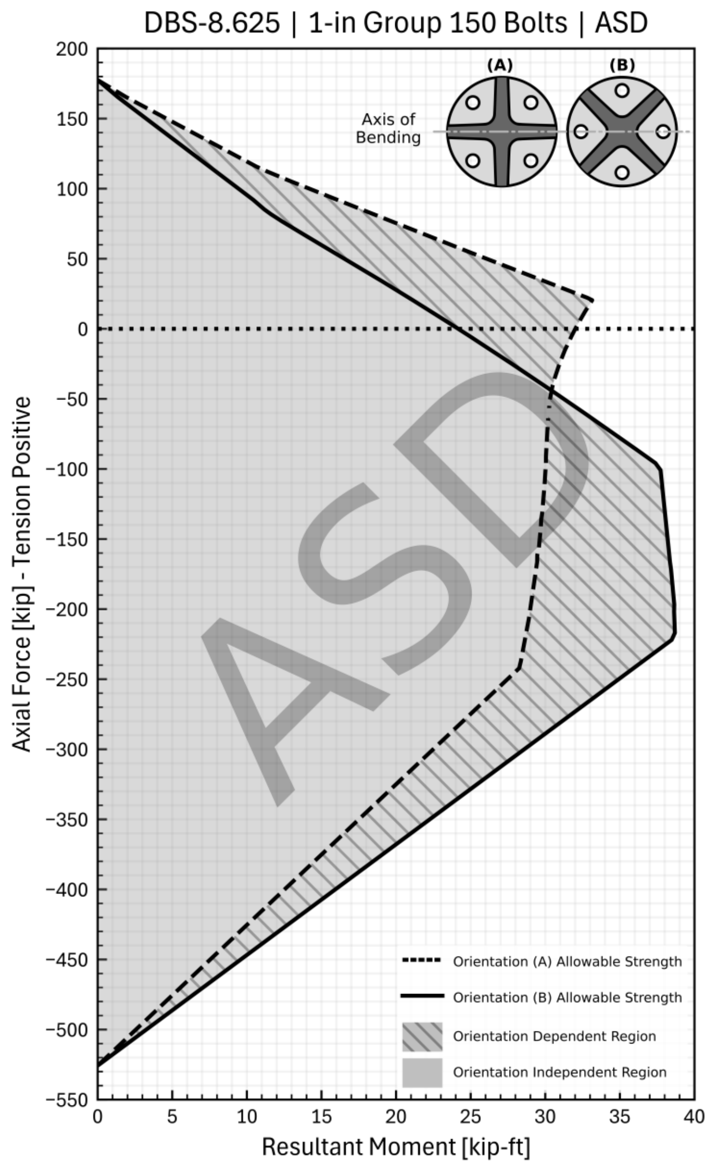

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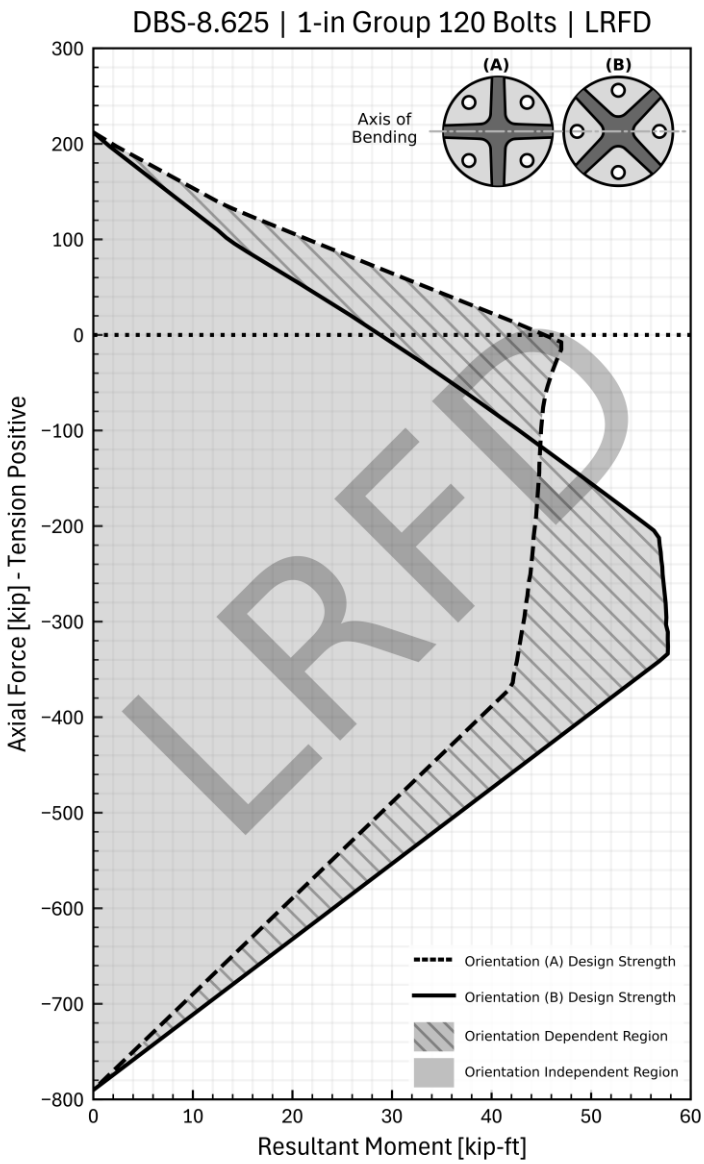

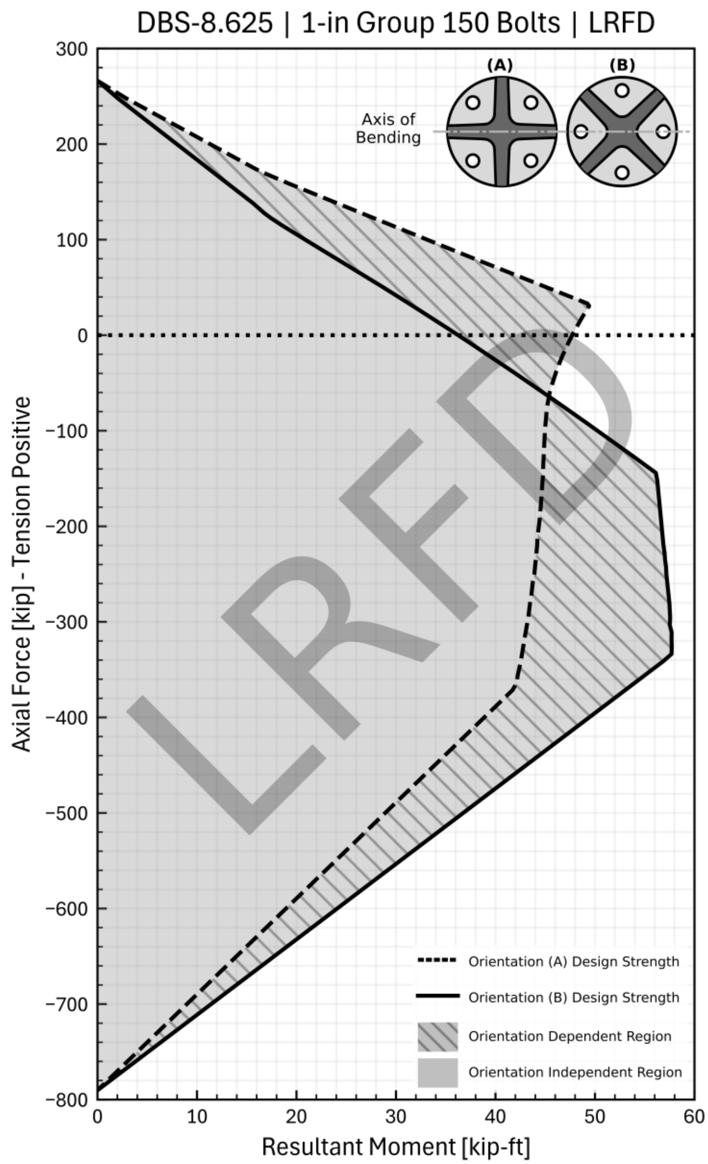

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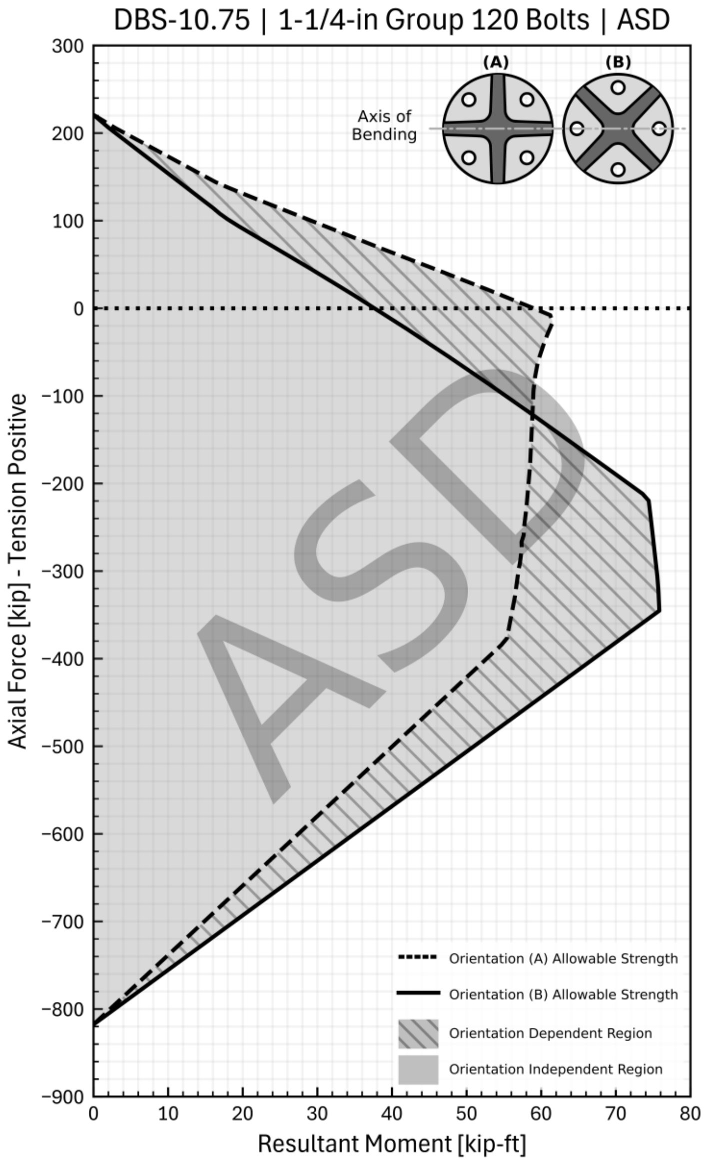

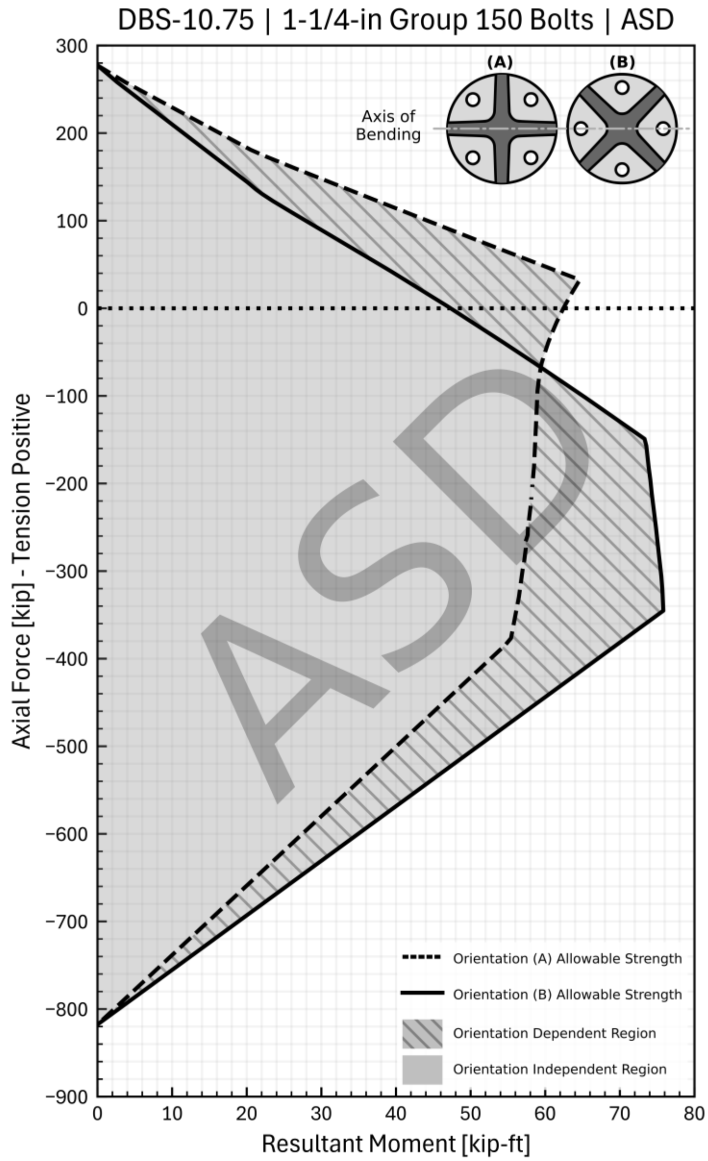

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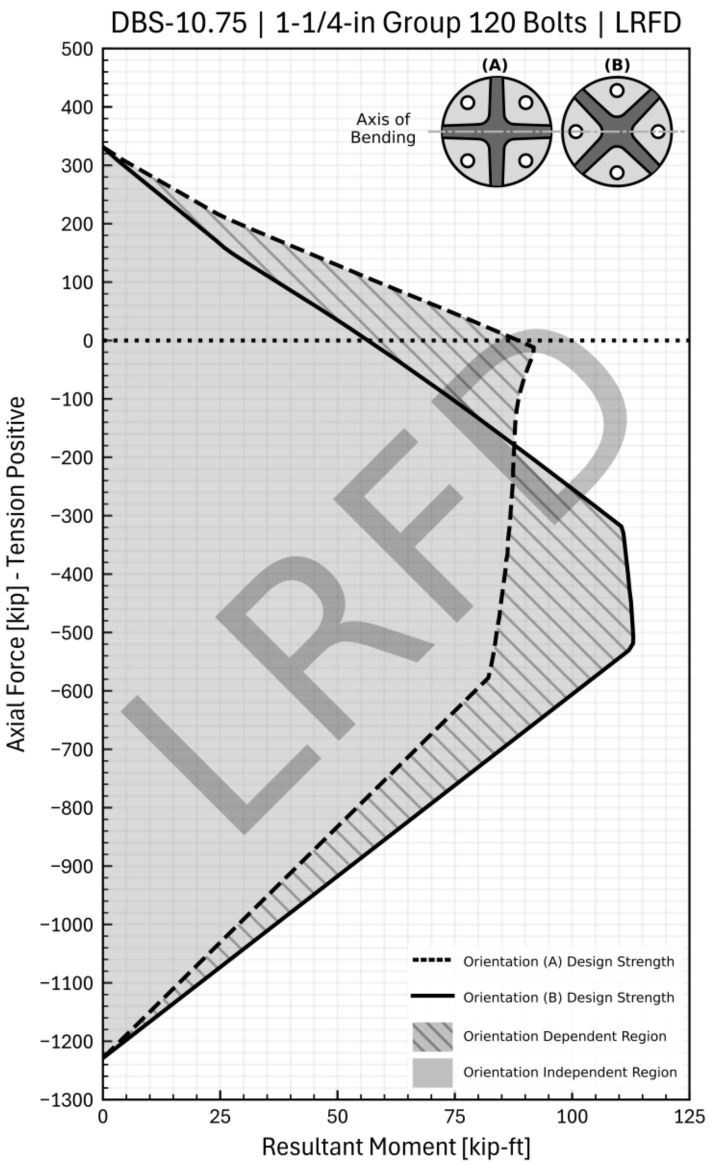

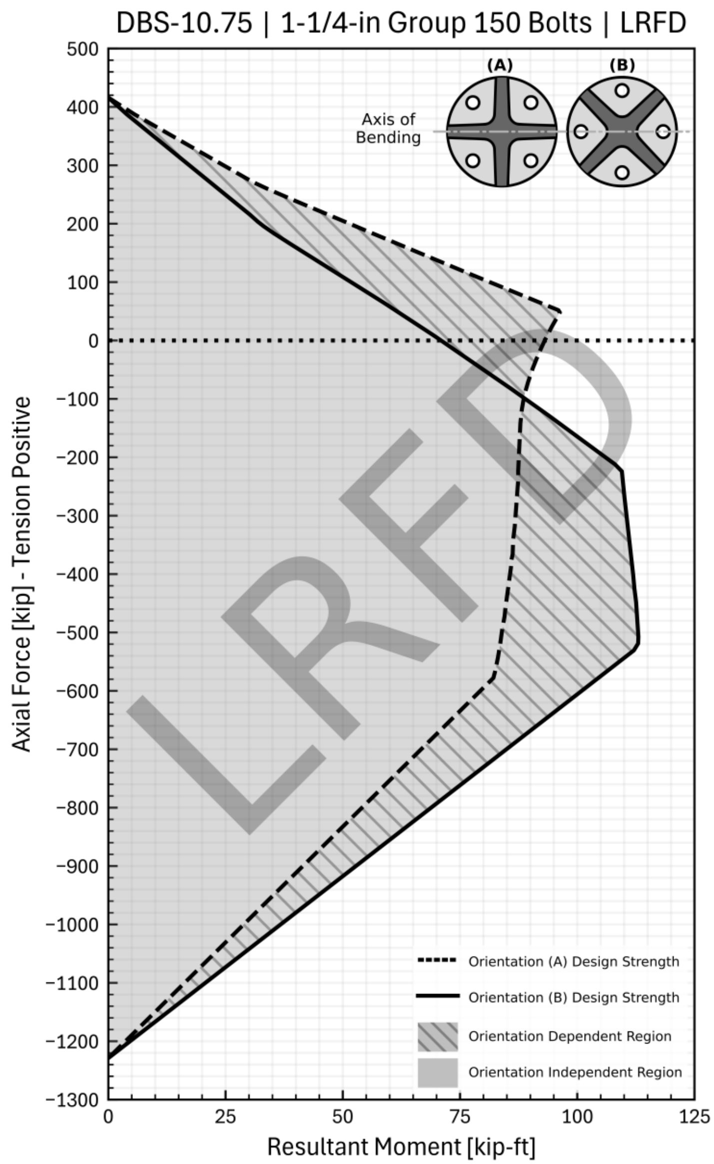

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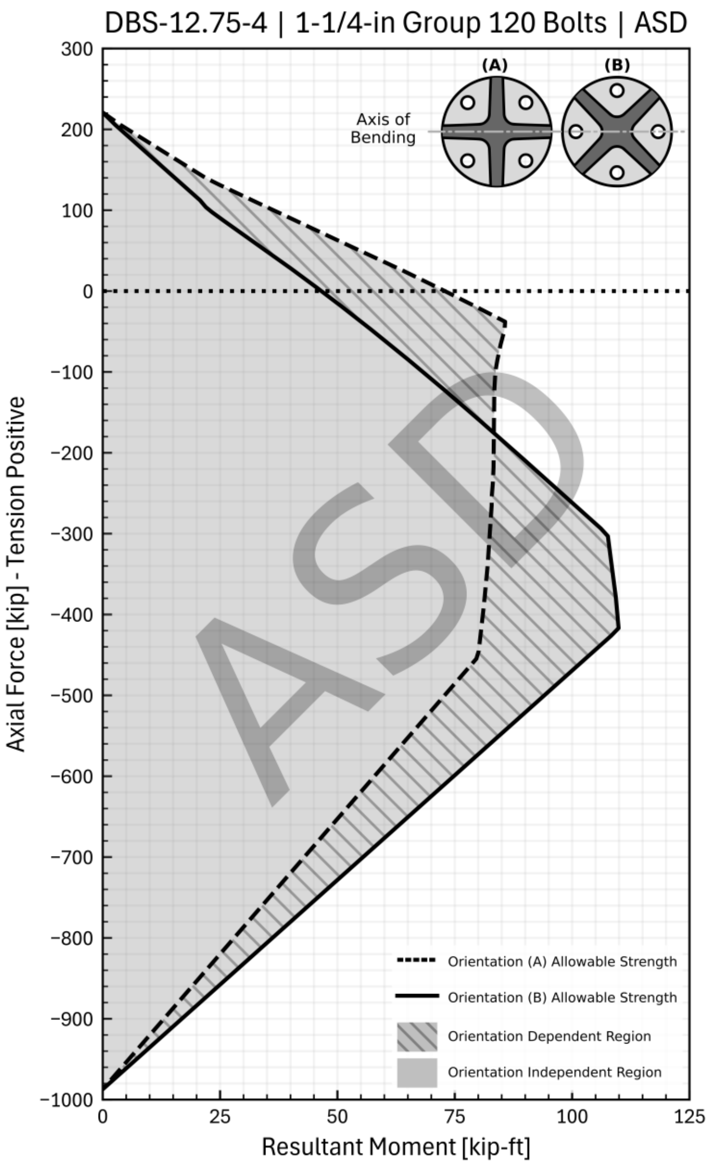

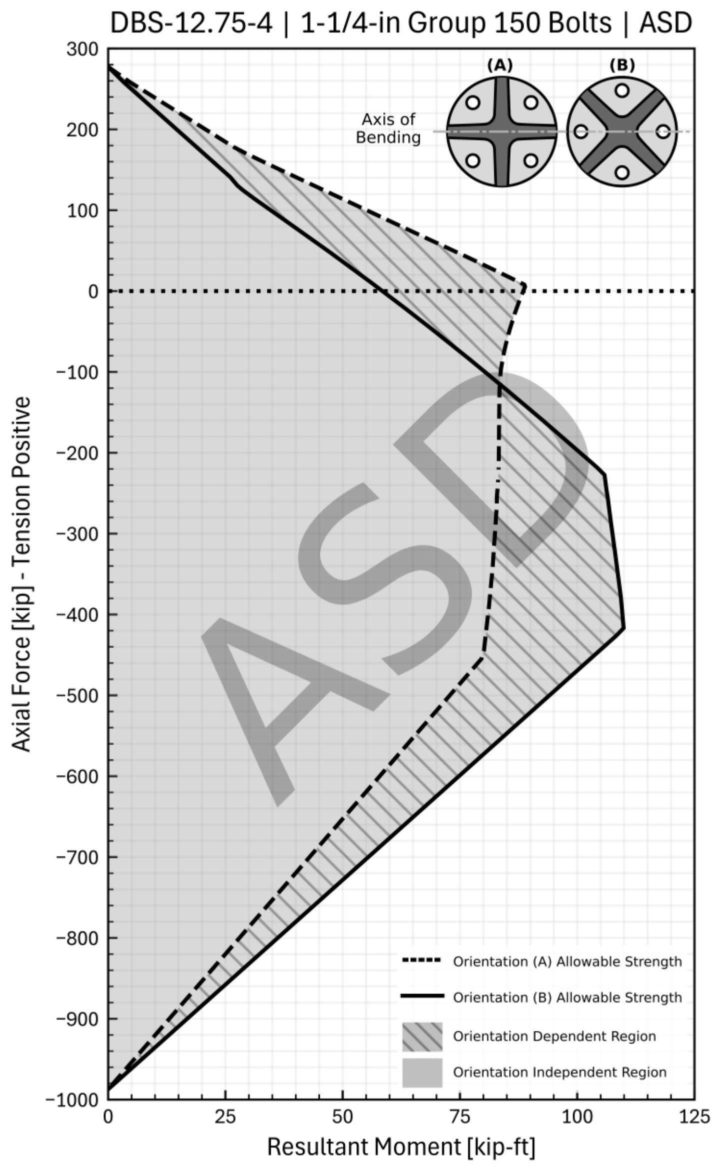

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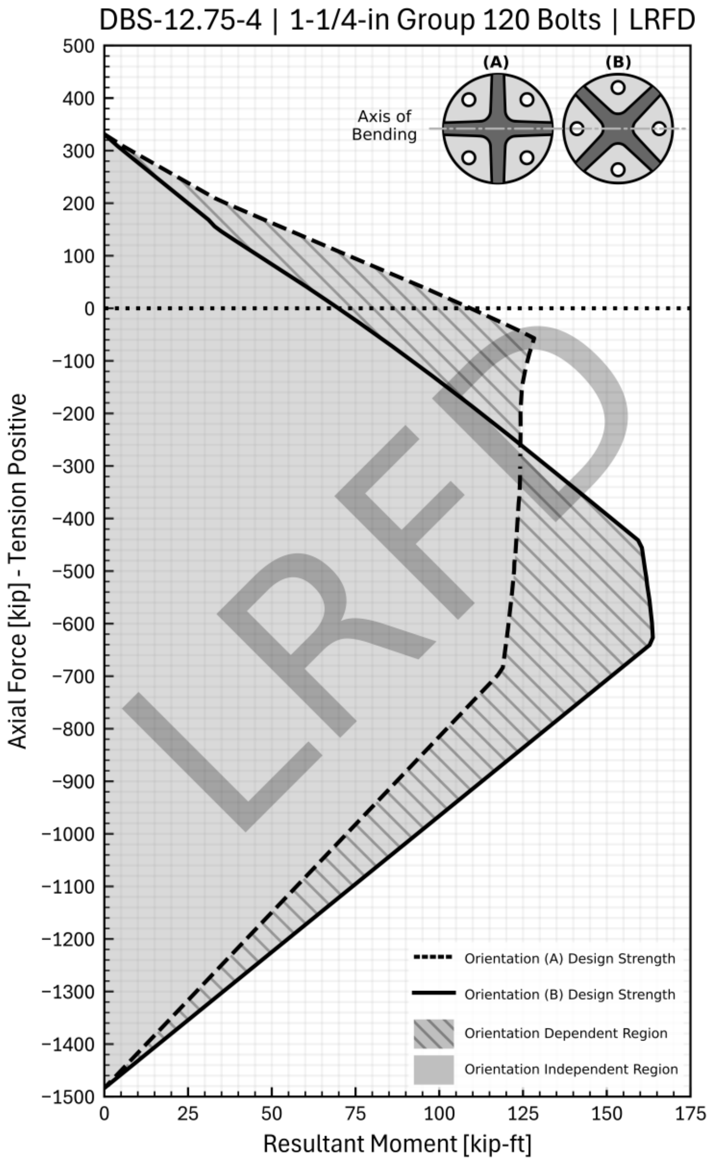

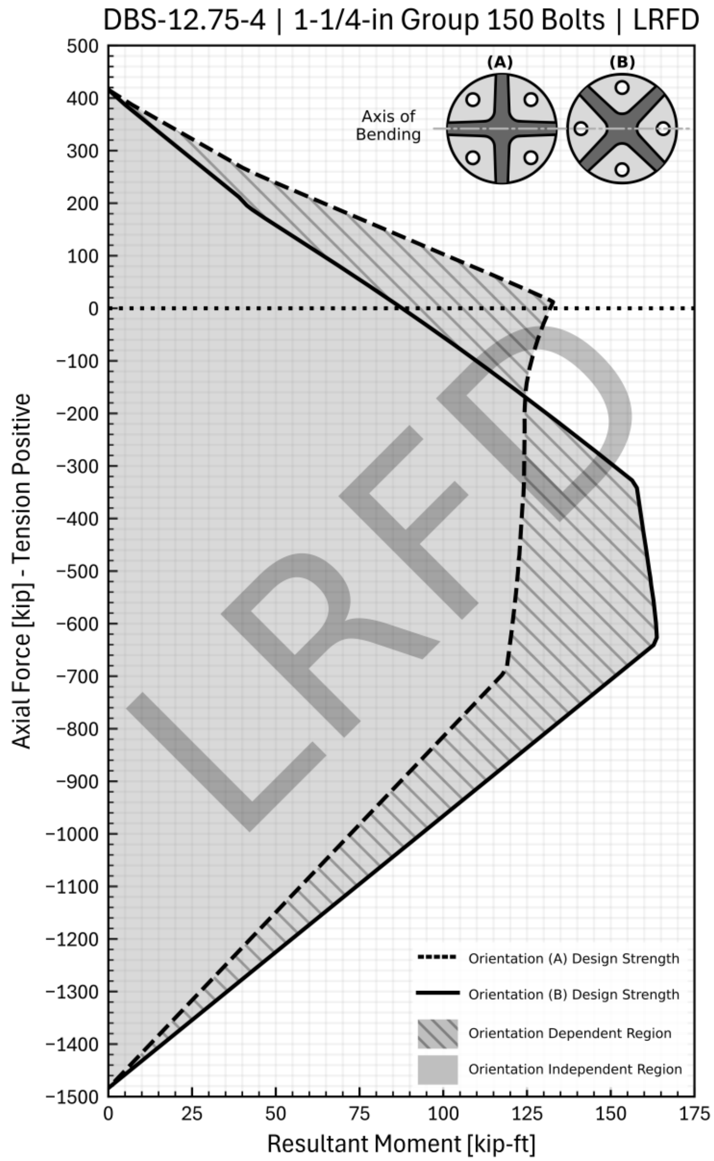

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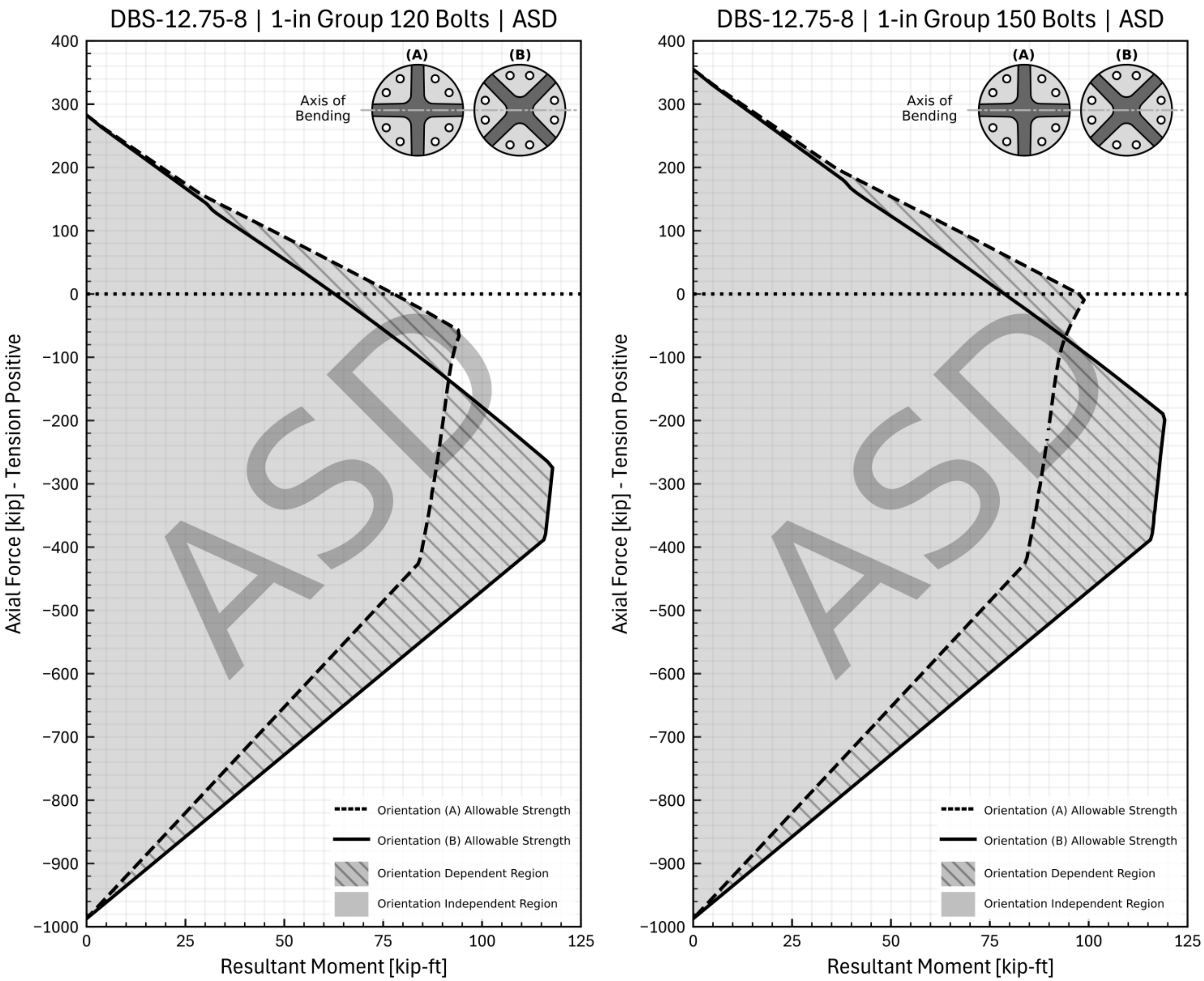

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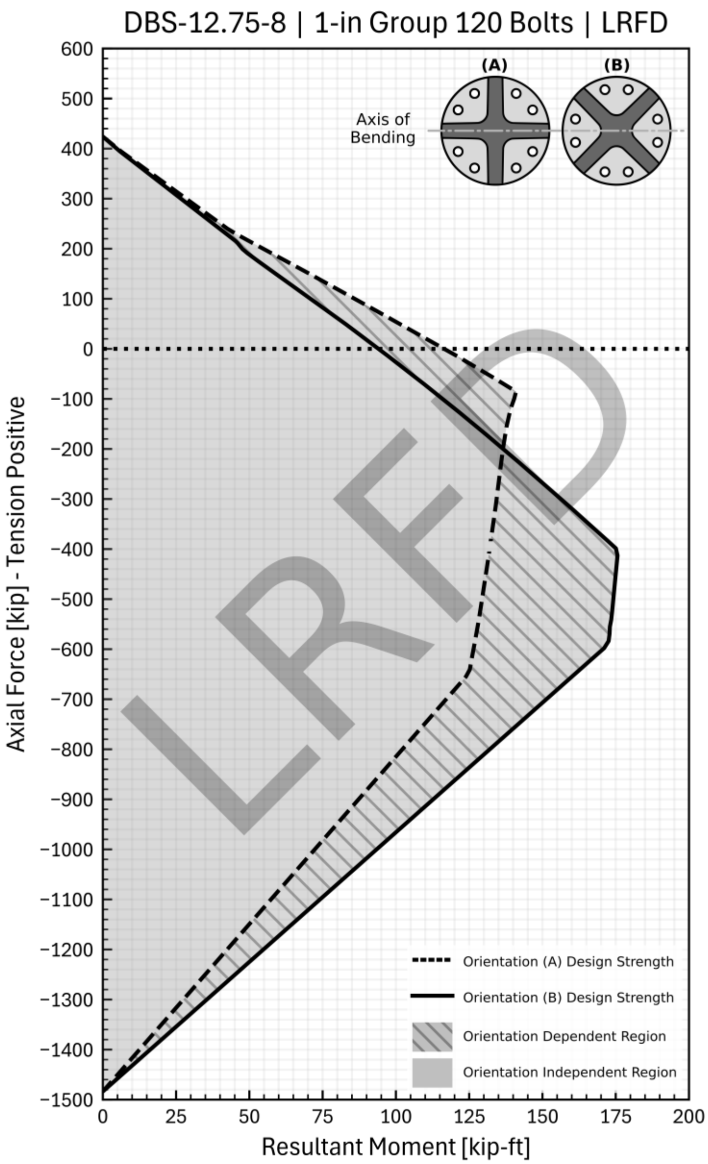

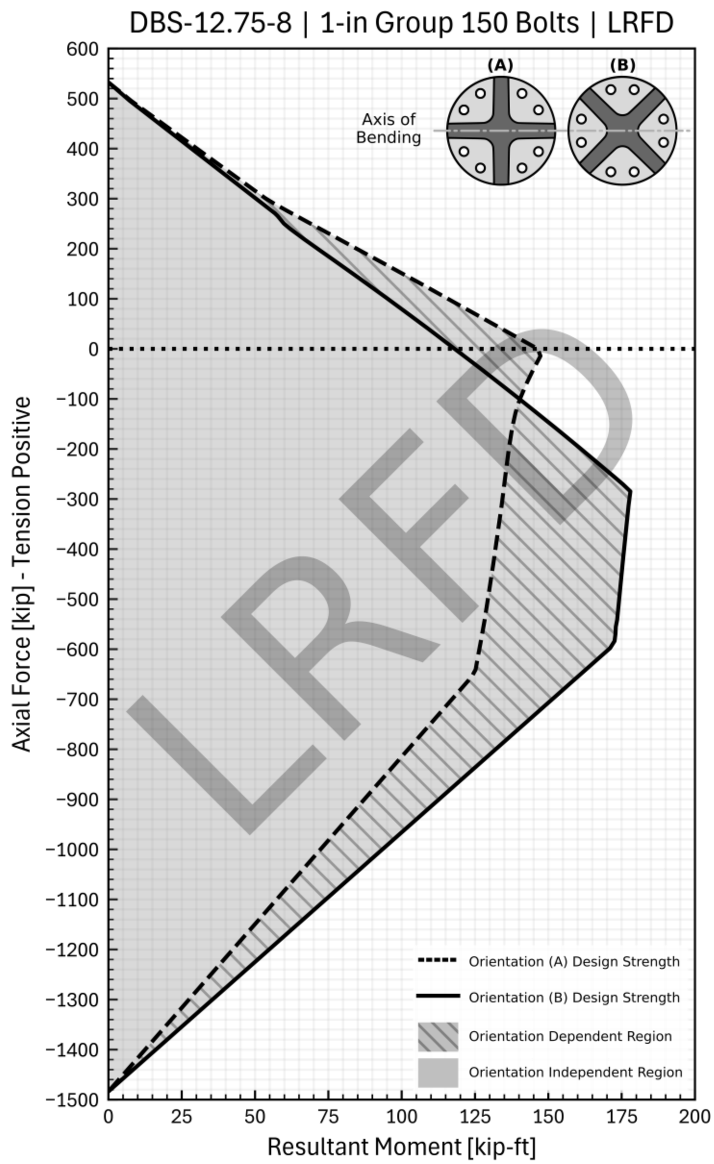

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- Load cases shall be evaluated separately.
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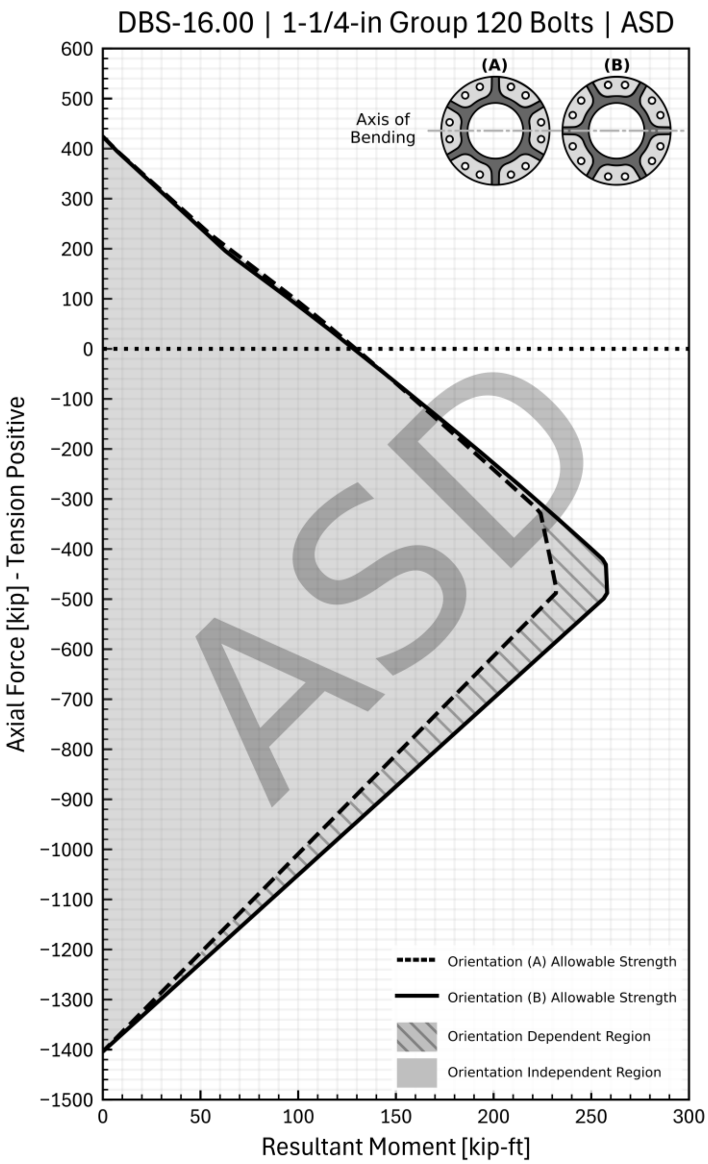
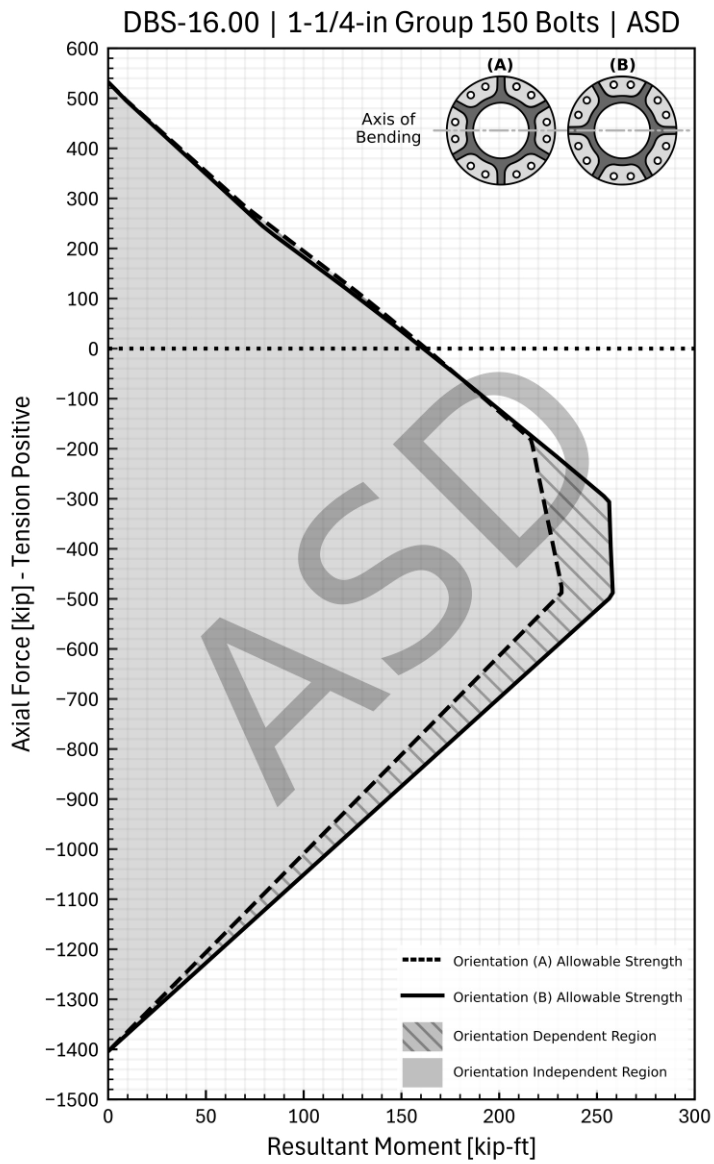
- Resultant Moment: $M_r = \sqrt{M_x^2 + M_y^2}$





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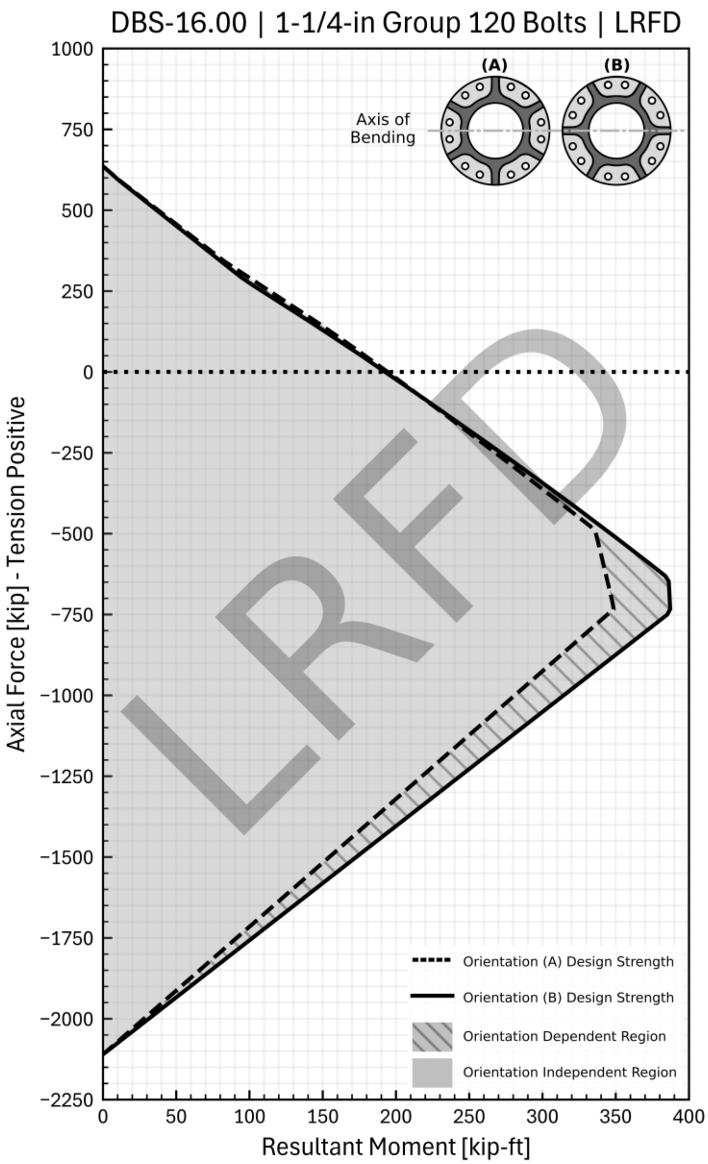

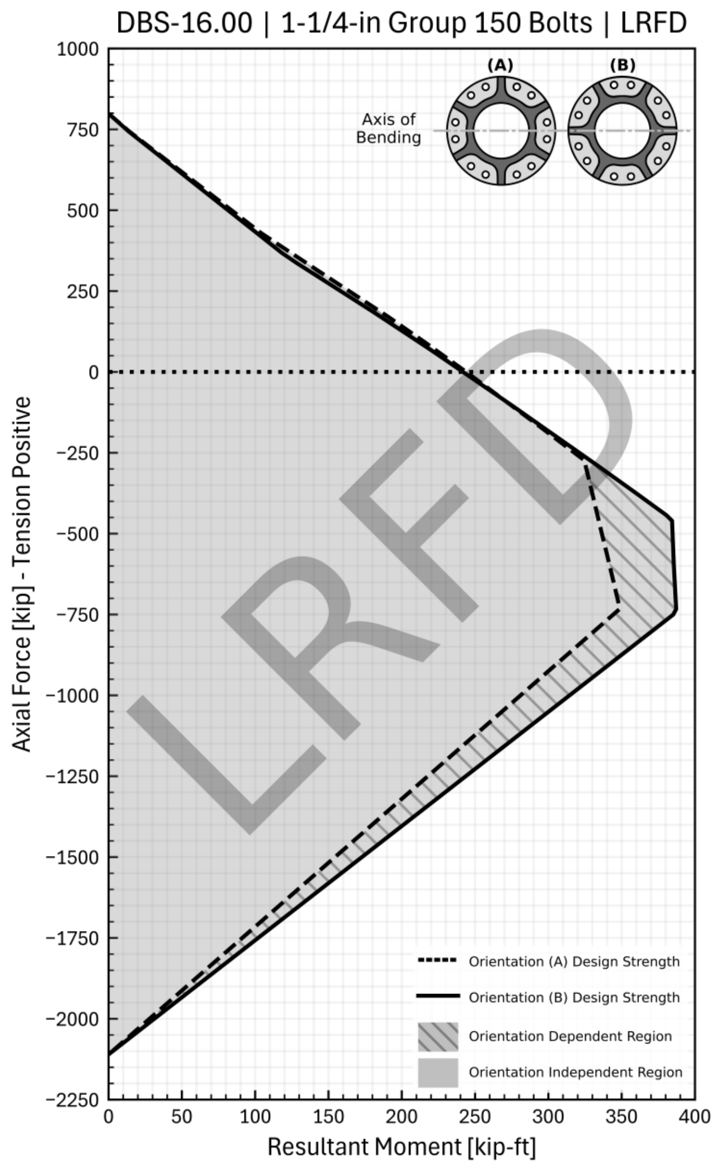

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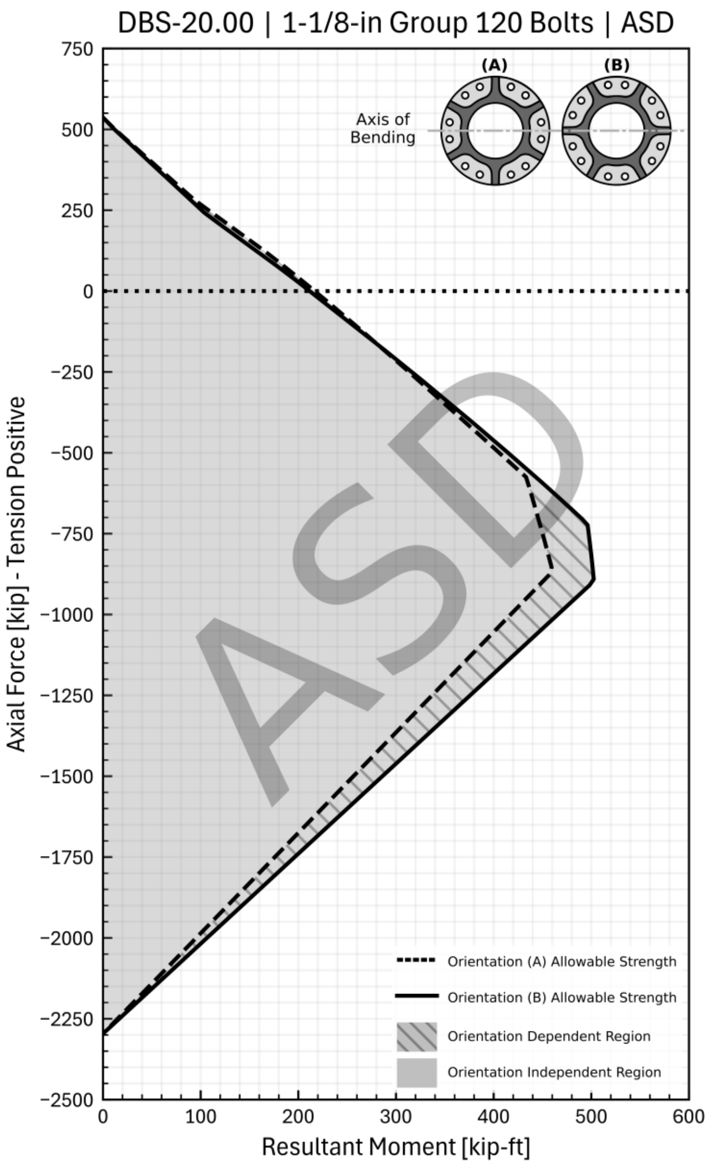

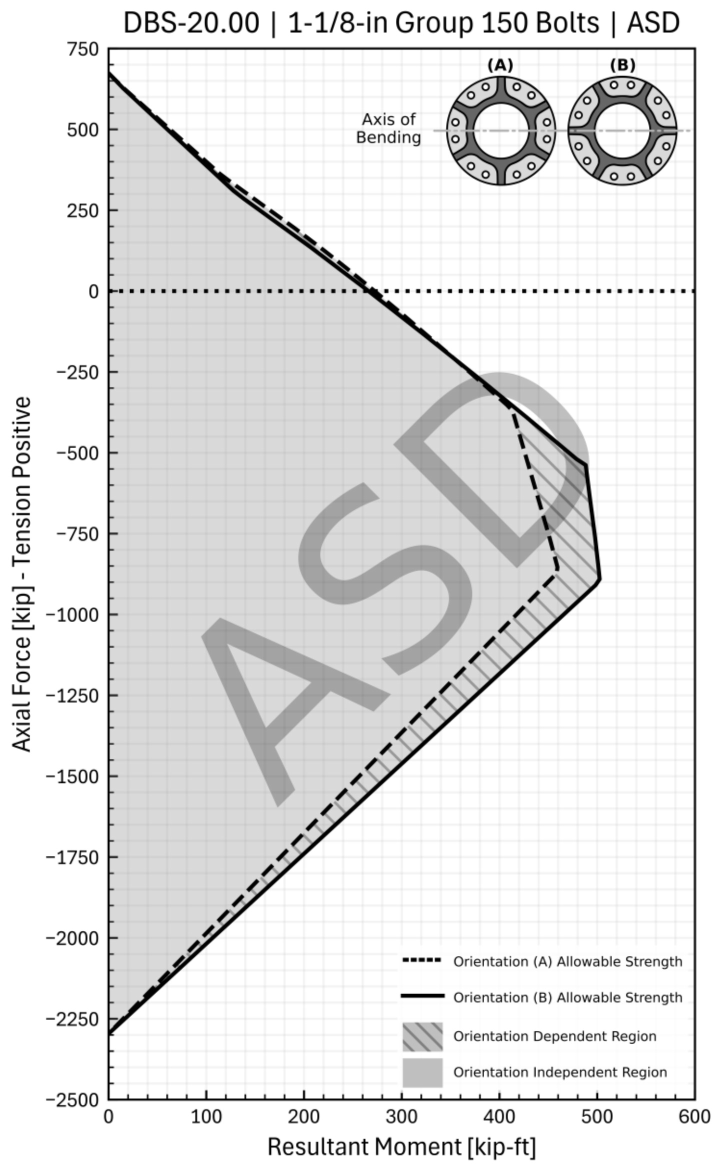

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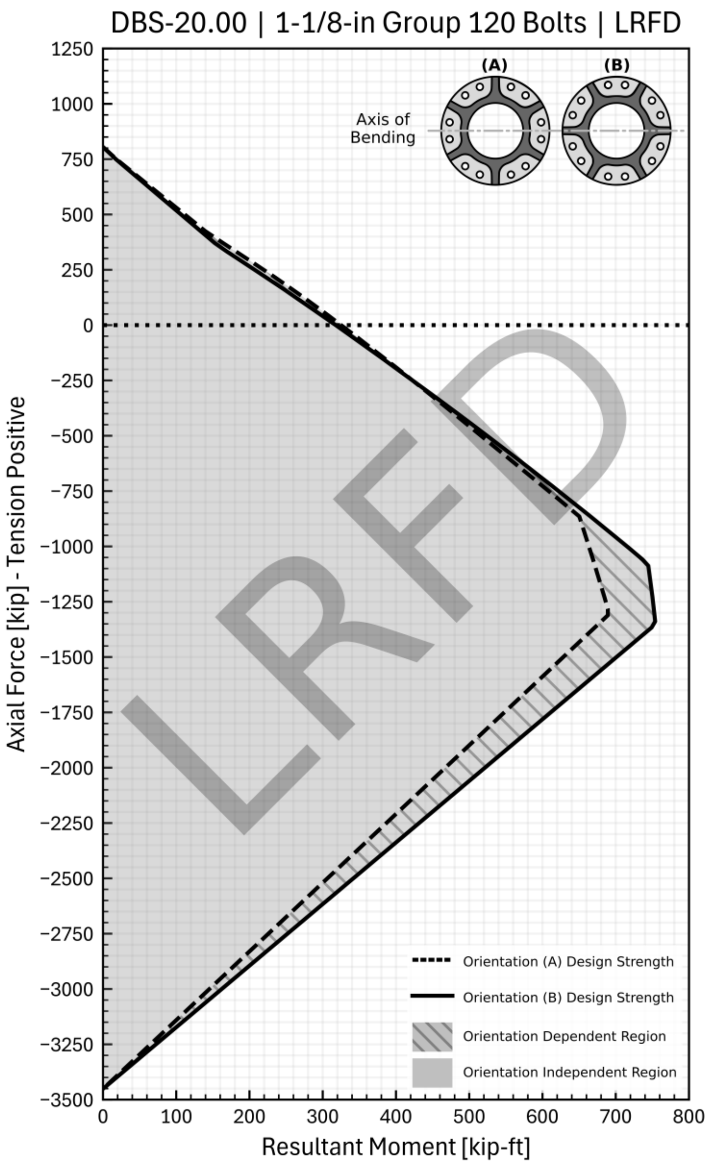

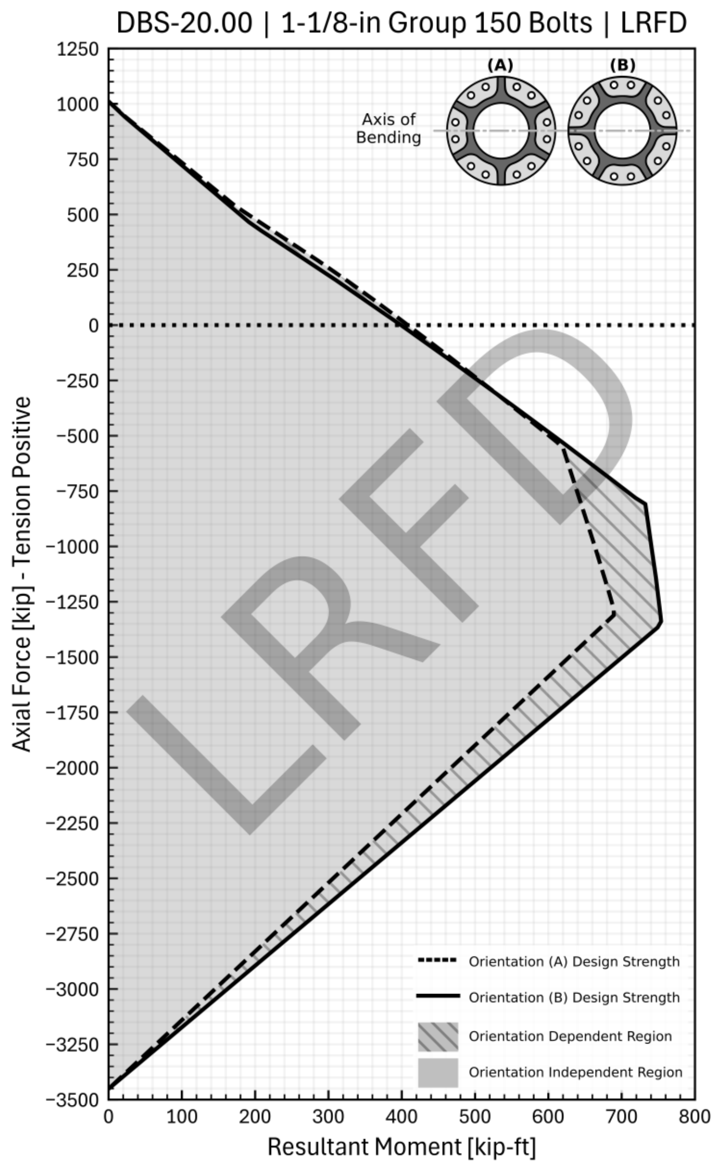

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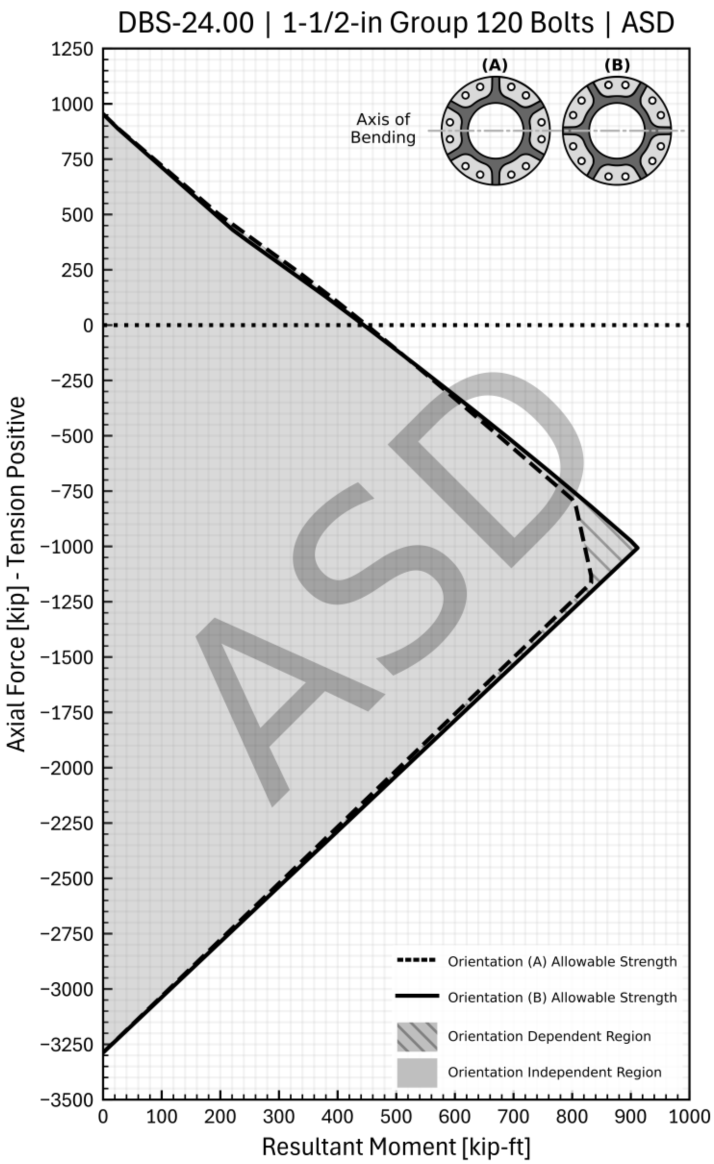

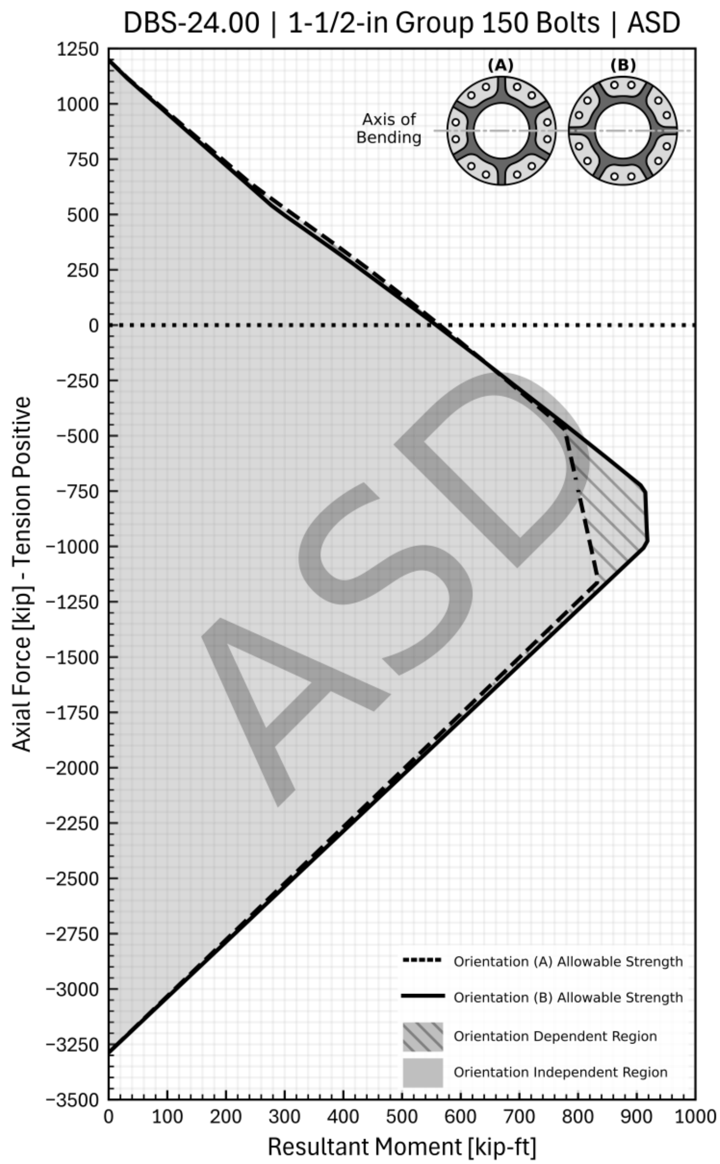

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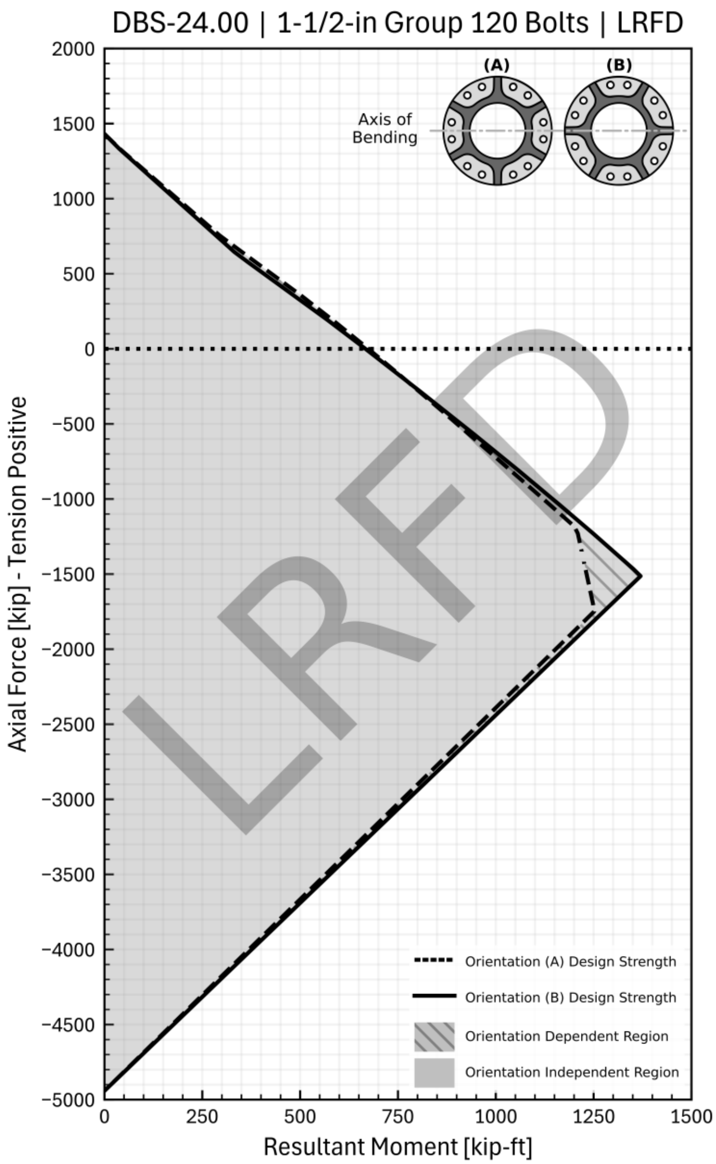

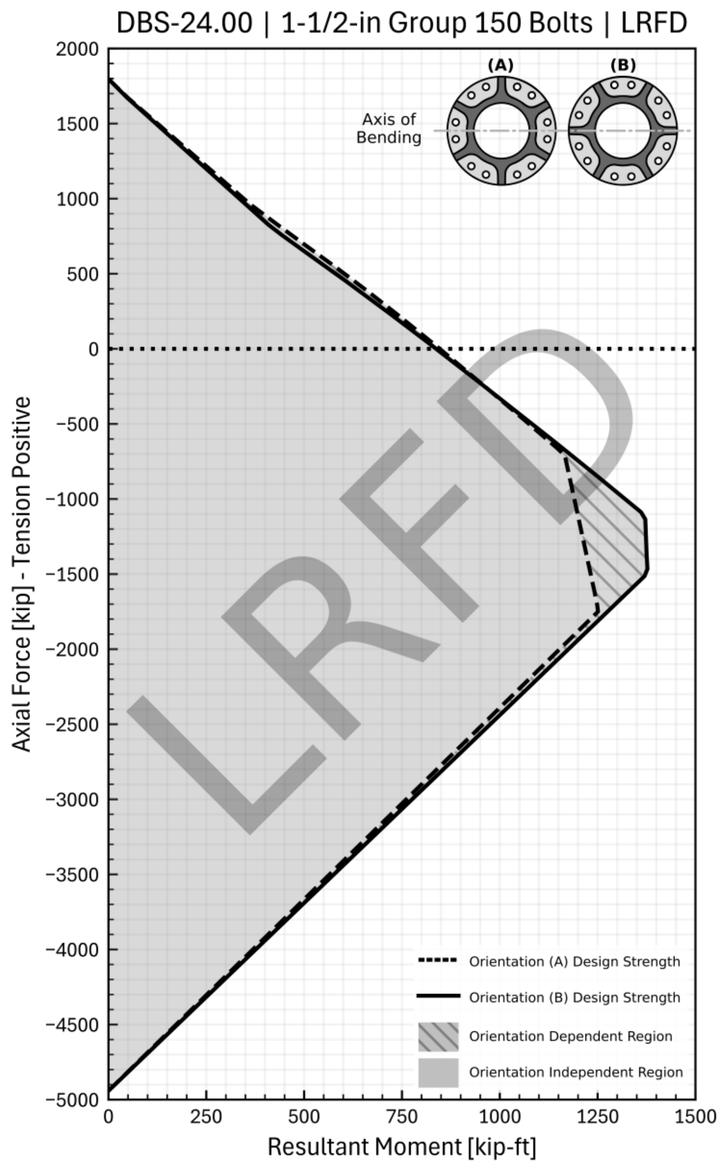

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Appendix A: Guidelines for Consideration of Applied Shear and Torsion

As per the user note in AISC 360-22 Section J7, the interaction between bolt shear and bolt tension need not be considered when the required shear stress in each bolt is less than or equal to 30% of the available shear stress of each bolt. The maximum required shear stress on a bolt in a DBS connector may be caused by applied shear and/or applied torsion.

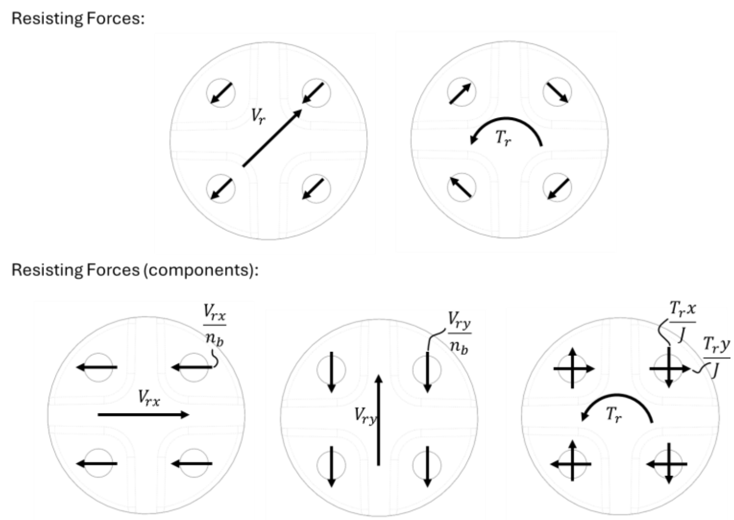

Figure A1: DBS resisting forces due to applied shear and torsion

Table 1: DBS Properties for Shear/Torsion Calculations

DBS Connector	**Number of bolts, n_b**	**Nominal Bolt Diameter, d_b**	**Bolt Area, A_b**	**Bolt Group Torsional Constant, J**
DBS-5.000	4	0.625 in	0.307 in^2	10.58 in^2
DBS-5.563	4	0.625 in	0.307 in^2	13.03 in^2
DBS-6.625	4	0.625 in	0.307 in^2	21.39 in^2
DBS-8.625	4	1.00 in	0.785 in^2	34.51 in^2
DBS-10.75	4	1.25 in	1.227 in^2	52.56 in^2
DBS-12.75-4bolt	4	1.25 in	1.227 in^2	85.56 in^2
DBS-12.75-8bolt	8	1 in	0.785 in^2	200 in^2
DBS-16.00	12	1 in	0.785 in^2	507 in^2
DBS-20.00	12	1.125 in	0.994 in^2	841 in^2
DBS-24.00	12	1.5 in	1.767 in^2	1200 in^2

The maximum required shear force at each bolt can be computed considering the force components due to the applied shear and torsion, as shown in the image above, where $J = \sum(x^2 + y^2)$ for all bolts with coordinates x and y (refer to DBS data sheet for DBS bolt pattern definition).

The maximum total required shear force at each bolt can be calculated as:

$$V_{r,bolt} = \sqrt{\left(\frac{V_{r,x}}{n_b} + \frac{T_r \cdot y}{J}\right)^2 + \left(\frac{V_{r,y}}{n_b} + \frac{T_r \cdot x}{J}\right)^2}$$

The required shear stress is:

$$F_{r,bolt} = \frac{V_{r,bolt}}{A_b}$$

Finally, the ratio of required shear stress to available shear stress can be confirmed (refer to AISC 360-22 Table J3.2 for relevant bolts shear strength values, F_{nv}):

For ASD, Group 120 bolts:

$$\left(\frac{F_{r,bolt}}{\frac{F_{nv,120}}{\Omega}}\right) = \left(\frac{F_{r,bolt}}{\frac{68\text{ ksi}}{2.0}}\right) \le 0.3$$

For LRFD, Group 120 bolts:

$$\left(\frac{F_{r,bolt}}{\phi F_{nv,120}}\right) = \left(\frac{F_{r,bolt}}{0.75 \cdot (68\text{ ksi})}\right) \le 0.3$$

For ASD, Group 150 bolts:

$$\left(\frac{F_{r,bolt}}{\frac{F_{nv,150}}{\Omega}}\right) = \left(\frac{F_{r,bolt}}{\frac{84\text{ ksi}}{2.0}}\right) \le 0.3$$

For LRFD, Group 150 bolts:

$$\left(\frac{F_{r,bolt}}{\phi F_{nv,150}}\right) = \left(\frac{F_{r,bolt}}{0.9\,(84\text{ ksi})}\right) \le 0.3$$

Should this ratio be greater than 0.3, the strength of the splice made using DBS connectors will be affected by the reduction in available bolt tensile strength due to combined tension and shear as per AISC 360-22 Section J3.8.

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