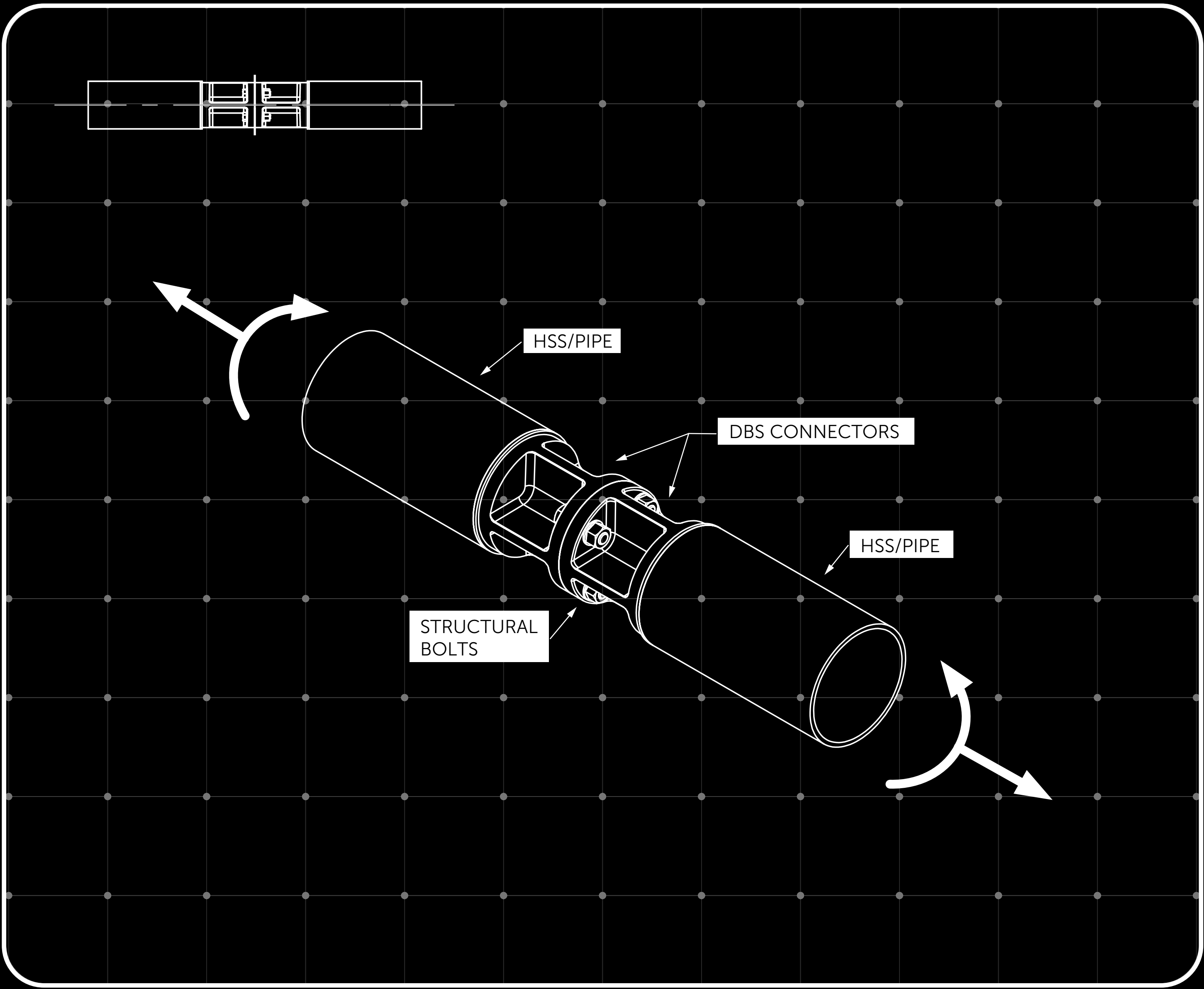

Diablo Bolted Splice™ (DBS)
User Guide for Combined Loading

CSA S16:24

PRINTED: 2026-04-24

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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 resistance a splice in an HSS member that is made with two DBS connectors is the lesser of the factored resistance 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 resistance of the bolted joint between adjoining DBS connectors (item 3 in the list above), as limited by the factored resistance of the DBS connectors themselves (item 4 in the list above).

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.

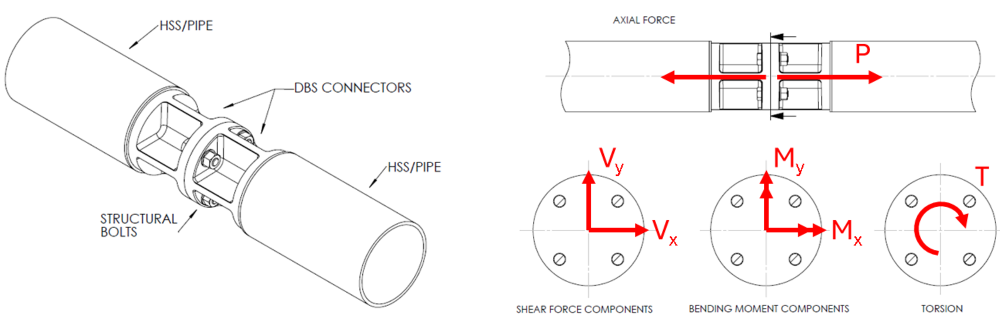

Figure 1: Forces and Moments on Typical DBS Connection

As outlined in CSA S16, the effects 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 factored resistance of a splice made with DBSs under combined loading must take into consideration multiple factors, including: the bolt type (A325 or A490) and the bending axis orientation ("strong", "weak", or off-axis). 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 Factored Resistance Envelope Plots* which present pre-calculated code-based resistance values under a range of possible loading conditions. The resistance 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 Factored Resistance Envelope Plots

Overview

The *DBS Factored Resistance 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 resistance of the bolt group, to the full compressive strength of the connection, which is the factored cross-sectional resistance of the DBS steel section as limited by the equation for combined forces in connection elements (refer to S16:24 Section 21.12 and further explanation below). 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 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.

For the portion of the plots governed by the DBS steel section resistance (between points E and D in Figure 2), the interaction equation for connection elements under combined forces and moments (S16:24 Section 21.12) was used: $\frac{M_f}{M_r} + \left(\frac{N_f}{T_r}\right)^2 + \left(\frac{V_f}{V_r}\right)^4 \leq 0.8$

This equation results in a limit on flexural utilization of 0.8 and a limit on axial utilization of $\sqrt{0.8} = 0.894$. Accordingly, the DBS compression resistance shown on the plots (point D in Figure 2) is 89.4% of the single-action factored compression resistance shown on the DBS data sheets. It is noted that the shear utilization term in this equation was ignored as the magnitude of shear utilization associated with the plots (up to 35% of the bolt group factored resistance, as explained in this report below), results in a negligible impact on axial and flexural capacity due to the quadratic exponent.

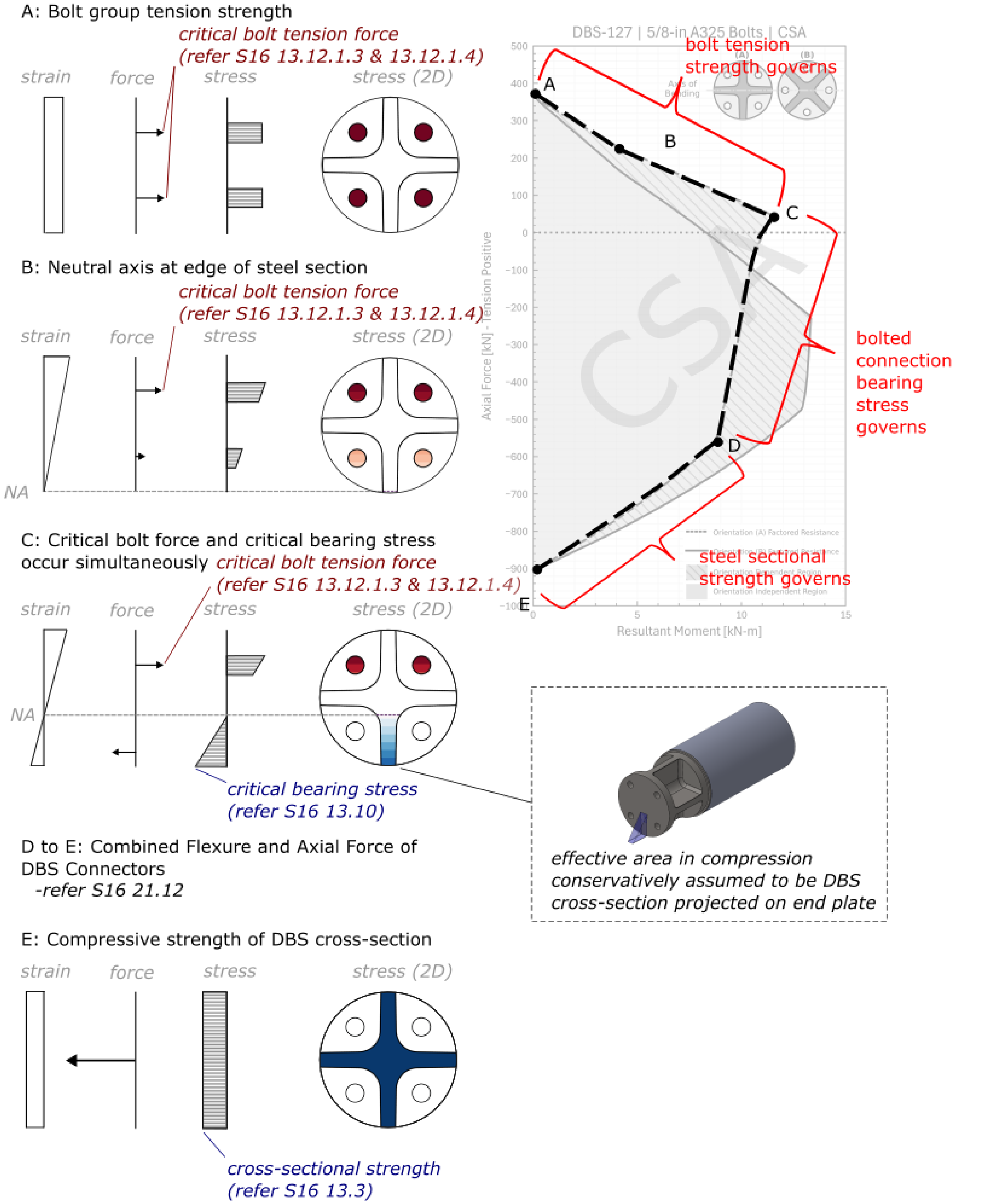

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Figure 2: Factored resistance envelope Plots Sectional Analysis

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 Factored Resistance Envelope Plot.*

Each *DBS Factored Resistance 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".

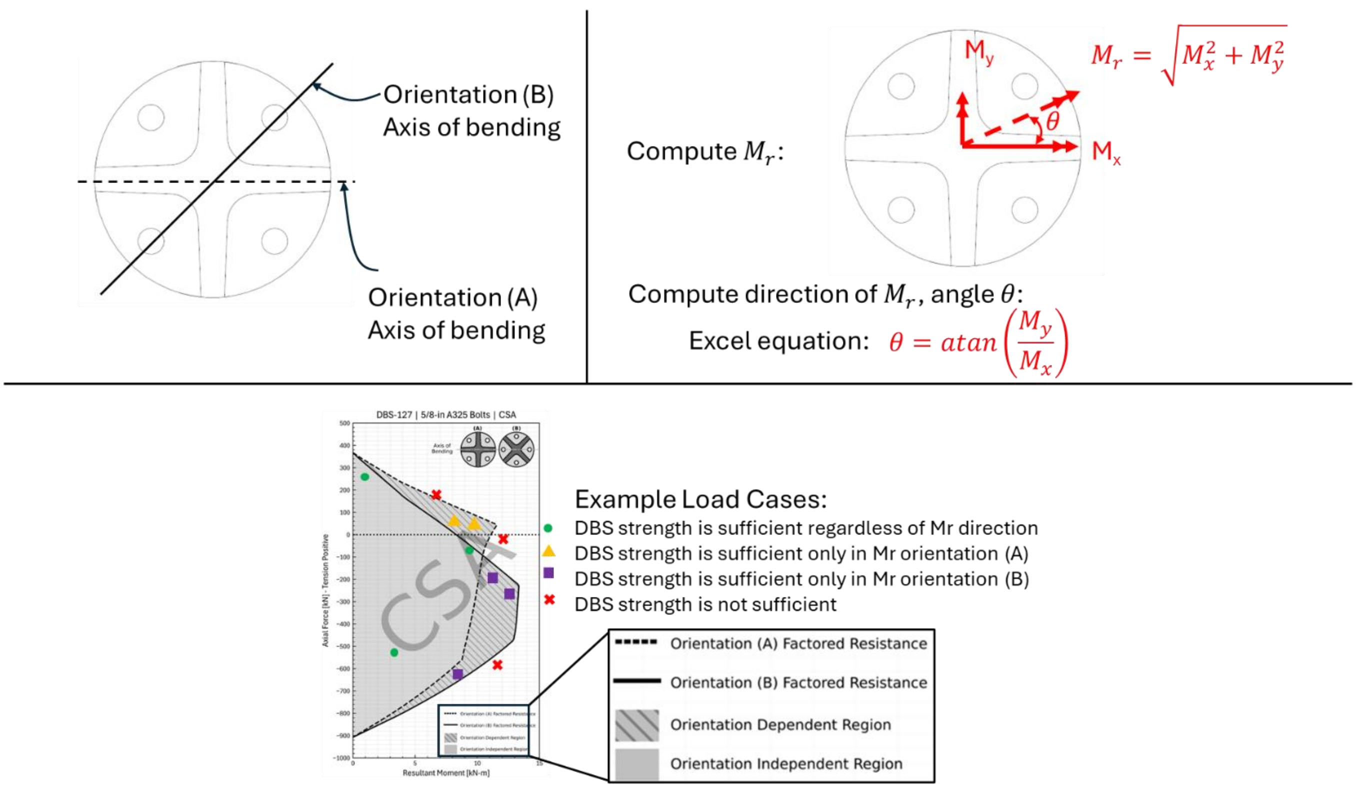


Figure 3: Example Confirmation of Load Sets

Consideration of shear/torsion

To enable use of the plots for a reasonable range of applied shear and torsion, the factored resistance plots were created considering a reduction in bolt tension resistance assuming a bolt shear utilization ratio, V_f/V_r of 35%. Using the equation from S16 Section 13.12.1.4, the bolt tension utilization associated with 35% shear utilization was calculated as follows:

$$\left(\frac{V_f}{V_r}\right)^2 + \left(\frac{T_f}{T_r}\right)^2 \leq 1$$

$$\frac{T_f}{T_r} = \sqrt{1-(0.35)\text{^}2} = 0.938$$

The critical bolt tension force used to generate the factored resistance plots was determined by applying this factor to the equation for T_r in S16 Section 13.12.1.3:

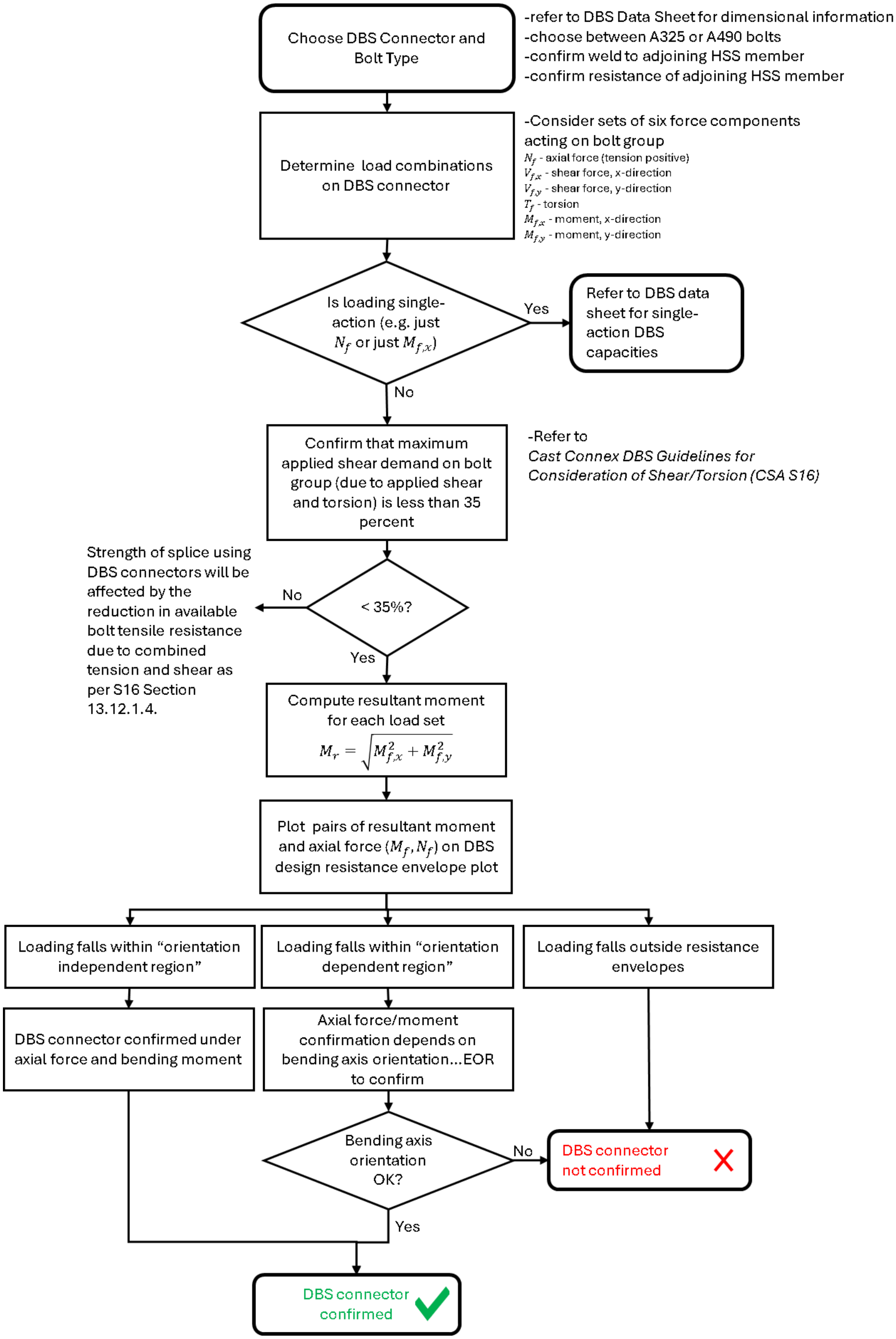
$$T_r = 0.75\phi_b A_b F_u \times 0.938$$

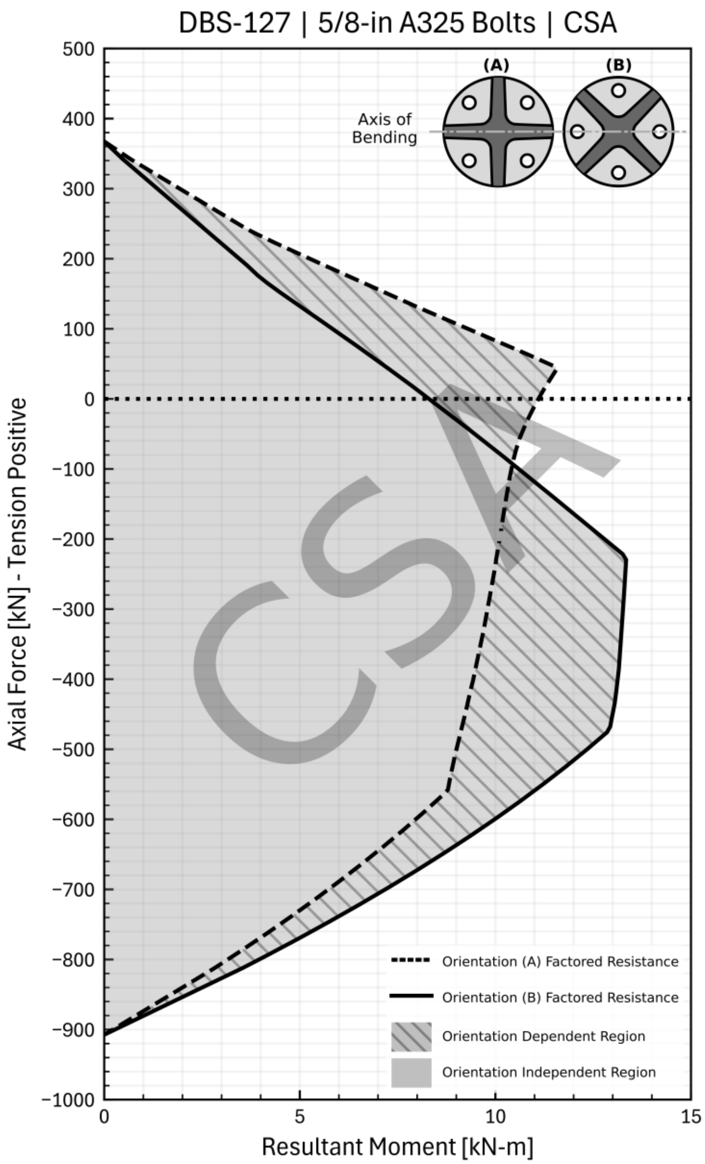
Thus, the bolt tension factored resistance shown on the plots (point A in Figure 2) is 93.8% of the single-action factored compression resistance shown on the DBS data sheets.

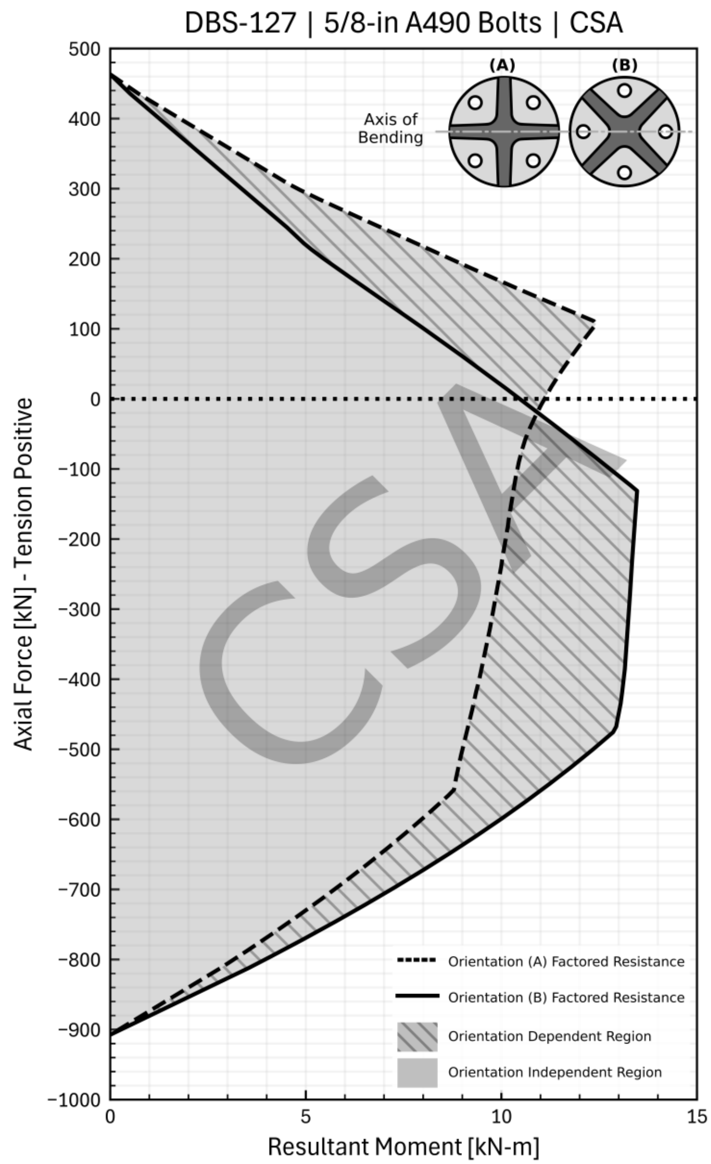
The plots presented in this report are only valid for maximum bolt shear stress utilization up to 35%. While it is expected that this range of shear utilization will cover most applications of the DBS connectors, the shear utilization of the bolt group should be confirmed to be less than 0.35 when using the *DBS Factored Resistance 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 Factored resistance envelope Plots.*

DBS Design Confirmation Flow Chart

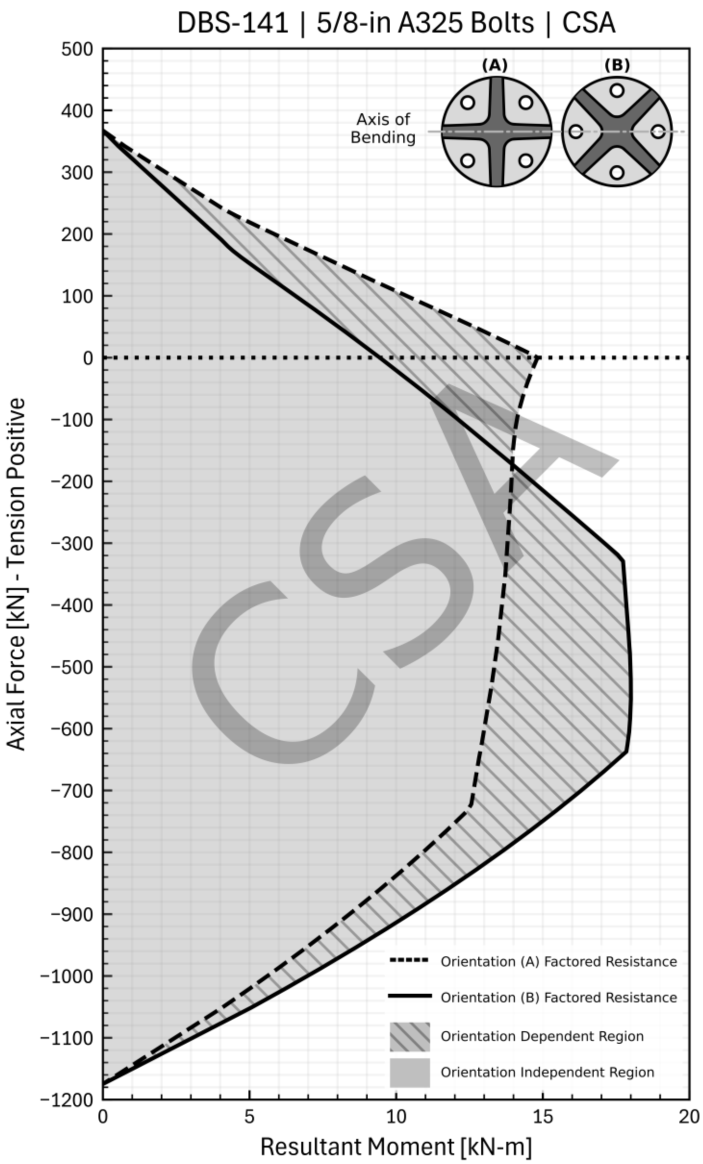


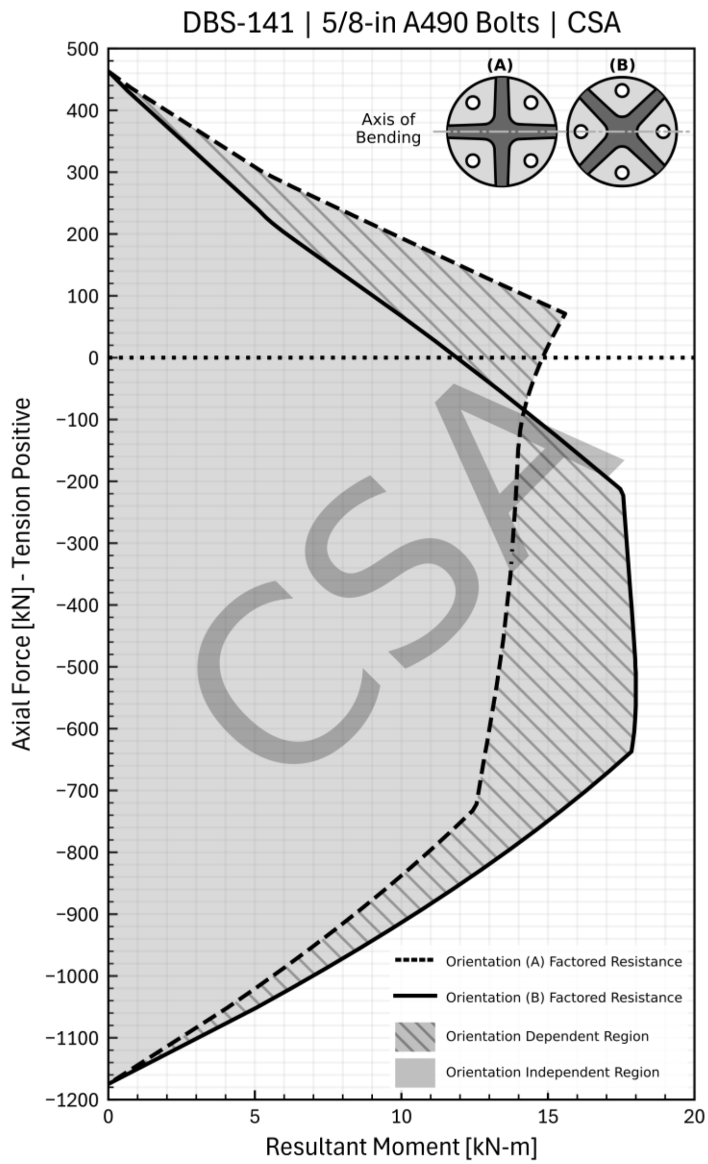




Notes:

- The factored resistance of the DBS connector is the minimum of (a) the factored resistance shown in the above plots, (b) the factored resistance of the CHS-to-connector welded connection, and (c) the factored resistance of the connecting CHS member.
- Plots indicate the factored resistance of the DBS connector considering a minimum of bolt tensile strength, and connector sectional capacity (refer to S16:24 Section 13.12.1.3 and S16:24 Section 21.12).
- Plots account for bolt group shear effects (due to applied shear and torsion) of up to 35% of the corresponding factored shear resistance.
- Plots are valid for factored load combinations.
- Load combinations shall be evaluated separately.
- The engineer responsible for design shall verify the orientation of the DBS in the orientation dependant regions.
- Resultant Moment: $M_r = \sqrt{M_y^2 + M_z^2}$





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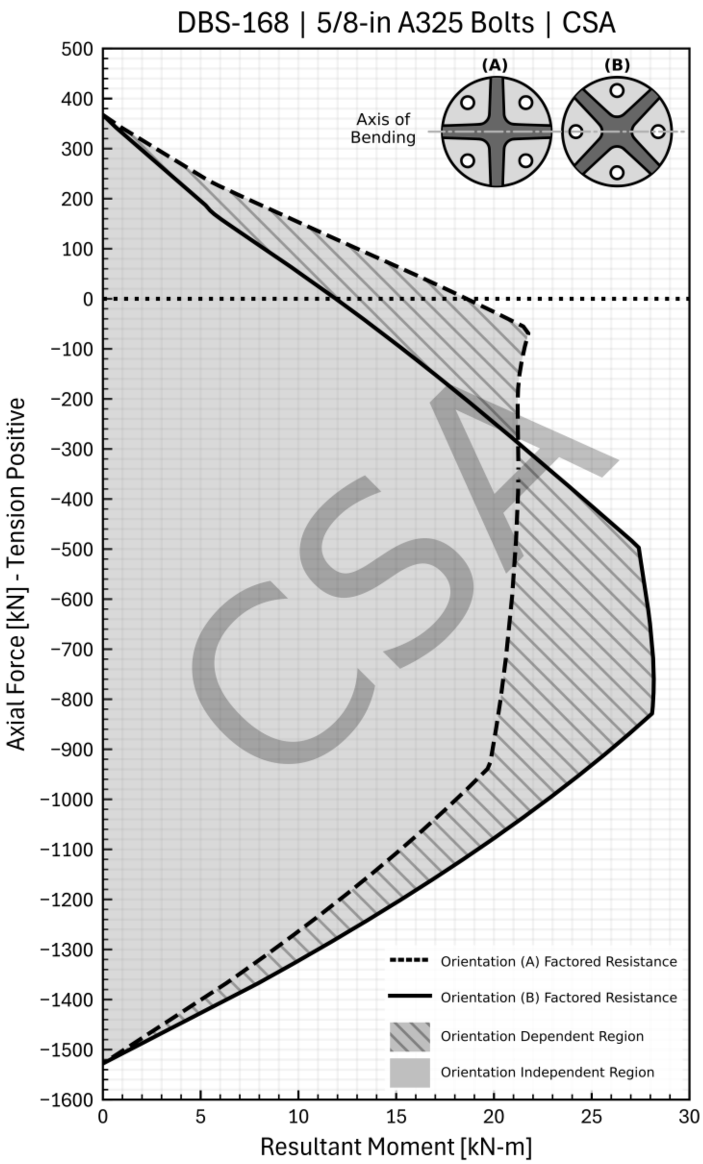

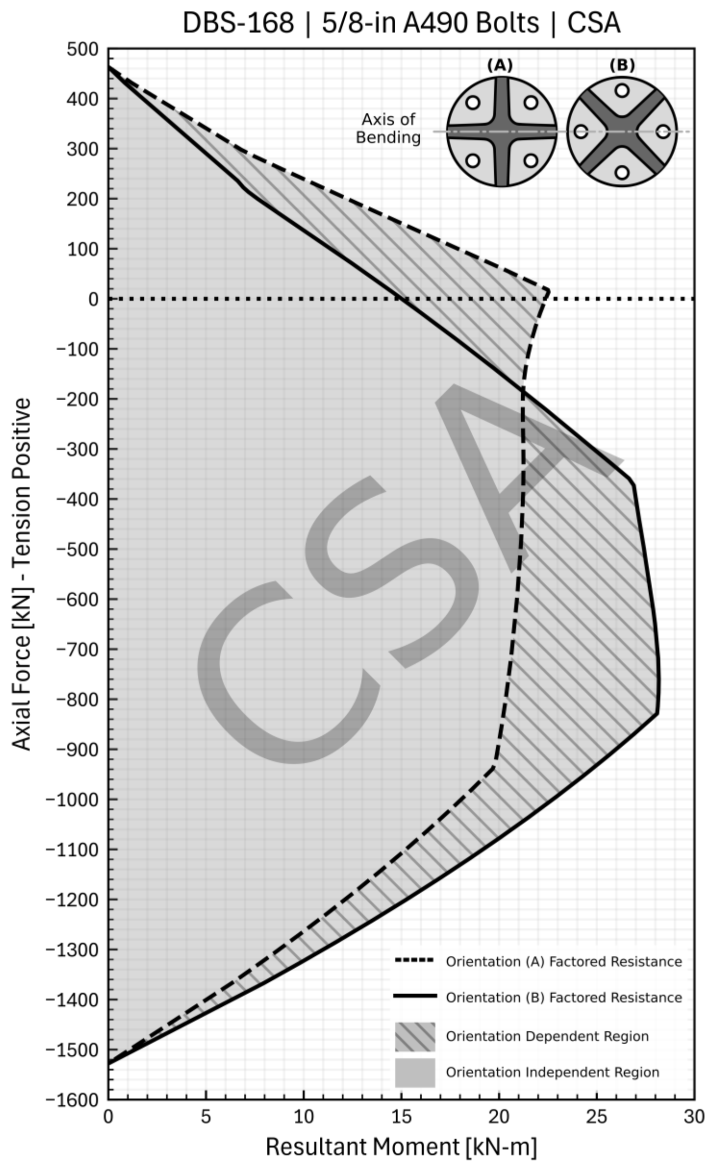

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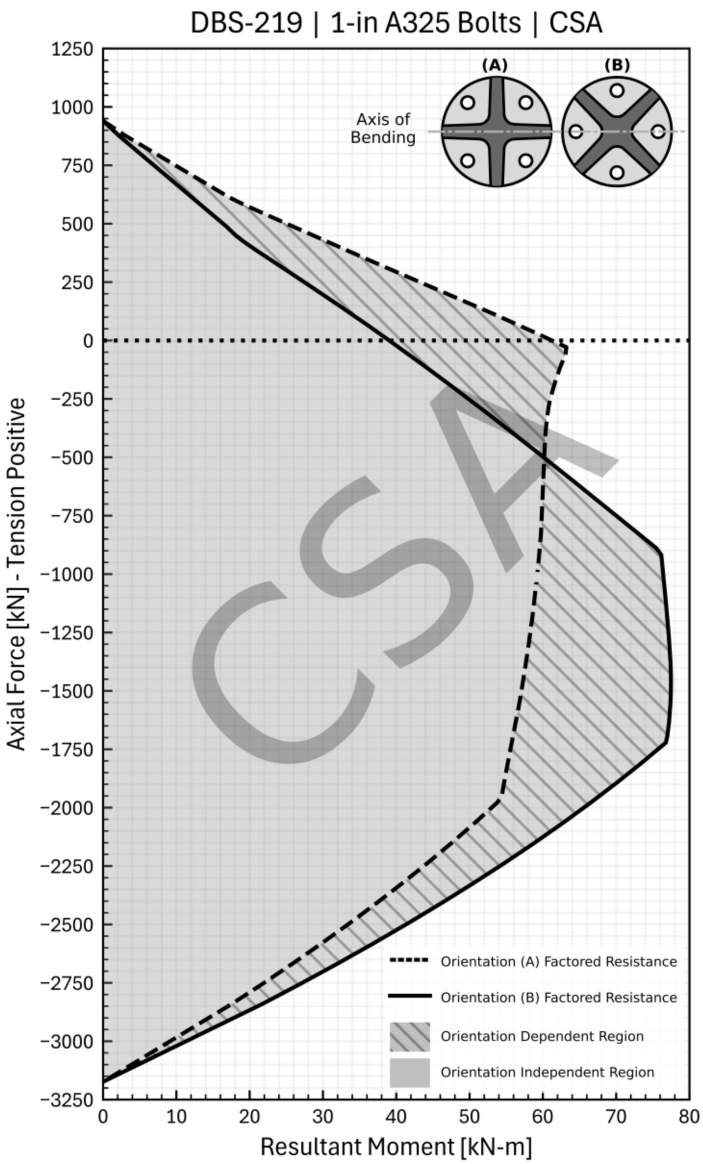

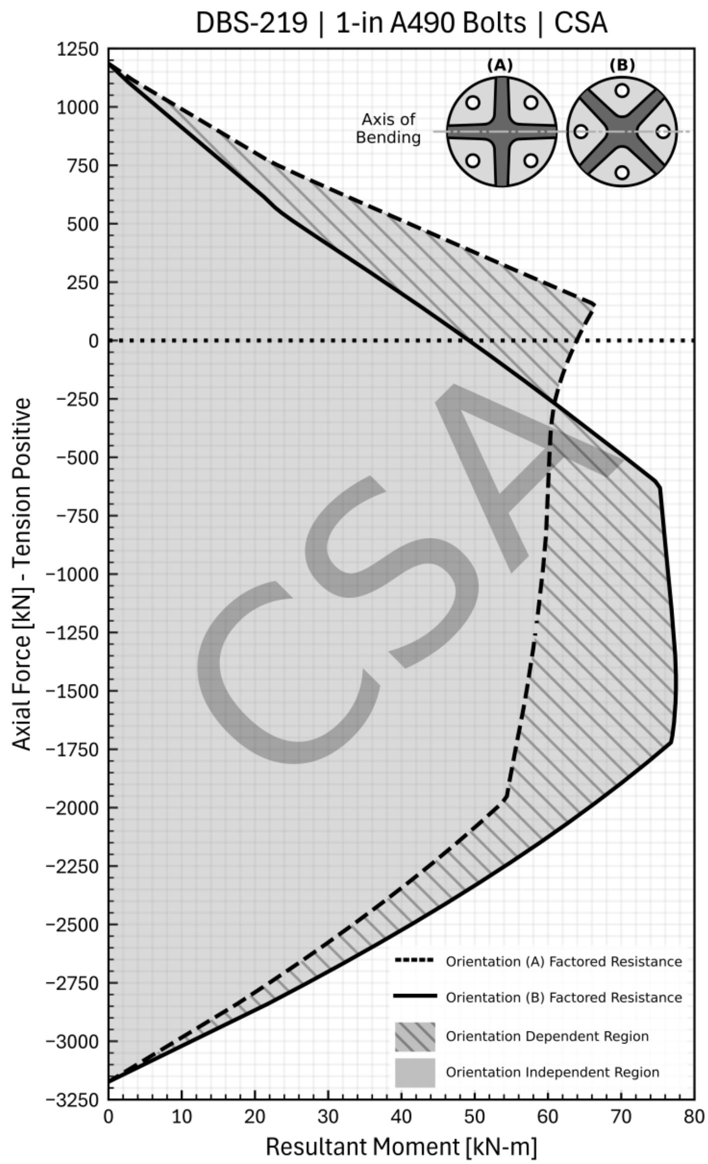

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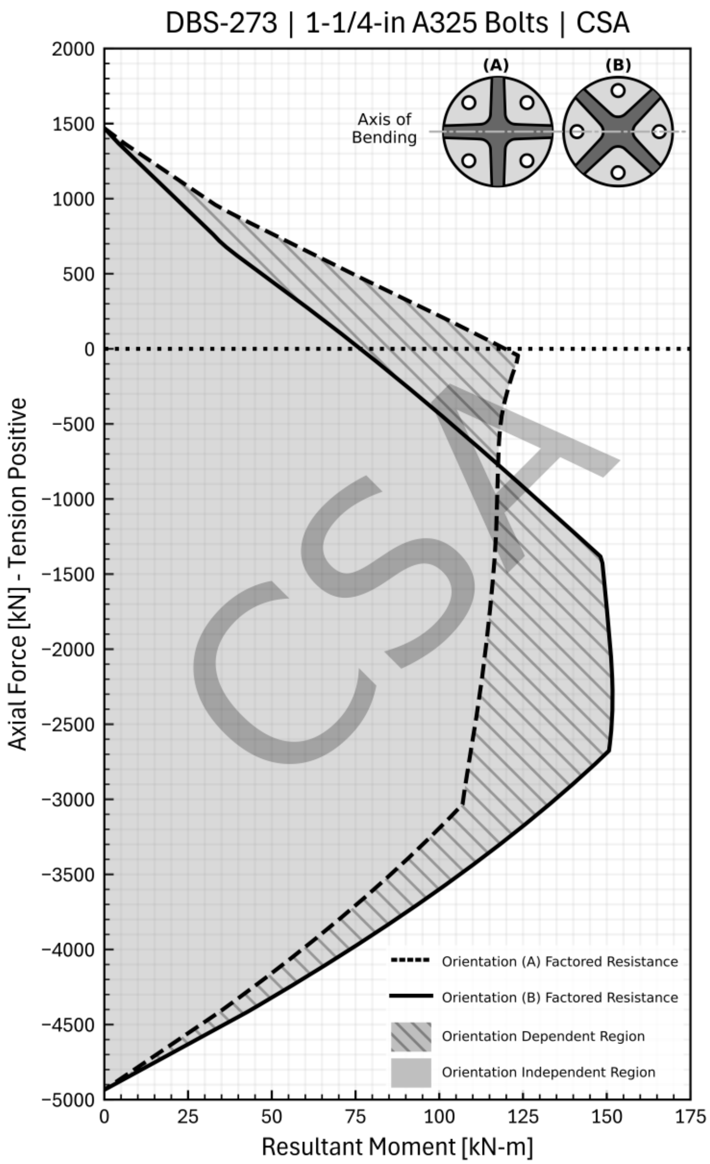

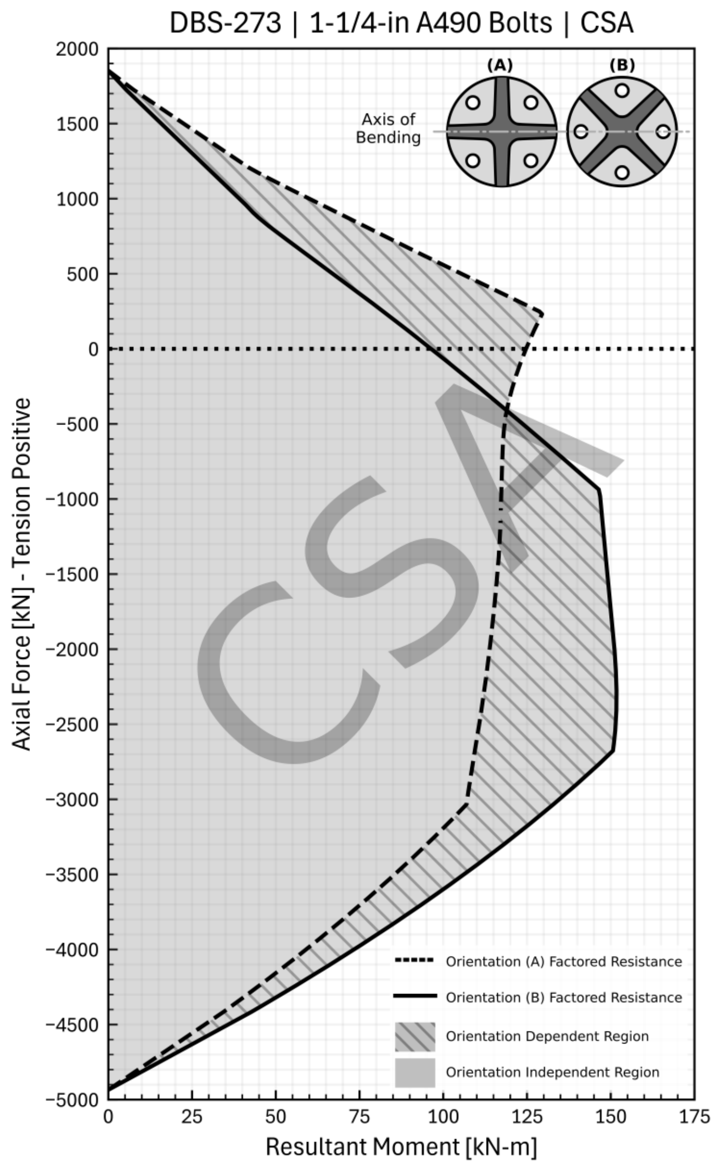

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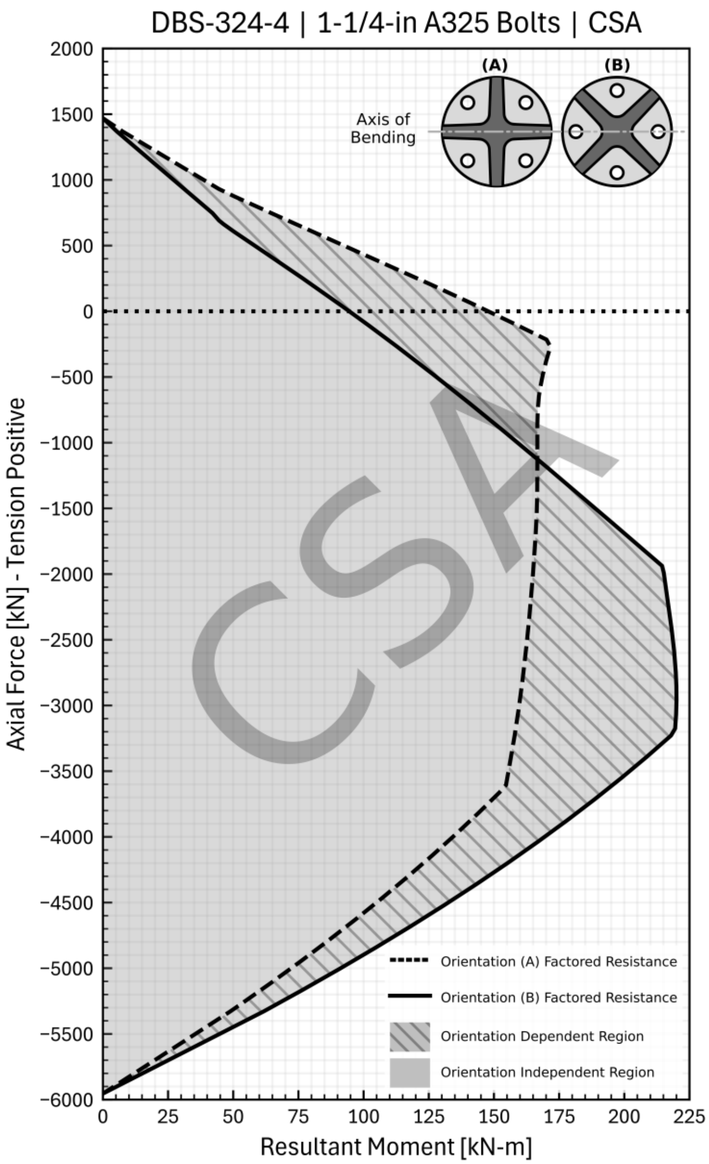

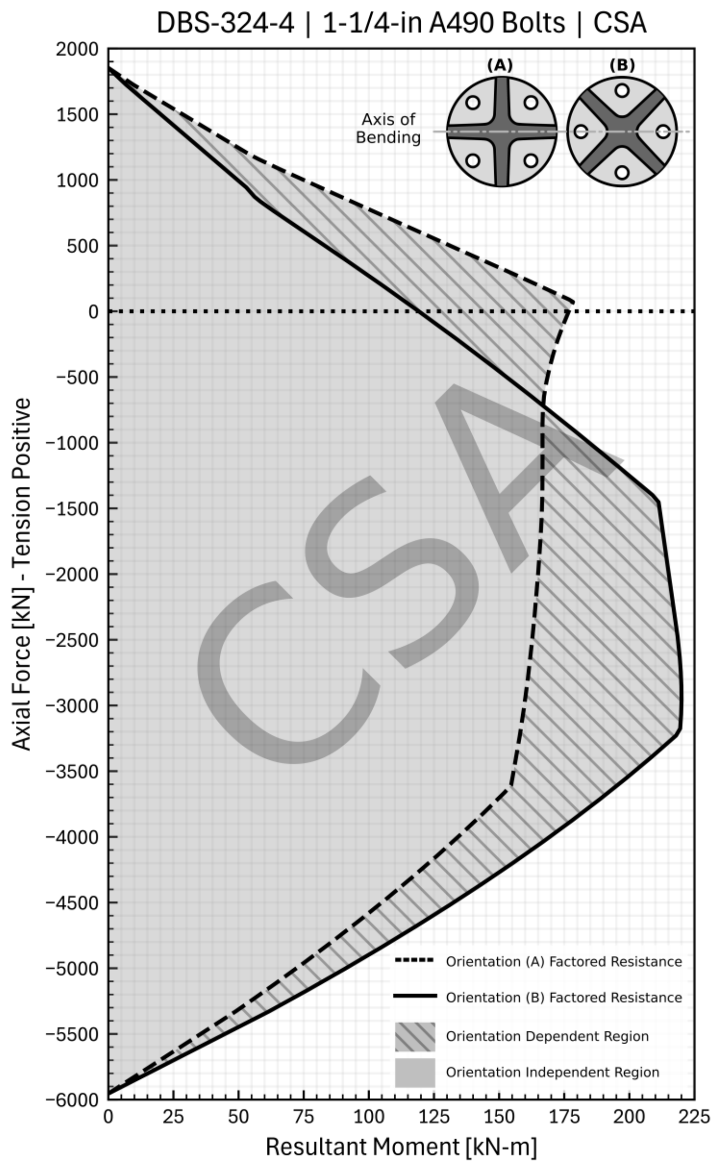

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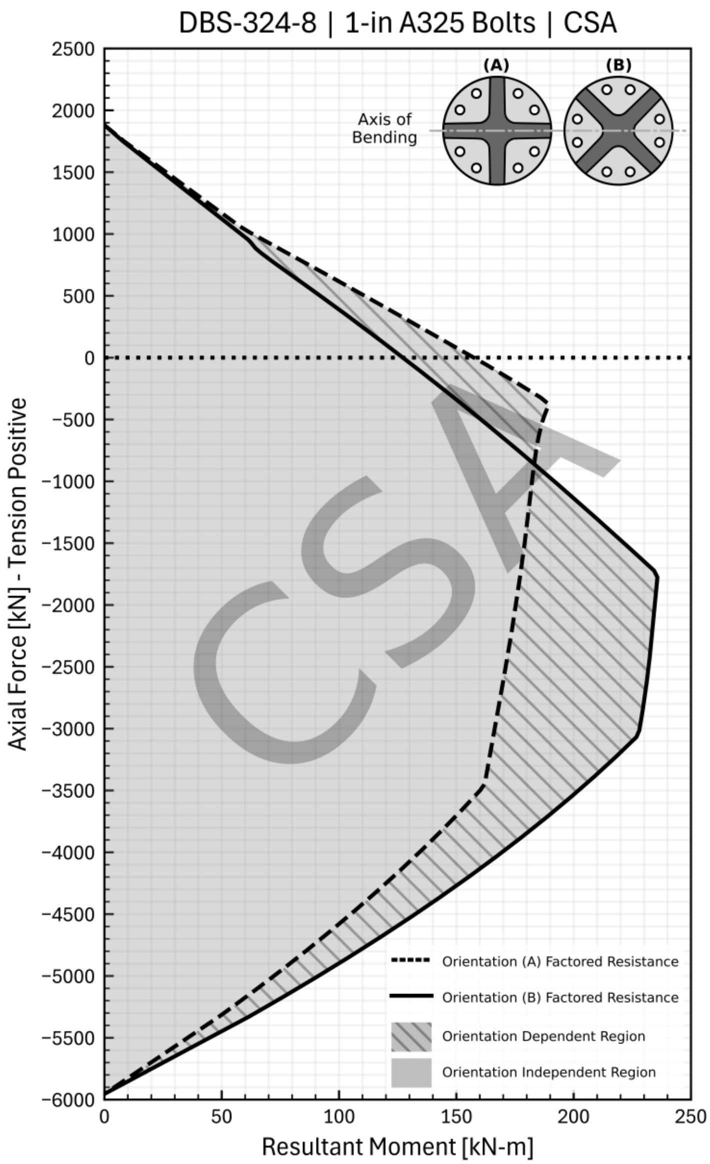

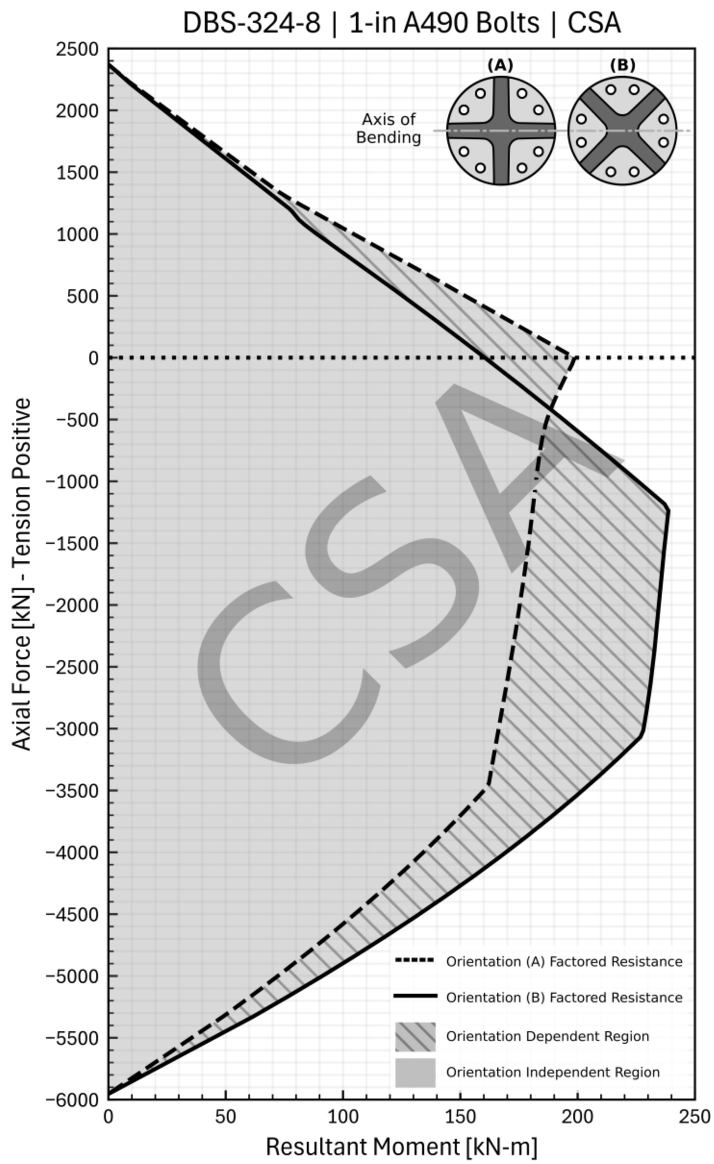

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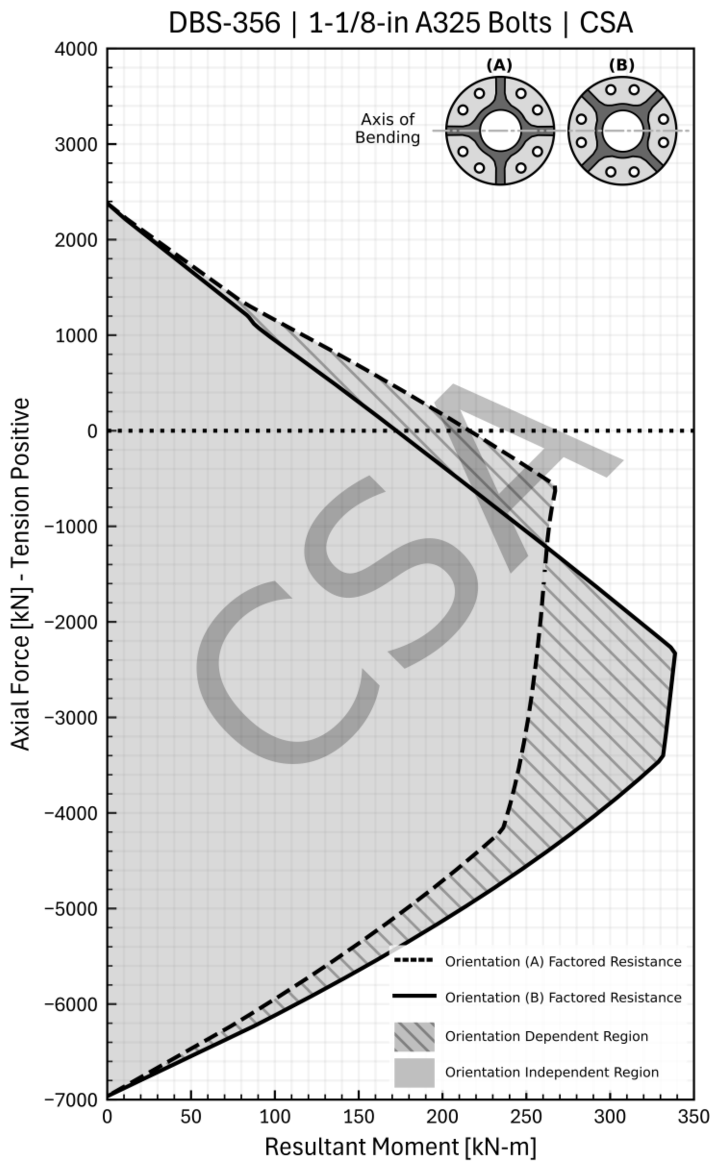

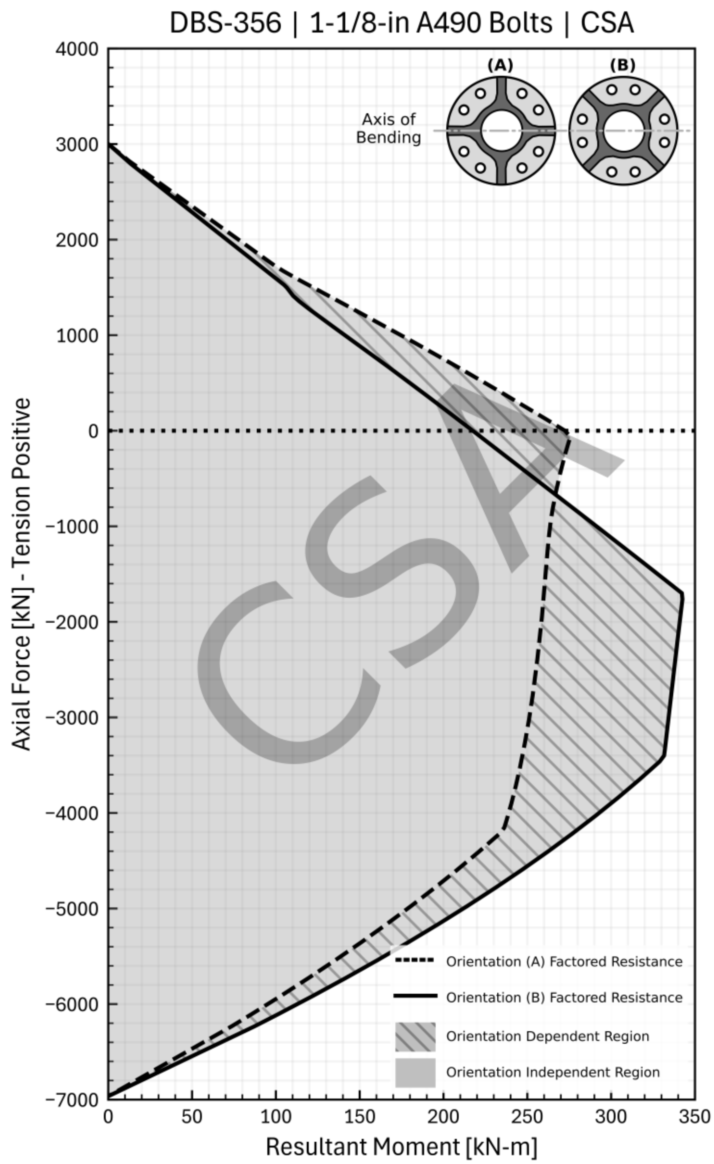

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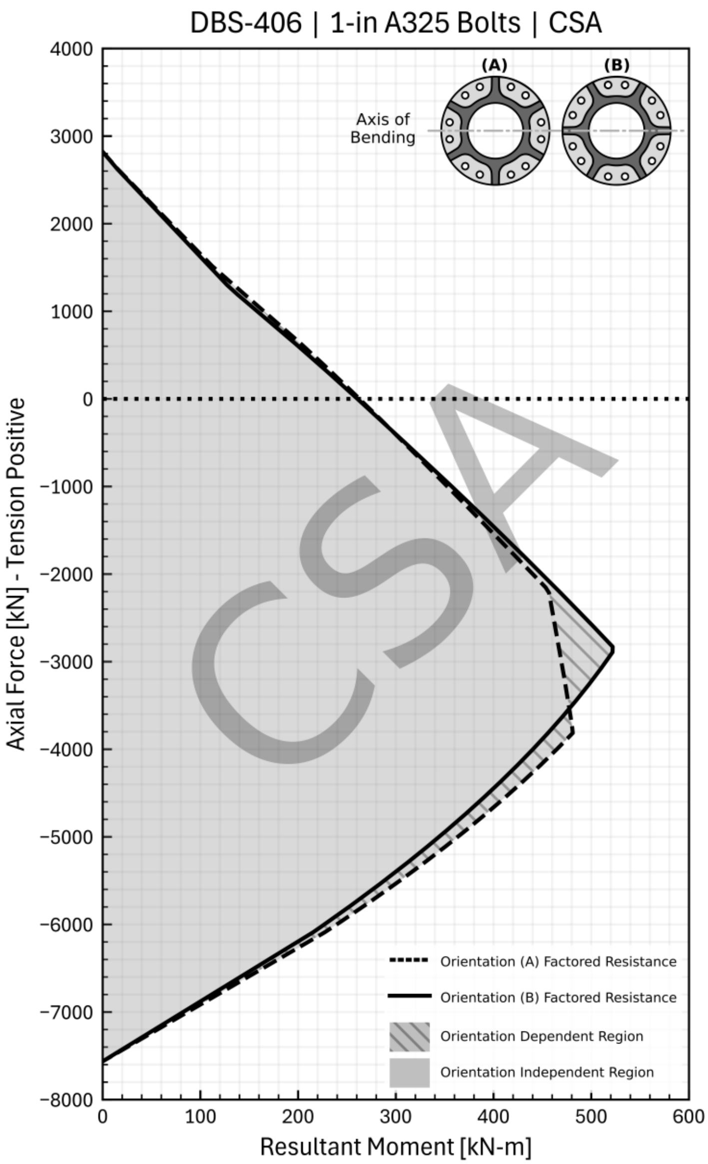

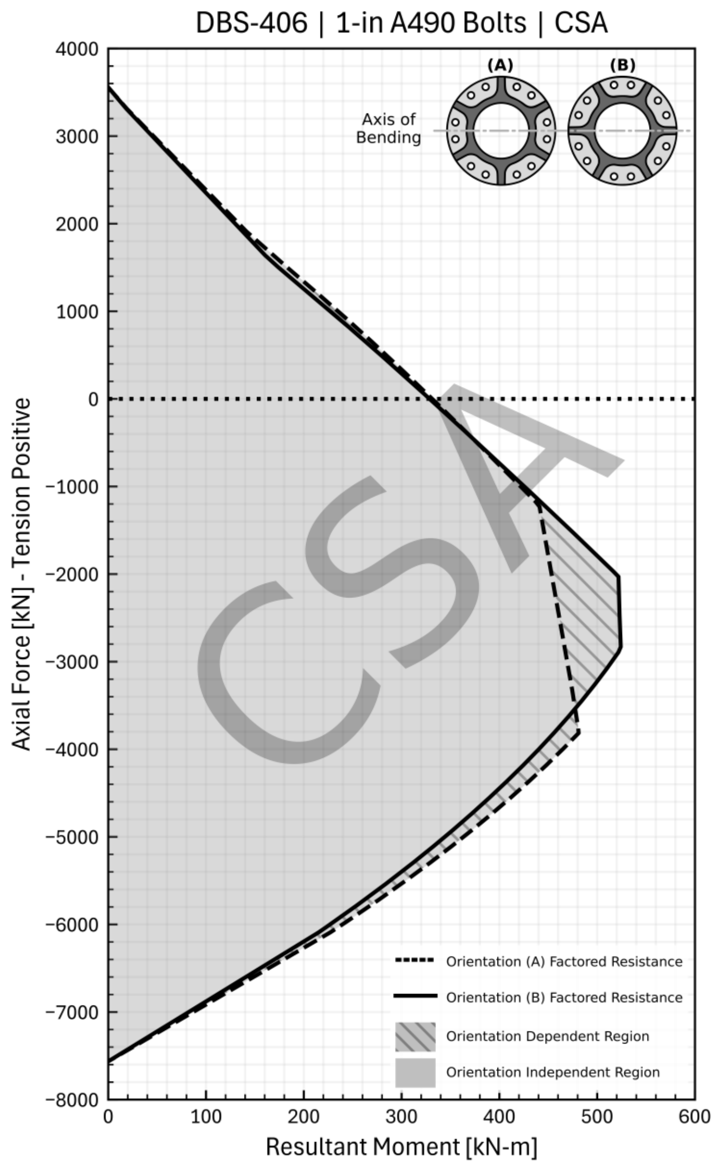

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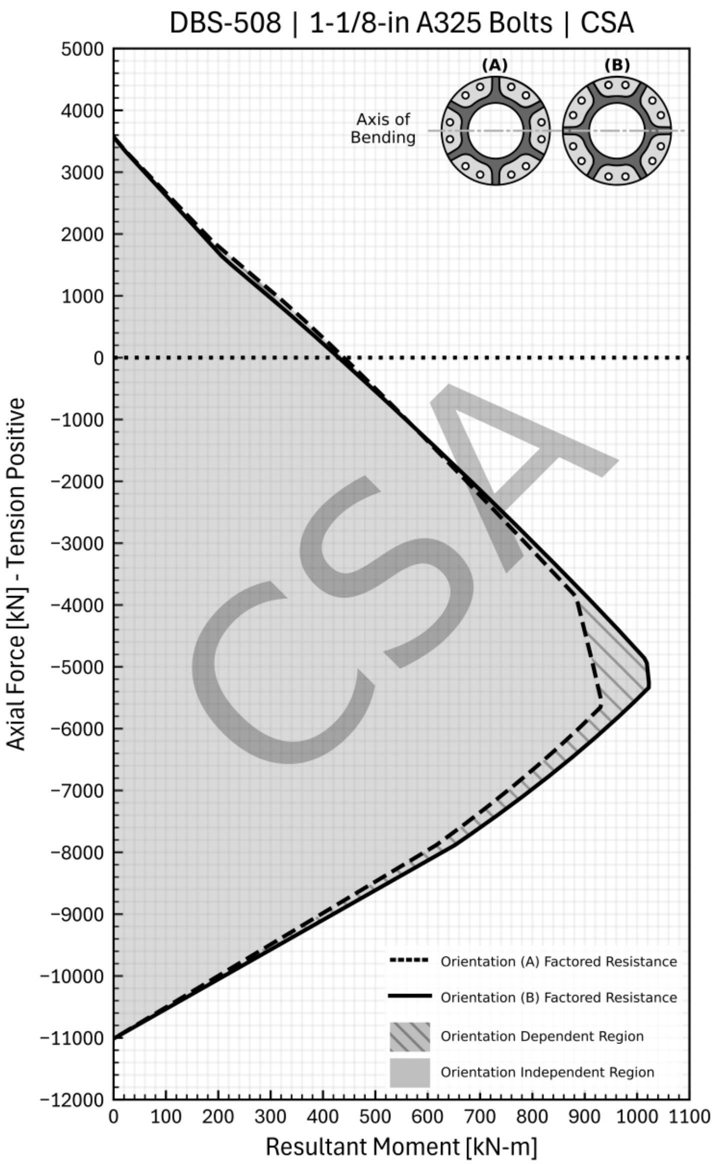

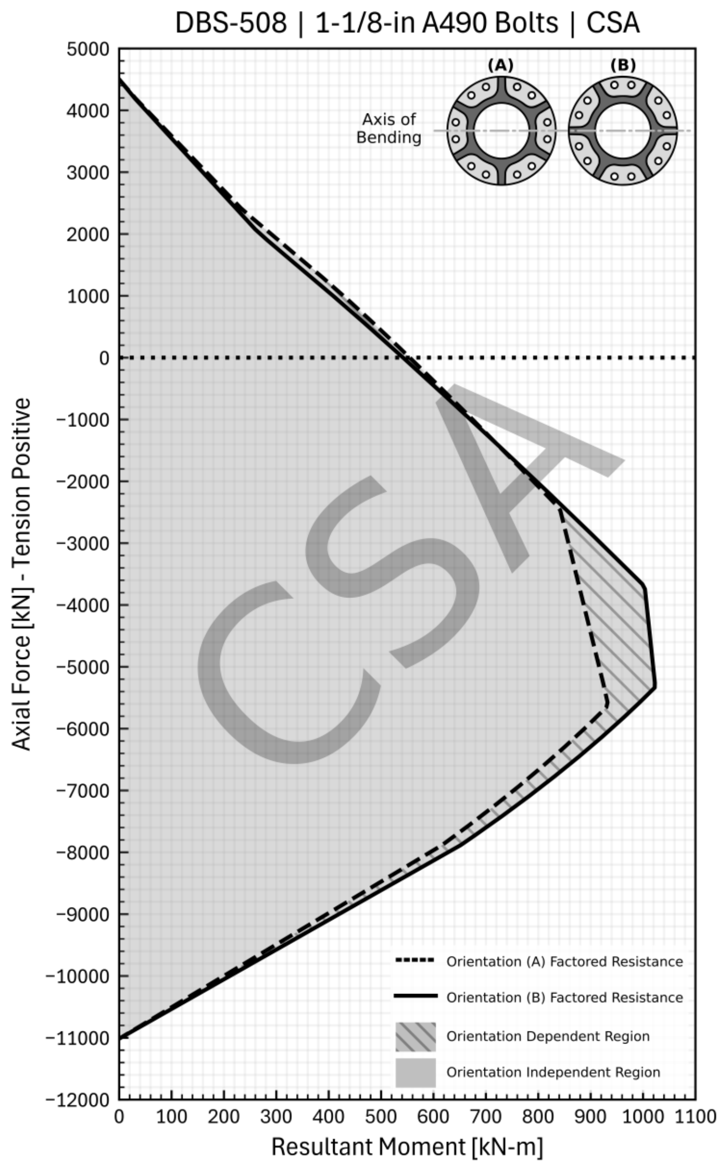

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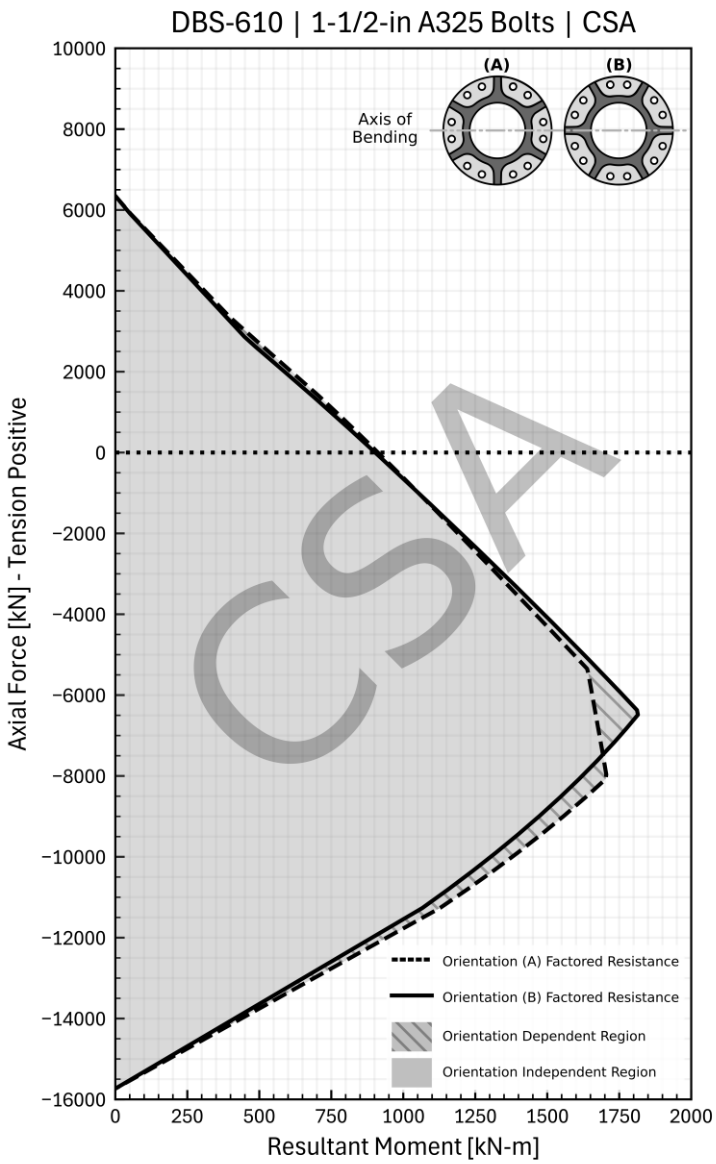

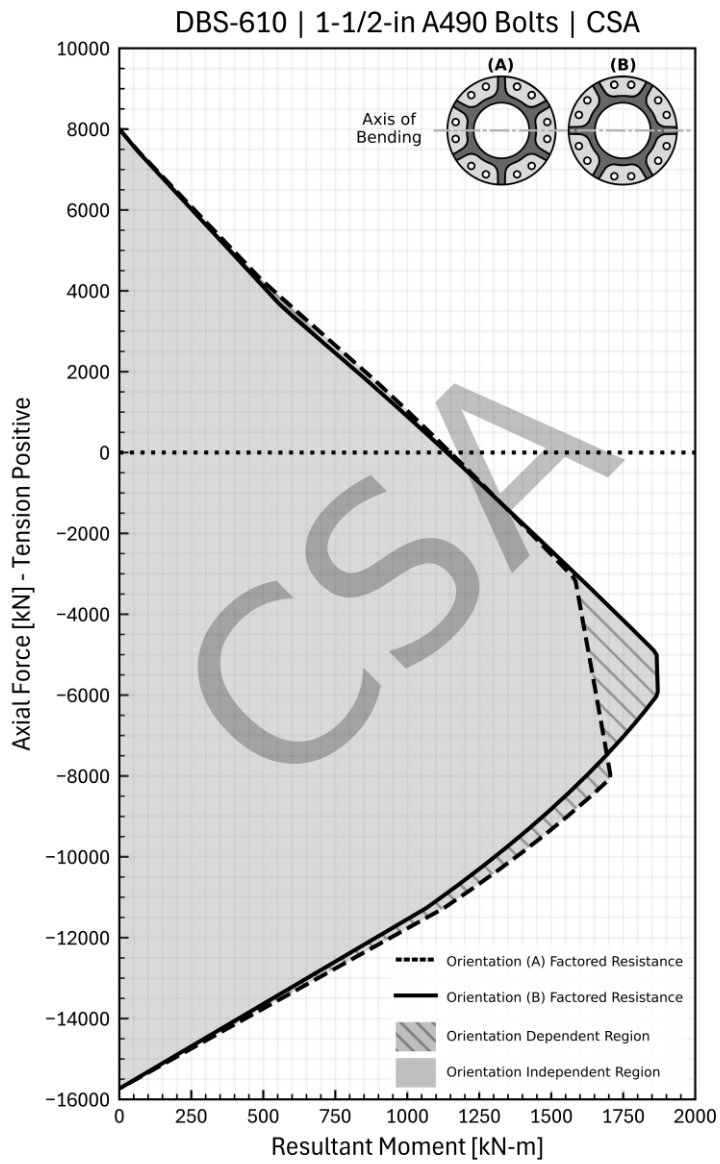

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Appendix A: Guidelines for Consideration of Applied Shear and Torsion

The plots presented in this guide were developed by considering a reduction in bolt factored resistance assuming a shear resistance utilization of up to 35%. This approach ensured a relatively small reduction in bolt tension resistance for a range of applied shear that should cover most applications of the DBS components. Thus, to use the plots, the shear resistance utilization must be confirmed to be less than 35%. The following guidelines are presented to assist in this confirmation.

The maximum required shear stress on a bolt in a DBS connector may be caused by applied shear and/or applied torsion.

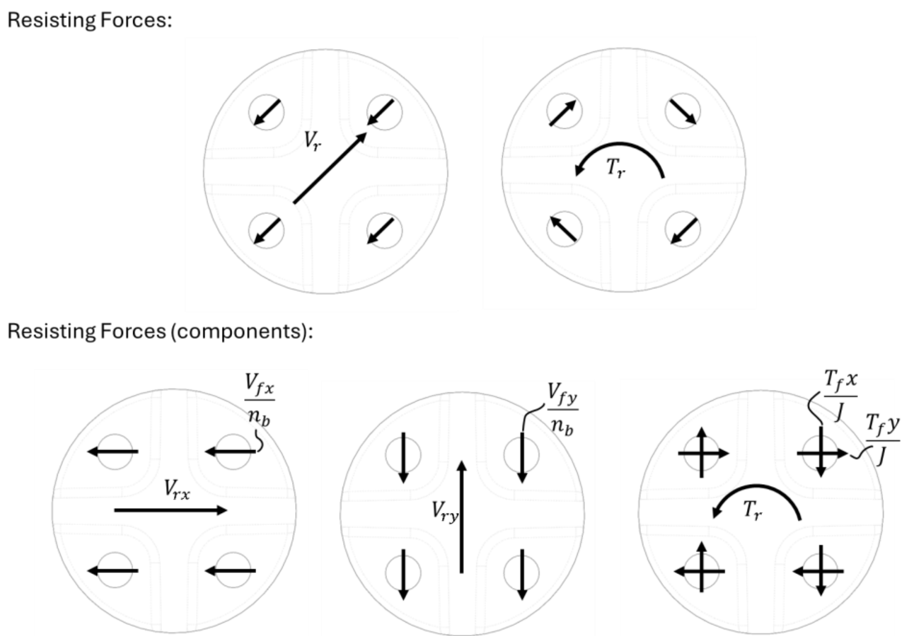

Figure A1: DBS resisting forces due to applied shear and torsion

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-127	4	15.875 mm	198 mm^2	6830 mm^2
DBS-141	4	15.875 mm	198 mm^2	8410 mm^2
DBS-168	4	15.875 mm	198 mm^2	13800 mm^2
DBS-219	4	25.4 mm	507 mm^2	22300 mm^2
DBS-273	4	31.75 mm	792 mm^2	3390 mm^2
DBS-324-4bolt	4	31.75 mm	792 mm^2	55200 mm^2
DBS-324-8bolt	8	25.4 mm	507 mm^2	129000 mm^2
DBS-356	8	28.575 mm	641 mm^2	152600 mm^2
DBS-406	12	25.4 mm	507 mm^2	327000 mm^2
DBS-508	12	28.575 mm	641 mm^2	543000 mm^2
DBS-610	12	38.1 mm	1140 mm^2	774000 mm^2

The maximum factored shear force in 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 factored shear force at each bolt can be calculated as:

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

Finally, the ratio of applied shear force to bolt shear resistance can be confirmed based on S16:24 Section 13.12.1.2c:

For A325 bolts with threads excluded:

$$\left(\frac{V_{f,bolt}}{0.6\phi_b F_u A_b}\right) = \left(\frac{V_{f,bolt}}{0.6 * 0.8 * (825\ MPa)A_b}\right) \leq 0.35$$

For A490 bolts with threads excluded:

$$\left(\frac{V_{f,bolt}}{0.6\phi_b F_u A_b}\right) = \left(\frac{V_{f,bolt}}{0.6 * 0.8 * (1035\ MPa)A_b}\right) \leq 0.35$$

Should this ratio be greater than 0.35, the strength of the splice made using DBS connectors will be further affected by the reduction in available bolt tensile resistance due to combined tension and shear as per CSA S16:24 Section 13.12.1.4.

CASTCONNEX®

info@castconnex.com | **TF:** +1 888-681-8786

www.castconnex.com

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