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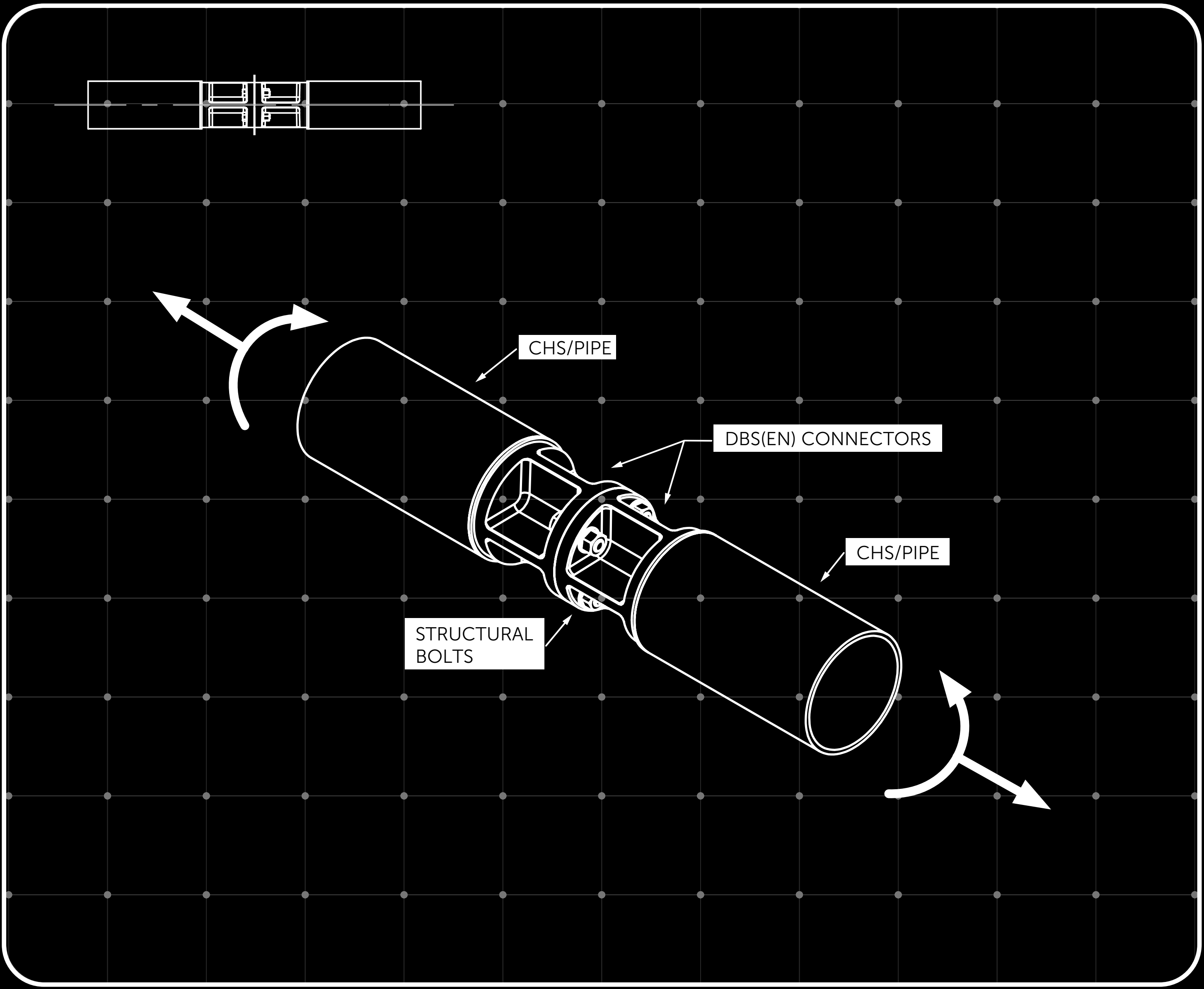

Diablo Bolted Splice™ (DBS)(EN) User Guide for Combined Loading

Eurocode 3 (2005)

PRINTED: 2025-07-18

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Introduction

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

The design resistance of a splice in an CHS member that is made with two DBS(EN) connectors is the lesser of the design resistance of:

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

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

This document refers to the following Eurocode standards:

EN 1993 1-1 (2005)
EN 1993 1-8 (2005)

Refer to the DBS(EN) data sheet for the partial factors used in developing the design resistance envelope plots presented in this report.

Background

DBS(EN) connectors create fixed structural connections between adjoining CHS members (though it should be noted that the torsional stiffness of a DBS(EN) splice is likely to be less than that of the adjoining CHS members). Accordingly, DBS(EN)s 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(EN) splices can be a reasonable structural analysis assumption, a more detailed evaluation of DBS(EN) splice stiffness may be necessary to accurately account for its impact on both structural deformations and forces, depending on the application.

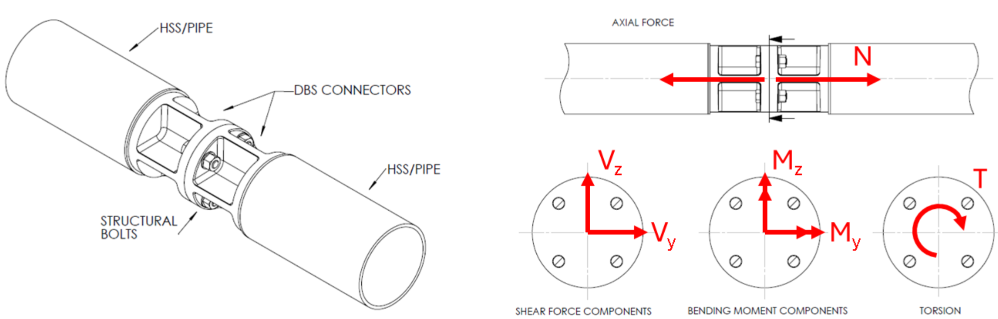


Figure 1: Forces and Moments on Typical DBS(EN) Connection

As outlined in Eurocode 3, the effects of all six force components must be considered when determining the resistance of a bolted end plate connection. Thus, the resistance of the bolted joint between two DBS(EN) connectors is governed by the *combined* effect of the forces acting at the joint.

Computation of the resistance of a splice made with DBS(EN)s under combined loading must take into consideration many factors, including: the bolt property class (Class 8.8 or Class 10.9) and the bending axis orientation ("major", "minor", or off-axis). These calculations must appropriately consider limit states for bolt tension resistance and DBS(EN) sectional resistance. Note that the DBS(EN) connectors have been proportioned such that end plate yielding does not govern the resistance of the splice.

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

DBS(EN) Design Resistance Envelope Plots

Overview

The *DBS(EN) Design Resistance Envelope Plots* are interaction curves which communicate the flexural resistance of the DBS(EN) connections at various axial force values. The axial force ranges from the full tensile resistance of the connection, which is the design tension resistance of the bolt group, to the full compressive resistance of the connection, which is the design cross-sectional resistance of the DBS(EN) steel section. In between this range of axial forces, the resistance of the DBS(EN) connection may be governed by bolt tension resistance (high axial tension + bending moment), or DBS steel sectional capacity (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 a bilinear elastic-plastic stress distribution in the connector steel cross-section solving for the force in each bolt and the bearing stress compression block at the interface between the connectors. Under combined axial force and bending moment, each bolt is assumed to resist an equal share of the axial force, and the moment is resisted by tension in the bolts above the neutral axis and compression below the neutral axis. 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(EN) cross-section projected onto the end-plate.

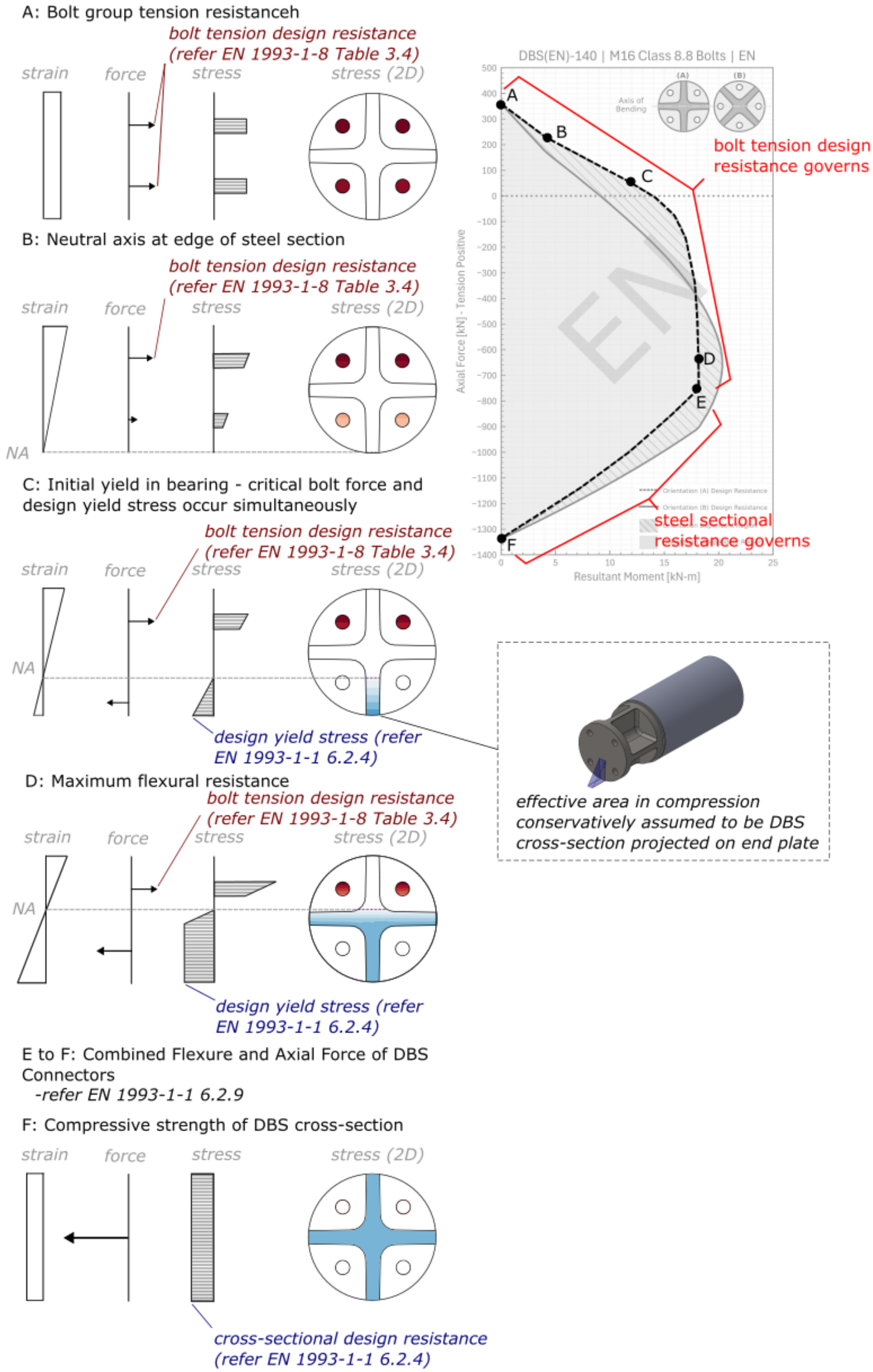


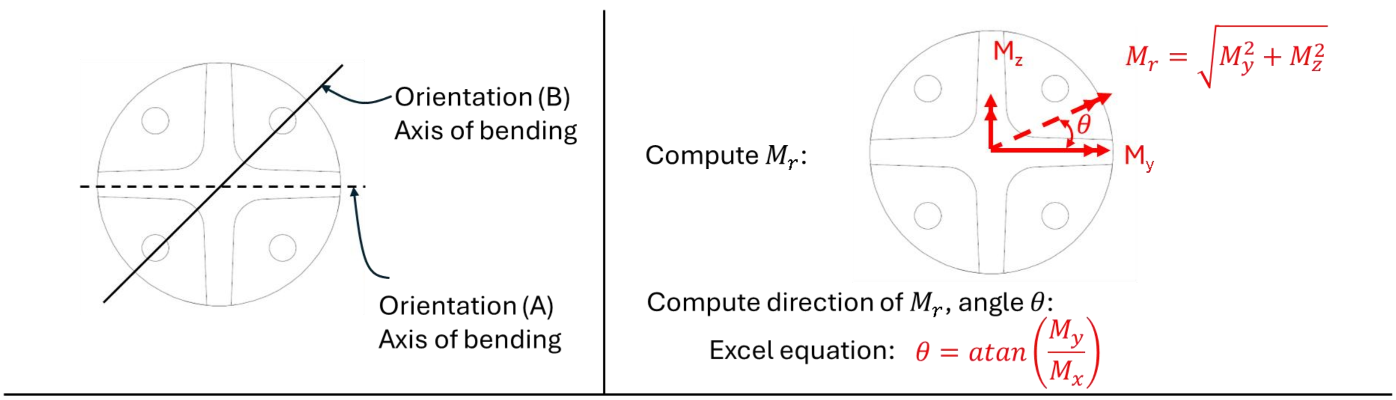
Figure 2: Design Resistance Envelope Curve Sectional Analysis

Consideration of biaxial bending

Biaxial bending (combined bending in both the y-direction and z-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(EN) Design Resistance Envelope Plot.*

Each *DBS(EN) Design Resistance Envelope Plot* presents two curves: one for each of the primary bending axes associated with the DBS(EN) 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 resistance of the DBS(EN) 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 (“major” versus “minor” 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 capacity for a point that represents a resultant moment and axial force that lies within the hatched “orientation dependent regions”.



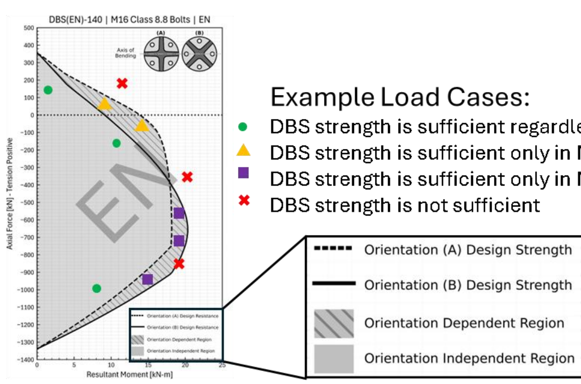


Figure 3: Example Confirmation of Load Sets

Consideration of shear/torsion

No reduction in bolt tensile resistance due to combined tension and shear has been incorporated into the *DBS(EN) Design Resistance Envelope Plots*. As per the "Combined shear and tension" equation in EN 1993-1-8 Table 3.4 the available bolt design shear resistance utilization considering full bolt tension design resistance can be calculation as follows:

Combined shear and tension equation from EN 1993-1-8 Table 3.4:

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} \leq 1.0$$

No reduction in bolt tension design resistance:

$$\frac{F_{t,Ed}}{F_{t,Rd}} = 1.0$$

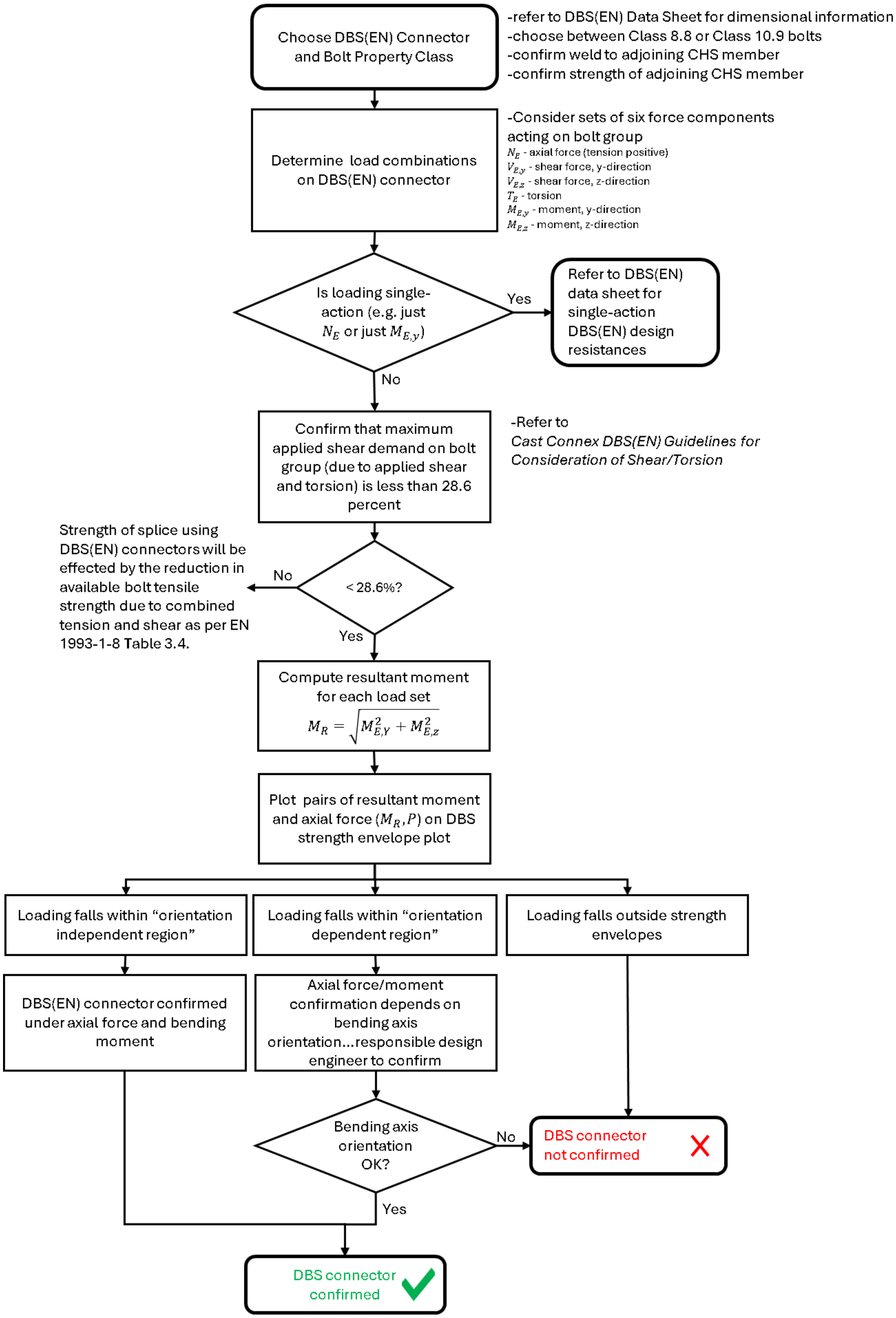
Solve for available bolt shear utilization:

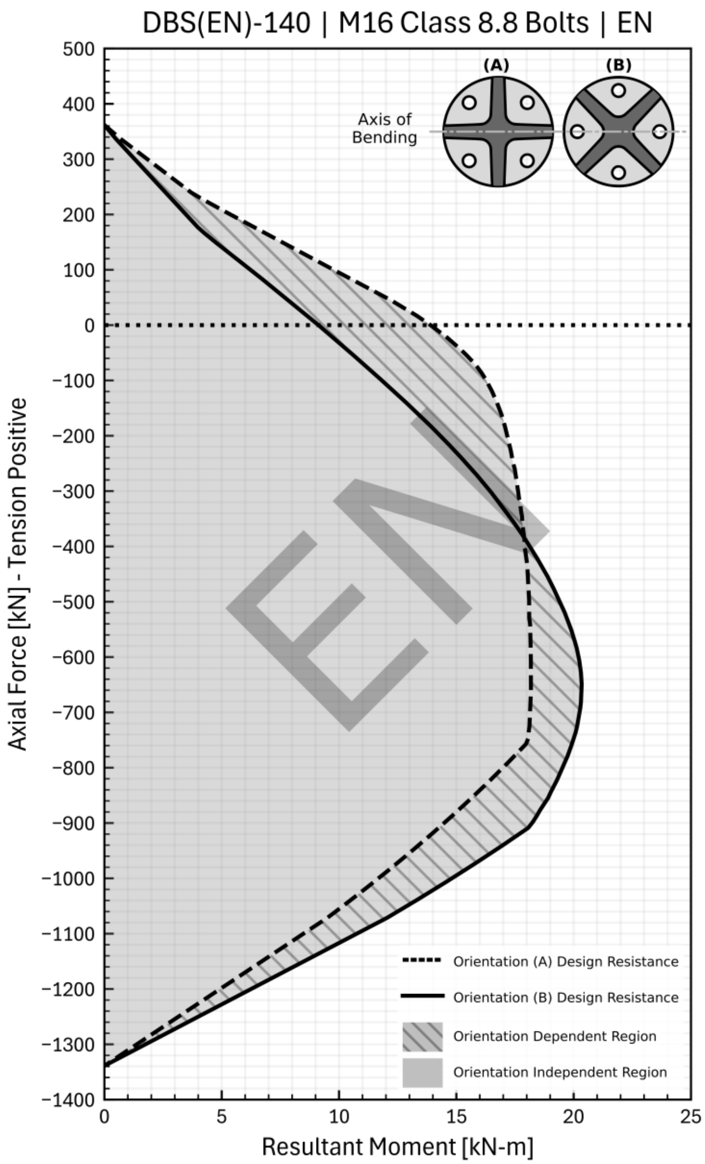
$$\frac{F_{v,Ed}}{F_{v,Rd}} = 1.0 - \frac{F_{t,Ed}}{1.4F_{t,Rd}} = 1.0 - \frac{1}{1.4} = 0.286$$

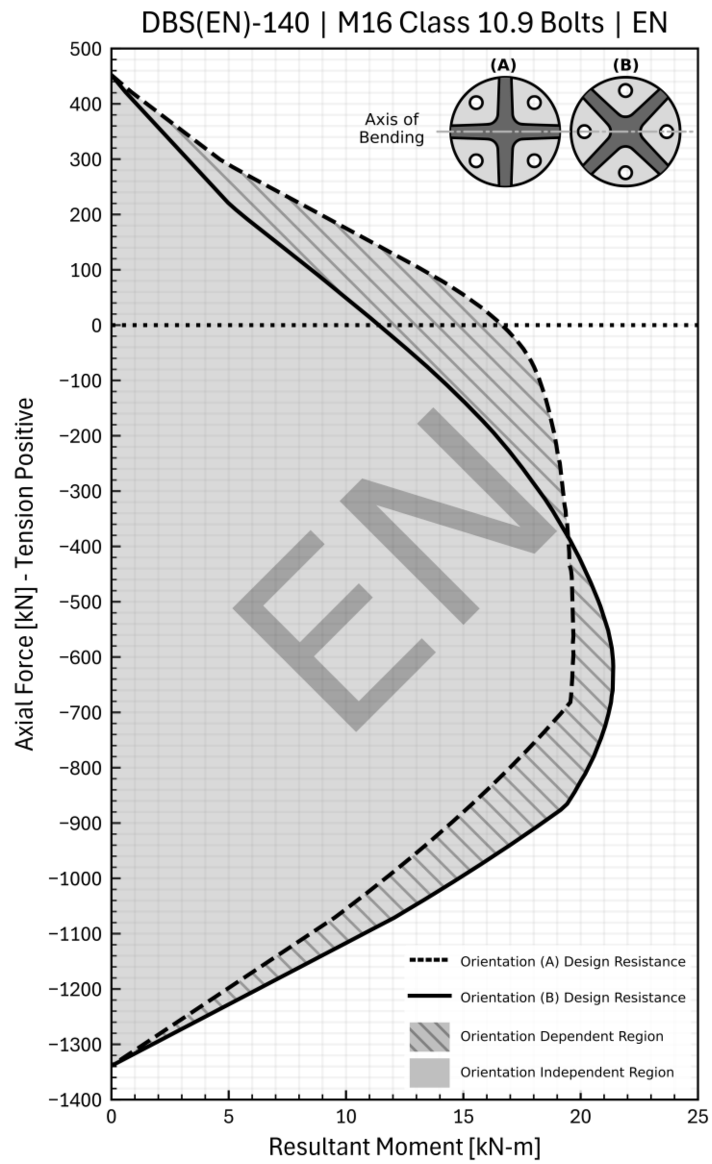
Thus, the *DBS(EN) Design Resistance Envelope Plots* are only valid for a maximum bolt shear stress utilization up to 28.6%. While it is expected that this range of shear utilization will cover most applications of the DBS(EN) connectors, the shear utilization of the bolt group should be confirmed to be less than 0.286 when using the *DBS(EN) Design 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(EN) Design Resistance Envelope Plots* .

DBS(EN) Design Confirmation Flow Chart

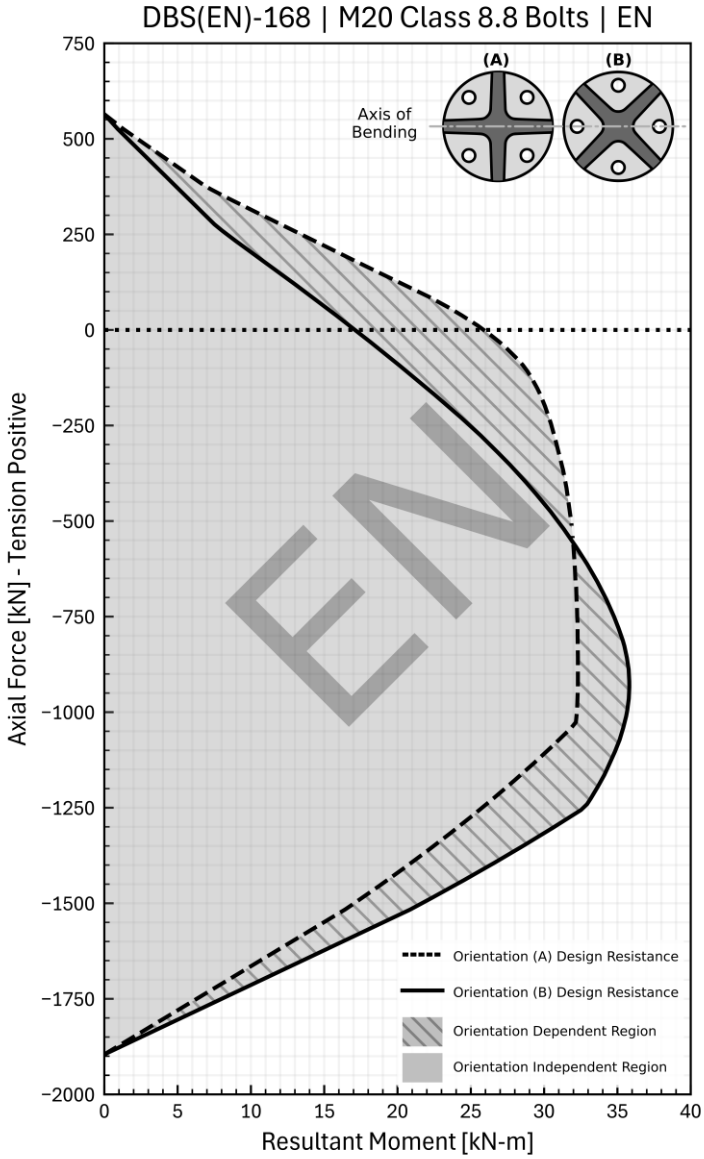


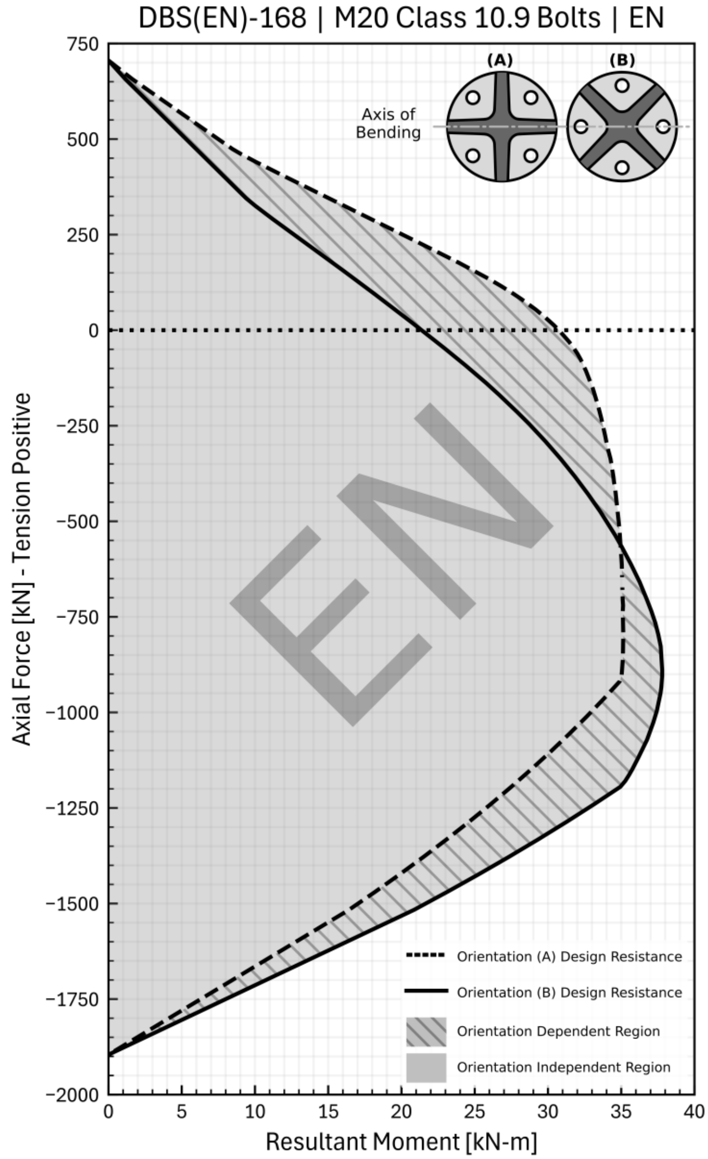




Notes:

- The design resistance of the DBS(EN) connector is the minimum of (a) the resistance shown in the above plots, (b) the design resistance of the CHS-to-connector welded connection, and (c) the design resistance of the connecting CHS member.
- Plots indicate the design resistance of the DBS(EN) connector considering a minimum of bolt tensile strength, and connector sectional capacity (refer to EN 1993-1-8 Table 3.4 and EN 1993-1-1 Sec. 6.2.9).
- Plots account for bolt group shear effects (due to applied shear and torsion) of up to 28.6% of the corresponding design shear resistance.
- Plots are valid for design combination of actions.
- Load cases shall be evaluated separately.
- The engineer responsible for design shall verify the orientation of the DBS(EN) in the orientation dependant regions.
- Resultant Moment: $M_r = \sqrt{M_y^2 + M_z^2}$





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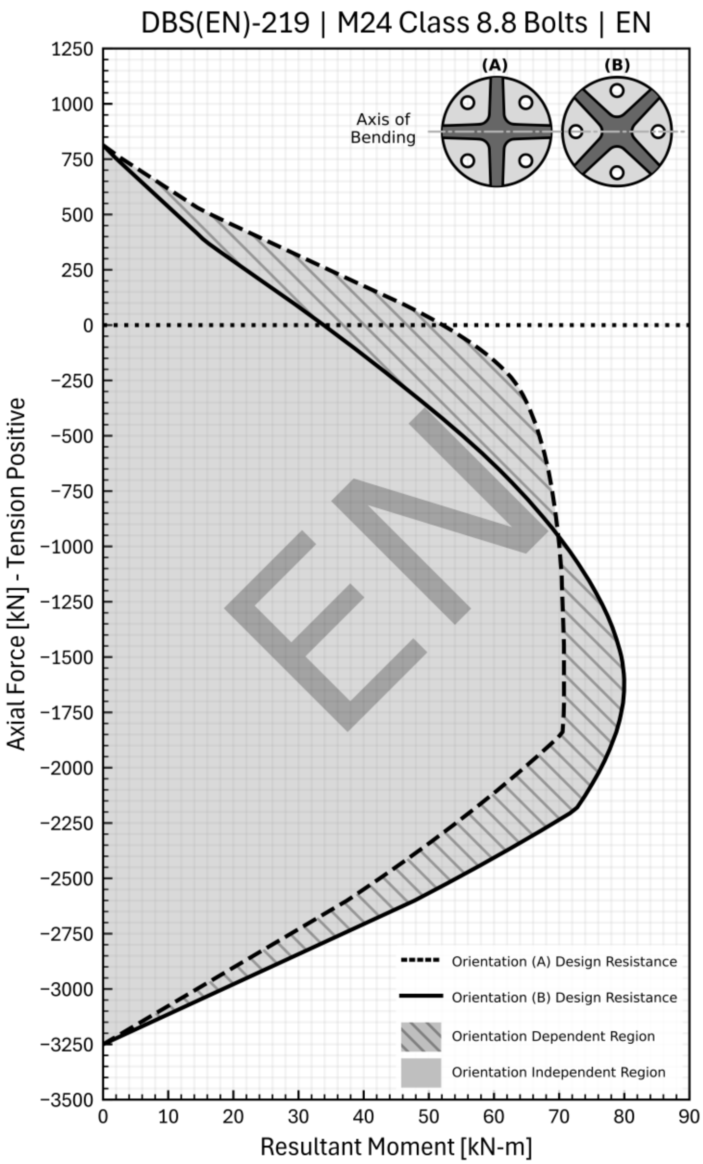

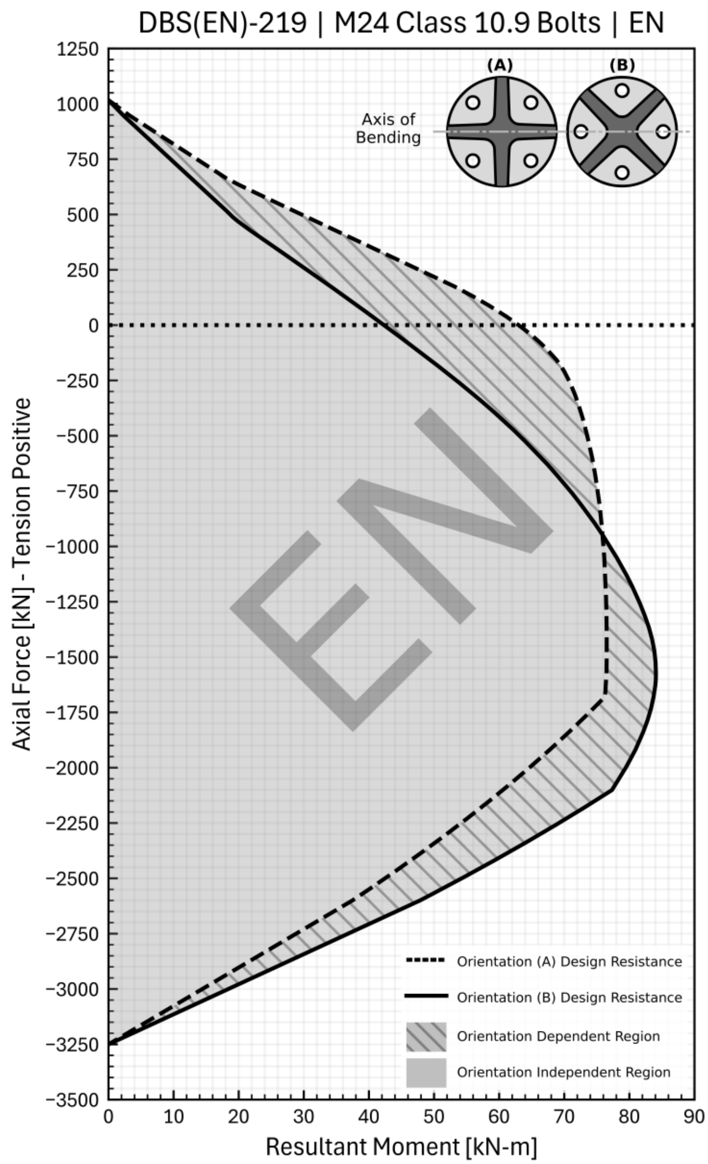

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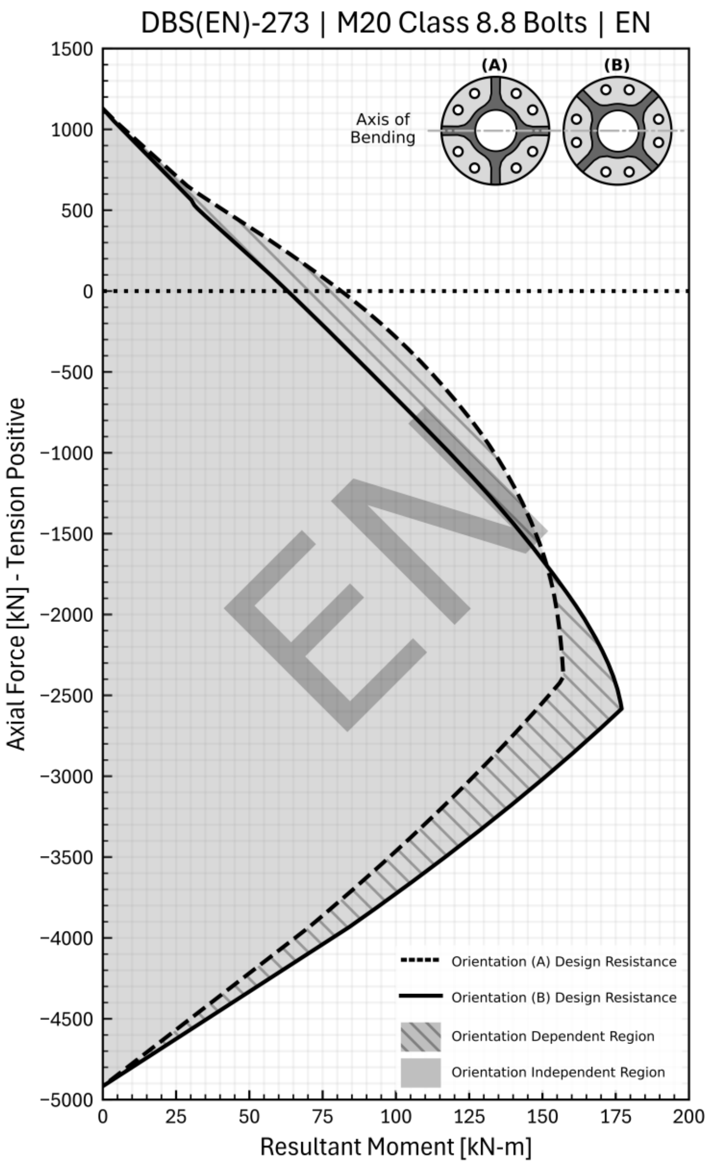

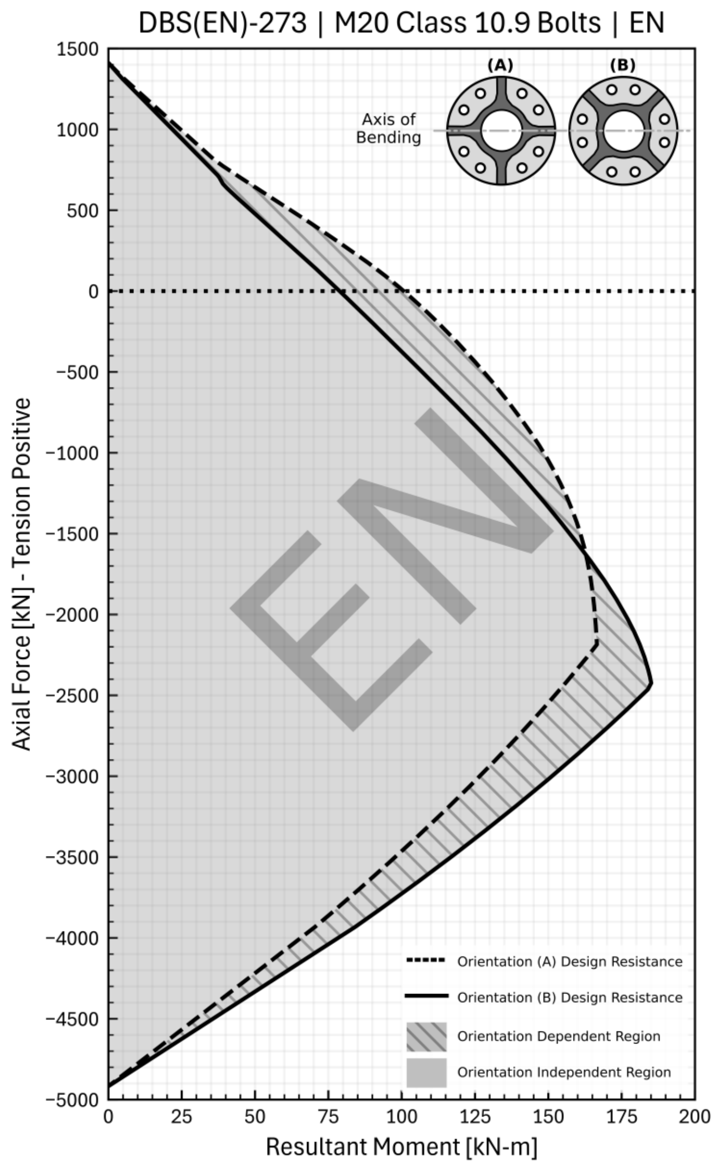

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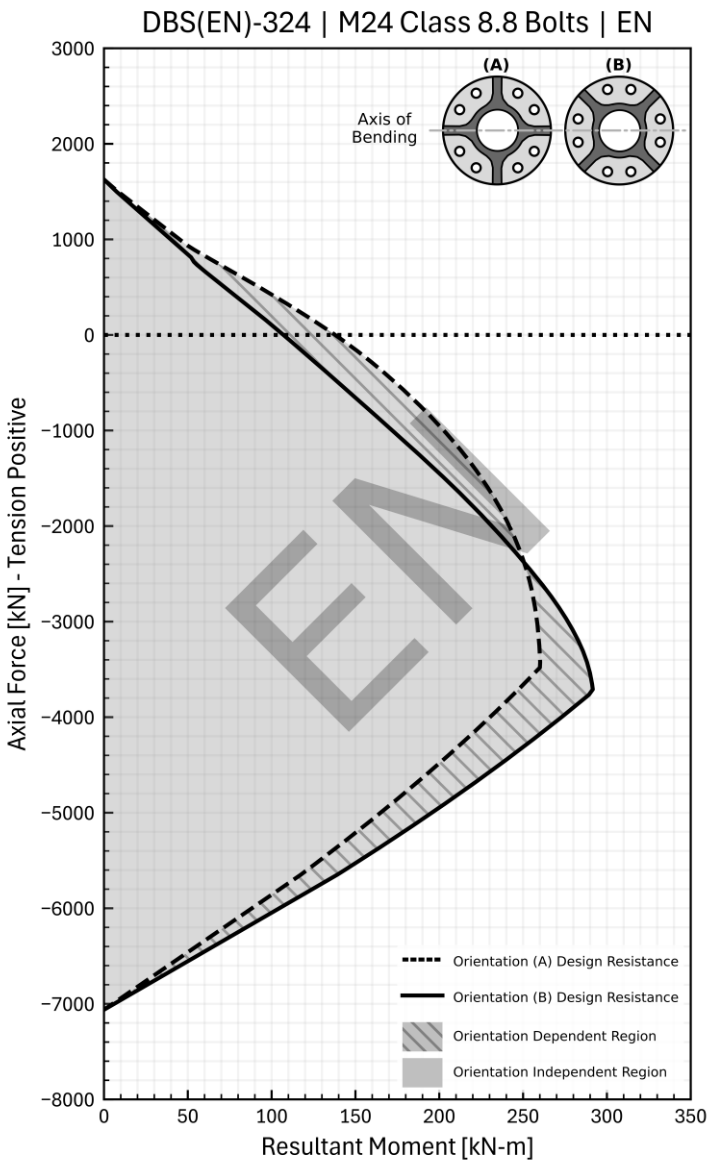

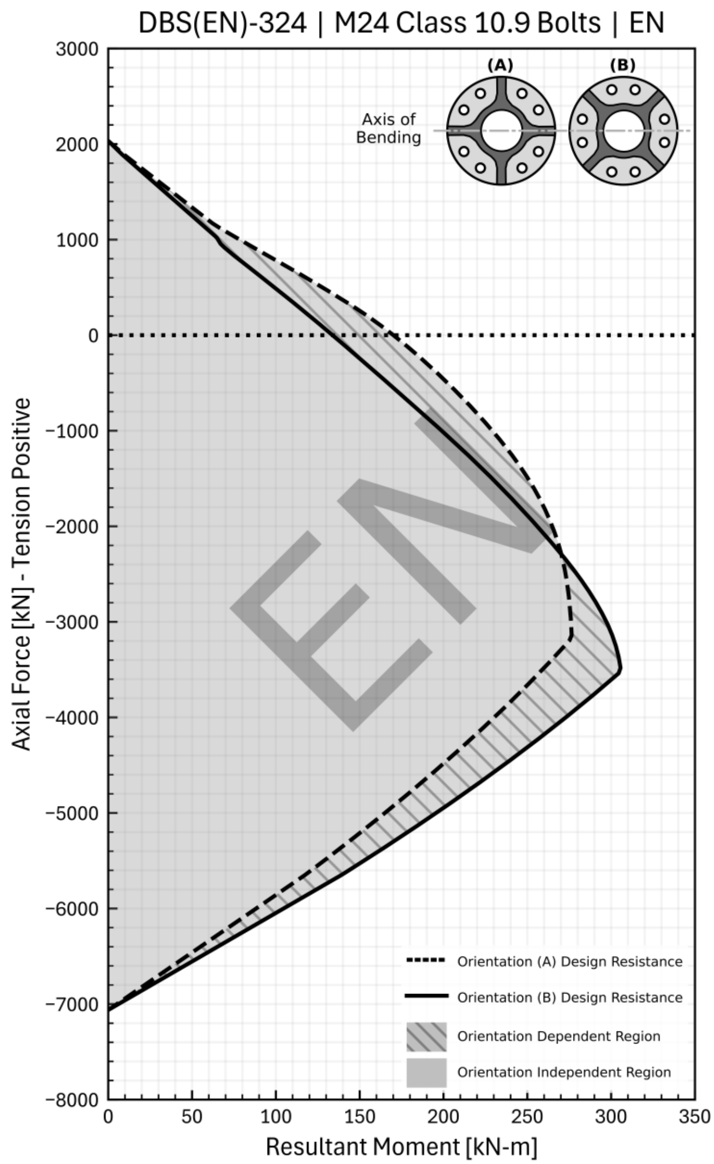

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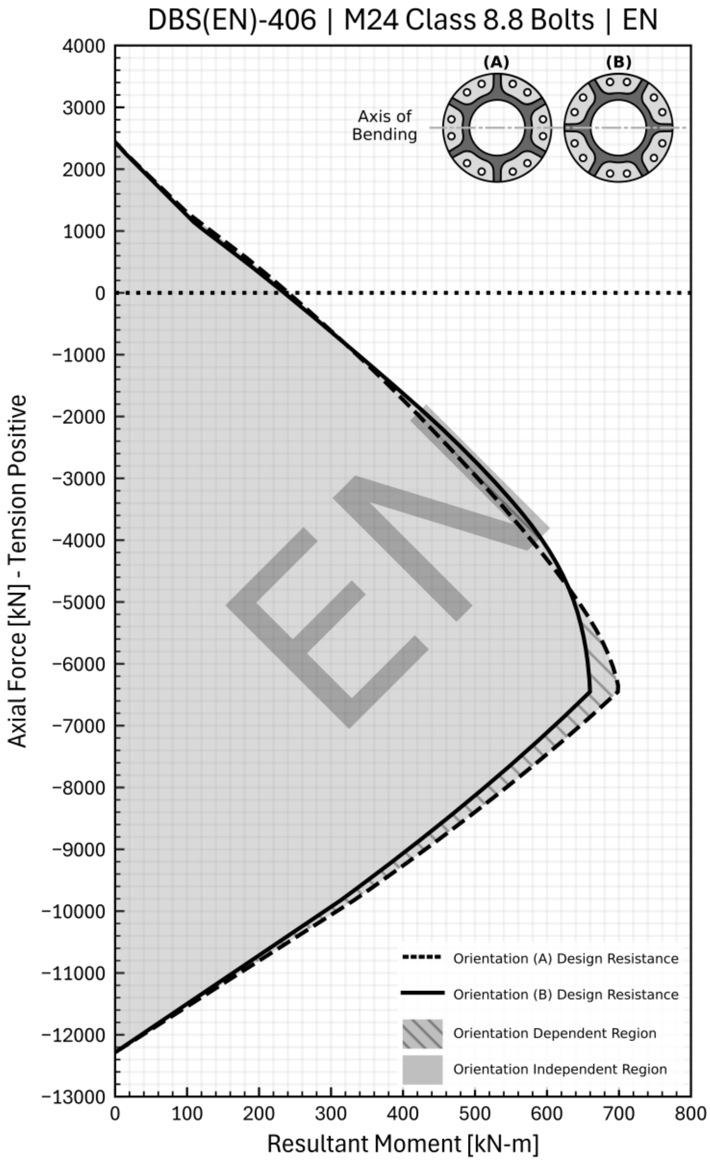

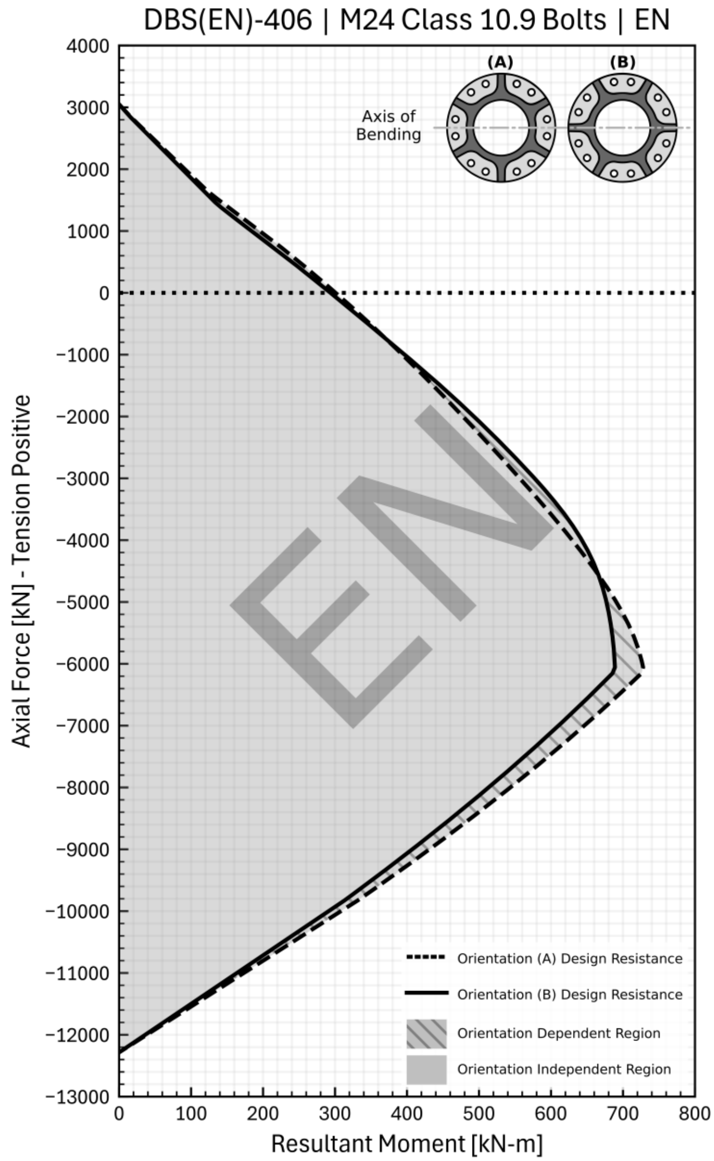

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Appendix A: Guidelines for Consideration of Applied Shear and Torsion

As permitted by the "Combined shear and tension" equation in EN-1993-1-8 Table 3.4, 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 28.6% of the available shear stress of each bolt. The maximum required shear stress on a bolt in a DBS(EN) connector may be caused by applied shear and/or applied torsion.

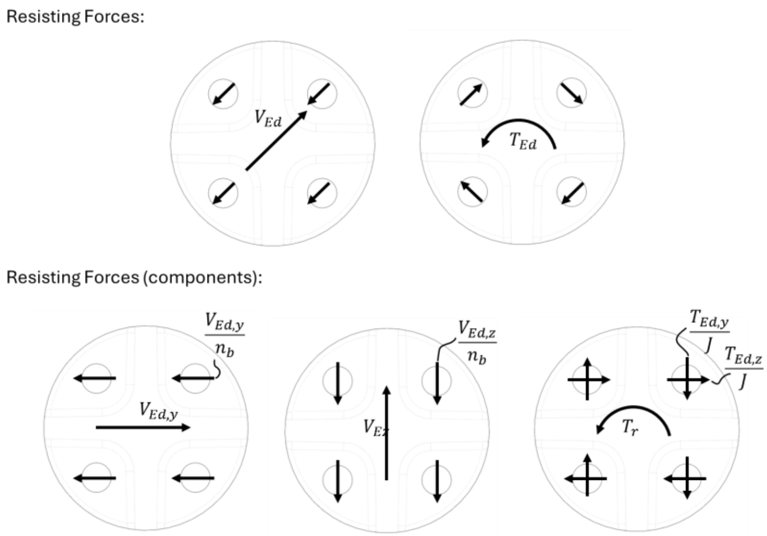

Figure A1: DBS(EN) resisting forces due to applied shear and torsion

Table 1: DBS(EN) Properties for Shear/Torsion Calculations

DBS(EN) Connector	**Number of bolts, n_b**	**Bolt Group Torsional Constant, J**
DBS(EN)-140	4	7400 mm^2
DBS(EN)-168	4	10820 mm^2
DBS(EN)-219	4	21300 mm^2
DBS(EN)-273	8	88200 mm^2
DBS(EN)-324	8	126000 mm^2
DBS(EN)-406	12	335000 mm^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 $J = \sum(y^2 + z^2)$ for all bolts with coordinates y and z (refer to DBS(EN) data sheet for DBS(EN) bolt pattern definition).

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

$$V_{Ed.bolt} = \sqrt{\left(\frac{V_{Ed,y}}{n_b} + \frac{T_{Ed}z}{J}\right)^2 + \left(\frac{V_{Ed,z}}{n_b} + \frac{T_{Ed}y}{J}\right)^2}$$

The required shear stress can be determined considering the bolt stress area A_s:

$$\sigma_{V,Ed,bolt} = \frac{V_{Ed,bolt}}{A_s}$$

Finally, the bolt shear force utilization can be calculated as per EN 1993-1-8 Table 3.4 considering the bolt stress area, A_s:

For Class 8.8 bolts:

$$\frac{V_{Ed,bolt}}{\left(\frac{\alpha_v f_{ub} A_s}{\lambda_{M2}}\right)} = \frac{V_{Ed,bolt}}{\left(\frac{0.6 * 800 * A_s}{1.25}\right)} \leq 0.286$$

For Class 10.9 bolts:

$$\frac{V_{Ed,bolt}}{\left(\frac{\alpha_v f_{ub} A_s}{\lambda_{M2}}\right)} = \frac{V_{Ed,bolt}}{\left(\frac{0.5 * 1000 * A_s}{1.25}\right)} \leq 0.286$$

Should this ratio be greater than 0.286, the resistance of the splice made using DBS(EN) connectors will be affected by the reduction in available bolt tensile resistance due to combined tension and shear as per the combined shear and tension equation in EN 1993-1-8 Table 3.4.

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