[5] Mathura, N.S. *Aspects of Bolted Connections for Fibre Reinforced Polymer Structures*. PhD Thesis, University of Warwick, 2014. Available from: http://wrap.warwick.ac.uk/67279/ [viewed 2023-09-15]

[6] Martins, D., Proenca, M., Correia, J.R., Gonilha, J., Arruda, M., Silvestre, N. Development of a novel beam-to-column connection system for pultruded GFRP tubular profiles. *Composite Structures*. 2017, **171**, 263–276. Available from: https://doi.org/10.1016/j.compstruct.2017.03.049

[7] ASTM D5379/D5379M-19e1. *Standard test method for shear properties of composite materials by the V-notched beam method*.

[8] ASTM D7078/D7078M-19e. *Standard test method for shear properties of composite materials by V-Notched rail shear method*.

[9] ISO 14130:1997. *Fibre-reinforced plastic composites — Determination of apparent interlaminar shear strength by short-beam method*.

[10] prEN 1990. *Eurocode - Basis of structural and geotechnical design*. (under preparation)

REPORT NUMBER	BR_12.2.3.3_PAR_2
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.3 Shear-out failure
PARAGRAPH	(2)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(2) For a laminate of constant thickness, for two rows of aligned bolts (i = 2), separated by spacing p_1 (distance between centres of holes in a line in the direction of load transfer, see Figures 11.2 and 12.6), the design value of the bearing force transferred by a column line of two bolts, $V_{\text{so,2,Ed}}$, for shear-out failure should satisfy the condition in Formula (12.18):

$$V_{\text{so,2,Ed}} \leq V_{\text{so,2,Rd}} \tag{12.18}$$

where

$V_{\text{so,2,Ed}}$ is taken equal to $\dfrac{N_{\text{1,Ed}}}{n_{\text{b,1}}} + \dfrac{N_{\text{2,Ed}}}{n_{\text{b,2}}}$;
$N_{\text{1,Ed}}$ is the contribution of N_{Ed} at the first row of bolts (i = 1);
$N_{\text{2,Ed}}$ is the contribution of N_{Ed} at the second row of bolts (i = 2);
$n_{\text{b,1}}$ is the number of bolts at the first row of bolts (i = 1) (see Figure 12.6);
$n_{\text{b,2}}$ is the number of bolts at the second row of bolts (i = 2) (see Figure 12.6);

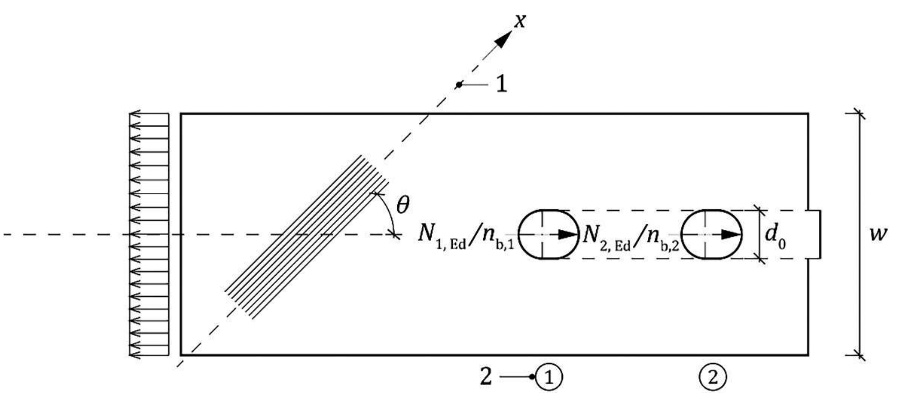
and where

$V_{\text{so,2,Rd}}$ is the design value of the shear-out resistance per column line of bolts, given by Formula (12.19),

$$V_{\text{so,2,Rd}} = 1{,}5\left(e_1 - 0{,}5 \cdot d_0 + p_1\right) \cdot t \cdot f_{\text{xy,v,d}} \tag{12.19}$$

where

e_1 is the end edge distance from the first row of bolts (Table 11.1 and 12.2.3.3.(3));
d_0 is the nominal bolt hole diameter;
t is the thickness of the laminate resisting $V_{\text{so,2,Ed}}$;
$f_{\text{xy,v,d}}$ is the design value of the in-plane shear strength of the laminate, obtained from Formula (12.17).



Key:

(1) Principal direction of laminate or direction of pultrusion and
(2) Row No. (i)

FIGURE 12.6 Shear-out failure mode for a multi-bolted connection having two rows of a single bolt.

SHEAR-OUT FAILURE

Background

Paragraph 12.2.3.3(2) with Figure 12.6 is for double-row multi-bolted connections and joints of fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. Figure 12.6 is a line drawing to depict the assumed shear-out failure paths for this bolting configuration that are used to formulate the resistance Formula (12.19). The figure shows that when the in-plane shear strength is exceeded it is assumed that a "rectangular" strip (in two parts) of laminate material shears out from the second row of bolts to the free end. This "strip", as seen in Figure 12.6, has a length equal to $e_1 - 0{,}5d_0 + p_1$ and a width equal to the bolt hole diameter, which is d_0.

References [1–4] give historical background and/or specific information from which paragraphs 12.2.3.3(1)–(4) were prepared. In [1] Formula (8.3.3-4) is the first source of Formula (12.19), yet its expression is with factor 0,9 in Formula (12.19) equal to 1,4. Also with factor 1,4, the same basic formula for this shear-out resistance is Formula (8.5b) in [2]. This factor difference of −0,5 is acceptable because of the calculation differences in establishing the "partial factors of resistance (γ_M)" given by $\gamma_{m\times}\gamma_{Rd}$ in the Eurocode approach to that in the LFRD limit state approach. In [1] the LRFD North American resistance factors (symbol φ) can, for comparison purposes, be taken as the inverse of the equivalent Eurocode partial factors of resistance. The specific form of the shear-out resistance formula for two bolt rows was developed when the LRFD pre-standard [1] was being drafted.

The characteristic value of the in-plane shear strength (xy plane) of the laminate, $f_{xy,v,k}$, can be determined using test standard ASTM D5379/D5379M [5] or D7078/D7078M [6]. There is no equivalent EN or ISO test standard and the interlaminar shear strength determined by test method EN ISO 14130 [7] is not appropriate.

Because the test results reported in [3, 4] were considered complete and reliable they were used by the drafting team to calibrate the partial factor of resistance, $\gamma_{Rd,}$ for the shear-out mode of failure. Factor 0,9 in Formula (12.19) for the two-bolt row shear-out mode of failure was determined from this calibration exercise using the prEN 1990 [8] procedure for the determination of the partial factor associated with the uncertainty in a resistance model (γ_{Rd}). For the shear-out mode of failure, γ_{Rd} = 1,5 and is reported in Table 4.5 in 4.4.6(3). The calibration of γ_{Rd} is presented in Background Report BR_4_4_6_PAR_3. BR_4.4.6_PAR_3 has a part on shear-out strength to develop now a calibration procedure was employed by the drafting team to establish that $\gamma_{Rd} = 1{,}5$.

Future characterisation work to determine the shear-out resistances of bolted connections that are scoped in CEN/TS 19101:2022 can be used with the appropriate values of $f_{xy,v,k}$ to confirm this hypothesis for the situation of bolted connections having two bolt rows.

References

[1] American Society of Civil Engineers (ASCE). *Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures*. Submitted by the American Composites Manufacturers Association (ACMA) to ASCE, ASCE, Reston, VA, 2010.

[2] Ascione, L., Caron, J.F., Correia, J.R., De Corte, W., Godonou, P., Knippers, J., Moussiaux, E., Mottram, T., Oppe, M., Silvestre, N., Thorning, P., Tromp, L. *Prospect for New Guidance in the Design of FRP Structures: Updated Report*. European Composites Industry Association (EuCIA), Available from: www.eucia.eu. 2018.

[3] Mathura, N.S. *Aspects of Bolted Connections for Fibre Reinforced Polymer Structures*. PhD Thesis, University of Warwick, 2014. Available from: http://wrap.warwick.ac.uk/67279/ [viewed 2023-09-15]

[4] Martins, D., Proenca, M., Correia, J.R., Gonilha, J., Arruda, M. and Silvestre, N. Development of a novel beam-to-column connection system for pultruded GFRP tubular profiles. *Composite Structures*. 2017, **171**, 263–276. Available from: https://doi.org/10.1016/j.compstruct.2017.03.049

[5] ASTM D5379/D5379M-19e1. *Standard test method for shear properties of composite materials by the V-notched beam method.*

[6] ASTM D7078/D7078M-19e. *Standard test method for shear properties of composite materials by V-Notched rail shear method.*
[7] EN ISO 14130:1997. *Fibre-reinforced plastic composites – Determination of apparent interlaminar shear strength by short-beam method.*
[8] prEN 1990. *Eurocode - Basis of structural and geotechnical design.* (under preparation)

REPORT NUMBER	BR_12.2.3.3_PAR_3
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.3 Shear-out failure
PARAGRAPH	(3)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT (3) When laminates in bolted connections have a flange outstand or web at the free end, the end distance e_1 to be included in Formula (12.16) or Formula (12.19) should be taken from the centre of the hole to the outstand or web edge plus 0 either 0,5 times the web height or 0,5 times the outstand width, whichever applies (see Figures 12.5 and 12.6).	

SHEAR-OUT FAILURE

Background

Paragraph 12.2.3.3(3) is for connections and joints of fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. To explain why the requirement in 12.2.3.3(3) is required, Figure 1 illustrates two situations where the resultant connection force is acting in directions that need the end distance e_1 to be specified.

The two single-row bolted connections in Figure 1 can be used to show how 12.2.3.3(3) is applied. The figure shows two fibre-polymer composite members with outstands of depth of h, and there is a connection force acting towards the outstand and perpendicular to it. Such a connection force might cause failure in the shear-out mode. 12.2.3.3(3) is used to establish the value of this end distance e_1, as defined in Figure 1. Note that the dashed lines for the end distance e_1 in the two figures is because what distance is seen is not the actual distance. In accordance with this paragraph, e_1 should be taken from the centre of the hole to the nearest outstand edge, which is distance c in Figure 1, plus 0,5 times the depth of the outstand height, h; that is, $e_1 = c + 0{,}5h$.

Note that when the calculated e_1 exceeds $4d$ for a single bolt or $2d$ when there are two or three rows of bolts (refer to values in Table 11.1 in 11.4(3)), there is going to be additional resistance to the shear-out mode of failure owing to the presence, at the “free-end”, of the fibre-polymer composite outstand, which is perpendicular to the direction of the connection force. This condition means that there is now no requirement to check if shear-out failure governs the bolted connection design.

For additional information on this design feature refer to Commentary C8.3.2 *Nominal strength of single row bolted connections* in [1], which at the time of finalising this background report is to be published as ASCE/SEI 74.

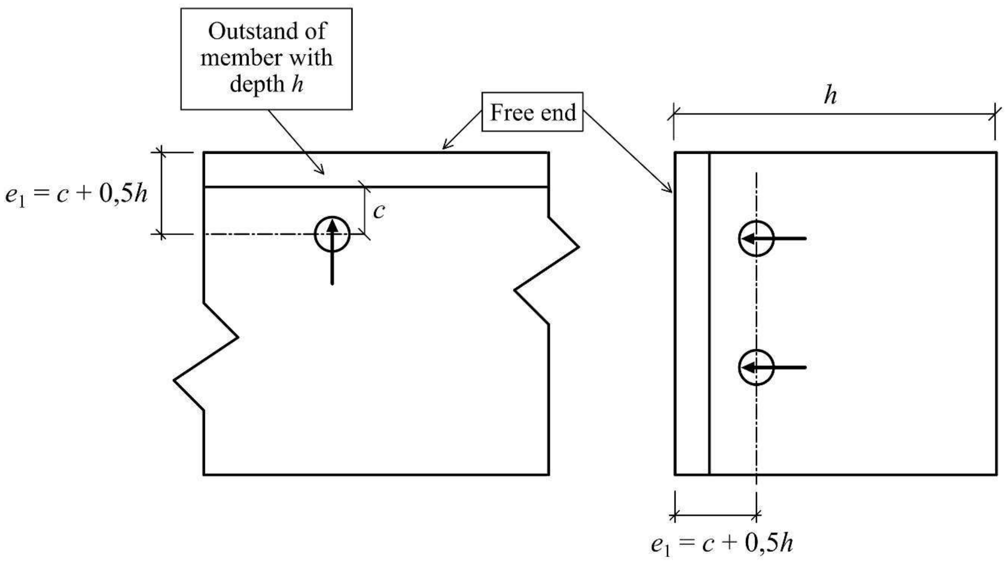


FIGURE 1 Two single-row bolted connections with an outstand at the free edge requiring the establishment of end distance e_1.

Reference

[1] American Society of Civil Engineers (ASCE). *Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures*. Submitted by the American Composites Manufacturers Association (ACMA) to ASCE, ASCE, Reston, VA, 2010.

REPORT NUMBER	BR_12.2.3.3_PAR_4
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.3 SHEAR-OUT FAILURE
PARAGRAPH	(4)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(4) For three or four rows of aligned bolts (i = 3 or 4) separated by spacing p_1, the design value of the bearing force transferred by a column line of bolts, $V_{\mathrm{so},i,\mathrm{Ed}}$, for shear-out failure should satisfy the condition in Formula (12.20):

$$V_{\mathrm{so},i,\mathrm{Ed}} \leq V_{\mathrm{so},i,\mathrm{Rd}} \tag{12.20}$$

where

$V_{\mathrm{so},i,\mathrm{Ed}}$ is given by $\sum_{i=1 \text{ to } j} \frac{V_{i,\mathrm{Ed}}}{n_i}$, where i is either 3 or 4 (see Figure 12.1);

$V_{\mathrm{so},i,\mathrm{Rd}}$ is the shear-out resistance per column line of bolts, $V_{\mathrm{so},3,\mathrm{Rd}}$ or $V_{\mathrm{so},4,\mathrm{Rd}}$, in the laminate of constant thickness, given by Formula (12.21),

$$V_{\mathrm{so},i,\mathrm{Rd}} = 1{,}3\left[\left(i-1\right)\cdot p_1\right]\cdot t \cdot f_{\mathrm{xy,v,d}} \tag{12.21}$$

where

t is the thickness of the laminate resisting $V_{\mathrm{so},i,\mathrm{Ed}}$;

p_1 is the spacing between centres of holes in a line in the direction of load transfer, see Figure 11.2;

$f_{\mathrm{xy,v,d}}$ is the design value of the in-plane shear strength of the laminate, obtained from Formula (12.17).

SHEAR-OUT FAILURE

Background

Paragraph 12.2.3.3(4) is for bolted connections and joints with three or four rows of bolts, and of fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. In reference [1], Formula (8.3.3–5), and in [2], Formula (8.5b), is also Formula (12.21) with factor 1,3 equal to 2,0. The shear-out resistance formula for three bolt rows (four bolt rows is not permitted in CEN/TS 19101:2002) in bolted connections was developed when the LFRD pre-standard [1] was being prepared. The Formula (12.21) factor with a difference of +0,7 is acceptable because of the calculation differences in establishing the "partial factors of resistance" given by $\gamma_{\mathrm{m}\times}\gamma_{\mathrm{Rd}}$ in the Eurocode approach to that in the LFRD limit state approach. In [1], the LRFD North American resistance factors (symbol φ) can, for comparison purposes, be taken as the inverse of the equivalent Eurocode partial factors of resistance.

For the shear-out mode of failure the partial factor associated with the uncertainty in a resistance model γ_{Rd} = 1,5 and is given in Table 4.5 in 4.4.6(3). The calibration of γ_{Rd} is presented in BR_4_4_6_PAR_3 (4. *Basics of Design*). It is noted that the calibration procedure does **not** include test results where the mode of failure is with three of four rows of a bolt in a single column.

Future characterisation work to determine the shear-out resistances of bolted connections that are scoped by this paragraph in CEN/TS 19101:2022 can be used with the appropriate values of $f_{xy,v,k}$ to verify or recalibrate the value of 1,5 for γ_{Rd}.

References

[1] American Society of Civil Engineers (ASCE). *Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures*. Submitted by the American Composites Manufacturers Association (ACMA) to ASCE, ASCE, Reston, VA, 2010.

[2] Ascione, L., Caron, J.F., Correia, J.R., De Corte, W., Godonou, P., Knippers, J., Moussiaux, E., Mottram, T., Oppe, M., Silvestre, N., Thorning, P., Tromp, L. *Prospect for New Guidance in the Design of FRP Structures: Updated Report*. European Composites Industry Association (EuCIA), Available from: www.eucia.eu. 2018.

REPORT NUMBER	BR_12.2.3.4_PAR_1
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.4 Block-shear failure
PARAGRAPH	(1)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(1) When the connection force is transferred in tension, is concentric to a symmetric group of bolts, and parallel to the x– or y–direction of laminates of constant thickness, its design value, N_{Ed}, for block-shear failure should satisfy the condition in Formula (12.22):

$$N_{\mathrm{Ed}} \leq N_{\mathrm{bs,Rd}} \tag{12.22}$$

where

$N_{\mathrm{bs,Rd}}$ is the design value of the block-shear resistance for a multi-bolted connection, given by Formula (12.23),

$$N_{\mathrm{bs,Rd}} = 0{,}5\left(A_{\mathrm{ns}} \cdot f_{\mathrm{xy,v,d}} + A_{\mathrm{nt}} \cdot f_{i,\mathrm{t,d}}\right) \tag{12.23}$$

where

A_{ns} is the net area of the laminate subjected to shear;
A_{nt} is the net area of the laminate subjected to tension, which should be taken as the gross area of the laminate less appropriate deductions of area for all holes, in accordance with the requirements of 12.2.3.4(2) or (3);
$f_{\mathrm{xy,v,d}}$ is the design value of the in-plane shear strength of the laminate, given by Formula (12.24),

$$f_{\mathrm{xy,v,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{xy,v,k}} \tag{12.24}$$

where

γ_{m} is defined in 4.4.5 (to be selected for $f_{\mathrm{xy,v,k}}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Block-shear failure);
η_{c} is defined in 4.4.7(to be selected for $f_{\mathrm{xy,v,k}}$);
$f_{\mathrm{xy,v,k}}$ is the characteristic value of the in-plane shear strength of the laminate; and where
$f_{i,\mathrm{t,d}}$ is $f_{\mathrm{x,t,d}}$ when N_{Ed} is parallel to x direction and is $f_{\mathrm{x,t,d}}$ when N_{Ed} is parallel to y direction, given by Formulae (12.25) and (12.26),

$$f_{\mathrm{x,t,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{x,t,k}} \tag{12.25}$$

$$f_{\mathrm{y,t,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{y,t,k}} \tag{12.26}$$

where

γ_{m} is defined in 4.4.5 (to be selected for $f_{\mathrm{x,t,k}}$ or $f_{\mathrm{y,t,k}}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Block-shear failure);
η_{c} is defined in 4.4.7(to be selected for $f_{\mathrm{x,t,k}}$ or $f_{\mathrm{y,t,k}}$);
$f_{\mathrm{x,t,k}}, f_{\mathrm{y,t,k}}$ is the characteristic value of the tensile strength of the laminate in the x and y directions.

BLOCK-SHEAR FAILURE

Background

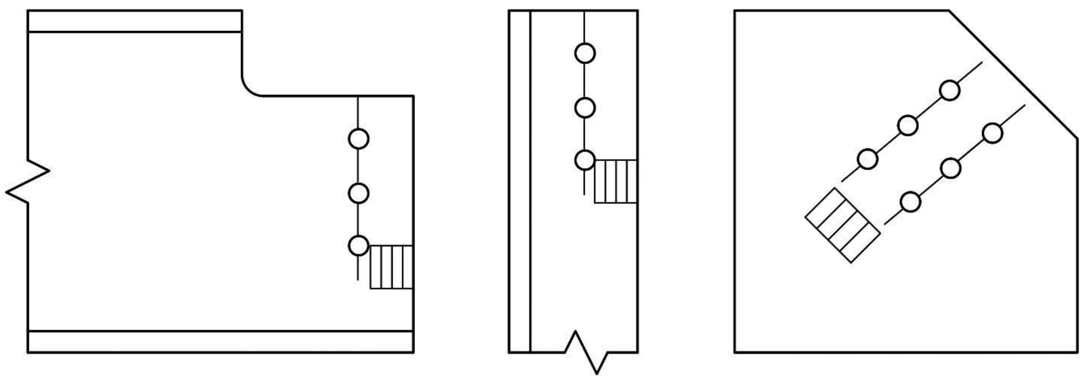
Paragraph 12.2.3.4(1) is for multi-bolted connections and joints of fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. References [1–3] give specific information from which subclause 12.2.3.4 was prepared. Prabhakaran *et al.* [1, 2] conducted a series of multi-row bolted double-lap shear connection tests with pultruded (plate/flat sheet) materials and concentric loading to show that Formula (12.23) in 12.2.3.4(1) can be applied in the design of bolted connections when the mode of failure is block-shear. Using the strength model in [3], with appropriate net cross-section areas, they assumed that, when the tension force is concentric to a symmetric group of bolts, each bolt carried an equal proportion of the connection force.

For illustration purposes only, Figure 1 shows several different block shear loading situations (taken from [3]). The hashed areas in the three illustrations for different multi-bolted connection configurations show the assumed direct stress distributions at the failure plane. Aside, it is noted here that such detailing of fibre-polymer composite components in joints may require stiffening details. Examples of the practical (shear failure) fracture paths for the block-shear mode of failure are depicted in Figure 1 by the solid lines passing through the centres of the bolt "columns" for these three concentric load cases. Accompanying the shear plane ruptures will be a tensile rupture where the assumed constant tensile stress profile is illustrated in the figure parts.

Regarding the block-shear mode of failure (in double-lap shear joints), we note that for multi-bolted connection configurations that can fail in block-shear, there can be one or more different fracture paths for this mode of failure. Each different fracture path must have its resistance checked to establish the required lowest block-shear strength. Guidance is given in Background Reports BR_12.2.3.4_PAR_2 and BR_12.2.3.4_PAR_3 on how to establish the values of the net area of the laminate subjected to shear, A_{ns}, and the net area of the laminate subjected to tension, A_{nt}.

No commentary is required herein to introduce the partial factor for a material or product property γ_m (defined in subclause 4.4.5 *Partial factors for materials* and corresponding to $f_{xy,v,k,}$ $f_{x,t,k}$ and $f_{x,t,k}$) and conversion factor, η_c (defined in subclause 4.4.7 *Nominal conversion factors*). The characteristic value of the tensile strength of the pultruded laminate material in the x and y directions, $f_{x,t,k}$ and $f_{y,t,k}$, can be determined using test standard EN ISO 527 [4]. The characteristic value of the out-of-plane shear strength (xz plane) of the laminate, $f_{xy,v,k}$, can be determined using test standard ASTM D5379/D5379M [5] or D7078/D7078M [6]. There is no equivalent EN or ISO test standard and the interlaminar shear strength determined by test method EN ISO 14130 [7] is **not** appropriate.

The following is taken from BR_4.4.6_PAR_3. Due to the lack of experimental data in the literature, it was not possible to apply the methodology described in BR_4.4.6_PAR_1 (used to



Single-row beam end connections Angle ends Gusset plates

FIGURE 1 Block-shear concentric loading situations with assumed direct stress distributions [7] (reproduced with permission from ASCE).

determine the values of the partial factor associated with the uncertainty in a resistance model γ_{Rd} for profiles and laminates) to determine a specific value γ_{Rd} for block-shear failure. Therefore, the value of $\gamma_{Rd} = 1{,}5$ for the block-shear mode of failure that is presented in Table 4.5 in 4.4.6(3) is based on the calibrated values of γ_{Rd} for the two failure modes of net-section and shear-out. The rationale for this assumption is based on the physical fact that block-shear failure may be regarded as a combination of shear-out and net-section failures. Future research is needed to confirm this hypothesis assumed by the project team drafting CEN/TS 19101:2022.

References

[1] Prabhakaran, R., Razzaq, Z., Devara, S. Load and Resistance Factor Design (LRFD) approach for bolted joints in pultruded composites. *Composites - Part B: Engineering*. 1996, **27**(3–4), 351–360. Available from: https://doi.org/10.1016/1359-8368(95)00021-6

[2] Prabhakaran, R., Devara, S., Razzaq, Z. An investigation of the influence of tightening torque and seawater on bolted pultruded composites joints. In: *Proceedings International Composites Expo '97, Composite Institute*, Society of the Plastics Industry (SPI), Washington, DC, Session 14-D, pp. 14, 1997.

[3] American Institute of Steel Construction (AISC). *Specification for Structural Steel Buildings and Commentary*. ANSI/AISC 360-10. AISC, Chicago, IL, 2016.

[4] EN ISO 527 (all parts). *Plastics – Determination of tensile properties*.

[5] ASTM D5379/D5379M-19e1. *Standard test method for shear properties of composite materials by the V-notched beam method*.

[6] ASTM D7078/D7078M-19e. *Standard test method for shear properties of composite materials by V-Notched rail shear method*.

[7] EN ISO 14130:1997. *Fibre-reinforced plastic composites – Determination of apparent interlaminar shear strength by short-beam method*.

REPORT NUMBER	BR_12.2.3.4_PAR_2
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.4 Block-shear failure
PARAGRAPH	(2)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT	
(2) Provided that the holes are not staggered, the total area to be deducted for holes should be the maximum sum of the sectional areas of the holes in a cross-section perpendicular to the direction of tensile connection force.	

BLOCK SHEAR FAILURE

Background

Paragraph 12.2.3.4(2) is for bolted connections and joints that connect one or more fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. Figure 1 shows two practical block-shear modes of failure for a bolted connection of fibre-polymer composite materials without staggered bolting and having two rows and two columns of bolts. For the "left-sided" block-shear mode of failure, the net tension area is $A_{nt} = A_{nt,1} + A_{nt,2} + A_{nt,3}$. According to the requirement in 12.2.3.4(2), this sectional area is equal to the width of the plate, w, minus two times the hole diameter, d_0, times the thickness, t, of the laminate; that is, $A_{nt} = (w - 2d_0)t$. For the "right-sided" block-shear mode of failure the net tension area $A_{nt} = A_{nt,2}$, which for the minimum p_2 spacing of $4d$ for the bolting will be equal to $(4d - d_0)t$.

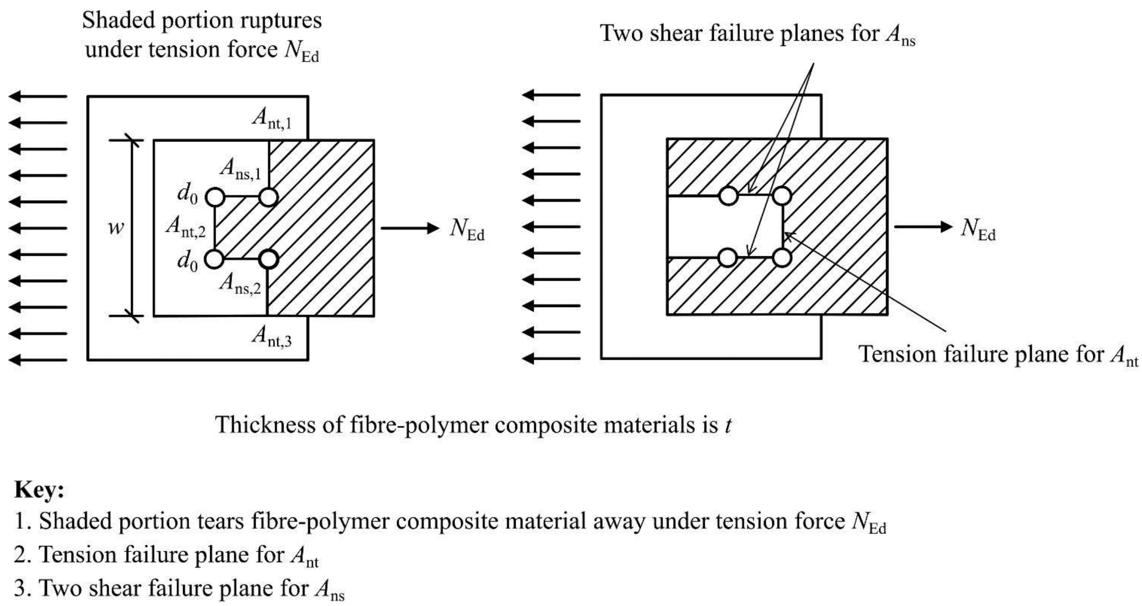


FIGURE 1 Block-shear loading for a concentric load condition.

REPORT NUMBER	BR_12.2.3.4_PAR_3
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.4 Block-shear failure
PARAGRAPH	(3)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(3) For a row of holes extending across a plate in any diagonal or zigzag pattern, the net width for staggered bolting (with $L = \sqrt{p_1^2 + s^2} > 4{,}4d$, see Figure 11.3) shall be determined by deducting from the gross width of the part the sum of all hole widths in the pattern and adding, for each p_2 spacing (see Figure 11.3), the quantity $\frac{s^2}{4p_2}$,

where

s is the staggered pitch, the spacing of the centres of two consecutive holes in the chain measured parallel to the member axis, see Figure 11.3;

p_2 is the spacing measured perpendicular to the load transfer direction between adjacent lines of bolts, see Figure 11.3.

BLOCK-SHEAR FAILURE

Background

Paragraph 12.2.3.4(3) is for multi-bolted connections and joints of fibre-polymer composite material components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. Note that Section 11 in CEN/TS 19101:2022 is for *Detailing* and Figure 1 reproduces Figure 11.3 of 11.4(3) because it defines symbols for a double-lap shear joint having staggered bolting, which are used in this background report.

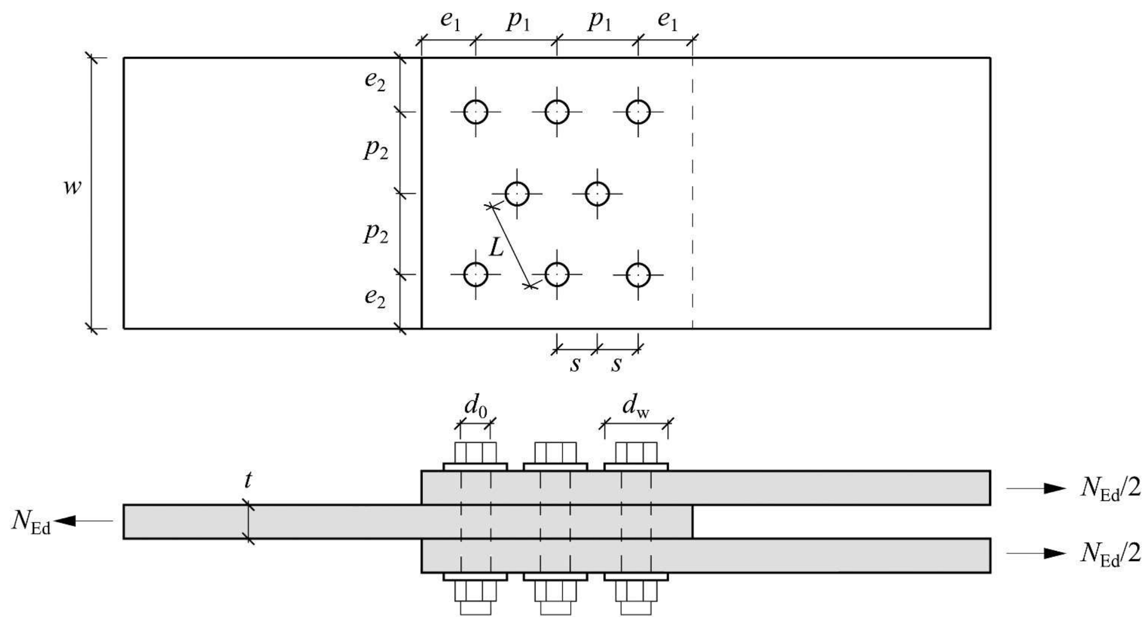


FIGURE 1 Detailing and symbols for bolted connections (Figure 11.3 from 11.4(3) of CEN/TS 19101:2022 [4]).

References [1, 2] give specific information from which 12.2.3.4(3) was prepared.

Prabhakaran *et al.* [1] conducted a series of multi-row bolted double-lap shear connection tests with pultruded (sheet/plate) material and concentric loading that ultimately failed with the block-shear mode of failure. The researchers observed that block-shear failure can occur when the bolt arrangement is staggered [1]. By way of illustrative Example 2, Prabhakaran *et al.* used the approach in J4 in ANSI/AISC 360-10 [2] for establishing the net width, L, for staggered bolts, which is required to calculate, A_{nt} (the net area of the laminate subjected to tension), in Formula (12.23) in 12.2.3.4(1) (refer to Background Report BR_12.2.3.4_PAR_1) or Formula (12.28) in 12.2.3.4(5) (refer to BR_12.2.3.4_PAR_5). Because Prabhakaran *et al.* [1] found this approach to be acceptable when establishing net widths for the prediction of strengths when failure is by the block-shear mode, it is adopted in CEN/TS 19101:2022. The same approach, as in 12.2.3.4(3), for the length deduction in establishing the gross width with staggered bolting is to be found in 6.2.2.2(4) in the steel Eurocode 3 part for the *Design of Steel Structures – Part 1-1: General Rules and Rules for Buildings* [3].

Figure 2 is for a bolted connection with a single row of bolts having a staggered bolt arrangement; loading can be assumed tensile and acting normal to the vertically drawn sides. The length, L, of the dashed line between the two bolt hole centres for A_{nt} is required to satisfy the geometrical condition $L = \sqrt{p_1^2 + s^2} > 4{,}4d$ (this length condition is specific to 12.2.3.4(3) and is based on the minimum bolt spacings given in Table 11.1 of 11.4(3), and with $s = 0{,}5p_2$). Now the value of A_{nt} is calculated from $Lt = (p_2 - s^2/4p_2)t$, where t is the constant thickness of the laminate.

Shown in Figure 1 is the length L for the single tension area A_{nt} along with the two shear areas such that for this staggered bolted connection configuration $A_{ns} = A_{ns,1} + A_{ns,1}$ (refer also to BR_12.2.3.4_PAR_1 and BR_12.2.3.4_PAR_5).

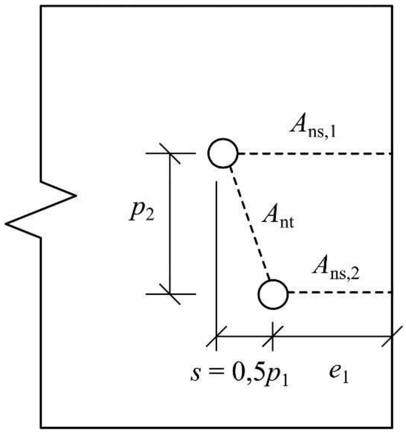


FIGURE 2 For a staggered bolt configuration the geometry for the calculation of the net area of the laminate subjected to tension (see area A_{nt}) and the net area of the laminate subjected to shear (see areas $A_{ns,1}$ and $A_{ns,1}$).

References

[1] Prabhakaran, R., Razzaq, Z., Devara, S. Load and Resistance Factor Design (LRFD) approach for bolted joints in pultruded composites, *Composites - Part B: Engineering*. 1996, **27**(3–4), 351–360. Available from: https://doi.org/10.1016/1359-8368(95)00021-6

[2] American Institute of Steel Construction (AISC). *Specification for Structural Steel Buildings and Commentary*. ANSI/AISC 360-10. AISC, Chicago, IL, 2016.

[3] EN 1993-1-1:2005. *Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings*.

[4] CEN/TS 19101:2022. *Design of fibre-polymer composite structures*.

REPORT NUMBER	BR_12.2.3.4_PAR_4
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.4 Block-shear failure
PARAGRAPH	(4)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT	
(4) The p_2 spacing for holes in adjacent legs of angles shall be taken as the sum of the values of spacing p_2 from the back of the angles less the thickness of the fibre-polymer composite angle.	

BLOCK-SHEAR FAILURE

Background

Paragraph 12.2.3.4(4) is for multi-bolted connections and joints with fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. There are no test results or alternative provenance to validate 12.2.3.4(4), which is based on there being no technical reason why the paragraph cannot be acceptable. Figure 1 illustrates a bolted joint configuration that can be used to explain the specific meaning of this paragraph for establishing the p_2 spacing. The end-on view figure shows an equal leg-angle of constant thickness, t, having bolting in both legs (say for two splice connections). The overall connection force (acting out of the page) is generated by bolt-bearing forces at the bolts in the line of bolting in both legs. There can be an equal number of bolts per leg or if bolting is staggered there could be one less bolt in either of the legs. Figure 1 illustrates how the p_2 spacing (i.e. the spacing measured perpendicular to the load transfer direction between adjacent lines of bolts), is "taken to be the sum of the values of the p_2 'spacings' from the back of the angles". These are in the figure the distances labelled $p_{2,\text{back},1}$ and $p_{2,\text{back},2}$, less the thickness of the fibre-polymer composite angle, which is t.

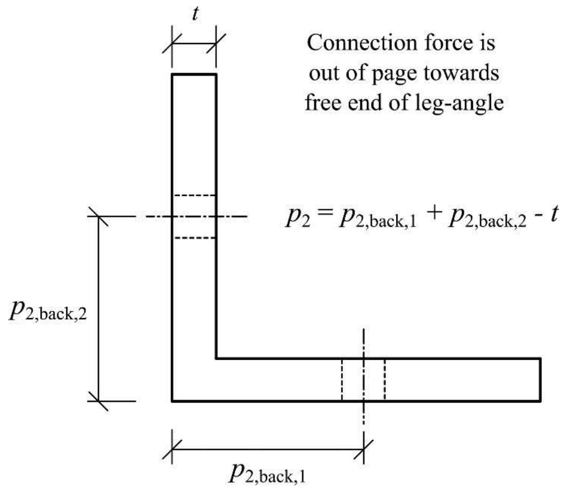


FIGURE 1 p_2 spacing for leg-angle with bolted joint having bolting in both legs.

REPORT NUMBER	BR_12.2.3.4_PAR_5
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.4 Block-shear failure
PARAGRAPH	(5)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(5) For a group of bolts subjected to eccentric in-plane tensile force (see Figure 12.7), its design value, N_{Ed}, for block-shear failure should satisfy the condition in Formula (12.27):

$$N_{\mathrm{Ed}} \le N_{\mathrm{bs,Rd}} \tag{12.27}$$

where

$N_{\mathrm{bs,Rd}}$ is the design value of the block-shear resistance of the multi-bolted connection with laminate of constant thickness, given by Formula (12.28),

$$N_{\mathrm{bs,Rd}} = 0{,}5\left(A_{\mathrm{ns}} \cdot f_{\mathrm{xy,v,d}} + 0{,}5 \cdot A_{\mathrm{nt}} \cdot f_{i,\mathrm{t,d}}\right) \tag{12.28}$$

where

A_{ns} is the net area of the laminate subjected to shear;
A_{ns} is the net area of the laminate subjected to tension, which should be taken as the gross area of the laminate less appropriate deductions of area for all holes, in accordance with the requirements of 12.2.3.4(2) or (3);
$f_{\mathrm{xy.v.d}}$ is the design value of the in-plane shear strength of the laminate, given by Formula (12.29),

$$f_{\mathrm{xy,v,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{xy,v,k}} \tag{12.29}$$

where

γ_{m} is defined in 4.4.5 (to be selected for $f_{\mathrm{xy,v,k}}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Block-shear failure);
η_{c} is defined in 4.4.7 (to be selected for $f_{\mathrm{xy,v,k}}$);
$f_{\mathrm{xy.v.k}}$ is the characteristic value of the in-plane shear strength of the laminate;

and where

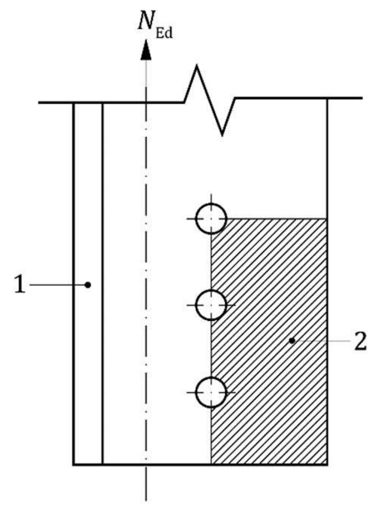
$f_{i,\mathrm{t.d}}$ is $f_{\mathrm{x,t,d}}$ when N_{Ed} is parallel to x direction and is $f_{\mathrm{y,t,d}}$ when N_{Ed} is parallel to y direction, given by Formulae (12.30) and (12.31),

$$f_{\mathrm{x,t,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{x,t,k}} \tag{12.30}$$

$$f_{\mathrm{y,t,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{y,t,k}} \tag{12.31}$$

where

γ_{m} is defined in 4.4.5 (to be selected for $f_{\mathrm{x,t,k}}$ or $f_{\mathrm{y,t,k}}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Block-shear failure);
η_{c} is defined in 4.4.7 (to be selected for $f_{\mathrm{x,t,k}}$ or $f_{\mathrm{y,t,k}}$);
$f_{\mathrm{x,t,k}}$, $f_{\mathrm{y,t,k}}$ is the characteristic value of the tensile strength of the laminate in the x and y directions.



Key:

(1) Flange outstand and
(2) Block shear failure

FIGURE 12.7 Illustrative example for a situation with eccentric tensile load.

BLOCK SHEAR FAILURE

Background

Paragraph 12.2.3.4(5) and Figure 12.7 are for multi-bolted connections and joints of fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. Reference [1] gives specific information from which 12.2.3.4(5) was prepared. More background information is to be found in Background Report BR_12.2.3.4_PAR_1, which is for the procedure giving the resistance when failure is by block shear mode and loading is for the concentric tensile load situation.

For illustration purposes only, Figure 1 shows an example of an eccentric in-plane tensile force loading situation (taken from reference [1]). This example is for a cope beam, which to the project team is an unknown detailing in the execution of fibre-polymer composite structures. It is however recognized that coping or notching of beams of I or H-profile cross section can be required to ensure

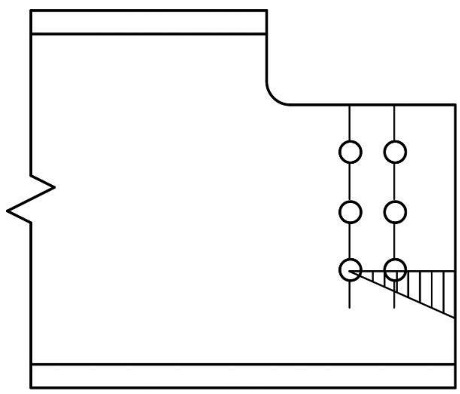


FIGURE 1 Block shear loading situations with assumed direct stress distributions [5] (reproduced with permission from ASCE).

that beam and column members can fit without conflict (interference). For buildability, it is often necessary in practice for fabricators to remove material from a flange or web for the intersecting components to fit.

The hashed area in Figure 1 shows the assumed direct stress distribution at the tensile failure plane, which has a linear increasing profile and is why the tensile force loading is classified as eccentric.

Resistance Formula (12.28) for eccentric loading is, as is the concentric load Formula (12.23) in 12.2.3.4(1) (refer to BR_12.2.3.4_PAR_1), taken from [1], and is for the situation where there is an eccentric tensile force in the bolted connection. Such a loading case is also illustrated in Figure 12.7 (in 12.2.3.4(5)) for a leg-angle member having a bolted connection in one leg (say for a splice connection). Formula (12.23) is modified for the eccentric loading resistance given by Formula (12.28) by having the addition of a 0,5 reduction factor to its tensile resistance component, given by $A_{ns} \cdot f_{i,t,d}$. Otherwise, Formula (12.28) has the same terms as Formula (12.23) (for information on this closed-form expression, refer to BR_12.2.3.4_PAR_1).

For fibre-polymer composite bolted connections there are **no** test results in the public domain known to the project team for the design situations where Formula (12.28) is deemed to be applicable.

Such structural situations with laminated components may require stiffening details, which are **not** illustrated in Figure 1 or Figure 12.7.

No additional commentary is required herein to introduce partial factor for a material or product property γ_m (defined in subclause 4.4.5 *Partial factors for materials* and corresponding to $f_{xy,v,k}$, $f_{x,t,k}$ and $f_{x,t,k}$) and conversion factor, η_c (defined in subclause 4.4.7 *Nominal conversion factors*). The characteristic values of the tensile strength of laminate materials in the x and y directions, $f_{x,t,k}$ and $f_{y,t,k}$, can be determined using test standard EN ISO 527 [2]. The characteristic values of the in-plane shear strength (xy plane) of the laminate materials, $f_{xy,v,k}$, can be determined using test standard ASTM D5379/D5379M [3] or D7078/D7078M [4]. There is no equivalent EN or ISO test standard. The interlaminar shear strength determined by test method EN ISO 14130 [5] is **not** appropriate for determining $f_{xy,v,k}$.

The following is taken from BR_4.4.6_PAR_3. Due to the lack of experimental data in the literature, it was not possible to apply the methodology described in BR_4.4.6_PAR_1 (used to determine the values of the partial factor associated with the uncertainty in a resistance model (γ_{Rd}) for profiles and laminates) to determine a specific value of γ_{Rd} for block-shear failure. Therefore, the value of γ_{Rd} = 1,5 for the block-shear mode of failure presented in Table 4.5 in 4.4.6(3) is based on the calibrated values of γ_{Rd} for the two failure modes of net-section and shear-out. The rationale for this assumption is concerned with the fact that block-shear failure may be regarded as a combination of shear-out and net-section failure. Future research is needed to confirm this hypothesis assumed by the drafting team.

References

[1] American Institute of Steel Construction (AISC). *Specification for Structural Steel Buildings and Commentary*. ANSI/AISC 360-10. AISC, Chicago, IL, 2016.
[2] EN ISO 527 (all parts). *Plastics – Determination of tensile properties.*
[3] ASTM D5379/D5379M-19e1. *Standard test method for shear properties of composite materials by the V-notched beam method.*
[4] ASTM D7078/D7078M-19e. *Standard test method for shear properties of composite materials by V-notched rail shear method.*
[5] EN ISO 14130:1997. *Fibre-reinforced plastic composites – Determination of apparent interlaminar shear strength by short-beam method.*

REPORT NUMBER	BR_12.2.3.6_PAR_1
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.6 Slip resistant bolted connections
PARAGRAPH	(1)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT	
(1) Resin injection bolts having a matrix material (e.g. of a polymer resin) filling the voiding between a bolt and the laminates (owing to presence of hole clearance, see Table 11.1) should make the bolted connection slip resistant.	

SLIP CRITICAL BOLTED CONNECTIONS

Background

Paragraph 12.2.3.6(1) is for bolted connections and joints of fibre-polymer composite components. References [1–5] give background (e.g. [1] is for the original site application of resin-injected bolts in old steel riveted bridges), and more specific information [2–5], from which 12.2.3.6(1) to 12.2.3.6(4) were prepared. For bolted connections of fibre-polymer composites, there are limited, yet positive, test results presented in [2, 3] on the long-term fatigue and slip-resistant properties of resin-injected bolted joints. References [4, 5] provide requirements and recommendations for the successful application with steel structures of resin-injected bolting in the field, which can be transferred appropriately for exploitation in fibre-polymer composite structures. The information in Annex J of standard BS EN 1090-2 [5] is derived from the seminal 1994 European Convention for Constructional Steel publication, that is, reference [4].

References

[1] Gresnigt, A.M., Sedlacek, G., Paschen, M. Injection bolts to repair old bridges. In: *Proceedings of the Fourth International Workshop Connections in Steel Structures IV*, Oct. 22–25, 2000, Roanoke, Virginia. American Inst. of Steel Construction. Chicago. 2000. 349–360. Available from: https://tinyurl.com/6j8hcvze [viewed 2023-09-15]

[2] Van Wingerde, A.M., Van Delft, D.R.V., Knudsen, E.S. Fatigue behaviour of bolted connections in pultruded FRP profiles. *Plastics, Rubber and Composites*. 2003, **32**(2), 71–76. Available from: https://doi.org/10.1179/146580103225009103

[3] Zafari, B., Qureshi, J., Mottram, J.T., Rusev, R. Static and fatigue performance of resin injected bolts for a slip and fatigue resistant connection in FRP bridge engineering. *Structures*. 2016, **7**, 71–84. Available from: https://doi.org/10.1016/j.istruc.2016.05.004

[4] European Convention for Constructional Steelwork (ECCS). *European Recommendations for Bolted Connections with Injection Bolts*. First Edition, ECCS Publication No. 79, Belgium, Brussels, 1994. Available from: https://tinyurl.com/y68r5agd [viewed 2023-09-15]

[5] EN 1090-2:2018. *Execution of steel structures and aluminium structures Part 2: Technical requirements for the execution of steel structures*.

REPORT NUMBER	BR_12.2.3.6_PAR_2
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.6 Slip resistant bolted connections
PARAGRAPH	(2)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT	
(2) Information on resin injection bolts in steelwork is given in Annex J to EN 1090-2 and this information may be used in the execution of a composite structure requiring slip resistant bolted connections.	

SLIP CRITICAL BOLTED CONNECTIONS

Background

Paragraph 12.2.3.6(2) is for bolted connections and joints of fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. The information in Annex J (informative) standard BS EN 1090-2 [1] is derived from the seminal ECCS publication, that is, reference [2]. Annex J in [1] provides information on the supply, installation and use of resin injection bolts.

Injection bolts may be used as non-preloaded or preloaded bolts, as specified. Filling of the clearance between the bolt and the inside surface of the hole is carried out by injecting a suitable polymer-based thermoset resin through a small hole (1) in the head of the bolt and a chamfered washer (2), as shown in Figure 1 (Figure J.1 in [1]). At the other end of the bolt, the washer has a groove (4) to let air escape as the resin fills the voiding. After injection and complete curing of the resin (3), the connection is slip-resistant.

Test results are presented by Zafari *et al.* [3] for plate-to-plate double lap bolted joints of pultruded material having resin injection bolts in accordance with BS EN 1090-2 [1] (with a modified

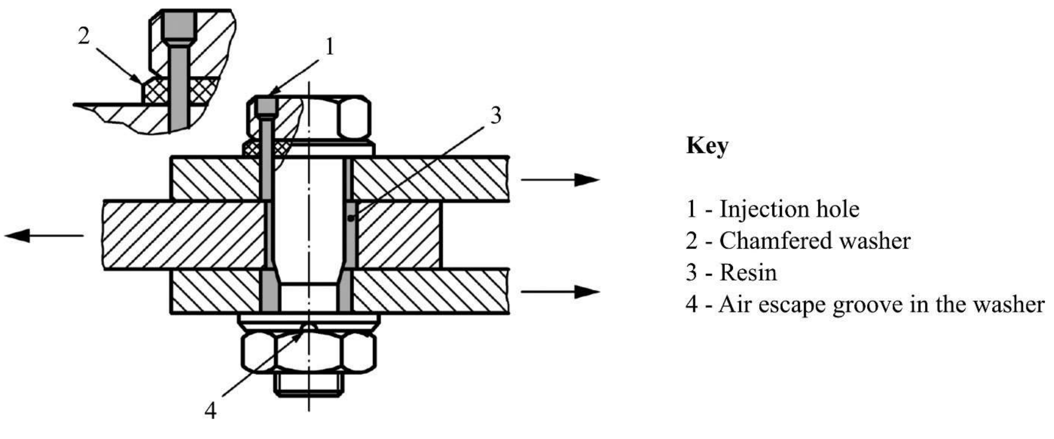


FIGURE 1 Injection bolt in a double lap joint [1] (permission to reproduce extracts from British Standards is granted by BSI Standards Limited (BSI). No other use of this material is permitted. British Standards can be obtained from BSI Knowledge knowledge.bsigroup.com).

washer detailing to aid resin flow), which are subjected to both static and fatigue actions. Reference [4] reports more static and fatigue loading test results where laminated joints have resin-injected bolted connections. One of the main findings from these two research and development contributions is that resin injection bolted joints show promise for structural engineering applications in fibre-polymer composite structures because they have the singular or dual requirements of slip and/or fatigue resistance.

References

[1] BS EN 1090-2:2018. *Execution of steel structures and aluminium structures Part 2: Technical requirements for the execution of steel structures.*

[2] European Convention for Constructional Steelwork (ECCS). *European Recommendations for Bolted Connections with Injection Bolts*. First Edition, ECCS Publication No. 79, Brussels, 1994. Available from: https://tinyurl.com/y68r5agd [viewed 2022-03-31]

[3] Zafari B., Qureshi J., Mottram J.T., Rusev R., Static and fatigue performance of resin injected bolts for a slip and fatigue resistant connection in FRP bridge engineering. *Structures*. 2016, **7**, 71–84. Available from: https://doi.org/10.1016/j.istruc.2016.05.004

[4] Abdelkerim, D.S.E., Wang, X., Ibrahim, H.A. and Wu, Z. Effect of connection techniques on the static and fatigue performance of pultruded basalt FRP multibolted joints. *Journal of Composites for Construction*. 2020, **24**(5), 04020046–2. Available from: https://doi.org/10.1061(ASCE)CC.1943-5614.00010

REPORT NUMBER	BR_12.2.3.6_PAR_3
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.6 Slip resistant bolted connections
PARAGRAPH	(3)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT (3) The design resistance of the resin injection bolted connection shall be determined by applying 12.1 to 12.2.3.5. In either 12.2.3.2(1) or (3) the reduction factor k_{cc} is taken equal to 1,0.	

SLIP CRITICAL BOLTED CONNECTIONS

Background

Paragraph 12.2.3.6(3) is for bolted connections and joints of fibre-polymer composite material components that satisfy relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. Because 12.2.3.6(3) is specific to CEN/TS 19101:2022, there is justification for why it requires this background report. The reduction factor $k_{cc} = \left(\frac{d_0}{d}\right)^2$, in Formula (12.10) or Formula (12.13) in subclause 12.2.3.2, is for pin-bearing resistances to account for the fact that the value of the nominal clearance hole d_0 is greater than the value of the nominal bolt diameter, d; that is $d_0 > d$ (refer to Background Report BR_11.4_PAR_3). Provance for the reduction factor k_{cc} is the PhD work by Oppe [1].

When we have a resin injection bolted connection there is no hole clearance because the voiding (for having a clearance) has been filled with a cured polymer-based thermoset resin. It is therefore now valid to assume that d_0 is equal to the nominal bolt diameter, d; that is $d_0 = d$. By applying this assumption, it follows that by 12.2.3.6(3) the reduction factor k_{cc} is taken equal to 1,0.

Reference

[1] Oppe, M., *Zur Bemessung geschraubter Verbindungen von pultrudierten faserverstärkten Polymerprofilen*. Schriftenreihe Stahlbau, Heft 66, Shaker-Verlag Aachen, 2009. (in German)

REPORT NUMBER	BR_12.2.3.6_PAR_5
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.6 Slip critical bolted connections
PARAGRAPH	(5)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT (5) As an alternative to resin injection bolts, a snug-fitting metal bushing or sleeve may be inserted in an over-sized hole.	

SLIP CRITICAL BOLTED CONNECTIONS

Background

Paragraph 12.2.3.6(5) is for bolted connections and joints with fibre-polymer composite components that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. When preparing 12.2.3.6(5) reference [1] reports the benefits of the application of snug-fitting steel bushings or steel sleeve inserts in the bolting on structural performance. The combined study for testing and finite element analysis demonstrates several benefits of introducing metal inserts, and these are as follows:

- the bolt preload relaxation is minimised;
- the load transfer by friction can be utilised;
- the joint efficiency is increased in terms of stiffness and strength.

Bolts predominantly loaded by static loads can be tightened to the *snug-tight* (spanner-tight) condition [2]. This tightness is attained by a person applying hand tightening with an ordinary metal spanner. This level of clamping with laminates is sufficient to produce a small friction force between the connected fibre-polymer composite components, which is enough for the bolted connection to transfer a small connection force with no slip between the components. Paragraph 12.2.1(15) (refer to Background Report BR_12.2.1_PAR_15) provides guidance on how to determine a bolt tightening torque that should prevent the possible failure mode of laminate crushing that might occur when there is no metal insert to react against the bolt tension for tightening. References [3, 4], after Mara *et al*. [1], are from an Australian research group who are studying for building structures the structural performance of mechanical metal inserts in bolted connections/joints in truss structures fabricated from hollow pultruded profiles.

References

[1] Mara, V., Haghani, R., Al-Emrani, M. Improving the performance of bolted joints in composite structures using metal inserts. *Journal of Composites Materials*. 2016, **50**(21). Available from: https://doi.org/10.1177/0021998315615204

[2] Kulak, G.L., Fisher, J.W., Struik, J.H.A. *Guide to Design Criteria for Bolted and Riveted Joints*. 2nd Edition, American Institute of Steel Construction, Inc., Chicago, IL, 2001.

[3] Hizam, R.M., Menalo, A.C., Karunasena, W., Bai, Y. Behaviour of pultruded GFRP truss system connected using through-bolt with mechanical insert. *Composites Part B – Engineering*. 2019, **168**, 44–57. Available from: https://doi.org/10.1016/j.compositesb.2018.12.052

[4] Hizam, R.M., Menalo, A.C., Karunasena, W., Bai, Y. Joint strength of single-bolted pultruded GFRP square hollow sections with mechanical inserts under elevated temperatures. *Journal of Composites for Construction*. 2020, **24**(1), 04019056. Available from: https://doi.org/10.1061/(ASCE)CC.1943-5614.0000984

REPORT NUMBER	BR_12.2.4.1_PAR_1
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.4.1 Pull-out failure
PARAGRAPH	(1)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	31 March 2022

CONTENT

(1) For out-of-plane (z direction) shear failure (see Figure 12.8) of laminates, the design value of the out-of-plane tensile force transferred at the bolt, $N_{z,Ed}$, for out-of-plane failure should satisfy the condition in Formula (12.32):

$$N_{z,Ed} \leq N_{po,Rd} \tag{12.32}$$

where,

$N_{po,Rd}$ is the design value of the pull-out resistance per bolt, given by Formula (12.33),

$$N_{po,Rd} = N_{z,Rd} = \pi \cdot d_w \cdot t \cdot f_{xz,v,d} \tag{12.33}$$

where

d_w is the diameter of the washer;
i is the total thickness of the laminate resisting $N_{z,Ed}$;
$f_{xz,v,d}$ is the design value of the out-of-plane shear strength (xz plane) of the laminate, given by Formula (12.34),

$$f_{xz,v,d} = \frac{\eta_c}{\gamma_m \cdot \gamma_{Rd}} \cdot f_{xz,v,k} \tag{12.34}$$

where

γ_m is defined in 4.4.5 (to be selected for $f_{xz,v,k}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Pull-out failure);
η_c is defined in 4.4.7 (to be selected for $f_{xz,v,k}$); $f_{xz,v,k}$ is the characteristic value of the out-of-plane shear strength (xz plane) of the laminate, which can be taken as the characteristic value of the interlaminar shear strength, $f_{xz,ILS,k}$.

NOTE: Formula (12.35) applies only if the material through the thickness t (see Figure 12.8) of the connection is of composite and is not applicable to sandwich panels.

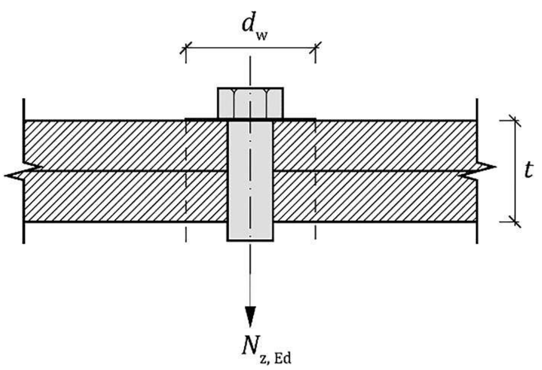


FIGURE 12.8 Pull-out failure caused by bolt tension force.

PULL-OUT FAILURE

Background

Paragraph 12.2.4.1(1) with Figure 12.8 is for bolted connections and joints of fibre-polymer composite components only. Should one component thickness in bolted connections be of another construction material, then 12.2.4.1(1) is invalid, and the pull-out failure strength should be determined by testing, in accordance with 4.5(1) in CEN/TS 19101:2022. Note that the pull-out failure mode is known also by the descriptor “pull-through” failure mode.

Resistance Formula (12.33) appears with a reduction factor of 0,5 as Equation (5.6) in the EUROCOMP Design Code and Handbook [1]. PhD thesis by Oppe [2] (in German language) gives specific technical information from which 12.2.4.1(1) was prepared. Formula (12.33) is Equation (3.5) in [2], developed using a test matrix of strength measurements for the pull-out failure mode, which in [2] is Table 4–10. These test results with pultruded materials are plotted in Figure 6–13 of the PhD thesis and have an accompanying evaluation discussion presented in Section 6.4 [2]. Reference [3] reports the PhD contribution in [2] for an analysis of the pull-out failure strength.

In reference [4], Turvey reports independent resistance test results for the pull-out failure mode, which could not be used to verify Formula (12.33). A reason for this is that Turvey did not make available in [4] the characteristic value of the out-of-plane shear strength (xz plane) of the laminate material, $f_{xy,v,k}$.

The characteristic value of the out-of-plane shear strength (xz plane) of the laminate, $f_{xz,v,k}$, may be taken to be the characteristic interlaminar shear strength determined by the test method in standard EN ISO 14130 [5].

No commentary is required herein to introduce partial factor for a material or product property γ_m (defined in subclause 4.4.5 *Partial factors for materials* and corresponding to $f_{xz,v,k}$) and conversion factor, η_c (defined in subclause 4.4.7 *Nominal conversion factors*).

The following is taken from Background Report BR_4.4.6_PAR_3. Due to the lack of experimental data in the literature, it was not possible to apply the methodology described in background report BR_4.4.6_PAR_1 (used to determine the values of the partial factor associated with the uncertainty in a resistance model (γ_{Rd}) for profiles and laminates) to determine a specific value of γ_{Rd} for pull-out failure. Therefore, the value of γ_{Rd} = 1,5 for pull-out failure reported in Table 4.5 in 4.4.6(3) is based on the calibrated values of γ_{Rd} for the two failure modes of net-section and shear-out. Future research to characterise the pull-out failure mode in bolted connections of fibre-reinforced polymer composites is needed to confirm this hypothesis.

References

[1] Clarke, J.L. (editor). *Structural Design of Polymer Composites. EUROCOMP Design Code and Handbook*. E & F Spon, London, 1996.

[2] Oppe, M. *Zur Bemessung geschraubter Verbindungen von pultrudierten faserverstärkten Polymerprofilen*. Schriftenreihe Stahlbau, Heft 66, Shaker-Verlag Aachen, 2009. (in German)

[3] Oppe, M., Knippers, J. Behaviour of bolted connections in GFRP subjected to tension loads. In: *Proceedings Fourth International Conference on Advanced Composites in Construction (ACIC 2009)*, Net Composites, Chesterfield, 495–506, 2009.

[4] Turvey, G.J. Experimental evaluation of bolt pull through in pultruded glass-fibre reinforced polymer plate. *Structures and Buildings*. 2011, **164**(5), 307–319. Available from: https://doi.org/10.1680/stbu.2011.164.5.307

[5] EN ISO 14130:1997. *Fibre-reinforced plastic composites – Determination of apparent interlaminar shear strength by short-beam method*.