REPORT NUMBER	BR_12.2.3_PAR_4
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3 Bolted connections subjected to in-plane actions
PARAGRAPH	(4)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(4) The design value of the connection shear force per bolt at the i^{th}-row of bolts, $V_{\text{b},i,\text{Ed}}$, should satisfy the condition in Formula (12.2):

$$V_{\text{b},i,\text{Ed}} = \frac{c_{\text{r},i}}{n_{\text{b},i}} N_{\text{Ed}} \tag{12.2}$$

where

N_{Ed} is the design value of the axial force for the connection force (tension or compression);
$c_{\text{r},i}$ is the bolt row load distribution coefficient listed in Table 12.1 for the i^{th}-bolt row, with reference to Figure 12.1;
$n_{\text{b},i}$ is the number of bolts at the i^{th} bolt row.

TABLE 12.1

Load distribution coefficients, $c_{\text{r},i}$, for the rows in a multi-bolted lap-shear connection of composite materials of constant thickness components

Row number ordering (composite)	Plate combination	Row 1 $c_{\text{r},1}$	Row 2 $c_{\text{r},2}$	Row 3 $c_{\text{r},3}$	Row 4 $c_{\text{r},4}$
1	composite/composite	1			
	composite/steel	1			
2	composite/composite	0,5	0,5		
	composite/steel	0,6	0,4		
3	composite/composite	0,4	0,2	0,4	
	composite/steel	0,5	0,3	0,2	
4	composite/composite	0,3	0,2	0,2	0,3
	composite/steel	0,4	0,3	0,2	0,1
> 4		Not permitted			

BOLTED JOINTS SUBJECTED TO IN-PLANE ACTIONS

Background

Paragraph 12.2.3(4) and Table 12.1 are for bolted connections and joints of fibre-polymer composite components that for the laminate(s) satisfy the 15 CEN/TS 19101:2022 paragraphs in subclause 12.2.1, except for 12.2.1(11), and the six paragraphs in subclause 12.2.2, except for 12.2.2(5). Table 12.1 is Table 5.3 *Fastener load distribution* in multi-row joint (as a proportion of average fastener load) in [1], with unknown provenance. The bolt force distributions in Table 12.1 of 12.2.3(4) are for bolted connections with both double-lap and single-lap shear configurations [1]. It is believed that they were obtained numerically from static (linear elastic and small displacement) finite element analysis using a modelling methodology that assumes the identical-sized bolts are just touching the perimeter of same-sized holes (i.e. no hole clearance) at the onset of tension loading being applied to the joint. The values for the case of three bolt rows and laminated plates are very similar to the numerical predictions using the independent analytical method from McCarthy *et al.* [2]. Note that Formula (12.2) is only indirectly linked to the resistance for failure of bolted connections in that it is used to establish the proportion of the total connection force, N_{Ed}, being resisted by the bolting at each of the bolt rows.

In the field, the load distribution between bolt rows will clearly be affected by the precise placement of the bolting in holes with hole clearance (nominally of size 1 mm). The redistribution of loading that occurs with initial clearance can be investigated theoretically using the McCarthy *et al.* [2] analysis method. Unlike ductile metals, fibre-polymer composite materials cannot redistribute "bearing" stresses that are caused by lack of fit, and so bolt placement in "bearing-type" connections (refer to Background Report BR_12.2.1_PAR_3) must be controlled when assembling fibre-polymer composite structures. It can be numerically shown that by simply adding more rows of bolts, there is not going to be a significant reduction in the proportion of force taken by the first row (where net-tension failure can occur). Accounting for the steel grades of bolting and range of diameters for the bolting in subclause 12.2.3 limits the maximum number of bolt rows to four.

For a first illustrative example, consider a 3 × 3 multi-row bolted connection of double lap shear configuration and the three plates of composite laminates, with N_{Ed} = 100 kN. According to Table 12.1 and Formula (12.2), the load distribution for the middle plate is at row i = 1 equal to 0,4 or 40 kN; row i = 2 equal to 0,2 or 20 kN; row i = 3 equal to 0,4 or 40 kN. In rows 1 and 3, each of the three bolts across the row of bolts according to 12.2.3(3) is to transfer a connection force of 13,3 kN (to the nearest 0,1 kN). The three bolts in row 2 each transfer a connection force of 6,7 kN (to the nearest 0,1 kN).

For a second illustrative example, consider a 4 × 4 multi-row bolted connection of double lap configuration, with a laminate sandwiched between two steel plates, and with N_{Ed} = 100 kN. According to Table 12.1 and Formula (12.2), the load distribution for the laminate is now at row i = 1 equal to 0,4 or 40 kN; row i = 2 equal to 0,3 or 30 kN; row i = 3 equal to 0,2 or 20 kN; row i = 4 equal to 0,1 or 10 kN. In row 1, each of the four bolts across the row of bolts according to 12.2.3(3) is to transfer a connection force of 10 kN. The four bolts in row 2 each transfer a connection force of 7,5 kN. The four bolts in row 3 each transfer a connection force of 5 kN, and finally, the four bolts in row 1 each transfer a connection force of 2,5 kN.

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REPORT NUMBER	BR_12.2.3.1_PAR_1
CLAUSE/ ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.1 Net-tension failure
PARAGRAPH	(1)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(1) When the net-tension force is oriented at an angle $0^\circ \leq \theta \leq \pm 5^\circ$ to the x direction of pultruded profiles or pultruded flat laminates of constant thickness (see Figures 12.2 and 12.3), its design value, N_{Ed}, for net-tension failure should satisfy the condition in Formula (12.3):

$$N_{Ed} \leq N_{x,nt,RD} \tag{12.3}$$

where

$N_{x,nt,Rd}$ is the design value of the net-tension resistance in the x direction, given by Formula (12.4),

$$N_{x,nt,Rd} = \frac{1}{k_{tc}} \cdot \left(w - n_{b,1} \cdot d_0 \right) \cdot t \cdot f_{x,t,d} \tag{12.4}$$

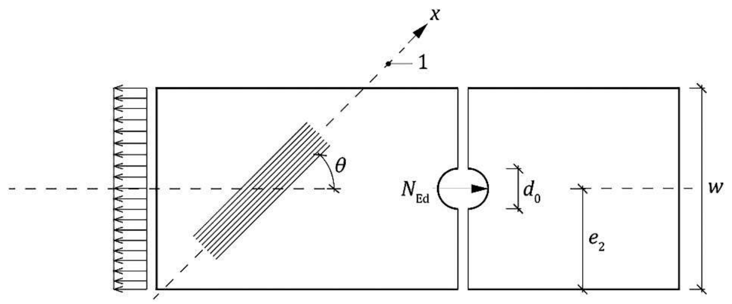
where

w is the width of the component ($w \geq 4d$, from Table 11.1), see also 12.2.3.1(5);
$n_{b,1}$ is the number of bolts across the first bolt row (Row 1) where the net-tension failure mode occurs (see Figures 12.2 and 12.3);
d_0 is the nominal bolt hole diameter;
t is the laminate thickness;
k_{tc} is a stress concentration factor that should be taken from Table 12.2 for specified bolted connection configurations that satisfy the geometry requirements in Table 11.1; for other bolted connection configurations, k_{tc} should be taken equal to 3,0;
$f_{x,t,d}$ is the design value of the tensile strength of the pultruded laminate in the x direction, given by Formula (12.5),

$$f_{x,t,d} = \frac{\eta_c}{\gamma_m \cdot \gamma_{Rd}} \cdot f_{x,t,k} \tag{12.5}$$

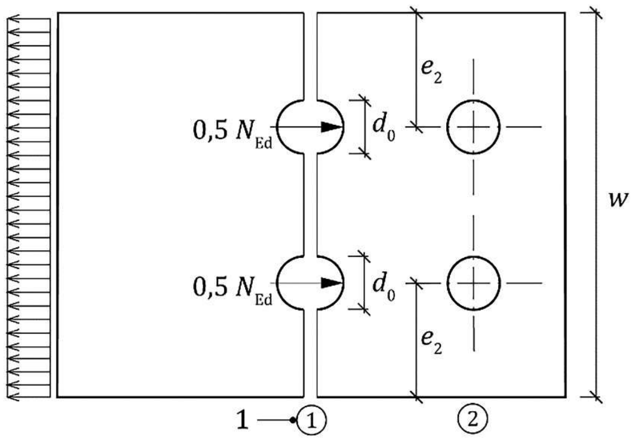
where

γ_m is defined in 4.4.5 (to be selected for $f_{x,t,k}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Net-tension failure);
η_c is defined in 4.4.7 (to be selected for $f_{x,t,k}$);
$f_{x,t,k}$ is the characteristic value of the tensile strength of the pultruded laminate material in the x direction.



Key:
(1) Principal direction of laminate or direction of pultrusion

FIGURE 12.2 Net-tension failure mode illustrated with a single bolt, $n_{b,1} = 1$.



Key:
(1) Row No. (i)

FIGURE 12.3 Net-tension failure mode illustrated with a 2 × 2 multi-bolted connection, $n_{b,1} = 2$.

TABLE 12.2

Values of stress concentration factor k_{tc} for specified bolted connection configurations when N_{Ed} is oriented with an angle $0° \leq \theta \leq \pm 5°$ to the major principal axis (x direction) of pultruded laminates with glass fibre reinforcement

Bolted connection configuration	k_{tc}
Single	2,0
1 × 2 (single row)	2,5
2 × 1 (single column)	2,5
1 × 3	2,5
3 × 1	2,5
2 × 2	2,0
3 × 3	1,5
1 × 1 (staggered)	2,0
2 × 2 (staggered)	2,0

NOTE: For staggered bolted configurations there is one bolt per bolt row. Configuration 1 × 1 (staggered) means there is a total of two bolts and two bolt rows, with distance between holes $L > 2{,}8$ (Table 11.1 and Figure 11.3).

NET-TENSION FAILURE

Background

Paragraph 12.2.3.1(1) is for bolted connections and joints of fibre-polymer composite components made by the pultrusion composite processing method that satisfy the relevant requirements in sub-clauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. References [1–9] give specific information from which 12.2.3.1(1) has been prepared. Figures 12.2 and 12.3 (in CEN/TS 19101:2022) illustrate two situations for net-tension failure at the first row of bolting. The situation of a single bolt row (here illustrated by the single bolt configuration) is shown in Figure 12.2. In this figure, the orientation of the principal direction of the laminate is defined in terms of the angle θ (in degrees) to the direction of loading that causes the net-tension mode of failure. For the net-tension strength to be based on the 0° direction tensile strength of the fibre-polymer composite laminate the direction of the loading must be oriented within 5° of the material's x-direction. A multi-bolted situation having two rows and two columns (for a 2 × 2 bolt configuration) is shown in Figure 12.3. For the multi-row case, the first row of bolts is most distant from the free edge. Note that for the resistance by Formula (12.4) to be valid the laminates are of constant thickness and there is to be symmetry with the in-plane geometry of the bolted connections.

The following study is for the preparation of Table 12.2 (in CEN/TS 19101:2022), which lists values of stress concentration factor k_{tc} for specified bolted connection configurations when N_{Ed} is oriented with an angle $0° \leq \theta \leq \pm 5°$ to the major principal axis (x-direction) of pultruded laminates having glass fibre reinforcement. It concerns the resistance Formula (12.4) when the mode of failure is net tension and there are different stress concentration factors (k_{tc}) for different bolted connection configurations. Formula (12.4) is for the situation when the tensile load is in the same direction as the principal direction of the laminate, which corresponds to the characteristic tensile strength $f_{x,t,k}$. In reference [2] the stress concentration factor k_{tc} is constant at 3,75 in the net-tension resistance Formula (8.3a). For the net tension mode of failure, reference [1] (see Figure 1) introduces the basic resistance Formula in (12.4) for a single bolted connection, without the stress concentration factor.

Table 1 reports experimental stress concentration factors (for k_{tc}) from plate-to-plate testing (often with only one (the middle) of the three plates in double lap shear specimens of pultruded fibre-polymer composite material), for several different single and multi-bolted connection configurations. The results are only for bolted connection configurations that satisfy the connection geometries specified in Table 11.1 of 11.4(2) in CEN/TS 19101:2022, and for completeness, Table 11.1 is reproduced below. This restriction in geometries means that several test results from several of the sources ([3–9]) had to be ignored in the analysis.

TABLE 11.1
Minimum requirements for bolted connection geometries (from CEN/TS 19101:2022)

Geometrical parameter	Requirement
Nominal bolt diameter (d)	$d \geq t_{min}$
(recommended range)	$\left(t_{min} \leq d \leq 1{,}5t_{min}\right)$
Nominal bolt-hole clearance	$d_0 - d \geq 1{,}0$ mm
Distances between holes	$p_1 \geq 4d$
	$p_2 \geq 4d$
	$L \geq 4{,}4d$
Distances from edges	side $e_2 \geq 2d$
single row	end $e_1 \geq 2{,}5d$ and $e_1 \geq 30$ mm
multi-rows	end $e_1 \geq 2d$

TABLE 1

Determination of the range of stress concentration factors from physical testing of plate-to-plate bolted connections with pultruded material having 0° orientation

Bolt configuration	Rosner [3][a] or Hassan [4][a]	Lutz [5][a] or Wang [6] or Turvey [7]	Prabhakaran Razzaq & Devara [8]	Matharu [9]	k_{tc} for Formula (12.5)
(1)	(2)	(3)	(4)	(5)	(6)
Single	1,0–1,6	1,5–1,6[a]; 1,5			**2,0**
1 × 2 (single row)	0,9–2,0	1,3–2,3; 1,6–2,2		1,5–1,8	**2,5**
2 × 1 (single column)	1,0–1,9	1,3–2,2	1,7	1,7	**2,5**
1 × 3	1,1–2,0				**2,5**
3 × 1	1,4–2,4				**2,5**
2 × 2	1,0–1,6	1,3–1,9, 1,4–2,1	1,8	1,2–1,3	**2,0**
3 × 3		1,2–1,4			**1,5**
1 × 1 × 2 (staggered)				1,9	**2,0**
2 × 1 × 2 (staggered)			2,1; 1,8; 2,1		**2,0**

[a] Width only 3*d* when geometry requirements specify a minimum of 4*d*.

In Table 1, the stress concentration factors (k_{tc}s) are established as follows:

1. Determine the net area tensile strength by using Formula (12.4) for 0° oriented material after setting k_{tc} = 1,0. The "mean" x-direction tensile strength of the pultruded material is taken from a source with the "mean" test results for strengths for a number of bolted connections failing in net tension.
2. Divide the predicted net area tensile strength calculated in Step 1 by the mean test strength taken directly from the source (which is a value in kN determined from test results for one to five specimens per batch).

Column (1) in Table 1 gives the bolted connection configurations that have been scoped by one or more of the sources offering relevant net-tension strength test results and material tensile strengths (mean values). It had to be assumed that the stress concentrations calculated from mean values would not be significantly different from the stress concentrations determined and reported in Table 1, had characteristic values been available. There is often one or more variables in a test programme that are not aligned exactly to what is specified by the paragraphs in 11.4 or Section 12 subclauses on bolted connections in CEN/TS 19101:2022. Columns (2)–(5) in the table report the range of stress concentration factors from the test results in sources [3–9] (with the connected laminates manufactured by the pultrusion composite processing method).

Using the data in Columns (2)–(5) leads to specifying in column (6) a limited number of different values for k_{tc} (which are < 3,75, with lowest at 1,5 and highest at 2,5), and these are used to prepare Table 12.2 that accompanies resistance Formula (12.4). Note that the k_{tc}s in column (6) are higher than their highest experimental-derived stress concentration, which in themselves, because of damage tolerance, are likely to be lower than the theoretical linear elastic stress concentration. These observations on the values of k_{tc} support the drafting team proposing that for other bolted connection configurations, the value of stress concentration factor k_{tc} can be taken to be equal to 3,0, its maximum value in Formula (12.4).

Because the test results from references [3, 4, 9] were considered complete and reliable, they were used to calibrate the partial factor associated with the uncertainty in a resistance model for the net-tension mode of failure. γ_{Rd} = 1,5 in Formula (12.4) was obtained from a calibration exercise using the procedure in prEN 1990 [10], and test results from [3, 4, 9]. The calibration for this partial factor of resistance, see Table 4.5 ((NDP) — Values of γ_{Rd} for bolted connections) in 4.4.6(3), is presented in Background Report BR_4.4.6_PAR_3. The characteristic value of the tensile strength of the pultruded laminate material in the x-direction, $f_{x,t,k}$, can be determined using test standard EN ISO 527 [11]. Future characterisation work to determine the net-tension resistances of bolted connections that are scoped in CEN/TS 19101:2022 can be used with the appropriate values of $f_{x,t,k}$ either to confirm γ_{Rd} = 1,5 or modify its value, which can be lower.

Using a different approach in [12], to establish the net-tension failure strengths of multi-bolted and multi-rowed bolted connections of pultruded fibre-polymer composites, Mottram shows that a value of k_{tc} = 3,75 in Formula (12.4) would be acceptable (i.e. for conservative design) for every conceivable joint configuration that satisfies subclause 12.2. This observation provides the designer with a conservative design approach should they prefer to use a single conservative value for the stress concentration factor k_{tc}.

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

References

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REPORT NUMBER	BR_12.2.3.1_PAR_2
CLAUSE/ ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.1 Net-tension failure
PARAGRAPH	(2)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(2) When the net-tension force is oriented at an angle $\pm 5° \leq \theta \leq \pm 90°$ to the x direction of pultruded profiles or pultruded flat laminates of constant thickness (see Figures 12.2 and 12.3), its design value, N_{Ed}, for net-tension failure should satisfy the condition in Formula (12.6):

$$N_{\mathrm{Ed}} \leq N_{\mathrm{y,nt,Rd}} \tag{12.6}$$

where

$N_{\mathrm{y,nt,Rd}}$ is the design value of the net-tension resistance in the y direction, given by Formula (12.7),

where

$$N_{\mathrm{y,nt,Rd}} = \frac{1}{k_{\mathrm{tc}}} \cdot \left(w - n_{\mathrm{b,1}} \cdot d_0\right) \cdot t \cdot f_{\mathrm{y,t,d}} \tag{12.7}$$

where

- w is the width of the component ($w \geq 4d$, from Table 11.1), see also 12.2.3.1(5);
- $n_{\mathrm{b,1}}$ is the number of bolts across the first bolt row where the net-tension failure mode occurs (see Figures 12.2 and 12.3);
- d_0 is the nominal bolt hole diameter;
- t is the laminate thickness;
- k_{tc} is a stress concentration factor that should be from Table 12.3 for specific bolted connection configurations that satisfy the geometry requirements in Table 11.1. For other bolted connection configurations k_{tc} should be taken equal to 3,0;
- $f_{\mathrm{y,t,d}}$ is the design value of the tensile strength of the pultruded laminate in the y direction, given by Formula (12.8),

$$f_{\mathrm{y,t,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{y,t,k}} \tag{12.8}$$

where

- γ_{m} is defined in 4.4.5 (to be selected for $f_{\mathrm{y,t,k}}$);
- γ_{Rd} is defined in 4.4.6 (Table 4.5, Net-tension failure);
- η_{c} is defined in 4.4. 7 (to be selected for $f_{\mathrm{y,t,k}}$);
- $f_{\mathrm{y,t,k}}$ is the characteristic value of the tensile strength of the pultruded laminate material in the y direction.

TABLE 12.3

Values of stress concentration factor k_{tc} for specified bolted connection configurations when N_{Ed} is oriented with an angle +5° ≤ θ ≤ ±90° to the major principal axis (x direction) of pultruded laminates with glass fibre reinforcement

Bolted connection configuration	k_{tc}
Single	2,5
1 × 2 (single row)	2,0
2 × 1 (single column)	2,0
1 × 3	2,0
3 × 1	2,0
2 × 2	2,0
3 × 3	1,5
1 × 1 (staggered)	2,0
2 × 2 (staggered)	2,0

NOTE: For staggered bolted configurations there is one bolt per bolt row. Configuration 1 × 1 (staggered) means there is a total of two bolts and two bolt rows, with distance between holes $L > 2{,}8$ (Table 11.1 and Figure 11.3).

NET-TENSION FAILURE

Background

Paragraph 12.2.3.1(2) is for bolted connections and joints of fibre-polymer composite material components made by the pultrusion composite manufacturing process that satisfy the relevant requirements in subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. References [1–8] give specific information from which 12.2.3.1(2) has been prepared. Note that for the resistance by Formula (12.7) to be valid the fibre-polymer composite material is of constant laminate thickness and that there is symmetry with the in-plane geometry of the bolted connections. For the net-tension strength to be based on the 90° direction tensile strength of the fibre-polymer composite the direction of the loading must be oriented > 5° to the material's x-direction.

The following study is for the preparation of Table 12.3 in CEN/TS19101:2022, which lists values of stress concentration factor k_{tc} for specified bolted connection configurations when N_{Ed} is oriented with an angle +5° ≤ θ ≤ ±90° to the major principal axis (x-direction) of pultruded laminates with glass fibre reinforcement. Note that when the angle of orientation is > 5° the net-tension resistance is based on the 90° tensile strength of the material, which is for a lower bound prediction of strength. It concerns the resistance Formula (12.7), when the mode of failure is net-tension and there are different stress concentration factors (k_{tc}) for different bolted connection configurations. Formula (12.7) is for the situation when the tensile load is oriented from 5° to 90° to the major principal direction of the fibre-polymer composite material/laminate. In reference [2] the stress concentration factor k_{tc} was constant at 3,75 in the net-tension resistance Formula (8.3b). Reference [1] (see Figure 1) introduces for the net-tension mode of failure the basic resistance formula for (12.7) for a single bolted connection, without the stress concentration factor.

Table 1 reports experimental stress concentration factors (for k_{tc}) from plate-to-plate testing (often with only one (the middle) of the three plates in the double lap shear specimens of pultruded fibre-polymer composite material), for several different single and multi-bolted connection configurations. The results are only for bolted connection configurations that satisfy the connection geometries specified in Table 11.1 from 11.4(2) in CEN/TS 19101:2022, which is reproduced next.

TABLE 11.1

Minimum requirements for bolted connection geometries (from CEN/TS 19101:2022)

Geometrical parameter	Requirement
Nominal bolt diameter (d)	$d \geq t_{\min}$
(recommended range)	$\left(t_{\min} \leq d \leq 1{,}5t_{\min}\right)$
Nominal bolt-hole clearance	$d_0 - d \geq 1{,}0$ mm
Distances between holes	$p_1 \geq 4d$
	$p_2 \geq 4d$
	$L \geq 4{,}4d$
Distances from edges	side $e_2 \geq 2d$
single row	end $e_1 \geq 2{,}5d$ and $e_1 \geq 30$mm
multi-rows	end $e_1 \geq 2d$

This restriction means several test results from a number of sources had to be ignored. In Table 1, the stress concentration factors (k_{tc}s) are established as follows:

1. Determine the net area tensile strength by using Formula (12.7) for 90° oriented material after setting k_{tc} = 1,0. The "mean" y-direction tensile strength of the pultruded material is taken from the publication with the "mean" test results for strengths for a number of bolted connections failing in net tension.
2. Divide the predicted net area tensile strength from step 1 by the mean test strength taken directly from the source (which is a value in kN from one to five specimens per batch).

Column (1) in Table 1 gives the bolted connection configurations that have been scoped by one or more of the sources of relevant net-tension strength test results and material tensile strengths. It had to be assumed that the stress concentrations calculated from mean values would not be significantly different to the stress concentrations determined and reported in Table 1, had characteristic values been available. There are often one or more variables in a test programme that are not aligned exactly with what is specified by the paragraphs in 11.4 or Section 12 in CEN/TS 19101:2022. Columns (2)–(5) in the table report the range of stress concentration factors from the publication sources [3] to [8] (with the connected fibre-polymer composite plates made by the pultrusion processing method).

Using the data in Columns (2)–(5) leads to specifying in column (6) a limited number of different values for k_{tc} (which are << 3,75, with lowest at 1,5 and highest at 2,5), and these are used to prepare Table 12.3 with Formula (12.7). Note that the k_{tc}s in column (6) are higher than their highest experimental-derived stress concentration, which in themselves, because of damage tolerance, are likely to be lower than the theoretical linear elastic stress concentration. These observations support the drafting team proposing that for other bolted connection configurations the value of stress concentration factor k_{tc} can be taken equal to 3,0.

Because the test results from references [3, 4, 8] were considered complete and reliable they were used to calibrate the partial factor associated with the uncertainty in a resistance model for the net-tension mode of failure. γ_{Rd} = 1,5 in Formula (12.7) was obtained from a calibration exercise using the procedure in prEN 1990 [9] and test results from [3, 4, 8]. The calibration for this partial factor of resistance is presented in Background Report BR_4.4.6_PAR_3. The characteristic value of the tensile strength of the pultruded laminate material in the y direction, $f_{y,t,k}$, can be determined using test standard EN ISO 527 [10]. Future characterisation work to determine the net-tensile resistances of bolted connections that are scoped in CEN/TS 19101 can be used with the appropriate values of $f_{x,t,k}$ either to confirm γ_{Rd} = 1,5 or modify its value, which can be lower.

TABLE 1

Determination of the range of stress concentration factors from physical testing of plate-to-plate bolted connections with pultruded material having 90° orientation

Bolt configuration	Rosner [3][a] or Hassan [4][a]	Lutz [5][a] or Wang [6] or Turvey [7]	Matharu [8]	k_{tc} for Formula (12.8)
(1)	(2)	(3)	(5)	(6)
Single	1,5–1,6	1,3–2,5	1,0–1,1	**2,5**
1 × 2 (single row)	1,0–1,9			**2,0**
2 × 1 (single column)	0,9–1,8			**2,0**
1 × 3	0,8–1,3			**2,0**
3 × 1	0,9–1,7			**2,0**
2 × 2	0,8–1,3			**2,0**
3 × 3				**1,5**
1 × 1 (staggered)				**2,0**
2 × 1 (staggered)				**2,0**

[a] Width only 3*d* when geometry requirements specify a minimum of 4*d*.

Using a different approach in [11], to establish the net-tension failure strengths of multi-bolted and multi-rowed bolted connections of pultruded fibre-polymer composites Mottram shows that a value of k_{tc} = 3,75 in Formula (12.7) would be acceptable for every configuration that satisfies subclause 12.2 in CEN/TS 19101:2022. This observation provides the designer with a conservative design approach should they prefer to use a single conservative value for the stress concentration factor k_{tc}.

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 $f_{x,t,k}$) and conversion factor, η_c (defined in subclause 4.4.7 *Nominal conversion factors*).

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

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REPORT NUMBER	BR_12.2.3.1_PAR_3
CLAUSE/ ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.1 Net-tension failure
PARAGRAPH	(3)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(3) For balanced symmetrical flat laminates, regardless of the composite manufacturing process, of constant thickness having plies reinforced with continuous glass fibres arranged in the two orthogonal directions x and y, Formulae (12.4) and (12.7) may be used:

- For N_{Ed} acting at an angle $0° \leq \theta \leq \pm 5°$ to the laminate's x direction, Formula (12.4) is used with $f_{y,t,k}$; the stress concentration factor k_{tc} should be taken from Table 12.2 or, for other bolted connection configurations, k_{tc} should be taken equal to 3,0.
- For N_{Ed} acting at an angle of between $\pm 5° \leq \theta \leq \pm 90°$ to the laminate's x–direction, Formula (12.7) is used with $f_{y,t,k}$; the stress concentration factor k_{tc} should be taken from Table 12.3 or, for other bolted connection configurations, k_{tc} should be taken equal to 3,0.

NET-TENSION FAILURE

Background

Paragraph 12.2.3.1(3) is for bolted connections and joints of fibre-polymer composite components that satisfy 12.2.2(2). 12.2.3.1(3) is valid when fibre-polymer composites are of balanced symmetrical flat laminates, regardless of the composite processing method used to manufacture them. This type of laminate is scoped in CEN/TS 19101:2022, and for background information on balanced symmetrical laminates, see reference [1]. 12.2.3.1(3) cannot be based on verification using test results to determine stress concentration factors, for the value of k_{tc} in either formula (12.4) or (12.7). This is principally because the test results required are not available. A pragmatic approach has therefore been taken by the drafting team. Knowing what has been established in 12.2.3.1(1) and 12.2.3.1(2) (refer to Background Reports BR_12_2_3_1_PAR_1 and BR_12_2_3_1_PAR_2), is acceptable to determine the net-tension resistance of bolted (double-lap) connections (joints) of pultruded laminates, the project team could not find any technical reason why the same design procedure cannot be extended to be used with laminates made by other composite processing methods, with the proviso that the fibre-reinforcement in the laminates is balanced and symmetrical.

Reference

[1] 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_12.2.3.1_PAR_5
CLAUSE/ ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.1 Net-tension failure
PARAGRAPH	(5)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT	
(5) When laminates in bolted connections have a flange outstand or web (often perpendicular to the plane of the laminate with the bolting) it may increase side distance e_2 (see Figures 12.2 and 12.3), to be included in establishing the width w in Formula (12.4) or Formula (12.7). Distance e_2 should be taken from the centre of the hole to the nearest outstand or web edge plus either 0,5 times the web height or 0,5 times the outstand width, whichever applies.	

NET-TENSION FAILURE

Background

Paragraph 12.2.3.1(5) is for 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. The single bolted connection in Figure 1 can be used as an illustrative example to show how 12.2.3.1(5) can be applied in establishing the width w in Formula (12.4) or Formula (12.7). The figure shows a leg-angle member with leg depths of h, and there is a tensile connection force in this leg-angle member that is resisted by the single bolted connection shown. 12.2.3.1(5) is required to establish the (upper) side distance e_2 on the side where there is the other leg-angle that is oriented perpendicular (and illustrated to be coming out of the page) to the leg in the plane of the view. In accordance with this paragraph, distance e_2 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. The "second" side's distance, e_2, has the dimension labelled in Figure 1.

Additional information on how to establish distances e_2 for the net-tension using another approach is given in the commentary sub-section C8.3.2.4 Net Tension Strength in [1].

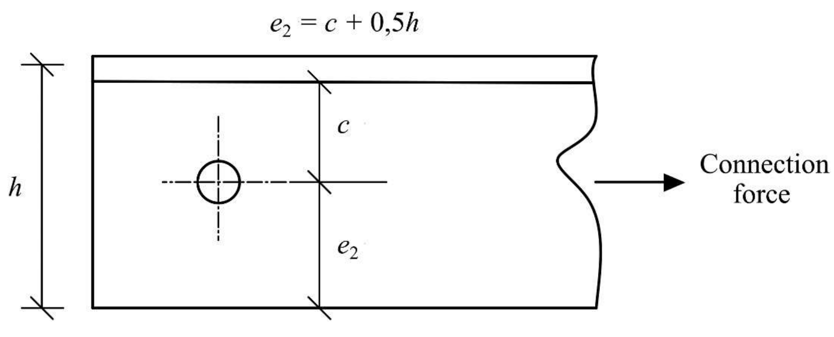


FIGURE 1 Leg-angle having a depth of the outstand height equal to h.

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_12.2.3.2_PAR_1
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.2 Pin-bearing failure
PARAGRAPH	(1)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(1) When the connection force per bolt is oriented at an angle 0° ≤ θ ≤ ±5° to the x direction of the laminate (see Figure 4), the design value of the bearing force transferred per bolt at the i^{th}-bolt row, $V_{\mathrm{br},i,\mathrm{Ed}}$, for pin-bearing failure should satisfy the condition in Formula (12.9):

$$V_{\mathrm{br},i,\mathrm{Ed}} \leq V_{\mathrm{x,br,Rd}} \tag{12.9}$$

where

$V_{\mathrm{br},i,\mathrm{Ed}}$ is given by Formula (12.2);
$V_{x,\mathrm{br,Rd}}$ is the design value of the pin-bearing resistance per bolt in the x direction, given by Formula (12.10),

$$V_{\mathrm{x,br,Rd}} = 1{,}5 \cdot \frac{1}{k_{\mathrm{cc}}} \cdot d \cdot t \cdot f_{\mathrm{x,br,d}} \tag{12.10}$$

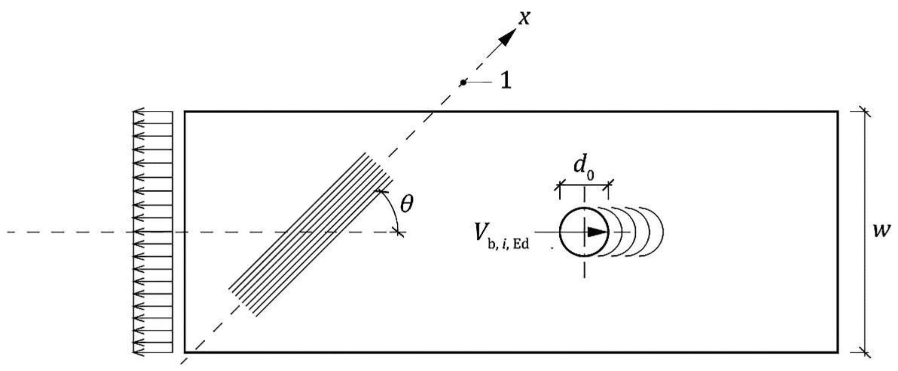
where

k_{cc} is the reduction factor $\left(\frac{d_0}{d}\right)^2$ accounting for the bearing compressive stress concentration in front of the bolt from having a clearance hole with limit on dimension as specified in Table 11.1;
d is the nominal bolt diameter;
d_0 is the nominal bolt hole diameter;
t is the thickness of the laminate resisting $V_{\mathrm{br},i,\mathrm{Ed}}$;
$f_{\mathrm{x,br,d}}$ is the design value of the pin-bearing strength in the x direction of the laminate, given by Formula (12.11),

$$f_{\mathrm{x,br,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{x,br,k}} \tag{12.11}$$

where

γ_{m} is defined in 4.4.5 (to be selected for $f_{\mathrm{x,br,k}}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Pin-bearing failure);
η_{c} is defined in 4.4. 7 (to be selected for $f_{\mathrm{x,br,k}}$);
$f_{\mathrm{x,br,k}}$ is the characteristic value of the pin-bearing strength in the x direction of the laminate that may be determined in accordance with the requirements of procedure C in ASTM D953, but allowing to consider testing with bolt diameters different to the laminate thickness.



Key:

(1) Principal direction of laminate or direction of pultrusion

FIGURE 12.4 Pin-bearing failure mode for a single bolt

PIN-BEARING FAILURE

Background

Paragraph 12.2.3.2(1) 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. References [1–14] give historical background or specific information from which the paragraph was drafted. Figure 12.4 illustrates the situations for pin-bearing failure at a single bolt, which can be one in a group of bolts for a multi-bolted connection. In this figure, the series of arc lines in front of the bolt is to illustrate progress bearing (crushing) failure in the laminate. Note that there will be delamination fractures, as well as other material failure fractures through the thickness of the laminate adjacent to the hole surface where the (plain) bolt shaft is in bearing to transfer the connection force, $V_{br,i,Ed}$ (refer to Background Report BR_12.2.3_PAR_4). The figure also shows that the orientation of the principal direction of the laminate is defined in terms of the angle θ (in degrees) to the direction of connection force that is causing the bearing mode of failure. For the bearing strength to be based on the characteristic value of the pin-bearing strength in the x direction or 0° direction of the laminate the direction of the loading must be oriented within ±5° of the laminate's x-direction.

Reference [1] is an earlier source for introducing Formula (12.10), but without factor $1{,}5 \times 1/k_{cc}$. Both sources [3, 4] have Formula (12.10), again without factor $1{,}5 \times 1/k_{cc}$. Publications [7, 8] are the outputs of two national projects to prepare a design standard for fibre-polymer composite structures. For the strength design of bolted connections, the resistance formula for the bearing mode of failure is, again, Formula (12.10), and, again, without factor $1{,}5 \times 1/k_{cc}$. The PhD work of Oppe [5] reports the development that leads to the expression in Formula (12.10) for reduction factor $1/k_{cc}$, which is in terms of nominal bolt diameter, d, and the larger nominal hole diameter, d_0.

Underlying principles in 12.2.3.2(1) were developed from the ASCE LRFD pre-standard (see 8.3.2.3(3) in [8]) and discussed in the Commentary sub-section C8.3.2.3, also in [8].

Commentary sub-section C8.3.2.3 in [8] explains that pin-bearing strength depends on several bolted connection parameters, including, but not limited to the fibre-polymer composite's mechanical properties and laminate thickness, the steel bolt diameter and the hole diameter (for bolt hole clearance). Values for the characteristic pin-bearing strength can be determined by testing with, for the bolted connections to be designed, the specific mechanical properties and thicknesses of the laminates, the specific pin or bolt diameters (with a plain/smooth shank), and the specific hole diameters (with geometry within allowed tolerances), as provided in subclause 12.2.1, and in accordance with test procedure C in ASTM D953 [14].

The relevance of [9] is that it gives details as to why test procedure C in the 2019 version of ASTM D953 [14] is appropriate to determine the characteristic pin-bearing strength when a component's dimensions (e.g. standard pultruded profiles) are not large enough to cut-out coupons with the required dimensions to conduct the pin-bearing strength test using the double lap-shear bolted connection test configuration and procedure A in [14]. The only modification from the requirements of procedure C is that the pin diameter is a test variable, and its dimension is **not** governed, as it is by [14], to be the laminate thickness.

Next, there's an introduction to testing with bearing the mode of failure that provides test results for bearing strengths, for knowledge and understanding that informed the drafting of 12.2.3.2(1). The importance of the bolted connection test results in [2], having three different levels of bolt tightening, is that they support the characteristic pin-bearing strength to be the pin-bearing value (when there is no lateral restraint) because the lower bound bearing strength is determined under the unrestrained test condition.

Test results for pin-bearing strengths of a fibre-polymer composite material manufactured using a vacuum-laminated composite processing method are reported in [6] and for pultruded fibre-polymer composite materials they are reported in [10] and [11]. These contributions provide evidence to specify when using Formula (12.7), for the design value of the pin-bearing resistance per bolt in the x direction ($V_{x,br,Rd}$), the limitation on connection force angle θ of $0° \leq \theta \leq \pm 5°$ to the x direction of the laminates, which is for the major principal axis of fibre-polymer composite materials.

The conference paper presenting test results by Troutman and Mosteller [13] is mentioned in this Background Report to highlight that manufacturers/fabricators do undertake programmes of physical testing to characterise the bearing strengths of their laminate materials.

CEN/TS 19101:2022 recommends not to have thread in bearing over a length greater than 1/3rd of a laminate thickness, refer to BR_12.2.1_PAR_7 for this design guideline. A bespoke series of pin-bearing strength tests were conducted by Matharu and Mottram [12] to have test results with (over the full-length) and without thread present in bearing. This data shows that if thread is permitted there is a requirement for a reduction factor for the presence of thread in bearing. Such a reduction factor was developed when [8] passed through a Standard Committee stage to account for the North American practice of having full-length threads in bearing. At the time of finalising this background report the ASCE LRFD standard, after [8], remains to be published as ASCE/SEI 74.

A comprehensive series of test results are presented in Matharu's PhD thesis [11] with a total of 1000 (aged and non-aged) pin-bearing strengths and 325 bolted connection/joint resistances.

The characteristic value of the pin-bearing strength in the x direction of the laminate, $f_{x,br,k}$, in Formula (12.10) in 12.2.3.2(1) can be determined in accordance with the requirements of procedure C in ASTM D953-19 [14], but allowing testing to proceed with bolt diameters different to the laminate thickness. There is no equivalent EN or ISO standard for the required procedure C test method. Annex E (normative) in EN 13706-2 [15] is for a test method for the determination of the pin bearing strength, yet its scope (see Table 1 in EN 13706-2) is only to determine the bearing strength to verify the specific requirement that the minimum property values presented in rows 1.6 and 1.7 in Table 1 of EN 13706-3 [3] are satisfied. This test method is not appropriate to determine, for example, the characteristic pin-bearing strength $f_{x,br,k}$ used in Formula (12.11).

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 $f_{x,br,k}$) and conversion factor, η_c (defined in subclause 4.4.7 *Nominal conversion factors*).

Factor 1,5 in Formula (12.10) was obtained from a calibration exercise using the prEN 1990 [16] procedure and the test results in [11]. The partial factor associated with the uncertainty in a resistance model (γ_{Rd}) for the pin-bearing mode of failure is 1,5 from Table 4.5 in 4.4.6(3). The calibration of γ_{Rd} is presented in BR_4_4_6_PAR_3.

Future characterisation work to determine the pin-bearing resistances of bolted connections that are scoped in CEN/TS 19101:2022 can be used with the appropriate values of $f_{x,br,k}$ to confirm $\gamma_{Rd} = 1,5$.

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

REPORT NUMBER	BR_12.2.3.2_PAR_3
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.2 Pin-bearing failure
PARAGRAPH	(3)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(3) When the connection force per bolt is oriented at an angle of ±5° ≤ θ ≤ ±90° to the x direction of the laminate (see Figure 4), the design value of the bearing force transferred per bolt at the i^{th}-bolt row, $V_{\mathrm{br},i,\mathrm{Ed}}$, for pin-bearing failure should satisfy the condition in Formula (12.12):

$$V_{\mathrm{br},i,\mathrm{Ed}} \leq V_{\mathrm{y,br,Rd}} \tag{12.12}$$

where

$V_{\mathrm{br},i,\mathrm{Ed}}$ is given by Formula (12.2);
$V_{\mathrm{y,br,Rd}}$ is the design value of the pin-bearing resistance per bolt in the y direction, given by Formula (12.13),

$$V_{\mathrm{y,br,Rd}} = 1{,}5 \cdot \frac{1}{k_{\mathrm{cc}}} \cdot d \cdot t \cdot f_{\mathrm{y,br,d}} \tag{12.13}$$

where

k_{cc} is the reduction factor $\left(\frac{d_0}{d}\right)^2$ accounting for the bearing compressive stress concentration in front of the bolt from having a clearance hole with limit on dimension as specified in Table 11.1;
d is the nominal bolt diameter;
d_0 is the nominal bolt hole diameter;
t is the thickness of the laminate resisting $V_{\mathrm{br},i,\mathrm{Ed}}$;
$f_{\mathrm{y,br,d}}$ is the design value of the pin-bearing strength in the y direction of the laminate, given by Formula (12.14),

$$f_{\mathrm{y,br,d}} = \frac{\eta_{\mathrm{c}}}{\gamma_{\mathrm{m}} \cdot \gamma_{\mathrm{Rd}}} \cdot f_{\mathrm{y,br,k}} \tag{12.14}$$

where

γ_{m} is defined in 4.4.5 (to be selected for $f_{\mathrm{y,br,k}}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Pin-bearing failure);
η_{c} is defined in 4.4.7 (to be selected for $f_{\mathrm{y,br,k}}$);
$f_{\mathrm{y,br,k}}$ is the characteristic value of the pin-bearing strength in the y direction of the laminate that may be determined in accordance with the requirements of procedure C in ASTM D953, but allowing to consider testing with bolt diameters different to the laminate thickness.

PIN-BEARING FAILURE

Background

Paragraph 12.2.3.2(3) 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. There are only two modifications between this paragraph and 2.2.3.2(1), and, so for background information, you should read Background Report BR_12.2.3.2_PAR_1.

The key modification in 12.2.3.2(3) is that the pin-bearing resistance for Formula (12.13) is being determined with the characteristic value of the pin-bearing strength in the y-direction of the fibre-polymer composite material, that is, $f_{y,br,k}$.

Test results for pin-bearing strength of a fibre-polymer composite material manufactured using a vacuum laminated processing method are reported in [1], and for pultruded fibre-polymer composite materials in [2, 3]. These contributions informed the second modification from 12.2.3.2(1), being that in Formula (12.10), with $f_{y,br,Rd}$, the connection force per bolt is oriented at an angle θ (in degrees) in the range $\pm 5° \leq \theta \leq \pm 90°$ to the x-direction of the laminates, which is for the major principal axis of fibre-polymer composite materials. Note that, except when θ is in the narrow range ±5° the characteristic pin-bearing strength for all other connection force orientations is to the lower bound value, given by characteristic pin-bearing strength $f_{y,br,k}$.

CEN/TS 19101:2022 recommends not to have thread in bearing over a length greater than 1/3rd of a laminate thickness, refer to BR_12.2.1_PAR_7 for this design guideline. A bespoke series of pin-bearing strength tests have been conducted by Matharu and Mottram [4] to have resistances with (over the full-length) and without thread present in the bearing. These test results show that if thread is permitted there is a requirement for a reduction factor for the presence of thread in bearing. Such a reduction factor was developed to account for the North American practice of having a full-length thread in bearing when an LRFD pre-standard [5] passed through a Standard Committee stage. At the time of finalising this background report the ASCE LRFD standard, after [5], remains to be published as ASCE/SEI 74.

A comprehensive series of test results are presented in Matharu's PhD thesis [3] for a total of 1000 (aged and non-aged) pin-bearing strengths and 325 bolted connection/joint resistances.

The characteristic value of the pin-bearing strength in the y-direction of the laminate, $f_{y,br,k}$, in Formula (12.13) in 12.2.3.2(3) can be determined in accordance with the requirements of procedure C in ASTM D953-19 [6], but allowing testing to proceed with bolt diameters different to the laminate thickness. There is no equivalent EN or ISO standard for the required procedure C test method. Annex E (normative) in EN 13706-2 [7] is for a test method for the determination of the pin bearing strength, yet its scope (see Table 1 in EN 13706-2) is only to determine the bearing strength to verify the specific requirement that the minimum property values presented in rows 1.6 and 1.7 in Table 1 of EN 13706-3 [8] are satisfied. This test method is not appropriate to determine, for example, the characteristic pin-bearing strength $f_{y,br,k}$ used in Formula (12.14).

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 $f_{y,br,k}$), and conversion factor, η_c (defined in subclause 4.4.7 *Nominal conversion factors*).

Factor 1,5 in Formula (12.13) was obtained from a calibration exercise using the prEN 1990 [9] procedure and test results from [3]. The partial factor associated with the uncertainty in a resistance model (γ_{Rd}) for the pin-bearing mode of failure is 1,5 from Table 4.5 in 4.4.6(3). The calibration of γ_{Rd} is presented in BR_4_4_6_PAR_3. It has been assumed that the calibrated value of $\gamma_{Rd} = 1,5$ in Table 4.5 of 4.4.6(3) for pin-bearing failure calculated using 0° direction (x-direction) material is valid for the 90° direction (y-direction) material and for material orientations in range $\pm 5° \leq \theta \leq \pm 90°$.

Future characterisation work to determine the pin-bearing resistances of bolted connections that are scoped by the Technical Specification can be used with the appropriate values of $f_{y,br,k}$ to confirm $\gamma_{Rd} = 1,5$.

References

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REPORT NUMBER	BR_12.2.3.2_PAR_4
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.2 Pin-bearing failure
PARAGRAPH	(4)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023
CONTENT	
(4) When there is consideration of bolt flexure (e.g., with the detailing in Figure 11.4) the design value of the pin-bearing strength $f_{x,br,d}$ in Formula (12.10) or $f_{y,br,d}$ in Formula (12.13) should be reduced by a factor of 0,5.	

PIN-BEARING FAILURE

Background

Paragraph 12.2.3.2(4) is for bolted connections and joints of fibre-polymer composite material components that satisfy the relevant requirements of subclauses 12.2.1 and 12.2.2 in CEN/TS 19101:2022. Bolted connections using closed sections of fibre-polymer composites that have limited or no access to an inside surface to introduce nuts to for individual bolted connections (as illustrated in Figure 11.4 in paragraph 11.4(7) and Figure 1) can cause bolt shaft flexure to develop. The

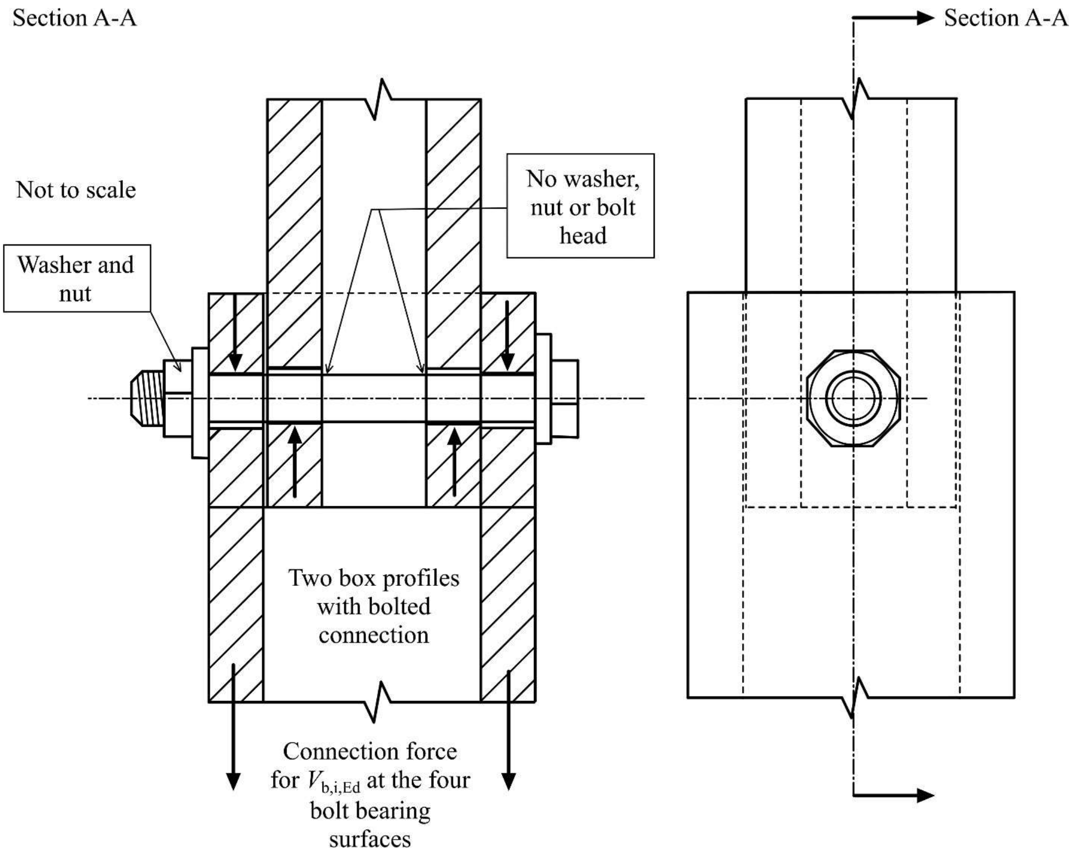


FIGURE 1 Form of closed section connection detailing when the characteristic pin-bearing strength in Formula (12.10) in paragraph 12.2.3.2(1) or Formula (12.13) in paragraph 12.2.3.2(3) is to be reduced by a factor of 0,5 to account for steel bolt flexure [1] (reproduced with permission from ASCE).

existence of bolt flexure generates bending deformations along the "bearing" length of the steel bolt shaft. This in turn may create a non-uniform bearing stress profile across the thickness of the laminate in the bolted connection. For this form of closed-section bolted connection detailing, where the central void remains unfilled, the recommendation is that the characteristic pin-bearing strength used in Formula (12.10) in 12.2.3.2(1) (refer to Background Report BR_12.2.3.2_PAR_1) or Formula (12.13) in 12.2.3.2(3) (refer BR_12.2.3.2_PAR_3) be reduced by a factor of 0,5 (to take account of the non-uniform bearing pressure and stress concentrations that is the consequence of bolt shaft flexure). This design condition will be for the situation, illustrated in Figure 1, where there is, for example, no bolt sleeve used through the full side length of the hollow section, which can include the two wall thicknesses (refer to Figure 11.4 in paragraph 11.4(7)). If such bolt sleeves or similar methods for internal stiffening against bolt shaft flexure are employed, then the pin-bearing design resistances of bolted connections/joints should be determined by strength testing in accordance with paragraph 4.5(1).

There are no test results to verify the reliability of the reduction of 0,5. It was first recommended by the drafting team who prepared the ASCE LRFD pre-standard [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_1
CLAUSE / ANNEX	12. CONNECTIONS AND JOINTS
SUBCLAUSE	12.2.3.3 Shear-out failure
PARAGRAPH	(1)
AUTHOR	J. Toby Mottram
REVIEWER(S)	Casper Kruger, Lee Canning
DATE	15 September 2023

CONTENT

(1) For laminates of constant thickness, the design value of the bearing force transferred by a bolt at the first row of bolts, $V_{so,1,Ed}$, for shear-out failure should satisfy the condition in Formula (12.15):

$$V_{so,1,Ed} \leq V_{so,1,Rd} \tag{12.15}$$

where

$V_{so,1,Ed}$ is taken equal to $V_{b,i=1,Ed} = \frac{N_{Ed}}{n_{b,1}}$ (in Figure 12.5 $n_{b,1}$ is taken equal to 1);
$V_{so,1,Rd}$ is the design value of the shear-out failure resistance, given by Formula (12.16),

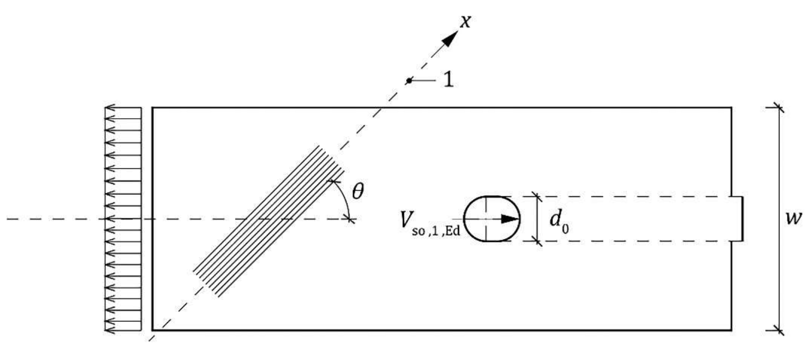
$$V_{so,1,Rd} = 1{,}5\left(e_1 - 0{,}5 \cdot d_0\right) \cdot t \cdot f_{xy,v,d} \tag{12.16}$$

e_1 s the end edge distance from the first row of bolts (Table 11.1 and 12.2.3.3(3));
d_0 is the nominal hole diameter;
t is the thickness of the laminate resisting $V_{so,1,Ed}$;
f_{xyvd} is the design value of the in-plane shear strength of the laminate, given by Formula (12.17),

$$f_{xy,v,d} = \frac{\eta_c}{\gamma_m \cdot \gamma_{Rd}} \cdot f_{xy,v,k} \tag{12.17}$$

where

γ_m is defined in 4.4.5 (to be selected for $f_{xy,v,k}$);
γ_{Rd} is defined in 4.4.6 (Table 4.5, Shear-out failure);
η_c is defined in 4.4. 7 (to be selected for $f_{xy,v,k}$);
$f_{xy,v,k}$ is the characteristic value of the in-plane shear strength of the laminate.



Key:

(1) Principal direction of laminate or direction of pultrusion

FIGURE 12.5 Shear-out failure mode for a single row of bolts.

SHEAR-OUT FAILURE

Background

Paragraph 12.2.3.3(1) and Figure 12.5 are for single-row 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. Figure 12.5 is a line drawing to depict the assumed shear-out failure paths for this bolting configuration that are used to formulate the resistance Formula (12.16). The figure shows that when the in-plane shear strength is exceeded a "rectangular" strip of laminate shears out. This strip, as seen in Figure 12.5, is assumed to possess a length from the hole-to-free edge, which is end distance e_1 minus 0,5 of the hole diameter d_0, and width equal to the bolt hole diameter, *d*.

References [1–6] give historical background and/or specific information from which paragraphs 12.2.3.3(1)–(4) were prepared. For 12.2.3.3(1) reference [1] presents the first form of Formula (12.16) that has factor 1,5 as 2,0 and is without the shear-out failure path length reduction of $0{,}5d_0$, which is half the diameter of the bolt hole. Formula (5.3) in [2] and Formula (8.5a) in [3] are similar to Formula (12.16), yet with factor 1,5, again, equal to 2,0. Finally, Formula (8.3.2–9a) in reference [4] is very similar to Formula (17.16), now with factor 1,5 equal to 1,4. This later factor difference of 0,1 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 [3] 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 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 [7] or D7078/D7078M [8]. There is no equivalent EN or ISO test standard and the interlaminar shear strength determined by test method EN ISO 14130 [9] is not appropriate.

As the test results reported in references [5, 6] were considered complete and reliable, they were used by the drafting team to calibrate the partial factor of resistance for the shear-out mode of failure. Factor 1,5 in Formula (12.16) for a single row of bolts was determined from this calibration exercise using the prEN 1990 [10] 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 presented in Table 4.5 in 4.4.6(3). The calibration of γ_{Rd} is presented in BR_4_4_6_PAR_3.

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 $f_{xy,v,k}$) and conversion factor, η_c (defined in subclause 4.4.7 *Nominal conversion factors*).

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 γ_{Rd} = 1,5.

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