Determination of Pin-bearing Strength for the Design of Bolted Connections with Standard Pultruded Profiles

J. Toby Mottram
School of Engineering

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Bearing strength and bolted connections

Study:

- To review standard test methods.
- To compare two test methods for pin-bearing strength.






WARWICK PP slide show is available from Personal Web-page.

Why study?

"*Standard for Load and Resistance Factor Design (LRFD) of Pultruded Fiber-Reinforced Polymer (FRP) Structures*" (ASCE and ACMA).

Eight chapters, we contribute for the "glory of it".

1. GENERAL PROVISIONS
2. DESIGN RESISTANCE
3. TENSION MEMBERS
4. DESIGN OF COMPRESSION MEMBERS
5. DESIGN FOR MEMBERS IN BENDING AND SHEAR
6. MEMBERS UNDER COMBINED FORCES AND TENSION
7. PLATES AND BUILT-UP MEMBERS
8. BOLTED CONNECTIONS.

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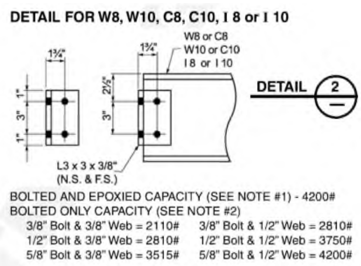
Connections and joints permitted

LRFD chapter for bolted connections combines design for frame joints, such as the web-cleated type shown on top-right (classify as simple using the principles in BS EN 1993-1-8:2006), with the design of plate-to-plate connections, such as there is in each of the cleat legs and bracing members (bottom-right).



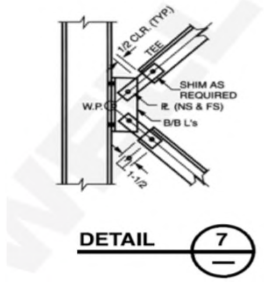


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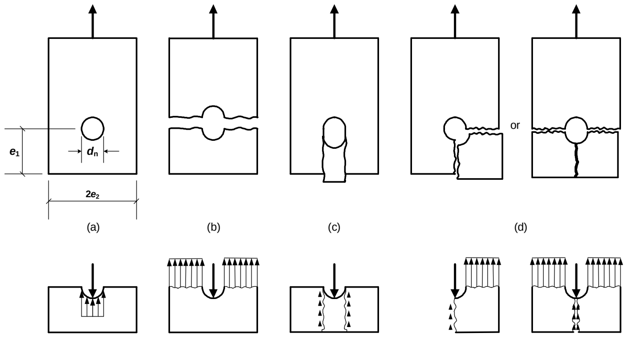
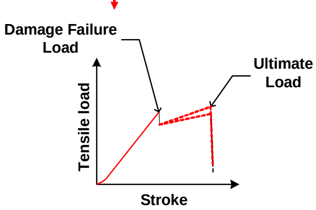
Plate-to-plate resistances

5

Distinct modes of failure (single-bolted connections)





(a) bearing, (b) net-tension, (c) shear-out, (d) cleavage

Failure mode can be made to change by varying the geometric ratios e_1/d (or e_1/d_n) and w/d (or w/d_n), with $w = 2e_2$. d is bolt diameter, < d_n.

WARWICK **Mix modes for off-axis and block shear with multi-rows.**

Strength formula - Bearing

6

$$R_{br} = t\,d\,F_{\theta}^{br}$$

t is thickness of FRP.

d is diameter of bolt.

F_{θ}^{br} is specified pin-bearing strength for the orientation of the resultant force at the bolt/FRP contact with respect to the direction of pultrusion.

Bearing failure (e_1/d = 5; w/d = 7 (w = 2e_2)), θ = 0 for Longitudinal material.

From Pu Wang, PhD thesis, Univ. of Lancaster, 2004.

For 6.4 mm EXTREN 525 flat sheet material, 9.8 mm diameter bolt, 10 mm hole, and 'finger-tightened' bolting a batch of three specimens gave a mean F_{0}^{br} = 280 N/mm^2. "No clearance hole and bolt tension"

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Permitted by LRFD standard

7

Flat sheets or structural profiles (I, H, etc.).

Thicknesses from 6.35 mm up to, and including to 25.4 mm.

Bolts and nuts (ASTM standards A304, A307 and A316).

d from 9.53 mm up to, and including, 25.4 mm.

Hardened flat circular washers - outer diameter at least 2d, and at least one washer is to be used at the head of the bolt and at the nut.

Bolts are to be torqued to the snug-tightened[1] condition (guidance for setting this relatively 'low' level of bolt tensioning still to be identified).

Nominal hole diameter, d_n, is to be 1.6 mm larger than d. (Hole clearance is therefore in the range 0.14d_n to 0.06d_n).

Holes are to be drilled or reamed.

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1. Now finger-tightened – changed after paper written

Standards for bearing strength

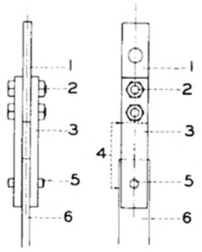
8

ASTM D 953-02 - scope is actually for rigid plastics, in either sheet or moulded form. Hardened steel pin (no lateral constraint) of d = 6.325 mm and a maximum hole d_n = 1.012d (maximum clearance of only 0.012d_n).

t = 6.4 mm, e_1/d = 3 and w/d = 3.7.

Pin-bearing strength is determined from load when the hole is deformed by 4% of its diameter.

"there is evidence for its unreliability"



1—Hardened spacer plate.
2—6.3-mm (-in.) steel bolts in reamed holes.
3—Hardened side plate.
4—Extensometer span.
5—Hardened steel pin in reamed hole.
6—Test specimen.

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Standards for bearing strength

ASTM D 5961-05 - scope is for with laminated composites (aerospace).

t = 3 to 5 mm, e_1/d = 3 and w/d = 6. "wider"

Metallic fastener (lightly torqued (2.2-3.4 N•m)) of d = 6 mm and a close-tolerance hole.

Bearing strength is determined from maximum load.

"this is desirable"

Because laminates are to be balanced and symmetric with respect to the load direction the bearing mode is most likely to occur with $e_1 = 3d$.

"with pultrusion this end distance ratio needs to be larger"

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Standards for bearing strength

EN 13706-2:2002 - for pultruded materials.

e_1/d_n = 6 and w/d_n is 6 (with d_n = 6.0±0.2 mm). "bigger end distance"

Diameter of pin (bolt without any lateral constraint) is actually not specified, d is to be 6 mm (for a close fitting bolt).

Pin-bearing strength is determined from maximum load.

Part 3 reports minimum properties that are required for each grade.

Minimum pin-bearing strengths F_0^{br} (F_{90}^{br}) (in N/mm^2) are 150 (90) for Grade 23 and 90 (50) for Grade 17 (the grade number is the minimum longitudinal tensile modulus).

"6.35 mm EXTREN 525 flat sheet material in RT tests is Grade 17; minimum F_0^{br} is 90 N/mm^2"

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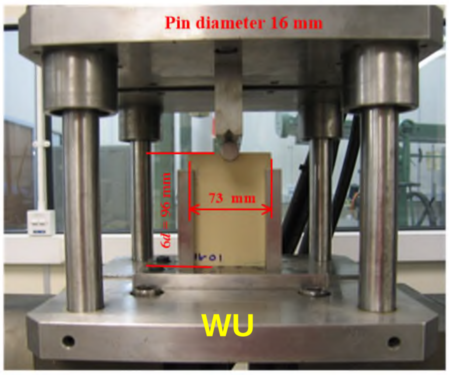
Comparison of test methods

11



Similar to ASTM D 5764-07 'timber' Compression loading Maximum specimen 120x73 mm (*d* = 20 mm)	&	In spirit of BS EN 13706-2 Tensile loading 220x120 mm

With and without 1 mm clearance, with bolt diameters of 8, 12 and 16 mm.

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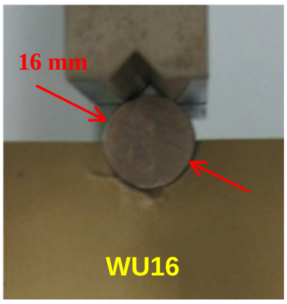
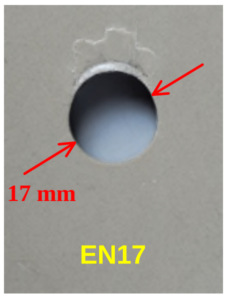
Comparison of test methods

12

Bearing failure for $\theta = 0$ (6.35 mm EXTREN 525 flat sheet)

Close fitting 'pin' | **1 mm clearance hole**





'ASTM D 5764-07 (timber)' & **'EN 13706-2'**

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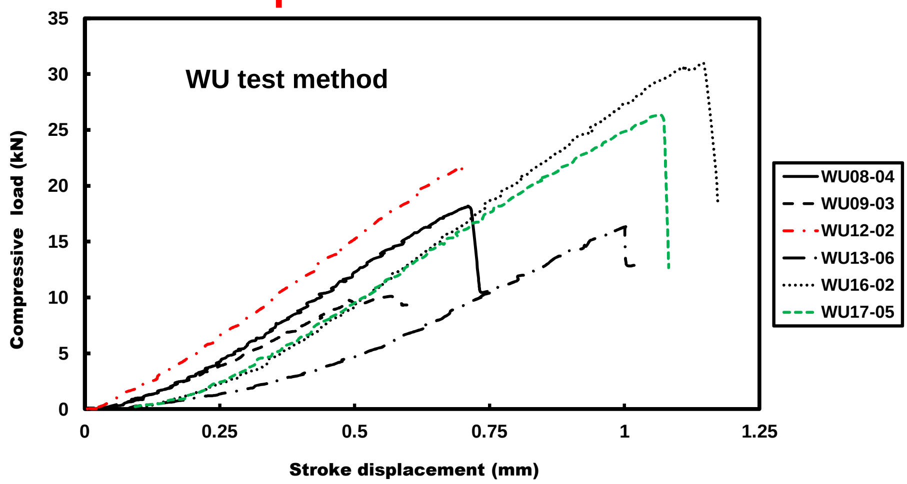
13

Comparison of test methods



Linear elastic response to pin-bearing failure; same when test is to EN 13706

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14

Comparison of test methods

WU

F_0^{br}	Batches of six specimens					
	WU08	WU09	WU12	WU13	WU16	WU17
Mean (N/mm²)	362	241	315	227	314	239
SD (N/mm²)	21.6	25.2	10.0	24.5	31.0	17.0
CoV (%)	6.0	10.5	3.2	10.8	9.9	7.1
Characteristic[1] (N/mm²)	314	186	293	174	246	202
Mean *d*/*t* ratio	1.25	1.27	1.92	1.91	2.55	2.54
Max. clearance (mm)	0.2	1.2	0.2	1.2	0.2	1.2

Blue font for 1+ mm clearance

EN

F_0^{br}	Batches of six specimens - EN09 with five					
	EN08	EN09	EN12	EN13	EN16	EN17
Mean (N/mm²)	324	232	298	201	297	235
SD (N/mm²)	10.4	17.6	19.5	7.6	22.2	19.6
CoV (%)	3.2	7.6	6.6	3.8	7.5	8.4
Characteristic[1] (N/mm²)	301	191	255	185	245	192
Mean *d*/*t* ratio	1.23	1.25	1.92	1.88	2.51	2.49

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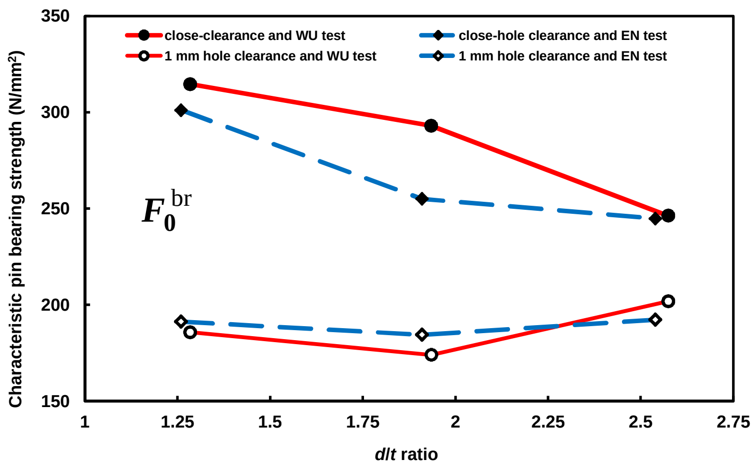
Note: 1. Mean – 2.18SD (batches of 6)

15

Comparison of test methods



Linear decrease in longitudinal strength with increase of *d/t*.
1 mm clearance can reduce the longitudinal strength by 50%.

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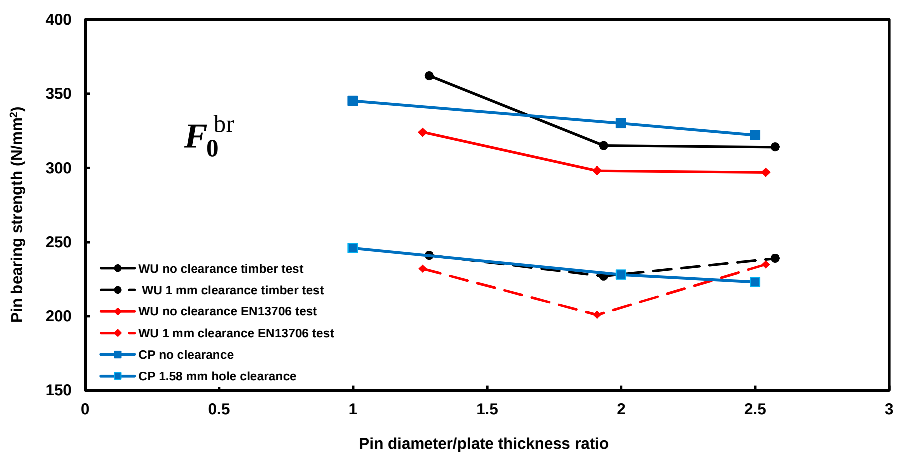
15-a

Comparison of test methods



Independent MEAN ultimate strength (modified) ASTM D 953-02 results from Creative Pultrusions Inc. confirms comparison. Coupons from 4" x 1/4" equal leg angle with polyester resin.

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Concluding Remarks

- Because of creep relaxation the pin-bearing strength is to be used in structural calculations.
- Current test standards require a tensile specimen that is too big.
- Current test standards do not allow for bolt diameters, clearance holes, and material thicknesses found in practice (and for the LRFD design standard).
- Comparison of test results (batch size of six) from two methods show similarities; presence of shaft flexure lowers the strength in the EN tests.
- With a close-fit bolt the mean longitudinal pin-bearing strength of 6.35 mm flat sheet is > 300 N/mm^2 and decreases linearly with increase of *d*/*t* ratio.
- With a 1 mm clearance the mean strength reduces by 20, up to 50%.
- Minimum characteristic pin-bearing strength (at RT) is found to be 180 N/mm^2; higher than 90 N/mm^2 (from Part 3 of EN 13706) and lower than 220 N/mm^2 (from pultruder's Design Manual). Reasons for this are obvious!

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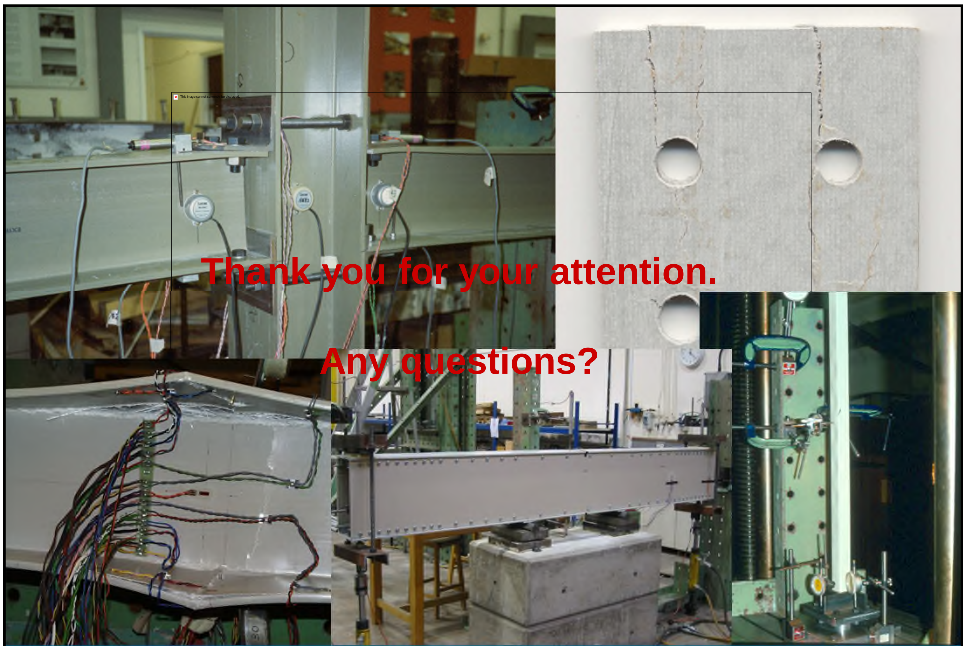

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