Bolted and dowelled joints I

STEP lecture C6
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Objectives

To describe ultimate limit state design procedures for bolted and dowelled joints including rules for spacings. To present empirical equations for the prediction of embedding strengths and fastener yield moments. To show briefly some possibilities for improving the performance of these joints.

Prerequisites

C2 Tension perpendicular to the grain in joints
C15 Multiple fastener joints

Summary

Design rules for ultimate limit state design for various types of bolted and dowelled joints are evaluated. The rules for spacings, end and edge distances are explained and the influence of load-to-grain angle is commented upon. Empirical equations for the embedding strengths of the members and the fastener yield moments are given. The effect of system properties (e.g. fastener surface friction) on the characteristic load-carrying capacity of the joints is described and possibilities to improve the joints' performance are presented. The load distribution between fasteners in line is discussed.

Introduction

Dowels (Figure 1) are slender cylindrical rods made of steel, mainly with a smooth surface. The minimum diameter is 6 *mm*. The tolerances on the dowel are –0,0 / +0,1 *mm* and the pre-drilled holes in the timber member should have a diameter not greater than the dowel itself. The holes in steel members may be pre-drilled 1 *mm* larger than the dowel diameter and due allowance may be made for any extra slip that may occur.

Bolts (Figure 1) are dowel-type fasteners with heads and nuts. They should be tightened so that the members fit closely, and they should be re-tightened if necessary when the timber has reached equilibrium moisture content. Bolt holes may have a diameter not more than 1 *mm* larger than the bolt. If a bolt is fitted in a hole which is not greater than its shank, the design method for dowelled joints can be applied. Washers with a side length or a diameter of at least 3 d and a thickness of at least 0,3 d (d is the bolt diameter) should be used under the head and nut. Washers should have a full bearing area.

Joints with dowels are used in timber construction to transmit high forces. This economic type of joint is easy to produce. In large dowelled connections it may be necessary to replace some dowels with fitted bolts in order to maintain the form of the joint. Dowelled joints are stiff, compared with bolted joints. Therefore, bolted joints should not be used in construction where large deformations impair the serviceability.

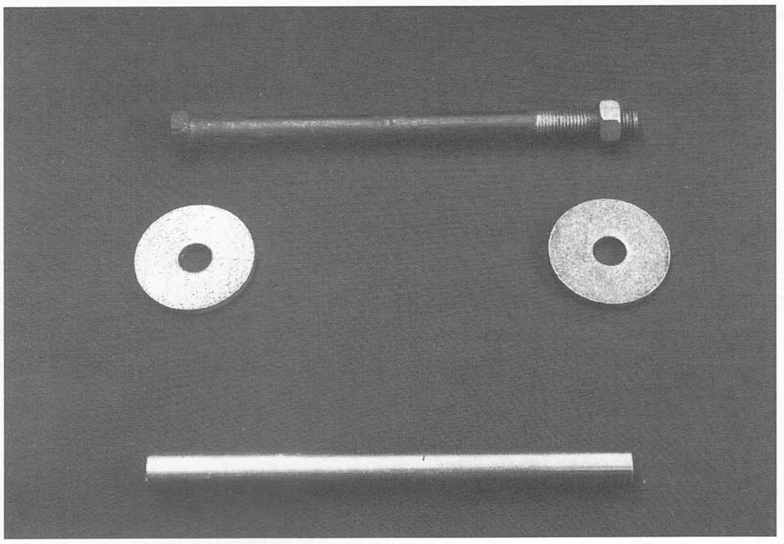


Figure 1 Bolt with washer and dowel.

Bolts and dowels can be used for timber-to-timber joints, panel-to-timber joints or steel-to-timber joints.

Ultimate limit states design

The dominant properties influencing the load-carrying capacities of dowel-type fasteners are

- the embedding strength of the timber or panel members,
- the geometry of the joint and
- yield moment of the fasteners.

The embedding strength itself depends on

- the density of the member,
- the diameter of the fastener,
- the angle between force and grain direction and
- the friction between fastener and timber.

The embedding strength can be assumed to increase linearly with increasing wood density. Small spacings as well as small end distances of the fasteners can cause premature failures. Therefore, splitting in timber joints should be avoided by appropriate spacings and distances.

When the force acts at an angle to the grain the influence of the tensile stresses perpendicular-to-grain shall be taken into account. Design methods for this are given in STEP lecture C2.

Embedding strength of timber and wood-based panels

The embedding strength should generally be determined in accordance with prEN 383 "Timber structures - Test methods - Determination of embedding strength and foundation values for dowel type fasteners" with the evaluation of the test results following the procedures given in EC5 Annex A. This strength is defined as the average compressive stress at maximum load in a specimen of timber or wood-based panel under the action of a stiff linear fastener with the fastener's axis perpendicular to the surface of the specimen. The embedding strength depends on the type of fastener, the manufacture of the joint and the wood density or the quality of the wood-based materials. Thus, the embedding strength is not a special material property, but a systems property. For bolts and dowels up to 30 *mm* diameter the following characteristic embedding strength values for timber should be used:

EC5:Part 1-1: 6.5.1.2 (1)

$$f_{h,0,k} = 0{,}082(1 - 0{,}01d)\ \rho_k \qquad N/mm^2 \tag{1}$$

with ρ_k in kg/m^3 and d in mm.

$$f_{h,\alpha,k} = \frac{f_{h,0,k}}{k_{90}\sin^2\alpha + \cos^2\alpha} \tag{2}$$

for softwood: $k_{90} = 1{,}35 + 0{,}015d$ (3)

for hardwood: $k_{90} = 0{,}90 + 0{,}015d$ (4)

α is the angle between load and grain direction.

The influence of the angle α between load and grain direction is illustrated in Figure 2.

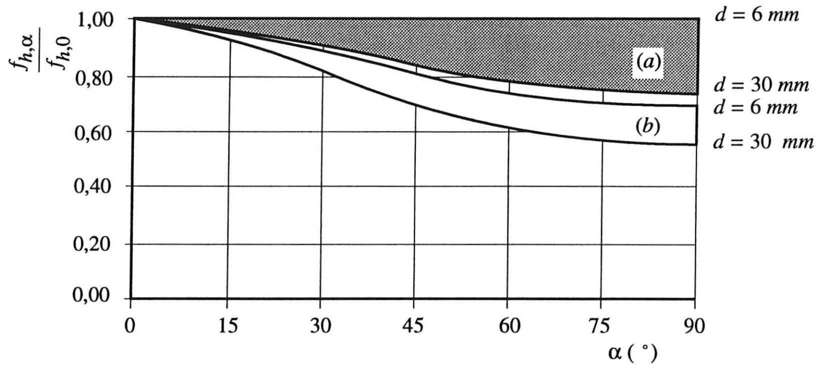


Figure 2 $f_{h,\alpha}$ / $f_{h,0}$ *plotted against angle* α *between load and grain direction; (a) hardwood; (b) softwood.*

EC5: Part 1-1: 6.5.1.3 (2)

For wood-based products characteristic embedding strength values to be used for bolted or dowelled joints are not yet available, except for plywood. EC5 recommends for plywood the following value:

$$f_{h,k} = 0{,}11(1 - 0{,}01d)\ \rho_k \qquad N/mm^2 \tag{5}$$

with ρ_k in kg/m^3 and d in mm.

These values are applicable independent of the angle between load and face grain direction.

Yield moment of fasteners

EC5: Part 1-1: 6.5.1.2 (2)

The yield moment of dowel-type fasteners should generally be determined in accordance with prEN 409 "Timber structures - Test methods - Determination of the yield moment of dowel type fasteners - Nails". Although prEN 409 is developed for nails only, it has been verified (Ehlbeck and Werner, 1992) that the test methods given in prEN 409 can in principle also be used for bolts and dowels. For round steel bolts and dowels the characteristic value for the yield moment should be calculated approximately as

$$M_{y,k} = 0{,}8\, f_{u,k}\, \frac{d^3}{6} \tag{6}$$

where f_u is the tensile strength of the fasteners.

Multiple - fastener joint

EC5: Part 1-1: 6.5.1.2 (3)

The loads in bolted and dowelled joints are non-uniformly distributed between the individual fasteners in a multiple fastener joint. For more than six fasteners in line with the load direction, the load-carrying capacity of the extra fasteners should be reduced by 1/3, i.e. for n fasteners the effective number n_{ef} is

$$n_{ef} = 6 + \frac{2}{3}(n - 6) \tag{7}$$

If the failure of the joint is not governed by splitting and if plastic deformations are possible, then the loads can be redistributed in the joint. For further information see STEP lecture C15.

Fastener spacings and distances

The minimum spacings as well as the end and edge distances for bolts and dowels are different because of the size of the washers. The minimum spacings and distances for bolts are given in Table 1, those for dowels in Table 2. The spacings parallel (a_1) and perpendicular (a_2) to the grain, the end (a_3) and edge (a_4) distances are defined in Figure 3-5.

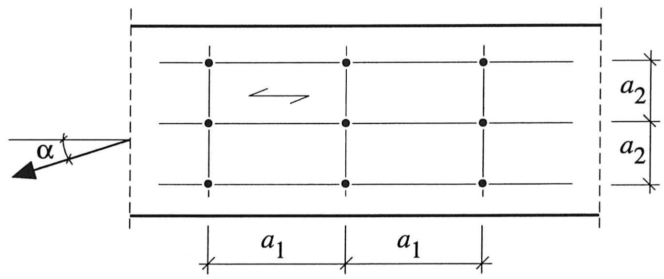
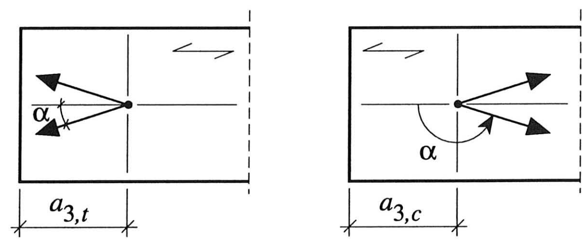
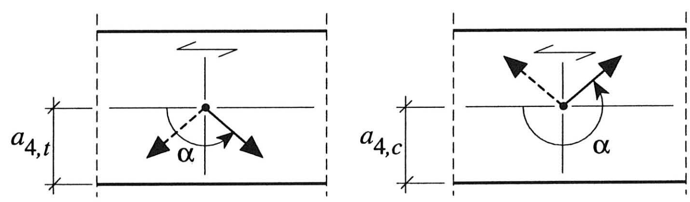


Figure 3 Fastener spacings parallel and perpendicular to grain - definitions.



-90° ≤ α < 90° 90° ≤ α < 270°

Figure 4 Fastener end distances - definitions (left: loaded end; right: unloaded end).



0° ≤ α < 180° 180° ≤ α < 360°

Figure 5 Fastener edge distances - definitions (left: loaded edge; right: unloaded edge).

a_1	Parallel to the grain	$(4 + 3 \mid \cos\alpha \mid)\, d$	
a_2	Perpendicular to the grain	$4d$	
$a_{3,t}$	$-90° \leq \alpha \leq 90°$	$7d$ (≥ 80 *mm*)	
$a_{3,c}$	$150° \leq \alpha \leq 210°$	$4d$	
	$90° < \alpha < 150°$		
	$210° < \alpha < 270°$	$(1 + 6 \mid \sin\alpha \mid)\, d$	($\geq 4d$)
$a_{4,t}$	$0° \leq \alpha \leq 180°$	$(2 + 2\ \sin\alpha\ )\, d$	($\geq 3d$)
$a_{4,c}$	all other values of α	$3d$	

α is the angle between load and grain direction

EC5: Part 1-1: 6.5.1.2 (4)

Table 1 Minimum spacings and distances for bolts.

a_1	Parallel to the grain	$(3\ + 4 \mid \cos\alpha \mid)\, d$	
a_2	Perpendicular to the grain	$3d$	
$a_{3,t}$	$-90° \leq \alpha \leq 90°$	$7d$ (≥ 80 *mm*)	
$a_{3,c}$	$150° \leq \alpha \leq 210°$	$3d$	
	$90° < \alpha < 150°$		
	$210° < \alpha < 270°$	$a_{3.t} \mid \sin\alpha \mid$	($\geq 3d$)
$a_{4,t}$	$0° \leq \alpha \leq 180°$	$(2 + 2\ \sin\alpha\ )\, d$	($\geq 3d$)
$a_{4,c}$	all other values of α	$3d$	

α is the angle between load and grain direction

EC5: Part 1-1: 6.6 (2)

Table 2 Minimum spacings and distances for dowels.

The spacings a_1 may be reduced to a minimum of $4d$. In this case the load-carrying capacity decreases due to the danger of splitting. Therefore, the characteristic embedding strength $f_{h,0,k}$ should be reduced by the spacing factor k_a:
for bolted joints

$$k_a = \sqrt{\frac{a_1}{(4 + 3|\cos\alpha|)\, d}} \qquad (8)$$

for dowelled joints

$$k_a = \sqrt{\frac{a_1}{(3 + 4|\cos\alpha|)\, d}} \qquad (9)$$

For plywood the spacing factor k_a can be disregarded.

Laterally loaded bolts and dowels

EC5: Part 1-1: 6.2

The design load-carrying capacities for bolted and dowelled joints can be calculated using the modified Johansen theory. This theory is described in STEP lecture C3.

EC5: Part 1-1: 2.3.3.2 and 3

The design values of the relevant material properties are calculated with the modification factor k_{mod} and the values of γ_M according to EC5.

Because of friction between the fastener and the timber and the constraints produced by the washer assembly in bolted joints, the load-carrying capacities, especially for fasteners with a profiled surface, are higher. This phenomenon is called the "chain effect". After significant fastener deformation the component of the axial load in the fastener parallel to the interface of the joint members can be added to the lateral shear load. The component perpendicular to the surfaces of the members forces these members into tight contact and may cause additional resistance in the direction of the joint load due to the friction between the members. This clamping effect diminishes gradually because of wood relaxation and shrinkage. The increase of strength in joints made with resin injected bolts (Rodd et al.,1989) has the same reason. The embedment characteristics are also superior to those of plain bolts in terms of both strength and stiffness.

The load-carrying capacities of a joint can substantially be increased by gluing a wood-based panel onto the members. (Blaß and Werner, 1988). In that case the spacings and distances of the fasteners may be reduced. The reinforcing material is able to spread highly concentrated loads uniformly while the glueline transfers the load into the timber member by shear stresses. Splitting in timber joints can be avoided. Design proposals are given by Werner (1993).

Axially loaded bolts

EC5: Part: 1-1: 6.5.2

The tensile strength of axially loaded bolts shall be checked in accordance with EC3: Part 1.1 "Design of steel structures - general rules and rules for buildings". The washers shall have a sufficient thickness in order to guarantee uniform compression stresses perpendicular to the grain. The design compressive stresses under the washer should not exceed

$$\sigma_{c,90,d} \leq 1,8\, f_{c,90,d} \qquad (10)$$

The compressive strength can be increased because the loaded area is small.

Concluding summary

- The design load-carrying capacities of bolted and dowelled joints should be calculated using the general design equations for dowel-type fasteners

- The decisive properties influencing the load-carrying capacities are the embedding strengths of the jointed members, the geometry of the joint, the yield moment and the diameter of the fastener.

- Bolted joints are, because of larger holes, not as stiff as dowelled joints and the minimum spacings required are greater.

- For more than six fasteners in line with the load direction the load-carrying capacity should be calculated with an effective, i.e. a reduced number of fasteners.

References

Blaß, H.J. and Werner, H. (1988). Stabdübelverbindungen mit verstärkten Anschlußbereichen. Bauen mit Holz 90: 601-607.

Ehlbeck, J. and Werner, H. (1992). Tragfähigkeit von Laubholzverbindungen mit stabförmigen Verbindungsmitteln. Research Report, Versuchsanstalt für Stahl, Holz und Steine, Abt. Ingenieurholzbau, Universität Karlsruhe, Germany.

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