Bolted and dowelled joints II

STEP lecture C7
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Objectives

To describe serviceability limit state design procedures for bolted and dowelled joints and to demonstrate the effect of slip. To present examples for designing laterally loaded, timber-to-timber, panel-to-timber and steel-to-timber joints.

Prerequisites

A17 Serviceability limit states - Deformations
C6 Bolted and dowelled joints I

Summary

Design rules for serviceability limit state design are presented for bolted and dowelled joints. The design procedure and the importance of fasteners' slip are demonstrated by examples.

Serviceability limit state design

The load-carrying capacity and the deformation behaviour of joints with dowel-type fasteners can be described by load-deformation curves. Figure 1 shows idealised load-deformation curves of bolted and dowelled joints with approximately the same load-carrying capacity. $F_{max,est}$ is the estimated maximum load.

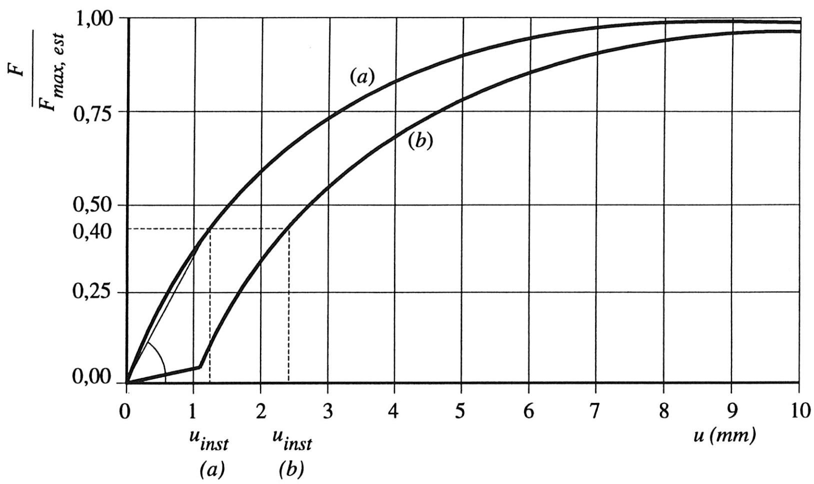

Figure 1 Idealised load-deformation curves of dowelled (a) and bolted (b) joints.

EC5: Part 1-1: 4.2 (1)

The instantaneous slip modulus K_{ser} is determined from such curves as a characteristic value of the joint. Based on many test data EC5 recommends an instantaneous slip modulus K_{ser} per shear plane per fastener under service load for dowelled joints

$$K_{ser} = \frac{1}{20} \rho_k^{1,5} d \quad N/mm \tag{1}$$

with ρ_k in kg/m^3 and d in mm.

EC5: Part 1-1: 4.2 (2)

If the characteristic densities of the two jointed members are different then ρ_k

should be taken as

$$\rho_k = \sqrt{\rho_{k,1}\ \rho_{k,2}} \qquad (2)$$

This procedure is, of course, not applicable for steel-to-timber joints.

The instantaneous slip u_{inst} should be calculated as

$$u_{inst} = \frac{F}{K_{ser}} \qquad (3)$$

EC5: Part 1-1: 4.2 (4)

F is the load per shear plane per dowel under service load. The final joint slip u_{fin} is given by

$$u_{fin} = u_{inst}\ \sqrt{(1+k_{def,1})(1+k_{def,2})} \qquad (4)$$

with k_{def} from EC5 Table 4.1.

Because of the bolt hole tolerances, bolted joints have an initial slip of about 1 *mm*.

Therefore, the instantaneous slip u_{inst} and the final joint slip u_{fin} are given by:

EC5: Part 1-1: 4.2 (5)

$$u_{inst} = \frac{F}{K_{ser}} + 1\ mm \qquad (5)$$

EC5: Part 1-1: 4.2 (6)

$$u_{fin} = (u_{inst} - 1\ mm)\ \sqrt{(1+k_{def,1})(1+k_{def,2})} + 1\ mm \qquad (6)$$

with K_{ser} for dowels of the same diameter.

Examples

Example 1: Dowelled timber-to-timber joint

Dowel d = 12 *mm*		$f_{u,k} = 360\ N/mm^2$
Structural timber-strength class C24 according to prEN 338		$\rho_k = 350\ kg/m^3$
Service class 2; load duration class:	short-term	$k_{mod} = 0,9$
Load for the governing load case:	permanent load	$G_k = 12\ kN$
	variable load	$Q_k = 14\ kN$

Ultimate limit state design

$$F_d = 1,35 \cdot 12 + 1,5 \cdot 14 = 37,2\ kN$$

Design values of material properties:

EC5: Part 1-1: 6.2.1 (2)

Embedding strength (γ_M = 1,3):

EC5: Part 1-1: 6.6 (2)

centre member: $a_1 = \frac{60}{12\ cos20°}\ d = 5,3d \qquad k_a = \sqrt{\frac{5,3}{7}} = 0,87$

EC5: Part 1-1: 6.5.1.2 (1)

$$f_{h,0,d} = f_{h,2,d} = 0,87 \cdot 0,082\ (1 - 0,01 \cdot 12) \cdot 350 \cdot \frac{0,9}{1,3} = 15,21\ N/mm^2$$

outer members: $a_1 = 4,43\ d\ >\ (3+4\ \cos 70°) = 4,37\ d$

$$f_{h,0,d} = 0,082\ (1 - 0,01 \cdot 12) \cdot 350 \cdot \frac{0,9}{1,3} = 17,48\ N/mm^2$$

$$k_{90} = 1,35 + 0,015 \cdot 12 = 1,53$$

$$f_{h,70,d} = f_{h,1,d} = \frac{17,48}{1,53\ \sin^2 70° + \cos^2 70°} = 11,91\ N/mm^2$$

EC5: Part 1-1: 6.2.1 (1) $\beta = \dfrac{15{,}21}{11{,}91} = 1{,}28$

EC5: Part 1-1: 6.2.1 (3) Yield moment ($\gamma_M = 1{,}1$):

EC5: Part 1-1: 6.5.1.2 (2) $M_{y,d} = 0{,}8 \cdot 360 \cdot \dfrac{12^3}{6} \cdot \dfrac{1}{1{,}1} = 75403\ Nmm$

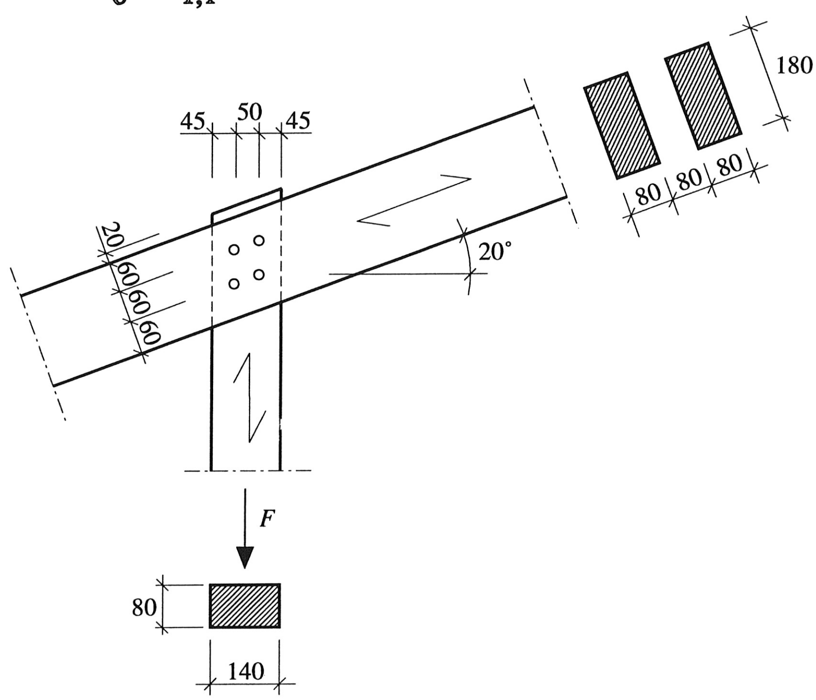

Figure 2 Double shear dowelled joint. Dimensions in (mm).

EC5: Part 1-1: 6.2.1 (1) Design load-carrying capacities per shear plane per dowel

$$R_d = \min \begin{cases} 11{,}91 \cdot 80 \cdot 12 \cdot 10^{-3} = 11{,}43\ kN \\ 0{,}5 \cdot 11{,}91 \cdot 80 \cdot 12 \cdot 1{,}28 \cdot 10^{-3} = 7{,}32\ kN \\ 1{,}1 \cdot \dfrac{11{,}91 \cdot 80 \cdot 12}{(2+1{,}28) \cdot 10^3}\left(\sqrt{5{,}84 + \dfrac{16{,}79 \cdot 75403}{11{,}91 \cdot 12 \cdot 80^2}} - 1{,}28\right) = \mathbf{5{,}40\ kN} \\ 1{,}1 \cdot \sqrt{\dfrac{2 \cdot 1{,}28}{1 + 1{,}28}}\ \sqrt{2 \cdot 75403 \cdot 11{,}91 \cdot 12}\ \cdot 10^{-3} = 5{,}41\ kN \end{cases}$$

design load-carrying capacity of the joint

$$R_{d,joint} = 2 \cdot 4 \cdot 5{,}40 = 43{,}20\ kN > F_d = 37{,}20\ kN$$

Serviceability limit state design

F_{ser} per shear plane per dowel:

$$F_{ser} = \frac{26{,}0}{2 \cdot 4} = 3{,}25\ kN$$

Instantaneous slip modulus per shear plane per dowel:

EC5: Part 1-1: 4.2 (1)

$$K_{ser} = \frac{1}{20} \cdot 350^{1,5} \cdot 12 = 3929 \ N/mm$$

Values for k_{def} in service class 2

permanent $k_{def} = 0{,}80$

short-term $k_{def} = 0{,}00$

instantaneous slip $u_{inst} = \frac{3250}{3929} = 0{,}83 \ mm$

EC5: Part 1-1: 4.2 (4)

final slip $u_{fin} = 0{,}46 \cdot 0{,}83 \cdot (1 + 0{,}8) + 0{,}54 \cdot 0{,}83 = 1{,}14 \ mm$

EC5: Part 1-1: 6.6 (2)

Dowel spacings and distances

	centre member	outer members
a_1	64 *mm* (5,3 *d*)	53 *mm* (4,4 *d*) > 4 *d*
a_2	50 *mm* (4,2 *d*) > 3 *d*	60 *mm* (5 *d*) > 3 *d*
$a_{3,t}$	85 *mm* (7,1 *d*) > 7 *d* > 80 *mm*	-
a_4	45 *mm* (3,8 *d*) > 3 *d*	60 *mm* (5 *d*) > 3,9 *d*

Example 2: Dowelled panel-to-timber joint

The same joint configuration as for example 1, except centre member made of plywood of 20 *mm* thickness.

$\rho_k = 650 \ kg/m^3$
$t_2 = 20 \ mm$

Ultimate limit state design

Embedding strength of plywood (γ_M=1,3; k_{mod} = 0,9):

EC5: Part 1-1: 6.5.1.3 (2)

$$f_{h,d} = 0{,}11 \ (1 - 0{,}01 \cdot 12) \cdot 650 \cdot \frac{0{,}9}{1{,}3} = 43{,}6 \ N/mm^2$$

EC5: Part 1-1: 6.2.1 (1)

$$\beta = \frac{43{,}56}{11{,}91} = 3{,}66$$

$$R_d = \min \begin{cases} 11{,}91 \cdot 80 \cdot 12 \cdot 10^{-3} = 11{,}43 \ kN \\ 0{,}5 \cdot 11{,}91 \cdot 20 \cdot 12 \cdot 3{,}66 \cdot 10^{-3} = 5{,}23 \ kN \\ 1{,}1 \cdot \frac{11{,}91 \cdot 80 \cdot 12 \cdot 10^{-3}}{2 + 3{,}66} \left(\sqrt{34{,}11 + \frac{82{,}86 \cdot 75403}{11{,}91 \cdot 12 \cdot 80^2}} - 3{,}66 \right) = 6{,}09 \ kN \\ 1{,}1 \cdot \sqrt{\frac{2 \cdot 3{,}66}{1 + 3{,}66}} \sqrt{2 \cdot 75403 \cdot 11{,}91 \cdot 12} \cdot 10^{-3} = 6{,}40 \ kN \end{cases}$$

design load-carrying capacity of the joint

$$R_{d,joint} = 2 \cdot 4 \cdot 5{,}23 = 41{,}84 \ kN > F_d = 37{,}20 \ kN$$

Serviceability limit state design

EC5: Part 1-1: 4.2 (2)

$$\rho_k = \sqrt{350 \cdot 650} = 477 \ kg/m^3$$

EC5: Part 1-1: 4.2 (1)

$$K_{ser} = \frac{1}{20} \cdot 477^{1,5} \cdot 12 = 6251\ N/mm$$

EC5: Part 1-1: 4.1 (6)

Values for k_{def} in service class 2

	timber	plywood
permanent	0,80	1,00
short-term	0,00	0,00

$$u_{inst} = \frac{3250}{6251} = 0,52\ mm$$

EC5: Part 1-1: 4.2 (4)

$$u_{fin} = 0,46 \cdot 0,52 \cdot \sqrt{(1 + 0,8)(1 + 1,0)} + 0,54 \cdot 0,52 = 0,74\ mm$$

Example 3: Dowelled steel-to-timber joint

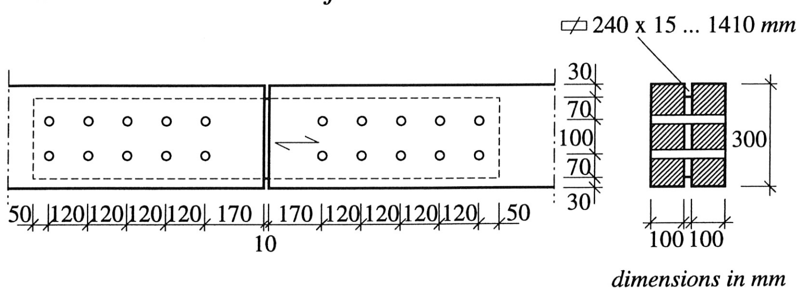

Figure 3 Dowelled joint with centre member of steel. Dimensions in (mm).

Dowel d = 24 *mm*		$f_{u,k}$ = 360 N/mm^2
Glued laminated timber according to prEN 1194:		
GL 24		ρ_k = 380 kg/m^3
Steel plate		t = 15 *mm*
Service class 1; load duration class:	short-term	k_{mod} = 0,9
Load for the governing load case:	permanent load	G_k = 130 *kN*
	variable load	Q_k = 195 *kN*

Dowel spacings and distances

EC5: Part 1-1: 6.6 (2)

a_1 = 120 *mm* (5 d) $\quad 4\ d \leq a_1 < 7\ d$
a_2 = 100 *mm* (4,2 d) > 3 d
$a_{3,t}$= 170 *mm* (7,1 d) > 7 d and > 80 *mm*
a_4 = 100 *mm* (4,2 d) > 3 d

Ultimate limit state design

$$F_d = 1,35 \cdot 130 + 1,5 \cdot 195 = 468\ kN$$

EC5: Part 1-1: 6.2.1(2)

Embedding strength (γ_M = 1,3):

EC5: Part 1-1: 6.5.1.2 (1)

$$f_{h,0,d} = 0,082\ (1 - 0,01 \cdot 24) \cdot 380 \cdot \sqrt{\frac{120}{168}} \cdot \frac{0,9}{1,3} = 13,9\ N/mm^2$$

EC5: Part 1-1: 6.2.1(3)

Yield moment (γ_M = 1,1):

EC5: Part 1-1: 6.5.1.2 (2) $M_{y,d} = 0,8 \cdot 360 \cdot \frac{24^3}{6} \cdot \frac{1}{1,1} = 603 \cdot 10^3\ Nmm$

EC5: Part 1-1: 6.2.2 (2) Design load-carrying capacities per shear plane per dowel

$$R_d = min \begin{cases} 13,9 \cdot 100 \cdot 24 \cdot 10^{-3} = 33,3\ kN \\ \frac{1,1 \cdot 13,9 \cdot 100 \cdot 24}{10^3}\left(\sqrt{2 + \frac{4 \cdot 603 \cdot 10^3}{13,9 \cdot 24 \cdot 100^2}} - 1\right) = 23,8\ kN \\ 1,5 \cdot \sqrt{2 \cdot 603000 \cdot 13,9 \cdot 24} \cdot 10^{-3} = 30,0\ kN \end{cases}$$

design load-carrying capacity of the joint

$R_{d,joint} = 2 \cdot 10 \cdot 23,8 = 476\ kN > 468\ kN$

A check should also be made on the strength of the steel plate (see EC3: Part 1.1 "Design of steel structures - general rules and rules for buildings" (ENV 1993-1-1)).

Serviceability limit state design

F_{ser} per shear plane per dowel

EC5: Part 1-1: 4.2 (1) $F_{ser} = \frac{(130 + 195)}{2 \cdot 10} = 16,3\ kN$

$K_{ser} = \frac{1}{20} \cdot 380^{1,5} \cdot 24 = 8890\ N/mm$

values for k_{def} in service class 1

permanent: $k_{def} = 0,60$ short-term: $k_{def} = 0,00$

$u_{inst} = \frac{16250}{8889} = 1,83\ mm$

EC5: Part 1-1: 4.2 (4) $u_{fin} = \frac{130}{325} \cdot 1,83 \sqrt{(1 + 0,60) \cdot 1} + \frac{195}{325} \cdot 1,83 = 2,02\ mm$

Example 4: Bolted steel-to-timber joint

The same joint configuration as for example 3, except bolts instead of dowels

Bolt spacings and distances

EC5: Part 1-1: 6.5.1.2 (4)

$a_1 = 120\ mm\ (5\ d)$ $4\ d \le a_1 < 7\ d$

$a_2 = 100\ mm\ (4,2\ d) > 4\ d$

$a_{3,t} = 170\ mm\ (7,1\ d) > 7\ d$ and $> 80\ mm$

$a_4 = 100\ mm\ (4,2\ d) > 3\ d$

Ultimate limit state design

Design procedure see example 3

Serviceability limit state design

$F_{ser} = 16,3\ kN$

$K_{ser} = 8890\ N/mm$

EC5: Part 1-1: 4.2 (5) $u_{inst} = 1\ mm + \frac{16300}{8890} = 2,83\ mm$

EC5: Part 1-1: 4.2 (6) $u_{fin} = (2,83 - 1)\left(\frac{130}{325}\sqrt{(1 + 0,6) \cdot 1} + \frac{195}{325}\right) + 1 = 3,02\ mm$