Toothed-plate connector joints

STEP lecture C10
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Objectives

To show the different types of toothed timber connectors and the fabrication of respective joints. To explain the background to the characteristic strength values of toothed-plate connector joints.

Prerequisite

C3 Joints with dowel-type fasteners - Theory

Summary

Various forms of toothed timber connectors are identified. The load-bearing behaviour of connections with toothed-plate connectors and bolts is described. The failure modes and their impact on the design values of the connection strength are discussed. Special attention is given to the required spacing, end and edge distances of the connectors in a joint.

Introduction

Like ring or shear-plate connectors, toothed-plate connectors are used in laterally loaded timber-to-timber and steel-to-timber joints, generally in combination with bolts. While ring and shear-plate connectors are placed into precut grooves (see STEP lecture C9), toothed-plate connectors are pressed into the timber members to be connected. Double-sided toothed-plate connectors are used in timber-to-timber joints; single-sided connectors may also be used if the connectors are installed before the assembly of the structure or if the joints should be demountable (see Figure 1). Single-sided connectors are also used for steel-to-timber joints. Because of the need to press the teeth into the timber, toothed-plate connectors can only be used in timber with a characteristic density of not more than about 500 kg/m^3.

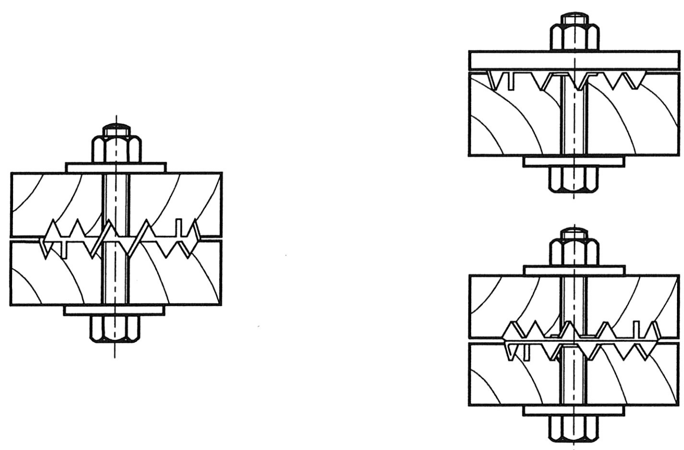

Figure 1 Double-sided (left) and single-sided (right) toothed-plate connector.

Toothed-plate connectors are available in a variety of shapes and sizes, with diameters ranging from 38 to 165 mm. They are mostly circular, but square and oval shapes are also available. The connectors are made either from cold rolled band steel, hot dipped galvanised mild steel or malleable cast iron. Those connectors commonly used in Europe are specified in prEN 912 "Timber fasteners - Specifications for connectors for timber". In prEN 912 toothed-plate connectors are denoted as Type C.

Toothed-plate connector joints are manufactured in a similar way to bolted joints. First, the bolt hole is drilled into the wood. Then, the connectors are placed between the timber members and the connection is pressed together. Because the pressing of the connector teeth into the timber requires considerable force, either a hydraulic press or a high strength bolt is used. Only for small connector diameters, up to about 65 *mm*, can the usual mild steel bolt be used. If bolts are used to press the connector teeth into the wood, large washers have to be used because of the otherwise high stresses perpendicular to the grain and the consequent crushing of the wood. After pressing, the mild steel bolt is inserted into the timber members and tightened. Coach screws may be used in connection with toothed-plates as an alternative to bolts.

Load-bearing behaviour and calculation model

The load in a double-sided toothed-plate connector joint is transferred from one timber member through embedding stresses into the teeth of the connector and further through the plate into the teeth on the opposite side and the other timber member. In single-sided toothed-plate connections, the load transfer is slightly different: after the transfer of the load into the connector, the bolt is loaded through embedding stresses between connector and bolt and the load transferred by shear in the bolt. Then, either the steel member or the second toothed-plate is loaded by the bolt. In single-sided connections the hole diameter in the toothed-plate consequently corresponds to the bolt diameter plus a small tolerance. Due to this tolerance, an initial slip can be expected in single-sided connections.

The failure of toothed-plate connections normally is caused by an embedment failure of the wood under both the connector teeth and the bolt, eventually combined with tooth bending. In tension joints with small end distances, however, splitting and shear out of the wood in front of the bolt is the governing failure mode. Generally since toothed-plate connector joints show a plastic failure mode, both bolt and connector contribute to the load-carrying capacity of the joint. Figure 2 shows a failed compression specimen with embedment failure under the connector teeth and the bolt and plastic deformations of connector teeth and bolt.

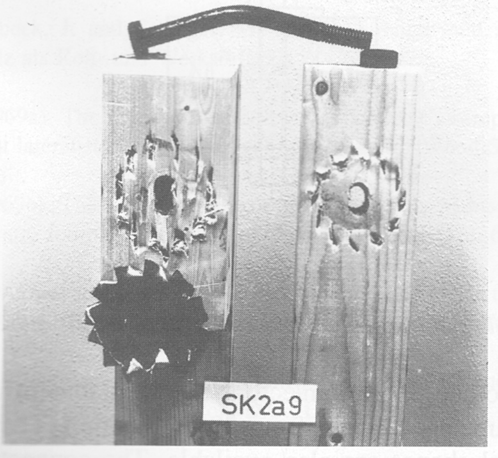

Figure 2 *Embedment failure of the wood under the connector teeth and the bolt. The bolt and the connector teeth are deformed plastically.*

The model used to describe the load-carrying capacity of toothed-plate connections is based on the assumption of a load-sharing between toothed-plate connector and bolt. The connection strength is consequently written as:

$$R_{j,k} = R_{c,k} + R_{b,k} \tag{1}$$

where

$R_{j,k}$ is the characteristic load-carrying capacity of the toothed-plate connection containing both toothed-plate and bolt,
$R_{c,k}$ is the characteristic load-carrying capacity of the toothed-plate connector and
$R_{b,k}$ is the load-carrying capacity of the bolt according to EC5 based on the characteristic values of the embedment strength and the fastener yield moment.

The characteristic load-carrying capacity of a circular toothed-plate connector can be described by the following empirical relationship:

$$R_{c,k} = A\, d_c^{1,5} \tag{2}$$

where

A is a factor depending on the connector type and determined through tests and
d_c is the connector diameter.

Strength and stiffness values from tests

The test results reported here are based on tests performed in the Stevin-Laboratory of Delft University of Technology and in the Danish Building Research Institute between 1957 and 1991. Only tests with one type of toothed-plate connector, the Bulldog connector, were evaluated. Circular connectors with diameters between 50 *mm* and 117 *mm*, two square shaped connectors with 100 *mm* and 130 *mm* side length and an oval connector 70 *mm* by 130 *mm* were tested in spruce (*Picea abies*) specimens. A total of 486 tests have been evaluated. A detailed description of the test results and their evaluation is reported in Blass et al. (1993).

Connection strength

From the timber dimensions and using a characteristic density of 350 kg/m^3 the characteristic load carrying capacity of the bolt was determined for each tested specimen according to EC5. The load-carrying capacity of the bolt was then deducted from the ultimate load of the connection before calculating the parameter A for each test specimen. Based on service classes 1 & 2 and a specified minimum timber member thickness, the characteristic value of the parameter A was found to be:

$$A_k = 18\ N/mm^{1,5} \tag{3}$$

Limiting values for the member thickness have been introduced, since small member thicknesses result in a splitting instead of an embedment failure mode and consequently the connection strength decreases. The evaluation of the test results is based on the same minimum timber member thicknesses as for ring and shear-plate connector joints, namely a minimum side member thickness of 1,5 h_c and a minimum middle member thickness of 2,5 h_c. h_c is the connector height for double-sided toothed-plate connectors and twice the connector height for single-sided toothed-plate connectors.

The results of the test evaluation show a slight decrease in the *characteristic* load-carrying capacity per connector with increasing number of connectors for up to three connector units per joint. The decrease in the *average* load-carrying capacity per connector with increasing number of connectors is more distinct.

Until further research can clarify the influence of the number of connectors, the effective number n_{ef} of more than two connectors in line with the load direction should be assumed as:

$$n_{ef} = 2 + (1 - n / 20)(n - 2) \qquad (4)$$

where n is the number of connectors in line with the load.

Although the number of tests with load-grain angles between 30° and 180° is quite small, the 5-percentile value of the parameter A seems to be independent of the load-grain angle.

Connection stiffness

For serviceability calculations, as well as for mechanically jointed components, slip moduli of the different types of mechanical timber connections are necessary. For serviceability limit states calculations, the slip modulus K_{ser} corresponds to the slip modulus k_s according to EN 26891. For the design of mechanically jointed components in ultimate limit states, the instantaneous slip modulus K_u is taken as two thirds of the corresponding value of the slip modulus K_{ser}.

EC5: Part 1-1: 5.3.3

Since the stiffness values of the tested connections vary considerably, a simple relationship was chosen to represent connection stiffness as a function of the connector diameter and the timber density. Load-grain angle, timber moisture content, member thickness and the number of connector units per joint were ignored. The following average value of the slip modulus k_s according to EN 26891 was determined for connector types C1 to C9 according to prEN 912:

$$k_s = 0{,}3\ d_c\ \rho_k\ (N/mm) \qquad (5)$$

Based on a comparison of stiffness values for different toothed-plate connectors in DIN 1052 (1988) the slip modulus k_s for connector types C10 and C11 according to prEN 912 may be assumed as:

$$k_s = 0{,}45\ d_c\ \rho_k\ (N/mm) \qquad (6)$$

where d_c is the connector diameter in *mm* and ρ_k is the characteristic density of the respective strength class in kg/m^3.

Design equations

The following equations to determine the characteristic strength of a toothed-plate connector joint per shear plane apply:

$$R_{j,\alpha,k} = R_{c,k} + R_{b,\alpha,k} \qquad (7)$$

where

EC5: Part 1-1: Fig. 6.3.1.2a

α is the angle between load and grain direction,
$R_{j,\alpha,k}$ is the characteristic load-carrying capacity of the connector joint and
$R_{c,k}$ is the characteristic load-carrying capacity of the connector:

$$R_{c,k} = 18\ k_\rho\ k_{a3}\ k_t\ d_c^{1,5}\ (N) \qquad (8)$$

for connector types C1 to C9 according to prEN 912 and

$$R_{c,k} = 30\ k_\rho\ k_{a3}\ k_t\ d_c^{1,5}\ (N) \tag{9}$$

for connector types C10 and C11 according to prEN 912 with d_c in *mm*.

EC5: Part 1-1: 6.5.1

$R_{b,\alpha,k}$ is the load-carrying capacity of the bolt according to EC5 based on the characteristic values of the embedment strength and the fastener yield moment.

EC5: Part 1-1: 6.5.1.2

Minimum spacings and distances for connector types C1 to C9 according to prEN 912 are given in Table 1, those for types C10 and C11 in Table 2. Additionally, minimum spacings and distances for the bolts have to be complied with.

a_1	Parallel to the grain	$(1,2 + 0,3\ \lvert\cos\alpha\rvert)\ d_c$
a_2	Perpendicular to the grain	$1,2\ d_c$
$a_{3,t}$	$-90° \le \alpha \le 90°$	$1,5\ d_c$ *)
$a_{3,c}$	$150° \le \alpha \le 210°$ $90° < \alpha < 150°$ $210° < \alpha < 270°$	$1,2\ d_c$ $(0,9 + 0,6\ \lvert\sin\alpha\rvert)\ d_c$ $(0,9 + 0,6\ \lvert\sin\alpha\rvert)\ d_c$
$a_{4,t}$	$0° \le \alpha \le 180°$	$(0,6 + 0,2\ \sin\alpha)\ d_c$
$a_{4,c}$	all other values of α	$0,6\ d_c$
*)	For tension joints ($-30° \le \alpha \le 30°$) the end distance $a_{3,t}$ may be further reduced to $1,1\ d_c$ if the characteristic load-carrying capacity is reduced proportionally.	

Table 1 Minimum spacings and distances for connector type C1 to C9.

a_1	Parallel to the grain	$(1,2 + 0,8\ \lvert\cos\alpha\rvert)\ d_c$
a_2	Perpendicular to the grain	$1,2\ d_c$
$a_{3,t}$	$-90° \le \alpha \le 90°$	$2\ d_c$ *)
$a_{3,c}$	$150° \le \alpha \le 210°$ $90° < \alpha < 150°$ $210° < \alpha < 270°$	$1,2\ d_c$ $(0,4 + 1,6\ \lvert\sin\alpha\rvert)\ d_c$ $(0,4 + 1,6\ \lvert\sin\alpha\rvert)\ d_c$
$a_{4,t}$	$0° \le \alpha \le 180°$	$(0,6 + 0,2\ \sin\alpha)\ d_c$
$a_{4,c}$	all other values of α	$0,6\ d_c$
*)	For tension joints ($-30° \le \alpha \le 30°$) the end distance $a_{3,t}$ may be further reduced to $1,5\ d_c$ if the characteristic load-carrying capacity is reduced proportionally.	

Table 2 Minimum spacings and distances for connector type C10 and C11.

The modification factors for timber density, loaded end distance and member thickness are defined as follows:

$$k_\rho = \min \begin{cases} 1,5 \\ \dfrac{\rho_k}{350} \end{cases} \tag{10}$$

where ρ_k is the characteristic density in kg/m^3 of the respective timber strength class.

For tension joints (-30° ≤ α ≤ 30°) a modification factor for the distance to the loaded end may be applied. For connector types C1 to C9 according to prEN 912 this factor is given as:

$$k_{a3} = \min \begin{cases} 1 \\ \dfrac{a_{3,t}}{1{,}5\ d_c} \end{cases} \tag{11}$$

Here $a_{3,t}$ is the distance to the loaded end with a minimum value of

$$a_{3,t,\min} = \max \begin{cases} 1{,}1\ d_c \\ 7\ d_b \\ 80\ mm \end{cases} \tag{12}$$

where d_b is the bolt diameter in *mm*.

For connector types C10 and C11 according to prEN 912, the modification factor for tension joints (-30° ≤ α ≤ 30°) is:

$$k_{a3} = \min \begin{cases} 1 \\ \dfrac{a_{3,t}}{2\ d_c} \end{cases} \tag{13}$$

with a minimum value for the distance to the loaded end, $a_{3,t}$:

$$a_{3,t,\min} = \max \begin{cases} 1{,}5\ d_c \\ 7\ d_b \\ 80\ mm \end{cases} \tag{14}$$

where d_b is the bolt diameter in *mm*.

$$k_t = \min \begin{cases} 1 \\ \dfrac{t_1}{1{,}5\ h_c} \\ \dfrac{t_2}{2{,}5\ h_c} \end{cases} \tag{15}$$

where t_1 and t_2 are the side and middle member thickness, respectively, and h_c is the connector height for double-sided toothed-plate connectors and twice the connector height for single-sided toothed-plate connectors. Equation (7) is applicable only, if t_1 and t_2 are larger than 1,1 h_c and 1,9 h_c, respectively.

Concluding summary

- Double-sided toothed-plate connector joints are used in laterally loaded timber-to-timber connections while single-sided toothed-plate connector joints can be used in steel-to-timber connections and in demountable timber-to-timber joints.

- Connector and timber dimensions as well as the load-carrying capacity of the bolt are the primary influences on the connection strength.

- Connection stiffness depends mainly on connector diameter and timber density.

- Toothed-plate connector joints can be used for timber with a characteristic density of not more than about 500 kg/m^3.

- The failure mode of toothed-plate connector joints is an embedment failure of the wood under the connector teeth and the bolt. Tension joints with small end distances, however, show a splitting or shear out failure mode of the wood in front of the bolt. Appropriate values of loaded end distances are therefore essential.

References

Blass, H.J., Ehlbeck, J. and Schlager, M. (1993). Characteristic strength of toothed-plate connector joints. Holz als Roh- und Werkstoff 51: 395-399.

Deutsches Institut für Normung (1988). DIN 1052 Teil 2 Holzbauwerke - Berechnung und Ausführung. Beuth Berlin, Germany, 27pp.