Punched metal plate fastener joints

STEP lecture C11
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Objectives

To develop an understanding of the design principles appropriate to joints made with punched metal plate fasteners, and to provide a working familiarity with the design method given in EC5.

Prerequisite

C1 Mechanical timber joints - General

Summary

The principal factors influencing the strength of punched metal plate fastener joints are introduced. The test methods used to establish plate properties are described, along with the method used in EC5 to establish required plate sizes for joints based on both their anchorage strength and their net cross-sectional steel strength. Finally, some general plate dimensioning rules are given, along with a description of the means by which the slip of punched metal plate fastener joints can be predicted under load.

Introduction

A punched metal plate fastener is defined in prEN1075 "Timber Structures - Joints made of punched metal plate fasteners" as a fastener made of metal plate having integral projections punched out in one direction and bent perpendicular to the base of the plate, being used to join two or more pieces of timber of the same thickness in the same plane.

They are generally manufactured from pre-galvanised mild steel or stainless steel strip with thicknesses varying from 0,9 *mm* to 2,5 *mm* (Figure 1). The innovation of using plates with pre-formed (integral) "nails" first took place in the USA in the late 1950's as a development of the conventional hand nailed steel or plywood gusset plate. Both systems brought about the ability to form in-plane timber connections, but punched metal plate fasteners were better suited to factory pre-fabrication of trusses and were able to transfer member forces with smaller connection areas, with consequent cost savings in materials.

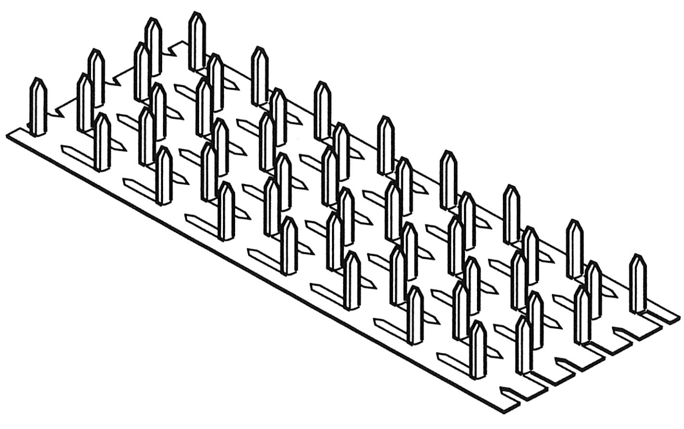

Figure 1 Typical punched metal plate fastener.

Nowadays, punched metal plate fasteners are widely used throughout the industrialised world to form truss connections as well as joints in many other plane timber structures (Figure 2a). Many different forms of punched metal plate fastener have been developed, involving a variety of nail patterns, nail lengths and nail shapes. The strength of all such plates is dictated by certain key influencing variables however, enabling a common design approach to be established in EC5 appropriate for all fasteners of this generic type.

Factors influencing the strength of punched metal plate fastener joints

Load is transferred in a punched metal plate fastener joint first from the member into the plate teeth, then from these teeth up into the plate steel and across the joint interface, then back down into the teeth in the member on the other side. The limiting strength of a punched metal plate fastener joint will therefore be determined by one of two criteria; either its anchorage (gripping) capacity in any of the jointed members or its net sectional steel capacity at any of the interfaces between these members. The factors affecting each of these strength criteria (with reference to Figure 8) may be summarised as follows:

Anchorage

- α is the angle between the force and the lengthways direction of the plate (defined as being parallel to the direction of the plate slots) i.e. the angle at which the individual plate teeth are being loaded. This affects the area of timber being loaded by each plate tooth.
- β is the angle between the force and the grain direction i.e. the angle to grain at which the plate teeth are loading the timber.
- The individual species or the strength class of the timber being jointed i.e. its resistance to loads applied via punched metal plate teeth.
- A_{ef} is the area of effective punched metal plate teeth in any member i.e. the plate contact area on any member, less any allowances for ineffective nails on the edges or ends of the timber and for any misplacement tolerances when positioning the plate. The effective contact area is defined as the smallest area arrived at, after first assuming that the plate could be misplaced from its correct position in any direction by a set tolerance (typically ± 5 *mm*), and that simultaneously any plate area which encroaches within a set distance (dependent upon the plate type) of the member edges or ends must be disregarded (see Figure 2b).
- r_{max} and I_p are respectively, the distance from the centroid of A_{ef} to the furthest point of A_{ef}, and the second moment of area of A_{ef} about its centroid i.e. the shape characteristics of A_{ef}. Note: These particular properties only matter when moments are being transferred by the punched metal plate fastener.

Steel capacity

- γ is the angle between the lengthways direction of the plate and the joint interface i.e. this dictates the net sectional steel area presented along the joint line.
- l, a_{net}, b_{net} are respectively, the net projected plate length along the joint interface, and in directions parallel and perpendicular to the plate direction at the joint interface i.e. the length of plate available at the joint interface to sustain loads in the two orthogonal plate directions.

- The steel type used to manufacture the plate i.e. the strength characteristics of the steel material itself.

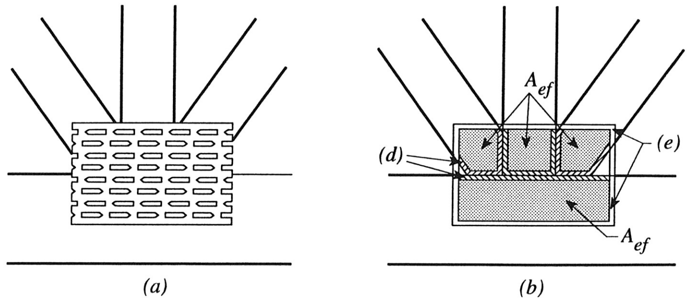

Figure 2 Typical joint - (a) pictorial view and (b) anchorage areas.

For the purposes of design, these variables are included in a number of formulae which predict the strength of joints based on certain key characteristic plate strength properties. These characteristic plate properties and the way in which they are established from tests are described in the next section.

Establishment of characteristic plate strength properties from tests

EC5: Part1-1: D6.3(1)

The following characteristic plate strength values are required in EC5 for the design of punched metal plate fastener joints:

$f_{a,\alpha\beta,k}$ is the characteristic teeth anchorage capacity per unit area at various angles α and β.

$f_{t,0,k}$ is the characteristic plate tension capacity per unit width of plate in the lengthways direction ($\alpha = 0°$).

$f_{t,90,k}$ is the characteristic plate tension capacity per unit length of plate in the widthways direction ($\alpha = 90°$).

$f_{c,0,k}$ is the characteristic plate compression capacity per unit width of plate in the lengthways direction ($\alpha = 0°$).

$f_{c,90,k}$ is the characteristic plate compression capacity per unit length of plate in the widthways direction ($\alpha = 90°$).

$f_{v,0,k}$ is the characteristic plate shear capacity per unit width of plate in the lengthways direction ($\alpha = 0°$).

$f_{v,90,k}$ is the characteristic plate shear capacity per unit length of plate in the widthways direction ($\alpha = 90°$).

Each of these plate properties should be established from standard tests, described in prEN 1075. These 5-percentile test values are later converted to design values by multiplying by the appropriate modification factor (k_{mod}) and dividing by the partial coefficient for materials (γ_m). For the anchorage strength these modification factors will relate to the timber, but for the plate strength they should be taken as 1,0 and 1,1 respectively.

The anchorage strength $f_{a,\alpha\beta,k}$ must be established over a range of α and β values. If sufficient values on the $f_{a,\alpha\beta,k}$ surface have been established then simple linear interpolation can be used between them, however fewer tests are necessary if a presumption is made as to its form. EC5 contains such a presumption which strictly requires the definition of just three constants from tests as follows:

a) $f_{a,\alpha 0,k}$ is the characteristic anchorage strength for specimens loaded parallel to grain (β = 0°). It is obtained from straight joints (Figure 3), typically with plate angles α = 0°, 15°, 30°, 45°, 60°, 75°, 90°. A lower bound bi-linear relationship may then be fitted to these data (Figure 4) yielding fitted constants k_1, k_2 and α_0 for use in the following predictive equations:

EC5: Part1-1: D6.4

$$f_{a,\alpha 0,d} = \begin{cases} f_{a,00,d} + k_1\alpha & \alpha \leq \alpha_0 \quad (1) \\ f_{a,00,d} + k_1\alpha_0 + k_2(\alpha-\alpha_0) & \alpha_0 < \alpha \leq 90° \quad (2) \end{cases}$$

where k_1, k_2, α_0 are fitted constants.

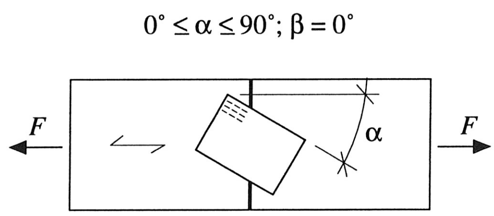

Figure 3
Standard test specimens (β = 0°).

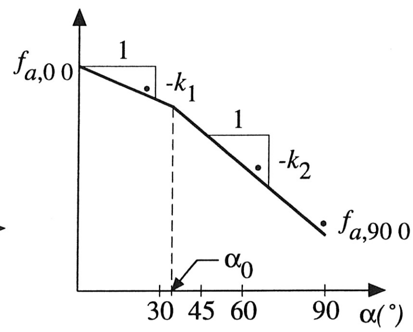

Figure 4
Derivation of constants k_1, k_2, α_0.

b) $f_{a,0\beta,k}$ is the characteristic anchorage strength for specimens loaded parallel to the plate direction (α = 0°). It is obtained from T-joints (Figure 5), typically with "T angles" β = 15°, 30°, 45°, 60°, 75°, 90°. A lower bound sinusoidal relationship may then be fitted to these data (Figure 6) as follows:

$$f_{a,0\beta} = f_{a,00}\,(1 - C\sin\beta) \qquad (3)$$

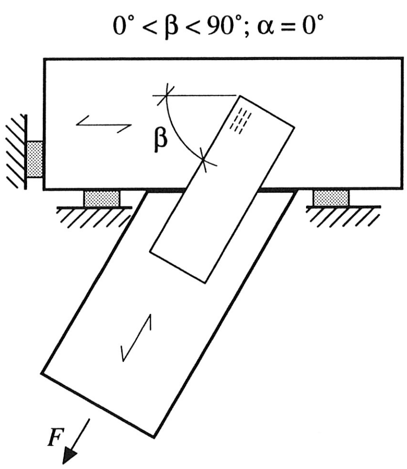

Figure 5
Standard test specimens (α = 0°).

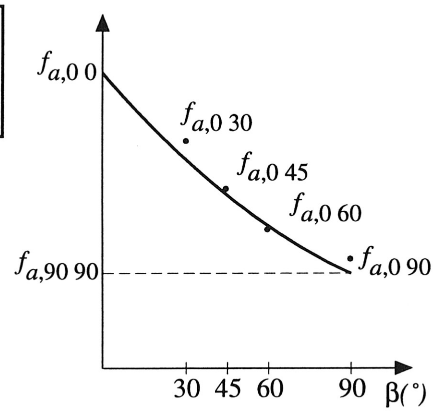

Figure 6
Derivation of constant C.

Generally $f_{a,090}$ is close to $f_{a,9090}$ and this being the case:

$$C = \frac{f_{a,00} - f_{a,9090}}{f_{a,00}}$$

Having established fitted lines describing the lower bound relationship between $f_{a,00}$ and $f_{a,900}$ (bi-linear) for straight joints, and the lower bound relationship between $f_{a,00}$ and $f_{a,090}$ or $f_{a,9090}$ (sinusoidal) for T-joints, an interpolation procedure is provided in EC5 for arbitrary values $f_{a,\alpha\beta}$ between these extremes:

EC5: Part1-1: D6.4

$$f_{a,\alpha\beta,d} = \max \begin{cases} f_{a,\alpha 0,d} - (f_{a,\alpha 0,d} - f_{a,9090,d})\beta/45 & (4) \\ & \beta \leq 45° \\ f_{a,00,d} - (f_{a,00,d} - f_{a,9090,d}) \sin(\max(\alpha,\beta)) & (5) \end{cases}$$

$$f_{a,\alpha\beta,d} = f_{a,00,d} - (f_{a,00,d} - f_{a,9090,d}) \sin(\max(\alpha,\beta)) \qquad 45° < \beta \leq 90° \qquad (6)$$

The characteristic shape of the fitted $f_{a,\alpha\beta,d}$ surface given by Equations (4) (5) and (6) compared with that given by the raw data for a typical plate is shown in Figure 7.

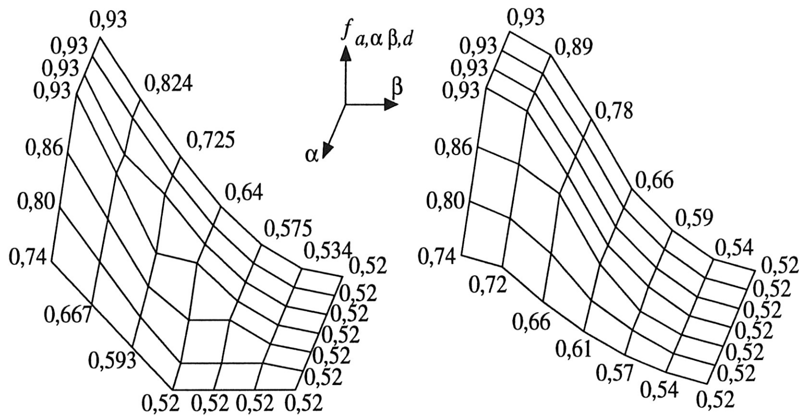

Figure 7 Typical $f_{a,\alpha\beta,d}$ surfaces - left: theoretical and right: experimental.

Punched metal plate design

EC5: Part1-1: D6.5.1(1)

Anchorage capacity

Induced stresses from both direct forces and moments acting on punched metal plate areas may be calculated as follows:

$$\tau_F = \frac{F_A}{A_{ef}} \qquad (7)$$

$$\tau_M = \frac{M_A \, r_{max}}{I_p} \qquad (8)$$

where:

F_A is the resultant direct force acting at centroid of A_{ef}.
M_A is the total moment acting at the centroid of A_{ef}.

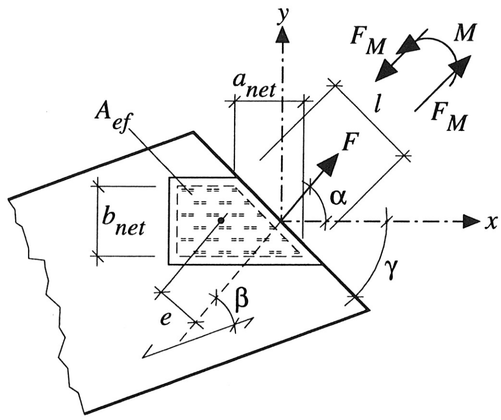

Figure 8 Punched metal plate fastener joint - Geometry and loading.

With reference to Figure 8, the total moment will comprise an internal eccentricity induced moment, and may also extend to include an external moment as desired:

$$M_A = F\,e + M \tag{9}$$

The internal eccentricity moment may sometimes counter the external moment of course.

EC5: Part1-1: D6.5.1(3)

The following ultimate limit state anchorage conditions need then to be satisfied in each member at a joint before an acceptable plate size and position can be said to have been found:

$$\tau_{F,d} \leq f_{a,\alpha\beta,d} \tag{10}$$

$$\tau_{M,d} \leq 2f_{a,9090,d} \tag{11}$$

$$\tau_{F,d} + \tau_{M,d} \leq 1{,}5\, f_{a,00,d} \tag{12}$$

Plate steel capacity

For the purposes of verifying the plate steel capacity at a joint interface, EC5 resolves all applied forces and plate resistances into each of the orthogonal plate directions x and y (Figure 8):

$$F_x = F \cos\alpha \pm 2\, F_M \sin\gamma \tag{13}$$

$$F_y = F \sin\alpha \pm 2\, \mathrm{F_M} \cos\gamma \tag{14}$$

where:

F is the resultant direct force on the joint (compression = negative).
F_M is the moment induced force in the joint where $F_M = 2M/l$ (Figure 8).

EC5:Part1-1:D6.5.2(2)

The design resistances in these directions are calculated as follows:

$$R_{x,d} = max \begin{cases} f_{ax,0,d}\; l \sin\gamma \\ \\ f_{v,0,d}\; l \cos\gamma \end{cases} \qquad f_{ax,0,d} = \begin{cases} f_{t,0,d} & \text{(if tension)} \\ & \text{or} \\ f_{c,0,d} & \text{(if compression)} \end{cases} \tag{15}$$

$$R_{y,d} = max \begin{cases} f_{ax,90,d}\ l\ \cos\gamma \\ \\ f_{v,90,d}\ l\ \sin\gamma \end{cases} \qquad f_{ax,90,d} = \begin{cases} f_{t,90,d} & \text{(if tension)} \\ & \text{or} \\ f_{c,90,d} & \text{(if compression)} \end{cases} \tag{16}$$

Then, the following limit state condition should be satisfied at each joint interface:

$$\left[\frac{F_{x,d}}{R_{x,d}}\right]^2 + \left[\frac{F_{y,d}}{R_{y,d}}\right]^2 \leq 1 \tag{17}$$

Plate dimensioning rules

In addition to the above calculation rules, the Eurocode includes certain ad-hoc rules for dimensioning punched metal plate fastener joints:

EC5: Part1-1: D6.5.1(2)

- In joints subject to a net compressive force, only 50% of the force needs to be transferred through the plate, the remainder being transferred by direct timber bearing.

EC5: Part1-1: D6.5.3(1)

- All joints should be capable of resisting a short-term handling force in any direction, equal to:

  $$F = 1{,}0 + 0{,}1\ L \quad kN \tag{18}$$

  where:

  L is span of the truss in metres.

EC5: Part1-1: D6.5.3(2)

- Irrespective of any other design requirements all punched metal plate fasteners should overlap the timber members by a minimum of 40 *mm* or by one-third of the depth of the timber member, whichever is the greater.

EC5: Part1-1: D6.5.3(3)

- Splice joints on external (chord) members should cover at least two-thirds of the member depth.

EC5: Part1-1: D2(1)

Splice joints may be modelled as rotationally stiff in the structural analysis if they occur in a zone where the bending stresses are no greater than 0,3 times the member bending strength and provided that the assembly would remain stable if the joints did act as pins, or if the splice joint is overdesigned by 50% under the combined action of the direct forces and moment present.

Joint slip

EC5: Part1-1: D2

Axial slip in punched metal plate fastener joints may either be allowed for in truss deflection calculations by the use of prescribed slips, u_{ser} (in *mm*) or slip moduli, K_{ser} (in *N/mm*) established from joint tests and determined in accordance with EN 26891 "Timber structures - Joints made with mechanical fasteners - General principles for the determination of strength and deformation characteristics".

These u_{ser} or K_{ser} values relate to the serviceability load level. Corresponding values may also be determined at the ultimate load level, for use in second-order (nonlinear) analysis, as follows:

$$u_u = 2\ u_{ser} \tag{19}$$

$$K_u = 2\ K_{ser}/3 \tag{20}$$

In addition to the axial slip moduli defined above, rotational slip moduli may also be determined for use in design, from tests described in prEN 1075.

Computer aided design

In practice most design of punched metal plate fasteners is undertaken by specialist fabrication companies using purpose written CAD packages. Many such programs exist, capable of dimensioning the members of timber trusses and determining the optimum size and position of plates in seconds. Access to this technology is easy to gain via specialist fabricators, making punched metal plate design convenient and easy to achieve in practice.

Concluding summary

- The design of punched metal plate fastener joints requires the definition of a two-dimensional teeth anchorage strength surface, and 6 separate plate steel strength characteristics. Standard tests for each of these properties are given in prEN 1075.

- Plate areas on joints must satisfy three separate verification equations accounting for direct forces applied to the plate, and moments induced from both internal and external sources.

- The net plate steel resistance at each joint interface is verified by an interaction equation written in terms of the applied stresses and plate resistances in both orthogonal plate directions.

- The punched metal plate design rules in EC5 are supported by many years of research in Scandinavia (Aasheim and Solli 1990, Kangas 1991, Källsner and Kangas 1991, Kangas and Kevarinmärki 1992) and can be said to represent the state-of-the-art as far as European knowledge is concerned.

References

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