Connector joints in trusses

STEP lecture D2
H. Hartl
Zivilingenieur für Bauwesen

Objectives

To present information about the different kinds of connector used in truss systems and to show examples of joints.

Summary

The lecture presents general information about connectors, which are used in truss systems.

Introduction

Apart from the fixing of individual beams, mechanical timber connectors have the function within trusses to transfer ring forces from one component to another. Forces are thus introduced into joints by compression and shear, depending on the stiffness of the connector and the embedding strength of the wood. Under these actions elastic and plastic deformations occur in the wood. The dowels used nowadays have been developed from carpenter's dowels. They were mainly produced from dry hardwood with a rectangular section. With the evolution of drilling and milling machines even round hardwood dowels could be placed in timber. Since the twenties a lot of different special dowel types have been developed and their use has been proved with tests. Today only rectangular hardwood dowels, rectangular and T-type metal dowels and special type dowels, made of cast-iron or aluminium, are of any importance. The principles of calculation are covered by lectures C9 and C10.

Joints in trusses in general

Eccentricity should be avoided, if possible, when joining the members in a truss systems otherwise considerable additional stresses are caused, see Figure 1. Whenever it is not possible to fulfil this aim the influence on the load-bearing capacity of the connection has to be verified. Tests carried out have shown that in such cases the reduction of the load-bearing capacity of joints can be as high as 30 %. The magnitude of the additional moment can be calculated as follows:

$$M = D_1 \sin \alpha_1 \, e = D_2 \sin \alpha_2 \, e$$
$$M = |M_1| + |M_2|$$

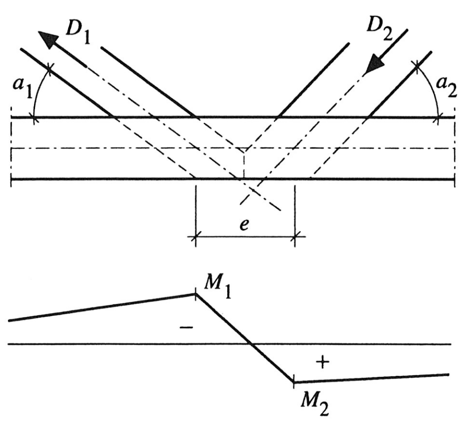

Figure 1 Effect of eccentric connections.

Examples of joints

Rectangular dowels are not often used for joints within trusses but an important example for the use of rectangular hardwood or metal dowels is the combination of a front side recess with a bracket, see Figure 2. This construction is necessary if a fully loaded diagonal member is joined to a bottom chord member and either the compression force cannot be transmitted on account of the load introduction length being too short or because the tie-beam must not be weakened by the recess. This constructional solution offers the advantage that the beams need not to be changed but the effect of any moments resulting from the eccentric connection has to be taken into account in the calculation.

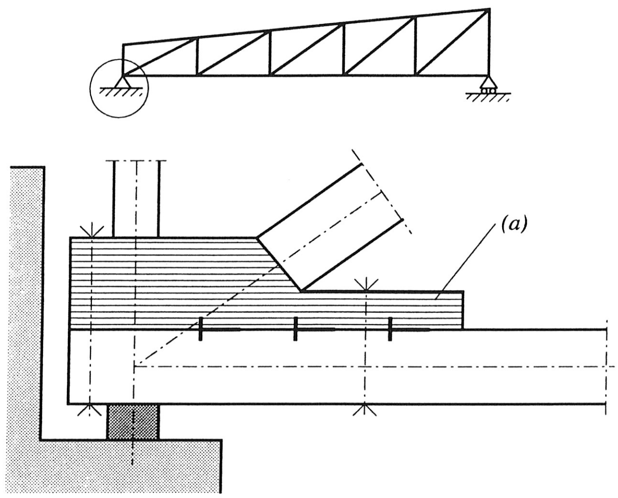

Figure 2 Use of T-shaped dowels in combination with a hardwood bracket (a).

Figures 3 to 25 illustrate the construction of joints in trusses with connectors. When designing the truss joints shown below the following points have to be considered:

- design loads,
- load-carrying capacity of connectors and bolts,
- minimum cross-sections of timber,
- end distances in the direction of grain,
- distance from the centre of the connection to the outer surface of the upper chord, with forces acting at an angle to the grain,
- minimum spacing.

Example:
Double-sided ring connector joint, type A1 according to EN912.

Calculation according to STEP lecture C9

F_d = 194 kN (tension)
k_{mod} = 0,8
t_1 = 60 mm $\quad$ b_1 = 160 mm
t_2 = 90 mm $\quad$ b_2 = 160 mm
d_c = 126 mm $\quad$ h_e = 15 mm

timber strength class C27 according to EN338
ρ_k = 370 kg/m^3

spacings and distances
a_1 = 250 mm $\quad$ $a_{3,t}$ = 250 mm

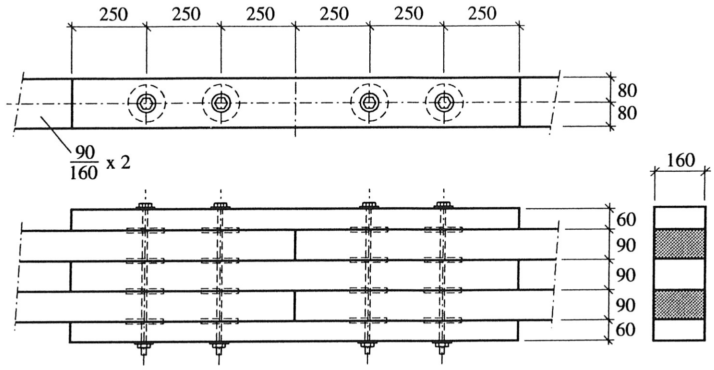

Figure 3 *Splice joint with ring connectors.*

α = 0°

n = 2 x 4 connectors

C9: Equation (12) n_{ef} = n = 2 x 4 connectors

minimum spacings

$a_{3,t,min} = 1{,}5\ d_c = 1{,}5 \cdot 126 = 189\ mm$

minimum thicknesses:

$t_{1,min} = 2{,}25\ h_e = 2{,}25 \cdot 15 = 33{,}8\ mm$

$t_{2,min} = 3{,}75\ h_e = 3{,}75 \cdot 15 = 56{,}2\ mm$

C9: Equation (16) $R_{c,k,1} = 35\ k_\rho\ k_{a3}\ k_t\ d_c^{1,5}$

$$k_\rho = \min \begin{cases} 1{,}75 \\ \dfrac{\rho_k}{350} = \dfrac{370}{350} = 1{,}06 \end{cases}$$

$k_\rho = 1{,}06$

$$k_{a3} = \min \begin{cases} 1{,}25 \\ \dfrac{a_{3,t}}{2\ d_c} = \dfrac{250}{252} = 0{,}992 \end{cases}$$

$k_{a3} = 0{,}992$

$$k_t = \min \begin{cases} 1 \\ \dfrac{t_1}{3\ h_e} = \dfrac{60}{45} = 1{,}33 \\ \dfrac{t_2}{5\ h_e} = \dfrac{90}{75} = 1{,}20 \end{cases}$$

$k_t = 1{,}00$

$R_{c,k,1} = 35\ k_\rho\ k_{a3}\ k_t\ d_c^{1,5} = 35 \cdot 1{,}06 \cdot 0{,}992 \cdot 1{,}0 \cdot 126^{1,5}$

$R_{c,k,1} = 51{,}9\ kN$

$R_{c,k,2} = 31{,}5\ k_\rho\ k_t\ h_e\ d_c = 31{,}5 \cdot 1{,}057 \cdot 1{,}0 \cdot 15 \cdot 126$

$R_{c,k,2} = 62{,}9\ kN$

$R_{c,k} = R_{c,k,1} = 51{,}9\ kN$

$$\mathbf{R_d = 2 \cdot 4\ \frac{R_{c,k}\ k_{mod}}{\gamma_M} = \frac{8 \cdot 51{,}9 \cdot 0{,}8}{1{,}3} = 256\ kN > F_d = 194\ kN}$$

Example:

Double-sided toothed-plate connector heel joint, type C10 according to EN912.

Calculation according to STEP lecture C10

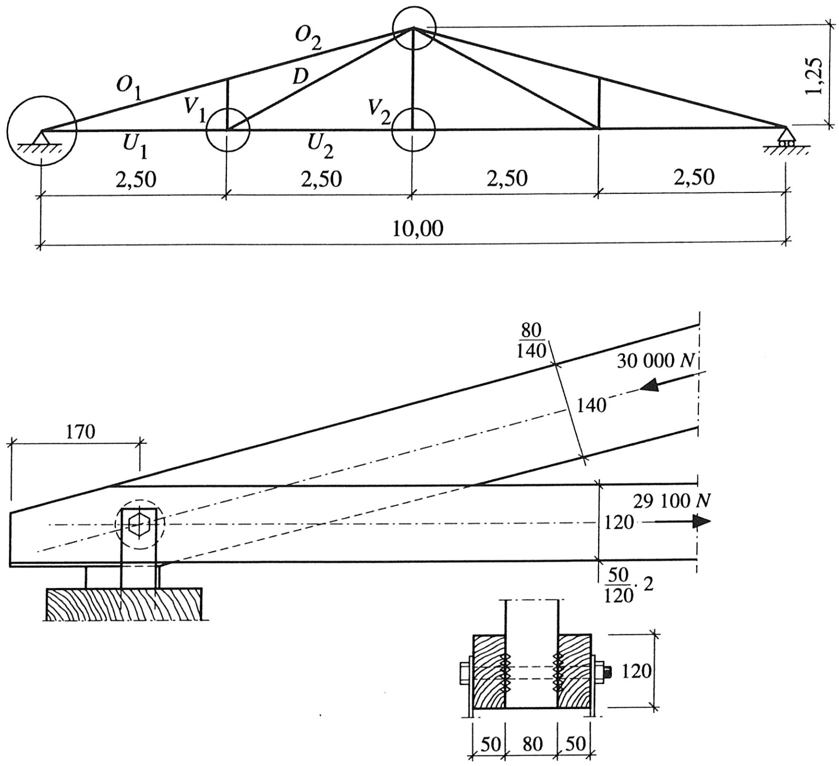

Figure 4 Truss heel joint with toothed-plates.

$O_{1,k}$ = 30,0 kN (compression) $U_{1,k}$ = 29,1 kN (tension)

$O_{1,d}$ = 41,5 kN (compression) $U_{1,d}$ = 42,8 kN (tension)

k_{mod} = 0,8

t_1 = 50 mm b_1 = 120 mm

t_2 = 80 mm b_2 = 140 mm

d_c = 80 mm h_c = 27 mm

timber strength class C27 according to EN338

ρ_k = 370 kg/m^3

bolt

d_b = 20 mm $f_{u,k}$ = 360 N/mm^2

spacings and distances

$a_{3,c}$ = 170 mm $a_{3,t}$ = 170 mm

α = 0° (the middle member is supported at the bottom)

n = 2 connectors

minimum spacings

$a_{3,c,min}$ = $1,2\ d_c$ $= 1,2 \cdot 80$ $= 96\ mm$

$$a_{3,t,min} = \max \begin{cases} 1,1\ d_c = 1,1 \cdot 80 = 88\ mm \\ 7\ d_b = 7 \cdot 20 = 140\ mm \\ 80\ mm \end{cases} \qquad (5)$$

minimum thicknesses:

$t_{1,min} = 1{,}1\ h_c = 1{,}1 \cdot 27 = 29{,}7\ mm$

$t_{2,min} = 1{,}9\ h_e = 1{,}9 \cdot 27 = 51{,}3\ mm$

Load-carrying capacity of the connector

C10: Equation (9) $R_{c,k} = 30\ k_\rho\ k_{a3}\ k_t\ d_c^{1,5}$

$$k_\rho = \min \begin{cases} 1{,}75 \\ \dfrac{\rho_k}{350} = \dfrac{370}{350} = 1{,}06 \end{cases}$$

$k_\rho = 1{,}06$

$$k_{a3} = \min \begin{cases} 1{,}00 \\ \dfrac{a_{3,t}}{1{,}5\ d_c} = \dfrac{170}{120} = 1{,}42 \end{cases}$$

$k_{a3} = 1{,}00$

$$k_t = \min \begin{cases} 1 \\ \dfrac{t_1}{1{,}5\ h_c} = \dfrac{50}{1{,}5 \cdot 27} = 1{,}24 \\ \dfrac{t_2}{2{,}5\ h_c} = \dfrac{80}{2{,}5 \cdot 27} = 1{,}19 \end{cases}$$

$k_t = 1{,}00$

$R_{c,k} = 30\ k_\rho\ k_{a3}\ k_t\ d_c^{1,5} = 30 \cdot 1{,}06 \cdot 1{,}0 \cdot 1{,}0 \cdot 80^{1,5}$

$R_{c,k} = 22{,}7\ kN$

$$R_{c,d} = 2\ \frac{R_{c,k}\ k_{mod}}{\gamma_M} = \frac{2 \cdot 22{,}7 \cdot 0{,}8}{1{,}3} = 27{,}9\ kN$$

Load-carrying capacity of the bolt

Design values of material properties:

EC5: Part 1-1: 6.2.1 (2) Embedding strength ($\gamma_M = 1{,}3$)

side member:

EC5: Part 1-1: 6.5.1.2 (1) $$f_{h,0,d} = f_{h,1,d} = 0{,}082\ (1 - 0{,}01 \cdot 20) \cdot 370 \cdot \frac{0{,}8}{1{,}3} = 14{,}9\ N/mm^2$$

middle member:

$k_{90} = 1{,}35 + 0{,}015 \cdot 20 = 1{,}70$

$$f_{h,14,d} = f_{h,2,d} = \frac{14{,}9}{1{,}70\ \sin^2 14^\circ + \cos^2 14^\circ} = 14{,}3\ N/mm^2$$

$$\beta = \frac{14{,}3}{14{,}9} = 0{,}96$$

EC5: Part 1-1: 6.2.1 (1)

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

EC5: Part 1-1: 6.5.1.2 (2) $$M_{y,d} = 0{,}8 \cdot 360 \cdot \frac{20^3}{6} \cdot \frac{1}{1{,}1} = 349\ Nm$$

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

$$R_{b,\alpha,d} = \min \begin{cases} 14{,}9 \cdot 50 \cdot 20 \cdot 10^{-3} = 14{,}9\ kN \\ 0{,}5 \cdot 14{,}9 \cdot 80 \cdot 20 \cdot 0{,}96 \cdot 10^{-3} = 11{,}4\ kN \\ 1{,}1\ \dfrac{14{,}9 \cdot 50 \cdot 20}{(2 + 0{,}96)\ 10^{3}} \left(\sqrt{3{,}76 + \dfrac{11{,}4 \cdot 349000}{14{,}9 \cdot 20 \cdot 50^{2}}} - 0{,}96 \right) = 11{,}4\ kN \\ 1{,}1 \sqrt{\dfrac{2 \cdot 0{,}96}{1 + 0{,}96}} \sqrt{2 \cdot 349000 \cdot 14{,}9 \cdot 20} \cdot 10^{-3} = 15{,}7\ kN \end{cases}$$

design load-carrying capacity of the joint

$$\mathbf{R_{j,\alpha,d} = R_{c,d} + R_{b,\alpha,d} = 27{,}9 + 2 \cdot 11{,}4 = 50{,}7\ kN > U_d = 42{,}8\ kN}$$

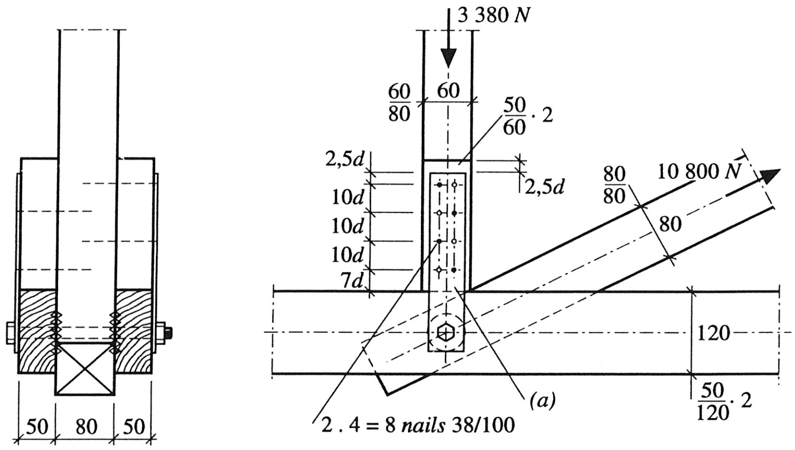

Figure 5 Bottom chord joint with toothed-plates and nails; (U_1, V_1, D, U_2).

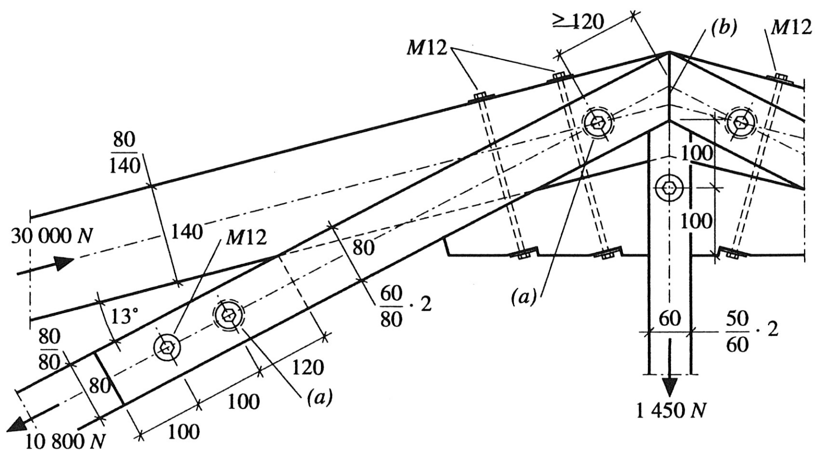

Figure 6 Truss apex joint with toothed-plates; (V_2, D, O_2). (a) Toothed-plate connectors type C10 according to EN 912, (b) contact joint.

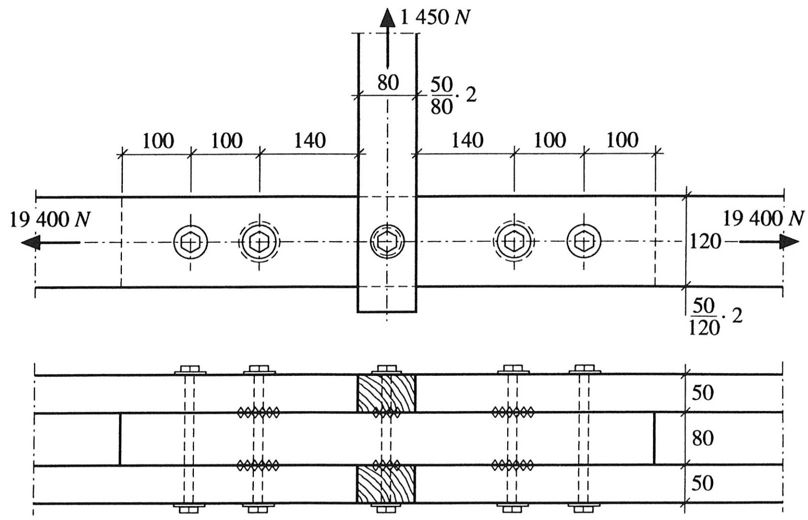

Figure 7 Bottom chord joint with toothed-plates and nails; (U_2, V_2,).

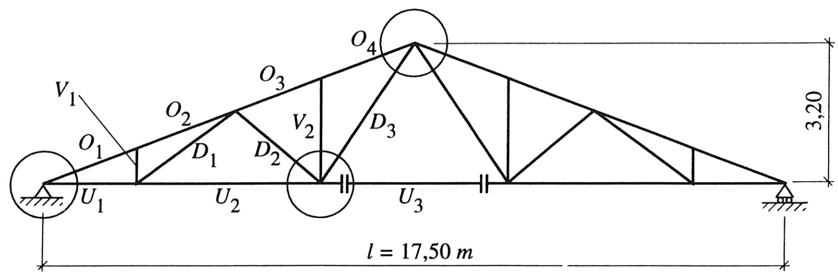

Figure 8 Triangular truss; possible joint details see Figures 9 to 23.

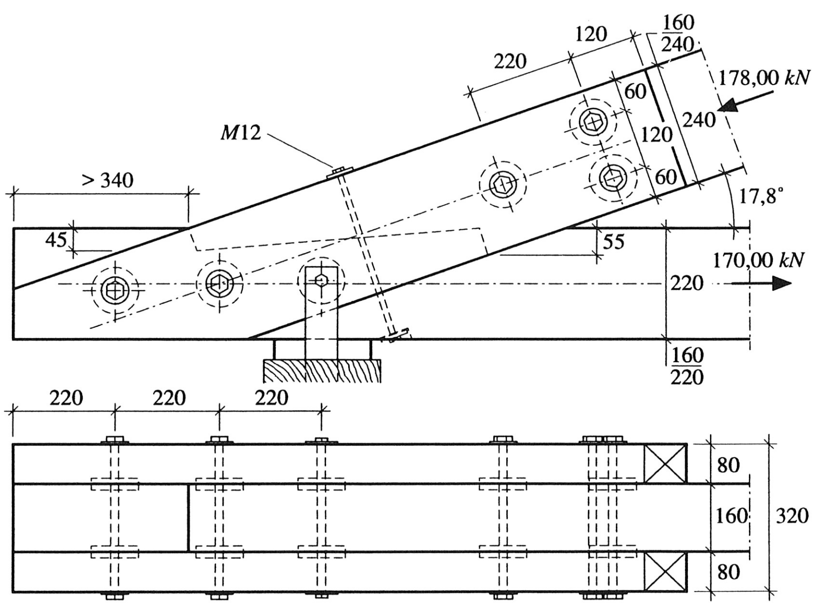

Figure 9 Ring connector heel joint; (O_1, U_1).

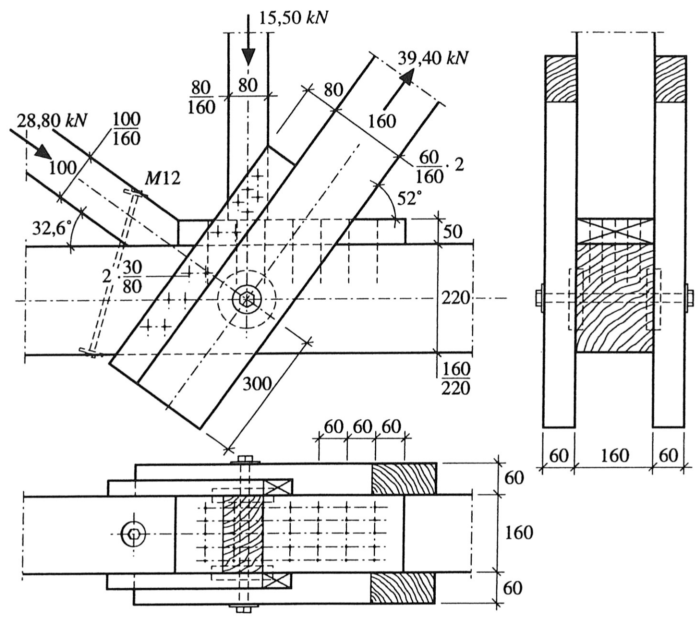

Figure 10 *Bottom chord joint with ring connectors and nails; (U_2, D_2, V_2, D_3, U_3).*

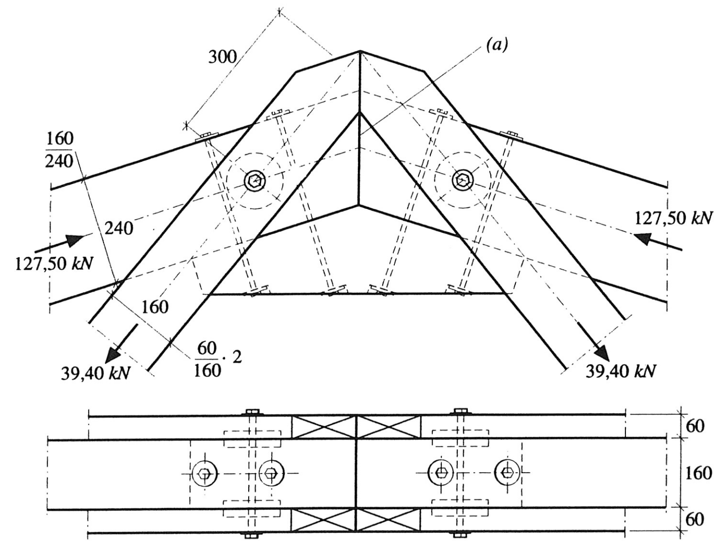

Figure 11 *Apex joint with ring connectors; (D_3, O_4). (a) Contact joint.*

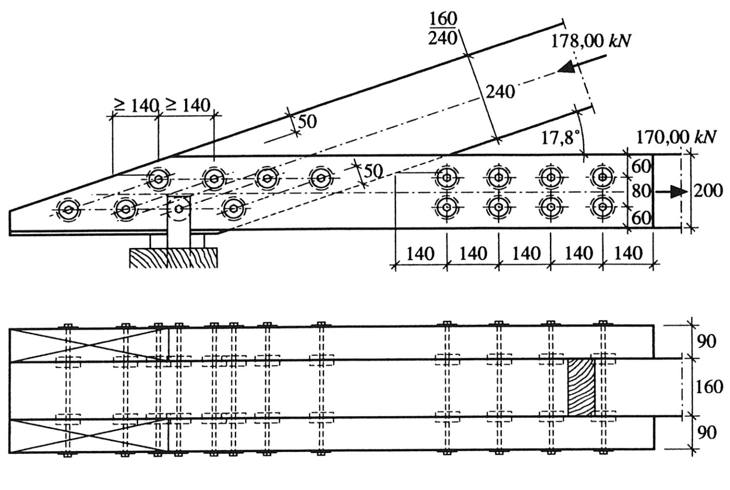

Figure 12 *Ring connector heel joint; (O_1, U_1).*

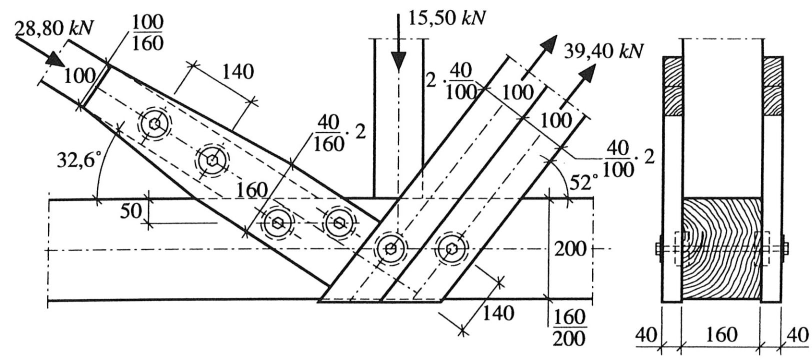

Figure 13 *Bottom chord joint with ring connectors and contact; (U_2, D_2, V_2, D_3, U_3).*

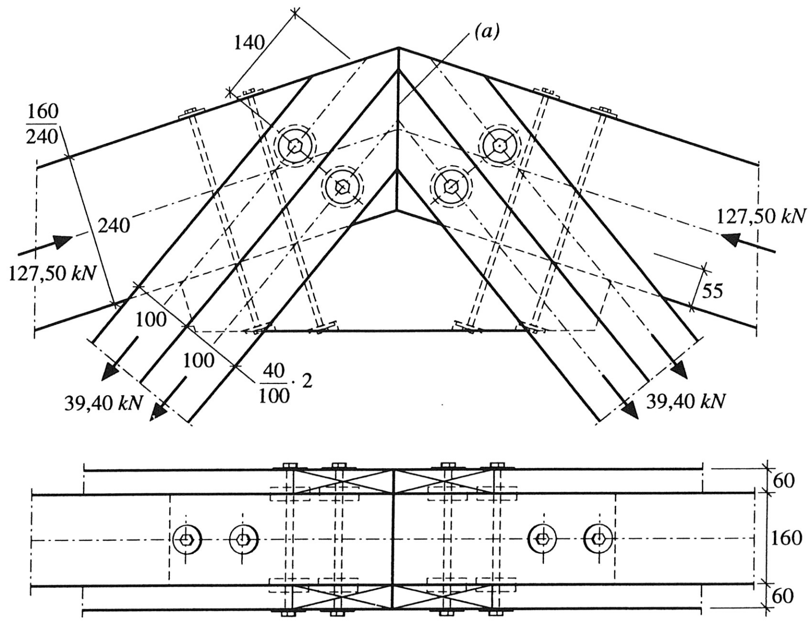

Figure 14 *Apex joint with ring connectors; (D_3, O_4). (a) Contact joint.*

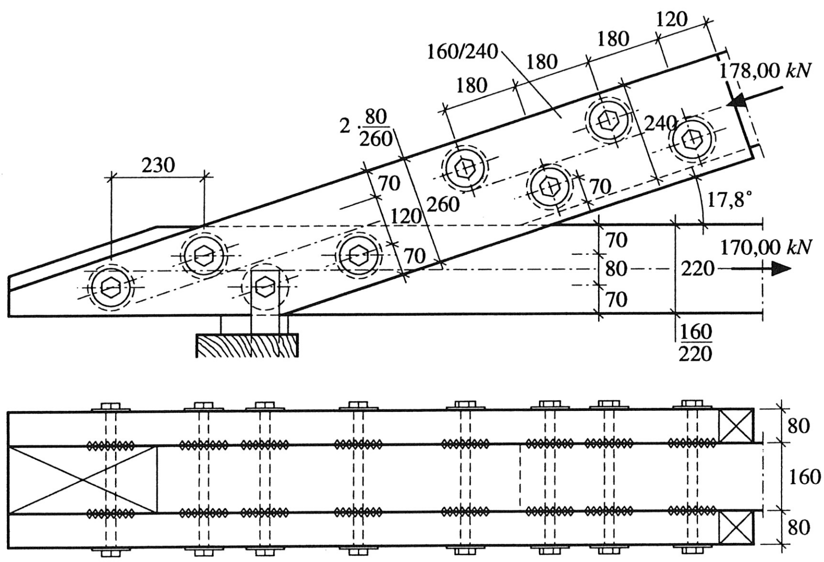

Figure 15 *Toothed-plate connector heel joint; (O_1, U_1).*

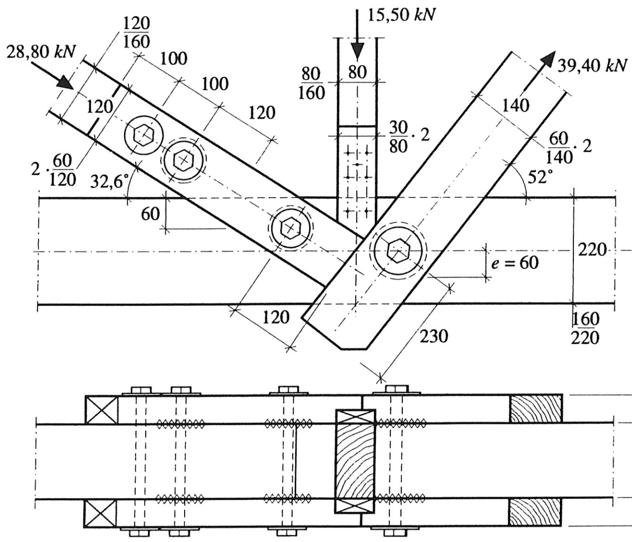

Figure 16 *Bottom chord joint with toothed-plate connectors and contact; (U_2, D_2, V_2, D_3, U_3).*

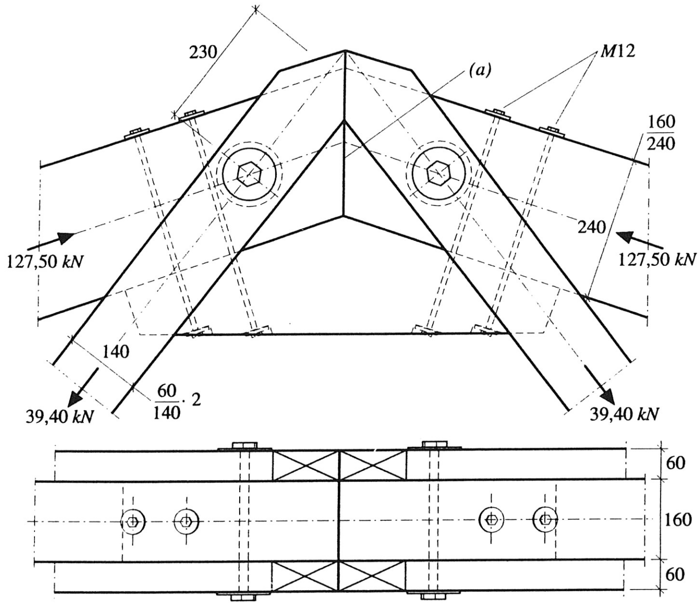

Figure 17 *Apex joint with bolts; (D_3, O_4). (a) Contact joint.*

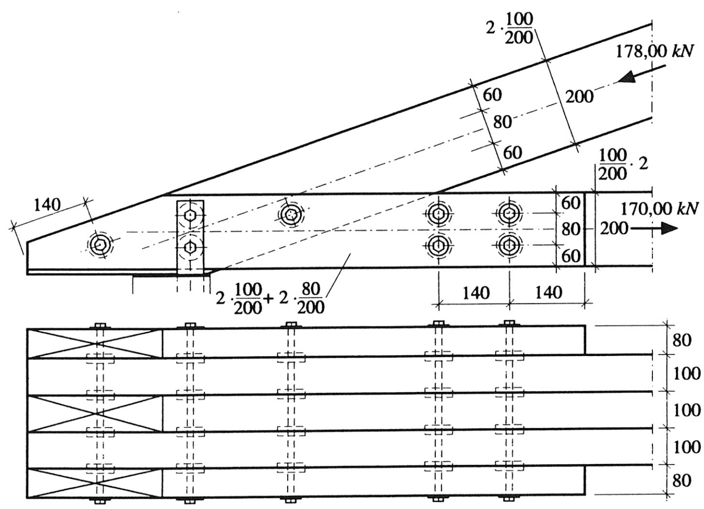

Figure 18 *Ring connector heel joint; (O_1, U_1).*

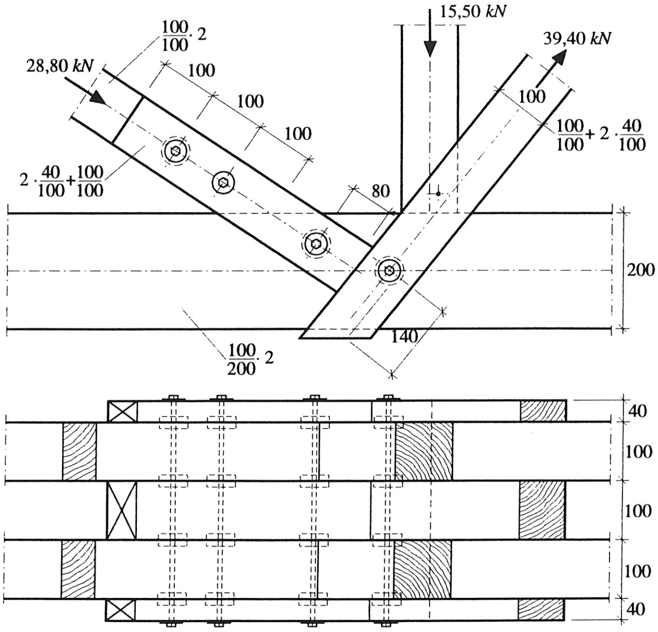

Figure 19 Bottom chord joint with ring connectors and contact; (U_2, D_2, V_2, D_3, U_3).

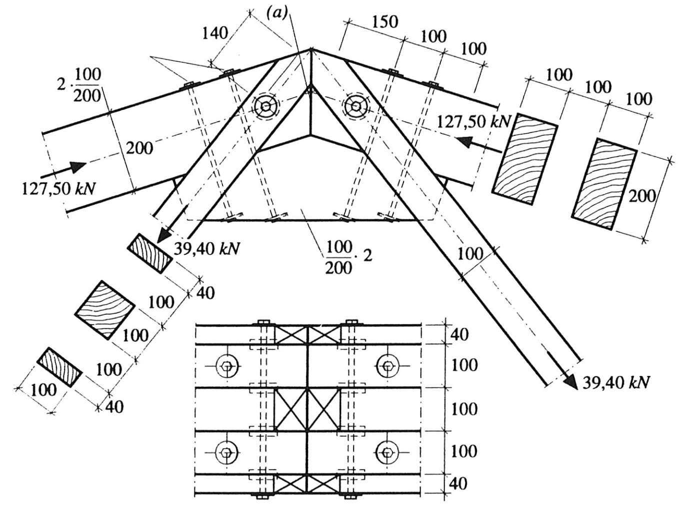

Figure 20 Apex joint with ring connectors; (D_3, O_4). (a) Contact joint.

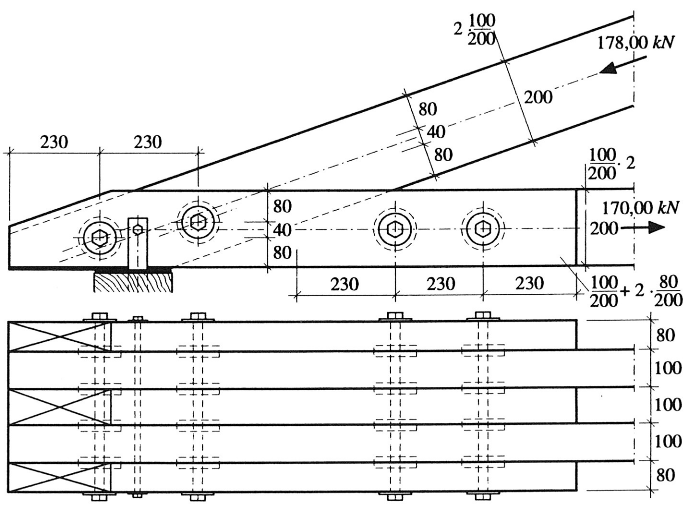

Figure 21 Ring connector heel joint; (O_1, U_1).

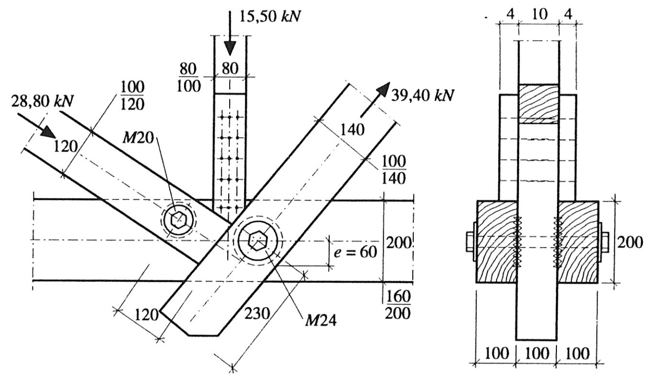

Figure 22 *Bottom chord joint with ring connectors and nails; (U_2, D_2, V_2, D_3, U_3).*

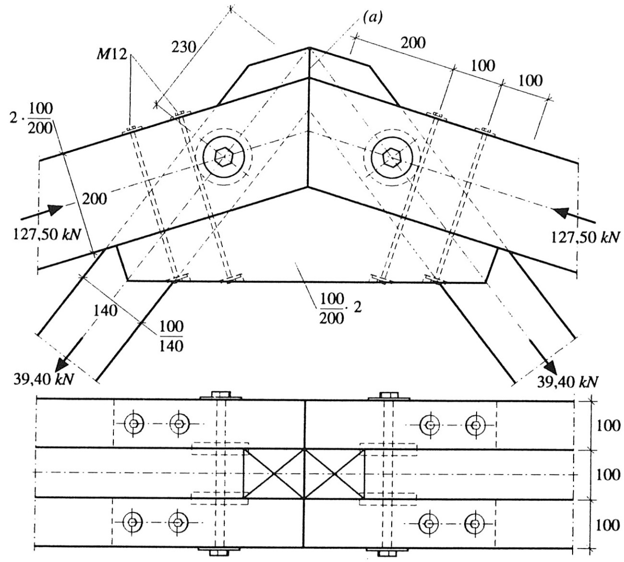

Figure 23 *Apex joint with ring connectors; (D_3, O_4). (a) Contact joint.*

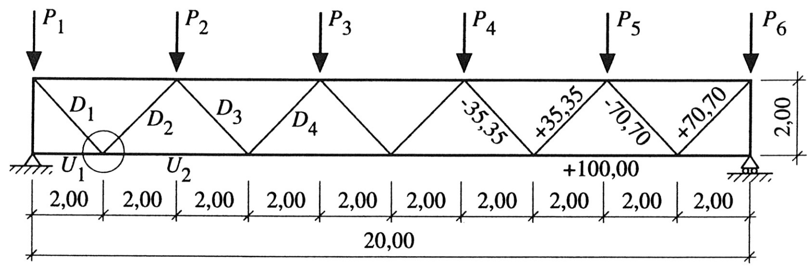

Figure 24 *Parallel truss; bottom chord detail see Figure 25.*

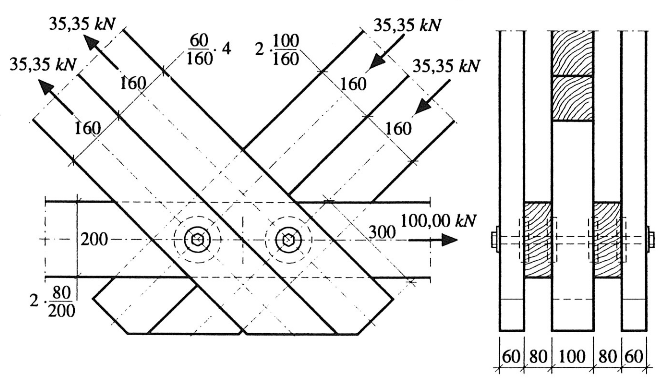

Figure 25 *Bottom chord joint with ring connectors; (U_1, D_1, D_2, U_2).*