Truss connections with dowel-type fasteners

STEP lecture D1
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Objectives

To present information about the different kinds of dowel-type fasteners used in truss systems, to demonstrate a method for calculating multiple shear joints and to give examples of the calculations involved in their design.

Summary

After a demonstration of a method for designing multiple shear timber-to-timber dowelled joints attention is paid to deciding what kind of timber and fasteners are to be used in practice. Examples of the calculation of typical joints and drawings of truss systems showing joints in detail are the main part of the lecture.

Introduction

Truss girders are a well established form for timber structures. They are mainly used to build roofs of sports halls, industrial buildings and agricultural buildings and come in many different forms. The advantages of these systems are their low dead weight and their low material requirements although the height of trusses at midpoint might be seen as a disadvantage compared to simple beams. The various members of trusses are either connected end to end with overlapping joints of several thicknesses or butt joints with steel plates. Multiple shear joints allow minimisation of the connection area, because the forces carried by the fastener can be distributed over several shear planes. Because of their high load-carrying capacity dowel-type fasteners are often used for joints in truss systems, either with timber to timber or timber to steel connections.

Multiple shear joints

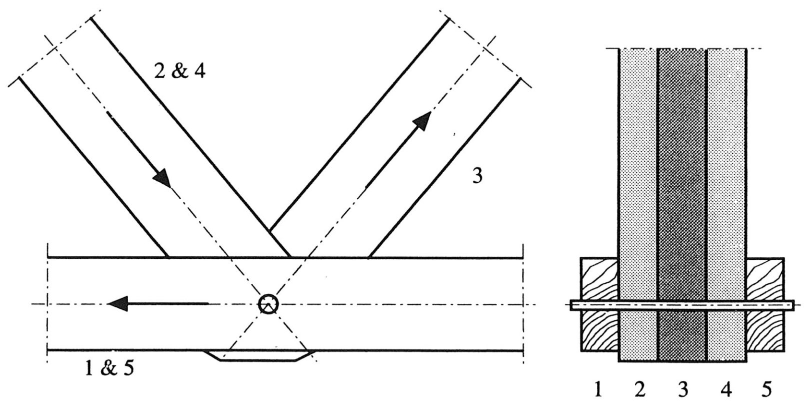

Figure 1 A typical built-up joint of a truss.

In Timber Engineering - STEP 1 only single shear and double shear joints are treated where only two or three elements are connected. However, in a number of cases a joint consists of more elements. An example is the joint in timber trusses with elements which are not situated in one plane as is the case for trusses with punched metal plates. The top and bottom cords are continuous and run from one support to the other. These structural elements might consist of more than one timber member. The diagonals and verticals frequently fit in between. At the junction of these members a built-up joint is created. An example is given in Figure 1. For simplicity the timber members are connected with one fastener.

The number of timber elements connected by the fastener is now five. The number of shear planes is four. The problem arises in how to determine the load-carrying capacity of each shear plane. However, a straightforward application of the conventional design equations is not possible without any modification. In this respect guidance is given by EC5: "In multiple shear joints the total load-carrying capacity should be determined by calculating the sum of the load-carrying capacity for each shear plane as if it were a part of a three member joint". This sentence has two parts. In the first part the phrase 'total load-carrying capacity of the joint' is used. However, since the load which has to be transmitted by every shear plane in general is different, as are the grain directions of the members, the total load-carrying capacity is not always of interest. Of importance is the load-carrying capacity of each shear plane. The second part of the sentence gives an idea of how to analyze this multiple shear joint. A method aimed at determining the load-carrying capacity of each shear plane is now presented.

For the analyses the example of Figure 1 is taken as reference. The forces in the members are indicated. It is essential to determine the direction of the force to be transmitted at every shear plane. In Figure 2 the dowel type fastener which in this case connects the members is enlarged and the forces introduced by the separate members are shown. As the loads are symmetrical, only half of the fastener is drawn. At the shear plane the fastener is cut into parts in order to show the direction of the shear force. These shear plane forces can easily be found by considering the equilibrium equations of the individual parts. In reality there are no loads but embedding stresses which act along the axis of the fastener. The basic assumption of the analysis given is that the fastener deforms and fails in the direction of the shear plane force. This direction is important because the embedding strength of the members is dependent on the load to grain angle.

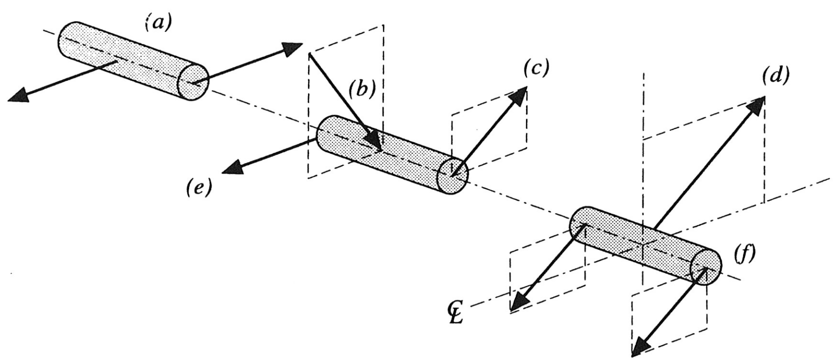

Figure 2 The equilibrium of forces between each shear plane.

A procedure to determine the load-carrying capacity of each shear plane is now given. As the joint considered is symmetrical only two shear planes have to be examined. First consider the shear plane between member 1 and member 2 and remove all other members. Mirror member 1 along the symmetry-axis of member 2. In Figure 3b the final situation is shown. The joint members now become 1, 2 and again 1. In this way a conventional double shear joint is created. The load-carrying capacity of this shear plane is now calculated according to Johansen's model (see STEP lecture C3). The embedding strength substituted in these design equations is modified corresponding to the shear plane load to grain direction of the members. The governing failure mode is noted. Now the next shear plane between member 2 and 3 is considered. Isolate member 2 and 3 and mirror member 2 in the same way, see Figure 3c. The load-carrying capacity as well as the governing failure mode are noted. To consider all possible failure modes of this shear plane one additional analysis is necessary, considering the combination 3-2-3, Figure 3d should finally be made. So for all shear planes which do not connect an outside member two analyses should be made.

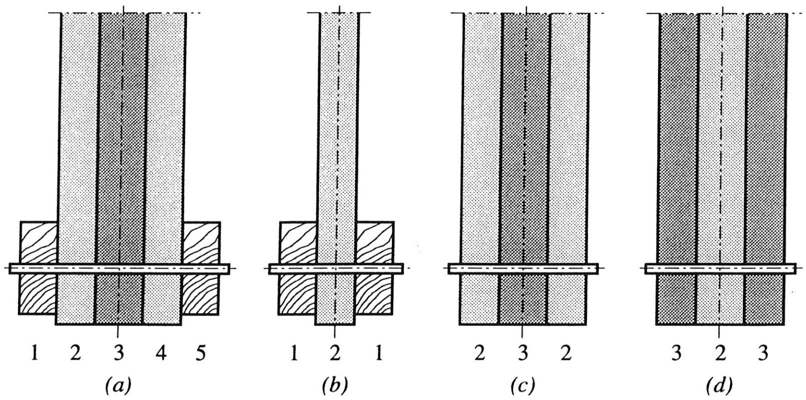

Figure 3 *Combination of members for the determination of the load-carrying capacity.*

The last, but not least important, consideration is the compatibility of the failure modes of the subsequent shear planes. For the shear plane which connects the outside member in principle all failure modes have to be analyzed. It is physically possible that the fastener end which sticks out of the side member may be inclined. However, for other shear planes this is not possible as at this end another shear plane exists and the dowel must be continuous through the joint. It is evident that the governing failure mode of the next nearby shear plane should be compatible with this failure mode.

Example

The joint of Figure 1 is considered. The angle between outside members and diagonals is 45°.

Members 1 and 5	b	=	45 *mm*
Member 3	b	=	75 *mm*
Members 2 and 4	b	=	35 *mm*
Steel 8.8 yield stress	$f_{u,k}$	=	640 N/mm^2
Fastener diameter	d	=	10 *mm*
Density of the timber members	ρ_k	=	380 kg/m^3

Table 1 shows the results. For the shear plane between members 1 and 2 the load-carrying capacity is 2970 *N* while for the next shear plane the capacity is 2130 *N*.

Member number	Angle between force and grain direction	Member number	Angle between force and grain direction	Member number	Angle between force and grain direction
1	0	2	90	3	0
2	45	3	0	2	90
1	0	2	90	3	0
Mode number	**Capacity [N]**		**Capacity [N]**		**Capacity [N]**
Ia	12600		4270		21000
Ib	**2970**		10500		**2130**
II	4540		~~2730~~		~~6940~~
III	4070		**3650**		6020

The load carrying capacities of incompatible failure modes are struck out.

Table 1 *Load-carrying capacities of the shear planes and compatibility of failure modes.*

Material selection

The direct connection of members, timber to timber carpenter style, is not always possible, because uneconomical member cross-sections would be needed. The section of the member has to be chosen to satisfy connection conditions and not the action effects in the member. To ensure maximum utilisation of the member cross-sections elements made of other materials, e.g. steel, are used to effect load transfer. The use of steel plates offers the advantage that the connection area can be kept small thus avoiding fixing moments and maintaining the assumptions made in the design method for trusses.

For truss systems glued laminated timber is becoming more and more significant on account of its better material properties, its higher resistance to deformation and the possibility of producing bigger cross-sections.

With respect to fastener selection a distinction must be made between permanent and temporary structures and whether fastener slip is of any importance. Dowels display a relatively high stiffness and can therefore be used in many kinds of connections. In contrast, the low stiffness of bolted connections is reason enough to restrict their use to cases where high slip can cause no damage to a structure. Bolts should be tightened in such way that the members fit closely and they should be easily accessible for retightening from time to time if necessary when the timber has reached equilibrium moisture content. For moveable structures, falsework or concrete formwork, which should be easily dismantled, bolts are preferred.

Design examples

Truss illustrated in Figure 4

The figure illustrates a typical triangular truss which is quite often used. The span of the truss is short enough that the member forces can be transmitted by nails. The internal forces have been calculated by using a computer program. The significant load case is determined considering the self weight and the snow load. It is assumed that the truss system is used in an area which has a heavy snow load for a prolonged period of time, for example the alpine regions in Austria. Therefore the load-duration class is regarded as medium term.

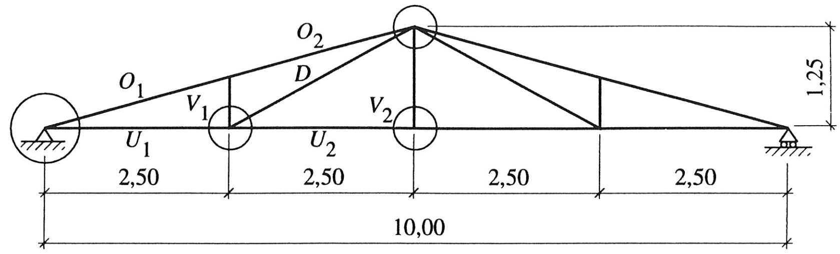

Figure 4 *Triangular truss.*

Nails: 3,1 x 70 - smooth shank and not predrilled
γ_M = 1,1
f_y = 600 N/mm^2

Timber: C27
ρ_k = 370 kg/m^3
γ_M = 1,3
service class 1
load duration class medium term
k_{mod} = 0,8

Characteristic and design embedding strength value for nails up to 8 *mm* without predrilled holes:

EC5: Part 1-1: 6.3.1.2a $f_{h,k}$ = 21,6 N/mm^2
EC5: Part 1-1: 6.2.1.1 $f_{h,d}$ = 13,3 N/mm^2
β = 1,0

Characteristic and design value for yield moment for common steel wire nails with a minimum tensile strength of 600 N/mm^2:

EC5: Part 1-1: 6.3.1.2c $M_{y,k}$ = 3410 *Nmm*
$M_{y,d}$ = 3100 *Nmm*

Nails in double shear:
The design value per nail is the minimum of the following values per shear plane.

EC5: Part 1-1: 6.2.1g R_d = 907 *N*
EC5: Part 1-1: 6.2.1h R_d = 495 *N*
EC5: Part 1-1: 6.2.1j R_d = 473 *N*
EC5: Part 1-1: 6.2.1k R_d = 556 *N*

R_d = 473 · 2 = 946 *N*

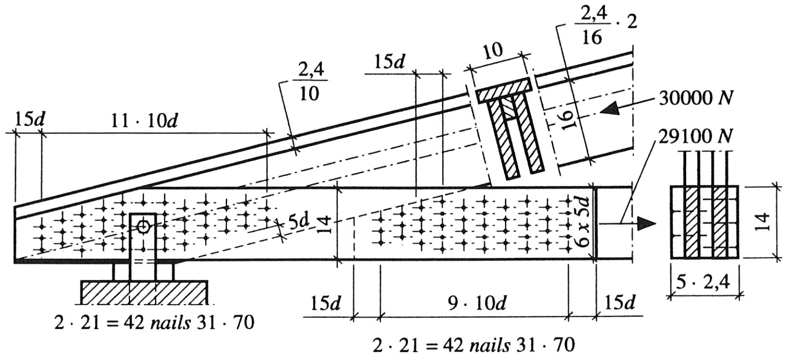

Figure 5 *Heel joint.*

Connection U_1 to O_1: Figure 5

F_d = 39300 N

n_{req} = 39300/946 = 41,5 say 42 nails

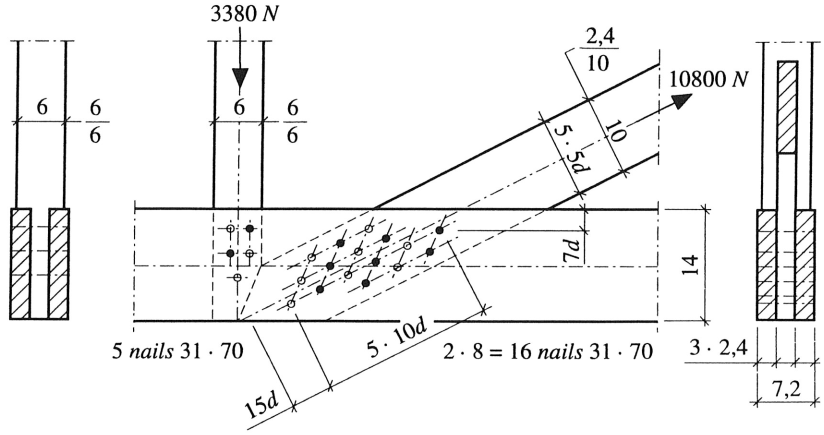

Figure 6 Lower chord node.

Connection V_1 to U: Figure 6

F_d = 4560 N

n_{req} = 4560/946 = 4,8 say 5 nails

Connection D to U_2: Figure 6

F_d = 14600 N

n_{req} = 14600/946 = 15,4 say 16 nails

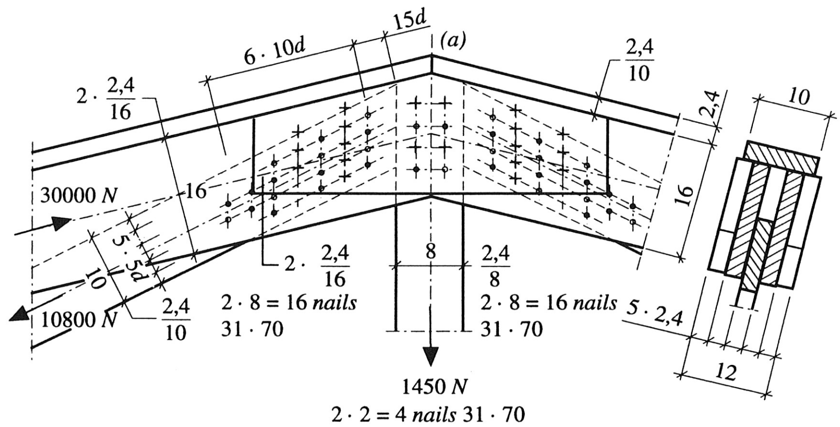

Figure 7 Apex joint.

Connection V_2 to O: Figure 7

F_d = 1960 N

n_{req} = 1960/946 = 2,1 say 4 nails

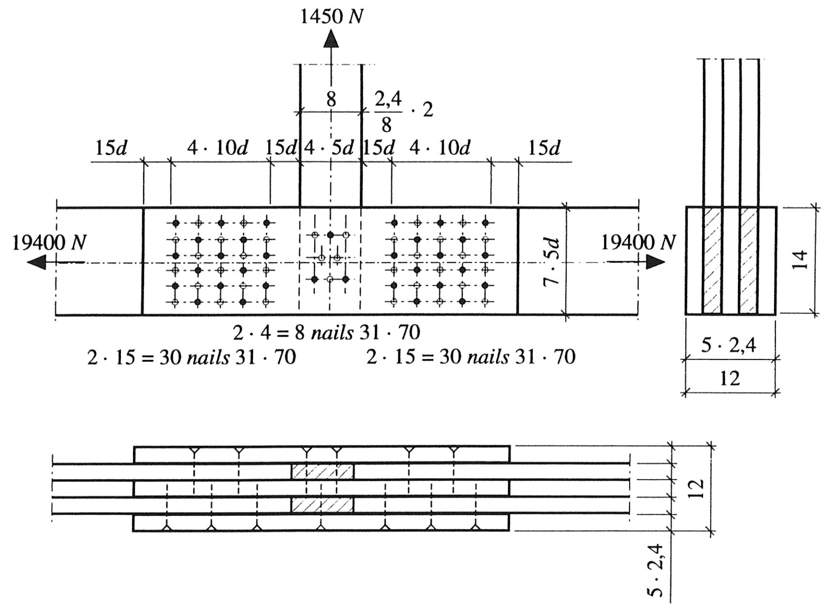

Figure 8 *Lower chord joint.*

Joint in U_2: Figure 8

$F_d = 26200\ N$

$n_{req} = 26200/946 = 27{,}7$ say 30 nails

Truss illustrated in Figure 9

The figure illustrates another triangular truss which is a little bit different from the example described before. The internal forces have been calculated by using a computer program and they are of such magnitude that for the connections in the joints dowels have to be used. The significant load case is also determined considering the self weight and the snow load for a load-duration class regarded as medium term.

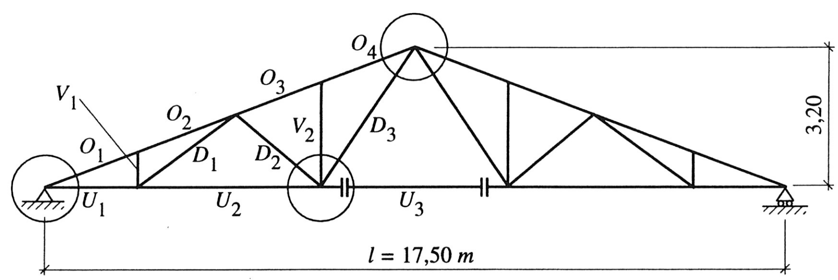

Figure 9 *Triangular truss.*

Dowels: Ø 20 *mm*

Fe 360

$\gamma_M = 1{,}1$

Timber: C24

$\rho_k = 350\ kg/m^3$

$\gamma_M = 1{,}3$

service class 1

load duration class medium term

$k_{mod} = 0{,}8$

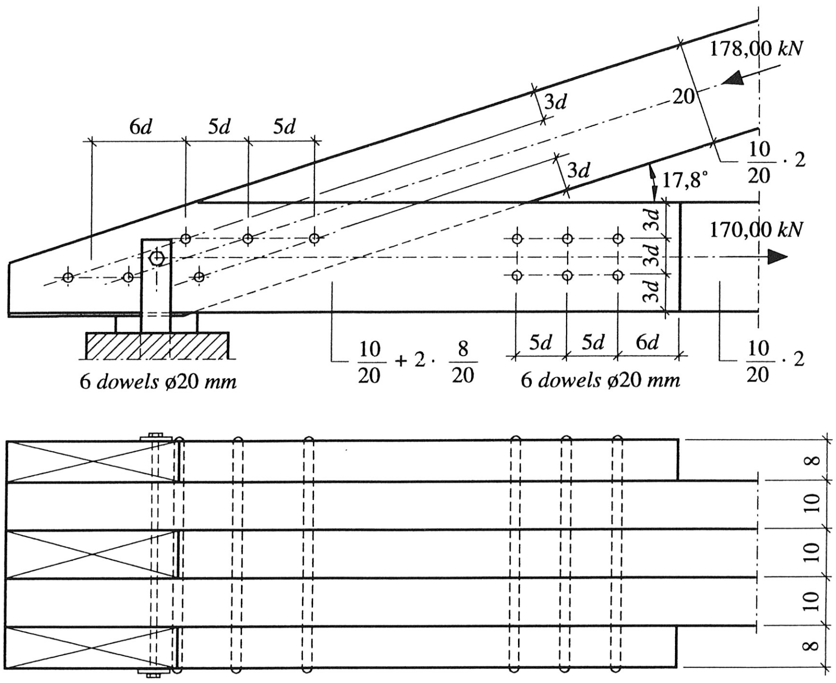

Figure 10 Heel joint.

Connection U_1 to O_1 : Figure 10

F_d = 290000 N

Characteristic and design value for yield moment for round steel bolts:

EC5: Part 1-1: 6.5.1.2e

$M_{y,k}$ = 384 Nm

$M_{y,d}$ = 349 Nm

Characteristic embedding strength value for bolts up to 30 *mm* parallel to the grain:

EC5: Part 1-1: 6.5.1.2a — $f_{h,0,k} = f_{h,1,k}$ = 23,0 N/mm^2

EC5: Part 1-1: 6.5.1.2c — k_{90} = 1,65

Characteristic embedding strength value for bolts up to 30 *mm* at an angle to the grain of 18 degrees:

EC5: Part 1-1: 6.5.1.2b — $f_{h,18,k} = f_{h,2,k}$ = 21,6 N/mm^2

Design values of the embedding strength:

EC5: Part 1-1: 6.2.1l — $f_{h,0,d}$ = 14,1 N/mm^2

EC5: Part 1-1: 6.2.1m — $f_{h,18,d}$ = 13,3 N/mm^2

β = 0,94

Dowels in double shear:
The design value per dowel is the minimum of the following values per shear plane.

EC5: Part 1-1: 6.2.1g — R_d = 28300 N

EC5: Part 1-1: 6.2.1h — R_d = 13300 N

EC5: Part 1-1: 6.2.1j — R_d = 13700 N

EC5: Part 1-1: 6.2.1k — R_d = 15200 N

R_d = 13300 N

n_{req} = 290000/(13300 · 2 · 2) = 5,4 say 6 dowels

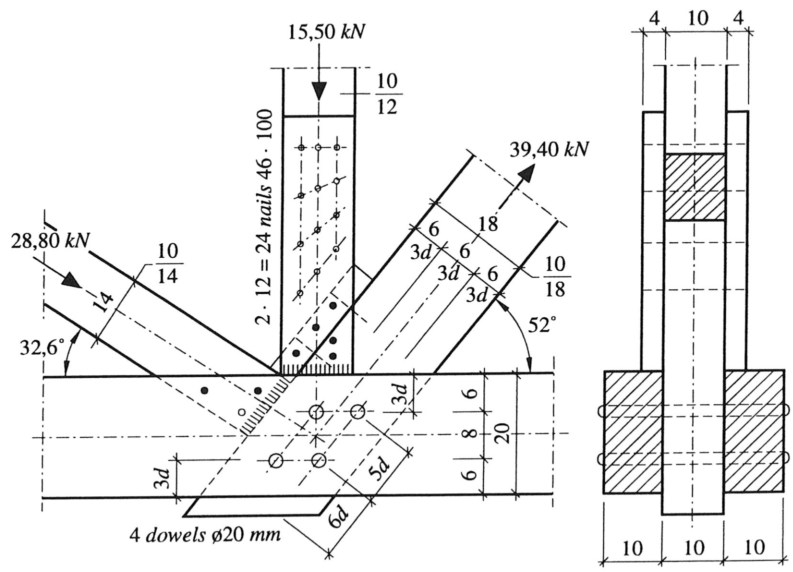

Figure 11 *Lower chord node.*

Connection D_3 to U_3: Figure 11
The sum of forces in D_2 and D_3 has to be connected.
F_d = 86900 N

Characteristic and design value for yield moment for round steel bolts:

EC5: Part 1-1: 6.5.1.2e $M_{y,k}$ = 384 Nm
$M_{y,d}$ = 349 Nm .

Characteristic embedding strength value for bolts up to 30 *mm* parallel to the grain:

EC5: Part 1-1: 6.5.1.2a $f_{h,0,k}$ = 23,0 N/mm^2
EC5: Part 1-1: 6.5.1.2c k_{90} = 1,65

Characteristic embedding strength value for bolts up to 30 *mm* at an angle to the grain of 18°:

EC5: Part 1-1: 6.5.1.2b $f_{h,18,k} = f_{h,1,k}$ = 21,6 N/mm^2

Characteristic embedding strength value for bolts up to 30 *mm* at an angle to the grain of 34°:

EC5: Part 1-1: 6.5.1.2b $f_{h,34,k} = f_{h,2,k}$ = 19,1 N/mm^2

Design values of the embedding strength:

EC5: Part 1-1: 6.2.1l $f_{h,1,d}$ = 13,3 N/mm^2
EC5: Part 1-1: 6.2.1m $f_{h,2,d}$ = 11,7 N/mm^2
β = 0,88

Dowels in double shear:
The design value per dowel is the minimum of the following values per shear plane.

EC5: Part 1-1: 6.2.1g — $R_d = 26600\ N$

EC5: Part 1-1: 6.2.1h — $R_d = 11700\ N$

EC5: Part 1-1: 6.2.1j — $R_d = 12900\ N$

EC5: Part 1-1: 6.2.1k — $R_d = 14500\ N$

$R_d = 11700\ N$

$n_{req} = 86900/(11700 \cdot 2) = 3{,}7$ say 4 dowels

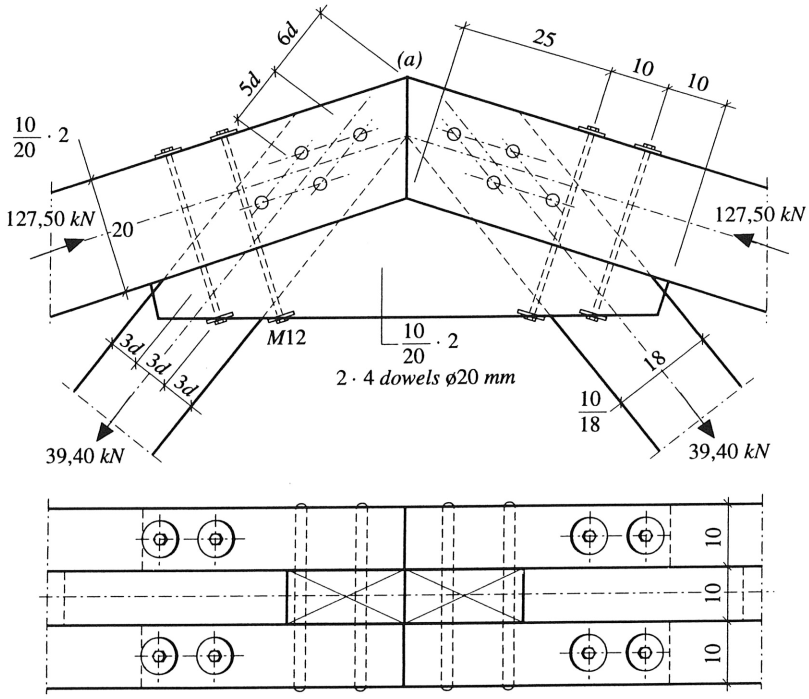

Figure 12 Apex joint.

Connection D_3 to O_4: Figure 12

$F_d = 67400\ N$

Characteristic and design value for yield moment for round steel bolts:

EC5: Part 1-1: 6.5.1.2e — $M_{y,k} = 384\ Nm$

$M_{y,d} = 349\ Nm$

Characteristic embedding strength value for bolts up to 30 *mm* parallel to the grain:

EC5: Part 1-1: 6.5.1.2a — $f_{h,0,k} = f_{h,1,k} = 23{,}0\ N/mm^2$

EC5: Part 1-1: 6.5.1.2c — $k_{90} = 1{,}65$

Characteristic embedding strength value for bolts up to 30 *mm* at an angle to the grain of 34°:

EC5: Part 1-1: 6.5.1.2b — $f_{h,34,k} = f_{h,2,k} = 19{,}1\ N/mm^2$

Design values of the embedding strength:

EC5: Part 1-1: 6.2.1l — $f_{h,0,d} = 14{,}1\ N/mm^2$

EC5: Part 1-1: 6.2.1m — $f_{h,34,d} = 11{,}7\ N/mm^2$

$\beta = 0{,}83$

Dowels in double shear:
The design value per dowel is the minimum of the following values per shear plane.

EC5: Part 1-1: 6.2.1g $R_d = 28300\ N$
EC5: Part 1-1: 6.2.1h $R_d = 11700\ N$
EC5: Part 1-1: 6.2.1j $R_d = 13400\ N$
EC5: Part 1-1: 6.2.1k $R_d = 14700\ N$

$R_d = 11700\ N$

$n_{req} = 67400/(11700 \cdot 2) = 2{,}9$ say 4 dowels

The further added examples should give an impression of how to carry out joints with dowel type fasteners used in different truss systems. Figure 13 shows a trapezoidal truss and Figure 14 the construction of a typical joint in this truss. Wide-spanning trusses, see Figures 15 and 16, often require joint constructions using steel plates to transmit the internal forces as illustrated in Figure 17. Figures 19 and 20 give details of joints of the parallel truss in Figure 18.

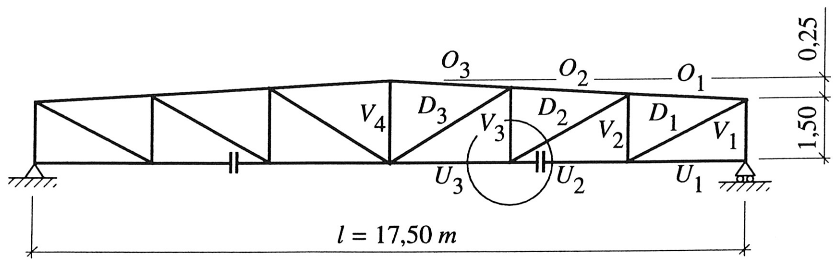

Figure 13 Trapezoidal truss.

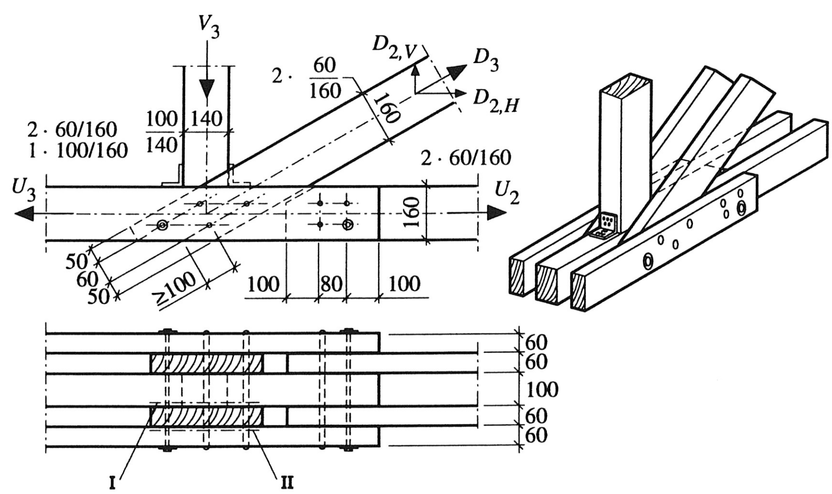

Figure 14 Example of a joint in the truss shown in Figure 13.

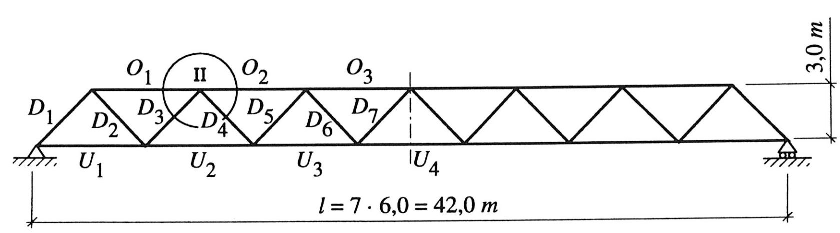

Figure 15 Timber truss with steel-to-timber connections.

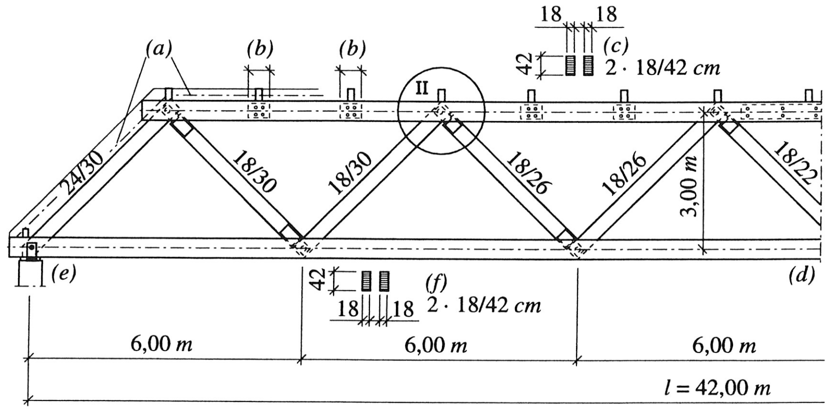

Figure 16 *Details of truss shown in Figure 15.*

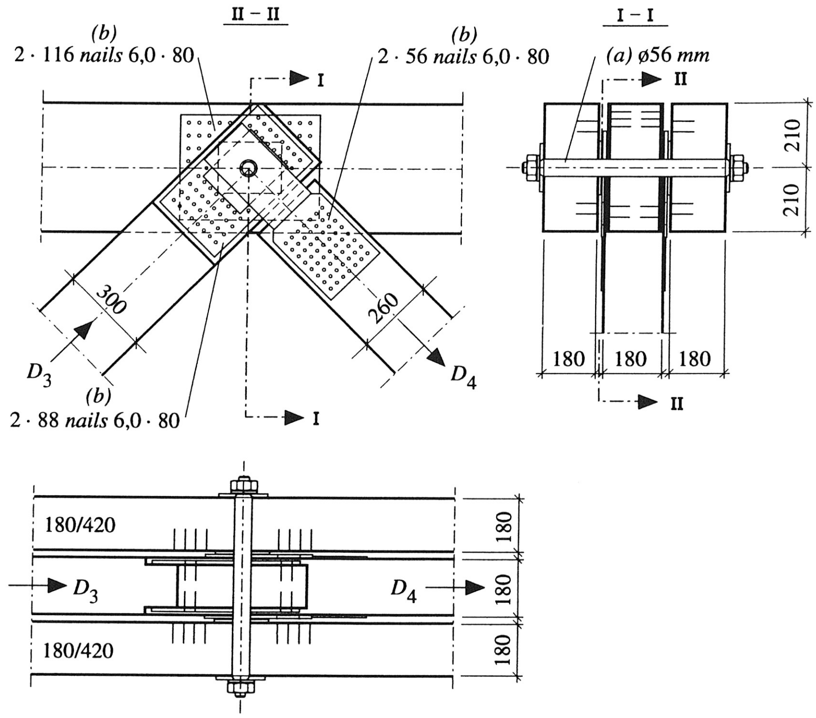

Figure 17 *Upper chord node with nailed-on steel plates and central bolt.*

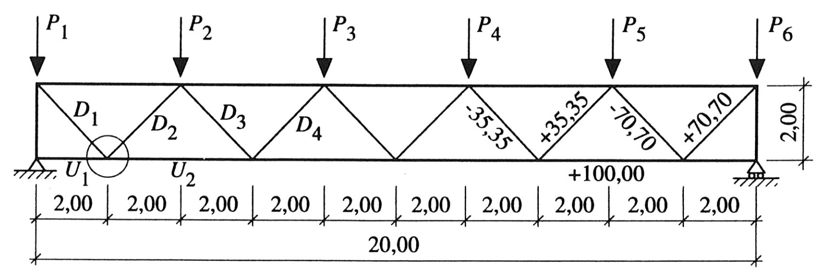

Figure 18 *Parallel chord timber truss.*

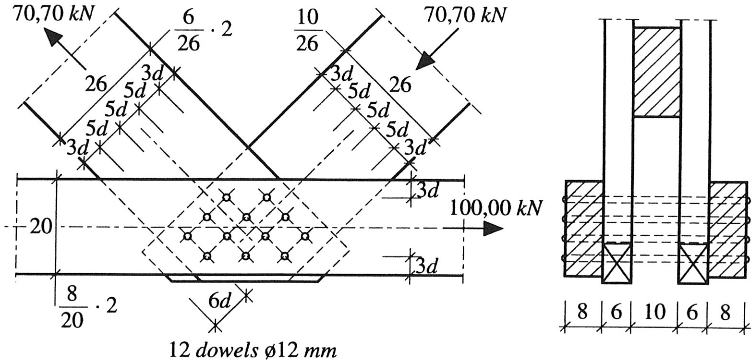

Figure 19 *Lower chord node of truss shown in Figure 18.*

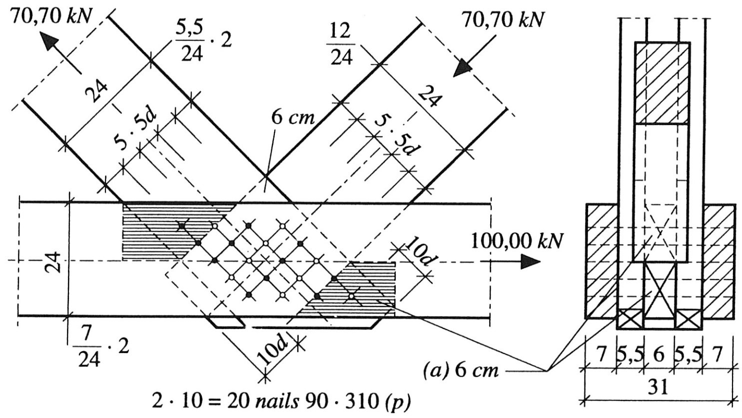

Figure 20 *Lower chord node of truss shown in Figure 18.*