Special connections using steel plates

STEP lecture D6
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Objective

To describe different ways of connecting and supporting timber elements in arches and frames by using steel plates.

Summary

The lecture describes the different principles to be followed when designing hinges and supports based on steel plates. The design of the details is discussed, and examples of actual hinges in existing timber structures are presented.

Introduction

As pointed out in STEP lecture C1, the serviceability and the durability of a timber structure depend mainly on the design of the joints between the elements. This statement includes the hinges and supports, which in large structures are often connections between two glulam parts.

Basic considerations

The selection and design of connections are controlled not only by the load-carrying and durability conditions, but include other considerations such as aesthetics, the cost-efficiency, the fabrication and the erection.

A basic requirement is that all steel details shall be well adjusted to the glulam parts, to avoid time-consuming and costly work at the building site.

It is very important to design the connections in such a way that shrinkage and swelling of the timber parts are possible without creating problems. The moisture content in the glulam during production is normally very well controlled, but the equilibrium moisture content in timber will vary during the year. If free movement due to shrinkage is not allowed, the result may be splitting of the timber caused by tension perpendicular to the grain.

The design should avoid the possibility of water being trapped in the joint area, and if necessary drainage holes or slots should be introduced.

It is essential to protect end grain from water, because the water absorption parallel to the grain is much larger than the absorption perpendicular to the grain. In many cases a moisture barrier is recommended or gaps may be introduced.

If exposed to the weather, or other severe conditions, corrosion of the steel parts may be resisted by rust proofing or by using corrosive-resistant metals. The designer should also consider the compatibility of the metal with the timber treatment. For example, as pointed out in STEP lecture C1, caution should be taken with the installation of steel components into timber treated with preservatives containing copper.

Beam-column and beam-beam connections

These connections are covered by STEP lecture D5.

Hinges for frames and arches

For hinges in the apex of frames and arches the details shown in Figure 1 may be used.

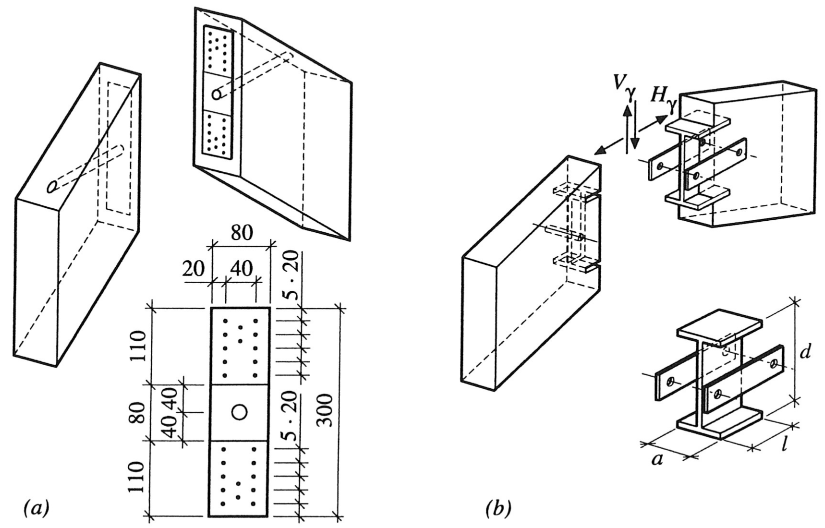

Figure 1 Hinges for frames and arches based on steel plates.

The details in Figure 1 are applicable in Service Classes 1 and 2 according to EC5. The hinge in Figure 1a may be used for frames and arches with slopes of 40 degrees or more. A bolt with a diameter of at least 20 *mm* should be used with nails as indicated in the figure.

In the detail shown in Figure 1b the bolts may be reinforced with single-sided toothed-plate connectors, if heavy lateral tension forces occur.

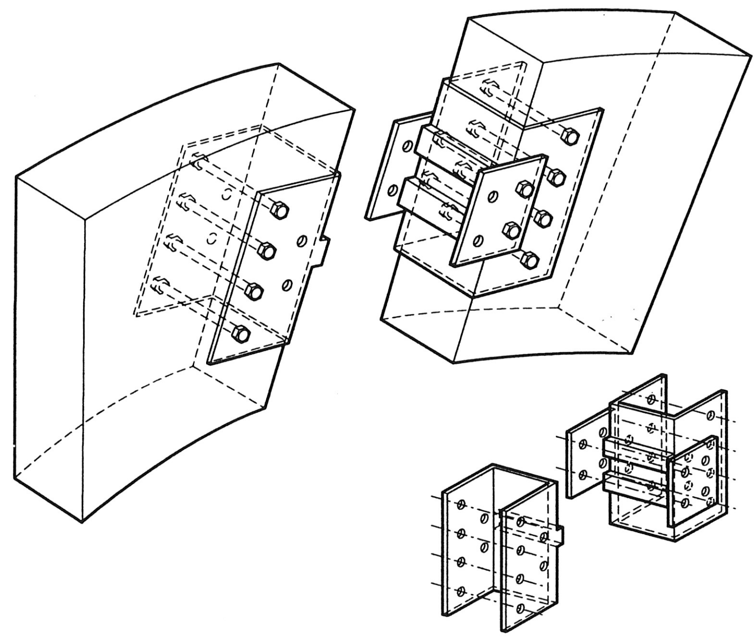

Figure 2 True hinge for frames and arches based on steel plates.

The hinge shown in Figure 2 is a true hinge, which may be used in Service Class 3.

Column supports

For simply supported columns, the details shown in Figure 3 may be used.

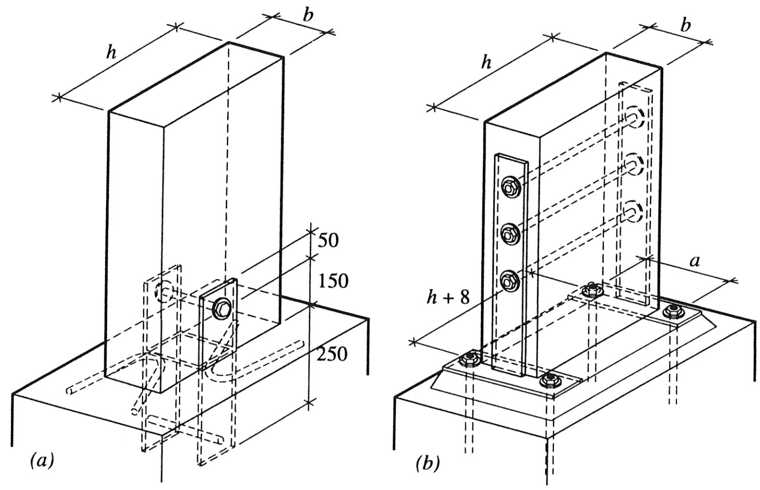

Figure 3 *Column supports based on steel plates, (a) for vertical and horizontal forces, (b) for vertical and horizontal forces and moment about the strong axis of the glulam member.*

The supports in Figure 3 are applicable in Service Classes 1 and 2 according to EC5. In Figure 3a the compression force is transferred directly through contact pressure and not via the bolt. The connectors indicated are "single-sided toothed-plate connectors" as described in STEP lecture C10, for example "Bulldog" connectors.

Supports for columns, frames and arches

For supporting light frames and arches, or for pin-ended columns, the details shown in Figure 4 may be used.

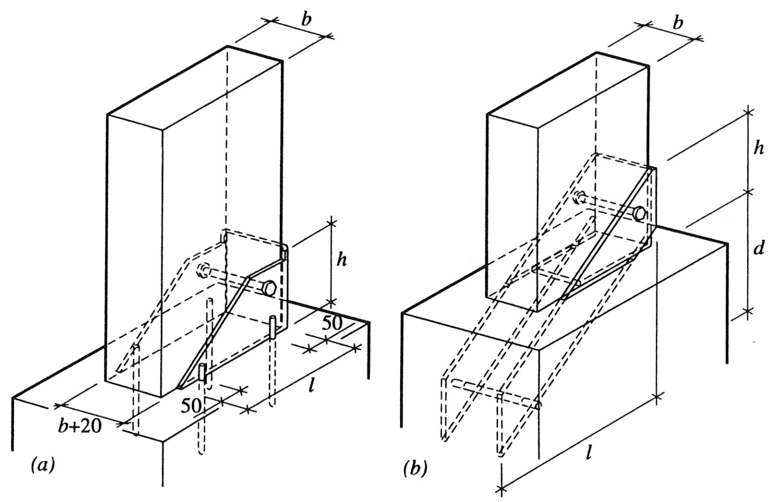

Figure 4 *Column supports or supports for light frames and arches based on steel plates.*

The supports in Figure 4 are applicable in Service Classes 1 and 2 according to EC5. The horizontal and vertical forces are transferred through contact pressure between timber and steel. Horizontal forces acting outwards and lifting forces are transferred through the bolt. The bolt may be reinforced with single-sided toothed-plate connectors.

The need for constructional tolerances when casting concrete bases is essential. A moisture barrier is necessary to avoid moisture transfer into end grain.

Supports for frames and arches

For simply supported frames and arches the details shown in Figure 5 may be used.

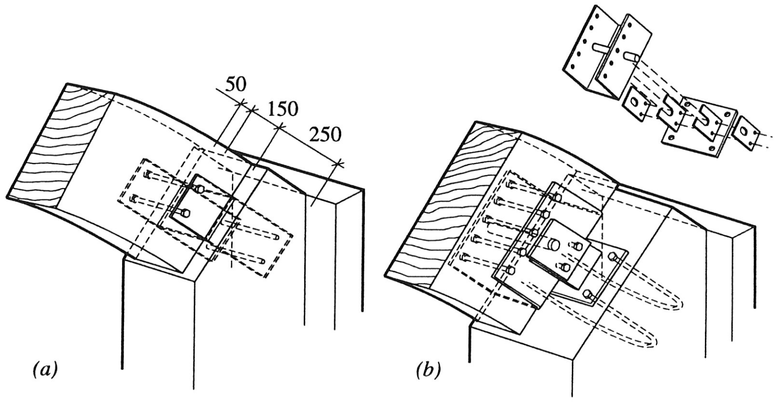

Figure 5 *Supports for frames and arches based on steel plates.*

The support in Figure 5a is applicable in Service Classes 1 and 2 according to EC5. Compression forces are not transferred through the bolts, and single-sided toothed-plate connectors may be added.

The support in Figure 5b is a true hinge anchorage, which may be used for outdoor exposure (Service Class 3).

Design of hinges and supports

All the steel plate based hinges and supports described in this lecture must be designed separately according to EC5. General joint design is discussed in STEP lecture C1.

Welding should be checked to accord with EC3.

The resistance to corrosion should meet the protection specifications in EC5 Table 2.4.3.

Examples

An example on an apex hinge is shown in Figure 6.

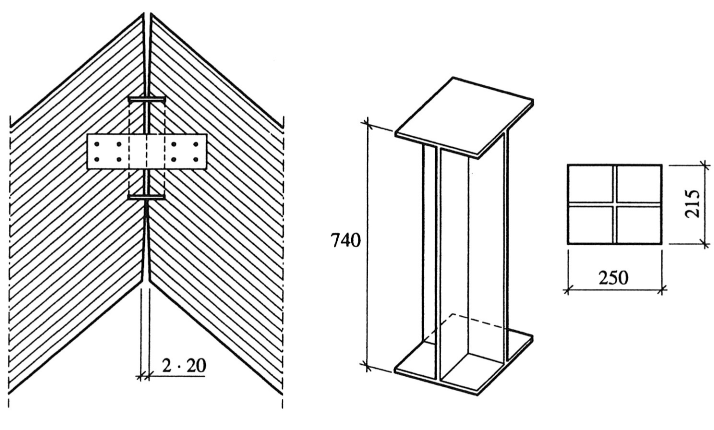

Figure 6 *Hinge example.*

The detail in Figure 6 is used in a warehouse building in Norway. The slotted-in "connector" is made of steel plates with thickness 8 *mm*. The outer steel plates (8 *mm* x 200 *mm* x 850 *mm*) are connected to the glulam members with four 20 *mm* bolts on each side of the hinge.

The support shown in principle in Figure 5b is used in many structures in Europe and other parts of the world. Figure 7a shows an example from a Norwegian structure.

Figure 7 *Support examples.*

The detail shown in Figure 7b is used to support the arched trusses in Håkon´s Hall Lillehammer, which was the main ice-hockey arena during the 1994 Winter Olympics in Norway. Slotted in steel plates are welded to the upper part of the steel support, and the glulam parts are connected to the steel plates using steel dowels.

Design example

Glulam frame with a cross section b x h = 180 x 900 *mm* at the support.
Strength class GL32 according to prEN 1194.

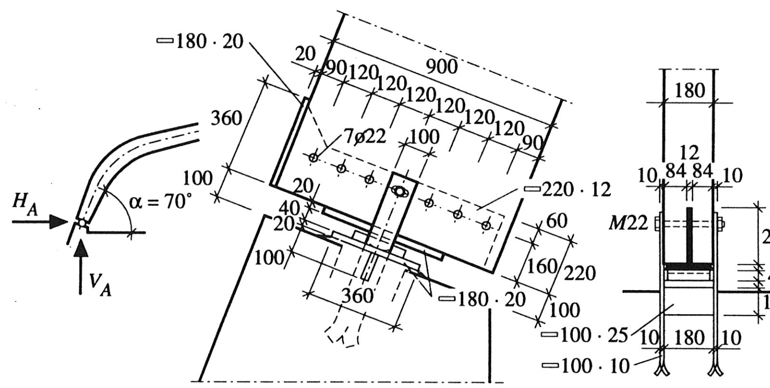

Figure 8 *Support design example.*

V_A = 250 *kN*, H_A = 300 *kN*, medium term loads, Service Class 2, γ_M = 1,3

$$V_d = H_A \sin\alpha - V_A \cos\alpha = 300 \cdot \sin 70° - 250 \cdot \cos 70° = 196\ kN$$

$$N_d = V_A \sin\alpha + H_A \cos\alpha = 250 \cdot \sin 70° + 300 \cdot \cos 70° = 338\ kN$$

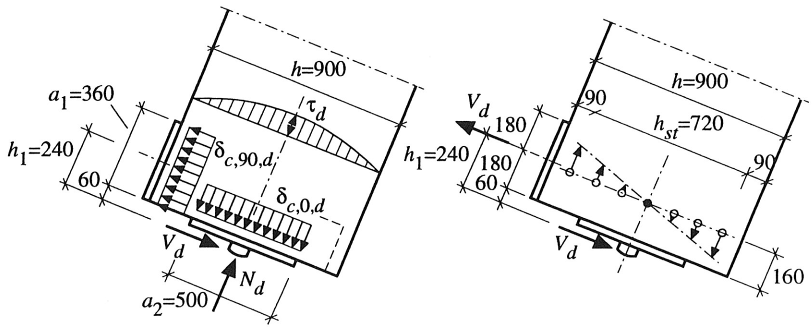

Figure 9 Static behavior.

Characteristic material properties according to prEN 1194:

$f_{v,g,k}$ = 3,5 N/mm^2
$f_{c,0,g,k}$ = 29 N/mm^2
$f_{c,90,g,k}$ = 6,0 N/mm^2

Design strength values:

$$f_{v,d} = \frac{k_{mod} \cdot f_{v,g,k}}{\gamma_M} = \frac{0,8 \cdot 3,5}{1,3} = 2,15\ N/mm^2$$

$$f_{c,0,d} = \frac{k_{mod} \cdot f_{c,0,g,k}}{\gamma_M} = \frac{0,8 \cdot 29}{1,3} = 17,8\ N/mm^2$$

$$f_{c,90,d} = \frac{k_{mod} \cdot f_{c,90,g,k}}{\gamma_M} = \frac{0,8 \cdot 6,0}{1,3} = 3,69\ N/mm^2$$

Shear stress:

$$\tau_d = \frac{1,5\ V_d}{b \cdot h} = \frac{1,5 \cdot 196000}{180 \cdot 900} = 1,82\ N/mm^2$$

Verification of failure condition:

$\tau_d \leq f_{v,d}$

1,82 < 2,15

The axial force is transferred through the steel foot plate:

$$\sigma_{c,0,d} = \frac{N_d}{A} = \frac{337000}{500 \cdot (180 - 20)} = 4,21\ N/mm^2$$

Verification of failure condition:

$\sigma_{c,0,d} \leq f_{c,0,d}$

$4{,}21 \quad < 17{,}8$

The shear force is transferred through the steel side plate:

$$\sigma_{c,90,d} = \frac{V_d}{A} = \frac{196000}{360 \cdot (180 - 20)} = 3{,}41 \; N/mm^2$$

Verification of failure condition:

$$\sigma_{c,90,d} \leq f_{c,90,d}$$

$$3{,}41 < 3{,}69$$

The moment $V_d \, h_1$ should be transferred through the steel dowels, see STEP lecture C1.

The steel parts should be checked according to EC3.

Concluding summary

- The serviceability and the durability of a timber structure depend mainly on the design of joints and supports.
- Design the joints and supports in such a way that shrinkage and swelling of the glulam parts are possible without creating problems.
- The details must be designed separately according to EC5, see STEP lecture C1.