Trusses made from laminated veneer lumber

STEP lecture E6
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Objectives

To describe the design of long span LVL-trusses with Multiple Nail Connectors and present typical examples of their use.

Summary

The lecture begins with a description of the use and application of Multiple Nail Connectors (MNCs) in LVL-trusses. It presents the analysis of MNC LVL-trusses, the strength verification of members and the capacities and the strength verification of MNC joints. Some examples of LVL-trusses used in structures are presented.

Introduction

The laminated veneer lumber truss is a long span roof header. LVL is a product similar to plywood except that veneers are parallel and longer lengths - nowadays up to 23 *m* - are available (see STEP lecture A9). Members of the LVL-truss are all constructed of two separate LVL-elements which are jointed together with Multiple Nail Connectors (MNCs), a jointing method of high load transfer capacity especially developed for this use. All members are jointed together with these MNCs to obtain centred node joints.

Multiple Nail Connector

A Multiple Nail Connector (MNC) is a joint element used for jointing members of glulam, solid timber or LVL-truss. It is a steel plate which has nails welded on both sides perpendicular to the plate. Its function is based on the nail joint between the steel plate and the timber element. Flat cone nails shown in Figure 1 have been chosen to give an economical MNC-type, based on tests performed by Kalliomäki et al. (1986). The nails are rectangular in section, 3 x 4 mm^2, and 50 *mm* long. The longer sides of the rectangular cross section of the nails are profiled to increase anchorage strength. The nails have a 4 *mm* long cone in the base for increasing the effective length of the nails to improve strength and rigidity of the joint. The nails in the corner plates of the truss are directed so that the longer sides of the nails are parallel to the truss member.

Nail spacing is usually 40 *mm* parallel to the grain (and thus the direction of the force) and 12 *mm* perpendicular to the grain in a staggered arrangement when the nail-type of Figure 1 has been used (see Figure 2). These nail spacings have been chosen according to calculations supported by joint tests (Kalliomäki et al., 1986), such that failure occurs by exceeding the yield moment of the nail. Thus the failure of the joint is always ductile, when the number of nails in the force direction is no more than six. This leads to a maximum length of the nail group of 220 *mm*. The peeling off of Kerto-LVL has been observed in tests when longer nail areas with these nails and nail spacings have been used in MNCs.

MNCs are produced by welding the nails with a peg welding machine to the steel plate which is cut to shape before welding. It can be cut either mechanically or with a cutting torch. To achieve a full strength weld the steel must be cleaned, normally by sand blasting. Generally the plate thickness is 10 *mm* and the steel grade Fe510D. The MNCs can be corrosion protected if it is needed; a zinc galvanization of 275 g/m^2 or a hot-dip zinc coating of 400 g/m^2 has been used.

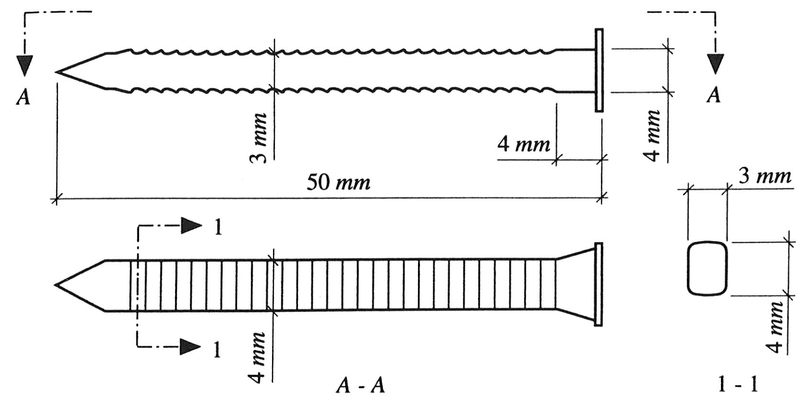

Figure 1 *The nail dimensions of a Multiple Nail Connector.*

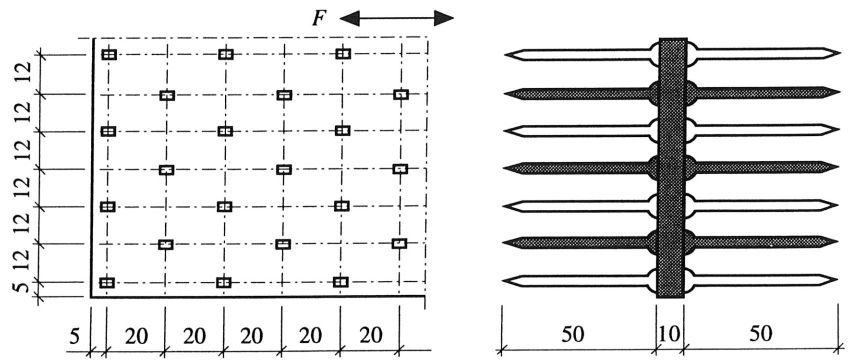

Figure 2 *Normal nail spacings in MNCs with the nail-type of Figure 1.*

The use of MNCs in Kerto-LVL-trusses

The members of Kerto-LVL-trusses are composed of two partial elements fixed together with MNCs. These members are also jointed with the same MNCs. In the truss nodes the members are assembled 1 to 2 *mm* apart (see Figure 3) so that the axial force of compression members is transferred through the MNC instead of by direct contact pressure between LVL members. Thus the MNC transfers forces according to the truss theory and no stresses perpendicular to grain are induced. The truss nodes are centred when MNCs are used. The shape of the joint element follows the shape of the truss corner and each transferred force in the members has a corresponding nail group on both sides of the steel plate.

The top and bottom chords of the truss are usually continuous if they are under 23 *m* long except at the ridge joint of the top chords. Due to these continuous chords the MNCs need to transfer only the difference of axial forces in two successive internal members and, in the case of loaded chords, the support reactions of the chords. The ridge joint differs from the other joints in that the top chord members are tightly together. Thus the horizontal proportion of the chord force is transferred by timber contact.

In manufacturing of the MNC Kerto-LVL-trusses, the timber elements of one side are spread out on an assembly jig after cutting. Then the MNCs are pressed into the elements using ribbed pressure plates. The plates are compressed one by one. The second set of side elements is assembled over the MNC nail points and pressed into position. The MNC nail pattern with the minimum nail spacings requires a compression pressure of about 7 N/mm^2 applied over the effective area of the steel plate during assembly.

The steel joint plates of Kerto-LVL-trusses can easily be fire protected if required by one of two methods. Either a groove to fit the steel plate is milled into the members or, more commonly, the gap of the steel plate thickness between the members is filled with a timber strip. No reduction of the design value of the connector capacity is required for either kind of protected joint for standard fire resistance not greater than R60 (STEP lecture C19). The charring rate of Kerto-LVL is 0,8 *mm/min* on the under side of Kerto-LVL beams based on information given by the manufacturer and type approval in Germany. Taking this charring rate value, the minimum protection thickness a_f is 12 *mm* in fire class R30 and 36 *mm* in R60 (see STEP lecture C19). For fire protection designed joints the distance between the MNC plate and member edge and the distance from the nail point to the LVL surface should be at least a_f.

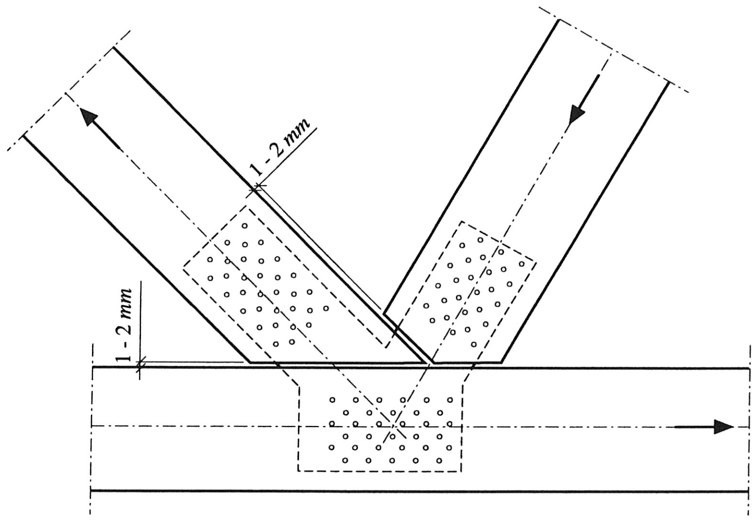

Figure 3 Truss joint assembled with a Multiple Nail Connector.

Load carrying capacity of MNCs

The nail capacity of MNCs may be calculated by Johansen's equations for steel-to-timber joints (see STEP lecture C3). The shear strength of the welded nails in MNCs is calculated by the equations for thick steel plates (equations 6.2.2c and d from EC5: Part: 1-1). A typical yield mechanism and a free-body diagram of a MNC nail is shown in Figure 4. The cone shaped thickening in the base of the nail is presumed to be so rigid, that the plastic hinge is formed at the top of the cone as shown in the figure. When the nails are shorter or more rigid the failure mode number 2 with only one plastic hinge located in the base of the nail is also possible (see STEP lecture C3). When a nail has a cone shaped thickening so that the distance from the first plastic hinge to the interface between the steel and the timber is l_{con}, the shear force capacity of the nail increases by a factor $l_{con}\, d f_{h,d}$. When the axial force effect is 10% as in EC5 (STEP C3), the equations of EC5 may be derived in the following form:

$$R_d = \min \begin{cases} 1{,}1\, f_{h,d}\,(t_1 - l_{con})\, d \left[\sqrt{2 + \dfrac{4\, M_{y,d}}{f_{h,d}\, d\, (t_1 - l_{con})^2}} - 1 \right] + 1{,}1\, l_{con}\, d\, f_{h,d} \\ 1{,}5 \sqrt{2\, M_{y,d}\, f_{h,d}\, d} + 1{,}1\, l_{con} d\, f_{h,d} \end{cases} \qquad (1)$$

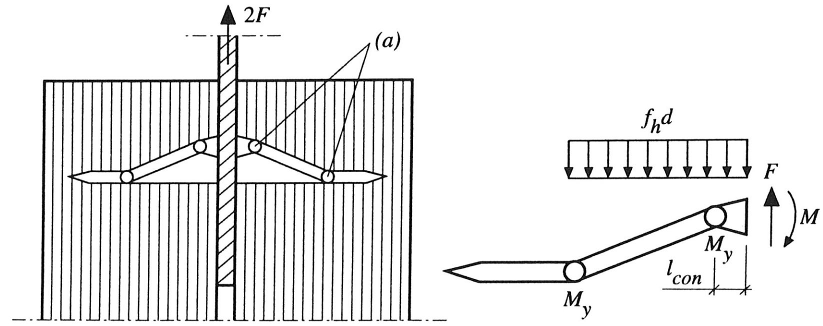

Figure 4 Function of nails in the MNC, and a free-body diagram of a nail. (a) Plastic hinges.

EC5: Part 1-1: 6.3.1.2

The embedding strength $f_{h,k}$ for MNC nails may be calculated from the nail size d and the LVL density ρ_k by the equation number 6.3.1.2a of EC5. The equation is for timber, but it is also suitable also for Kerto-LVL (Koponen et al., 1992). The characteristic density of Kerto-LVL ρ_k is 480 kg/m^3 (see STEP lecture A9). The design value of the embedding strength $f_{h,d}$ is calculated using the actual value of the modification factor k_{mod} given for plywood in EC5 (see STEP lecture A9) and the partial coefficient $\gamma_M = 1,3$.

The equations for yield moments $M_{y,k}$ of round and square nails are presented in EC5 (Part 1-1: 6.3.1.2c and d). In these equations the characteristic strength of the nail steel $f_{y,k}$ has been assumed to be $0,8 f_{u,k}$, where the tensile strength $f_{u,k}$ is 600 N/mm^2. The yield moment calculated using the equations in EC5 corresponds with plastic theory when the nail size, d, is 8 *mm*, that is also the maximum nail size accepted by EC5. With smaller nails the yield moment of EC5 is higher than the calculated value. For example with nails where $d = 3,5$ *mm* the calculated $M_{y,k}$ value is exceeded by 36%. Higher yield moments for the special shape, or profile nails, or for high strength nail steel, may be utilized only if the nail yield moment $M_{y,k}$ has been tested according to prEN409 (see STEP lecture C4).

EC5: Part 1-1: 6.3.1.4(2)

The minimum spacings and distances of MNCs nails may be designed according to EC5 using the rules given for nailed steel-to-timber joints with the density value $\rho_k = 480$ kg/m^3. So in MNCs the minimum nail spacing in the main direction parallel to the grain and force is 10,5 d and the spacing perpendicular to the main direction is 4,9 d. The distance from the first nail line to the end of the Kerto-LVL member should be at least 20 d in tension and 15 d in compression. The edge distance between the truss member and the nail group should be at least 7 d. However, the peeling off of Kerto-LVL has been observed in tension tests when long nail areas are used in MNCs (see Figure 5). If the minimum values are used for the nail spacings, a nail group length over 220 *mm* in the loading direction should not be used in tension joints unless it has been confirmed by testing. Higher tension loads may be transferred without the risk of brittle failure by greater nail spacings or by two separate nail groups with an un-nailed part between the groups in the MNC plate.

According to EC5 any influence in number of fasteners on the load-carrying capacity of nailed connections may be neglected (see STEP lecture C15). The tests of MNCs have shown that the number of nails has no significance on the mechanical behaviour of a single nail unless there are so many that the peeling off of Kerto-LVL has been observed. A big reduction for more than six MNC nails in line with the load direction has been required: the load carrying capacity of the extra nails being reduced by 60%, i.e. for n nail rows the effective number n_{ef} is:

$$n_{ef} = 6 + 2\,(n - 6)\,/\,5 \qquad (2)$$

with $6 < n \leq 15$.

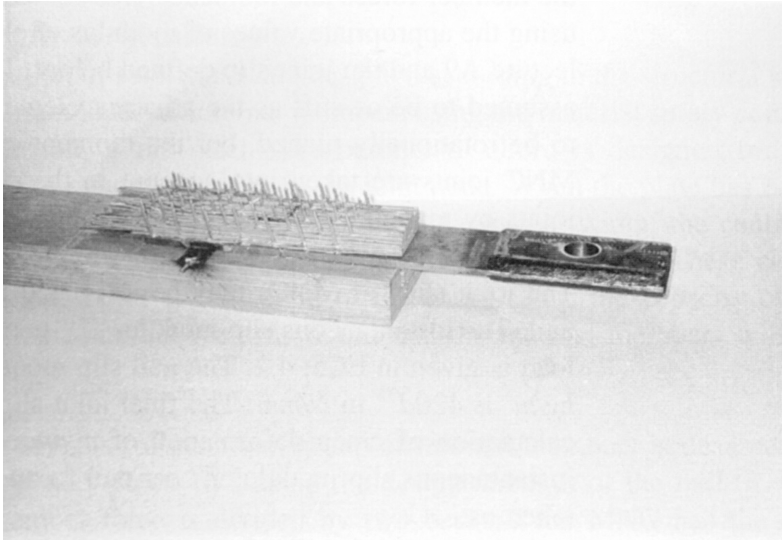

Figure 5 *Peeling off failure mode of a MNC test joint with Kerto-LVL.*

The following concerns load-carrying capacity of the MNC nail shown in Figure 1. The calculated yield moment $M_{y,k}$ parallel to the longer side of the nail (4 *mm*) is 7850 *Nmm*, when the increase over the theoretical value is taken into account, as in EC5 for a nail size d = 3,5 *mm*. The embedding strength $f_{h,k}$ of Kerto-LVL is 28,3 N/mm^2 calculated according to EC5 when the nail size d is 3 *mm* perpendicular to the force. The length of cone l_{con} is 4 *mm* in the base, and the length of nail t_1 is 50 *mm*. According to Equation (1) the characteristic load-carrying capacity R_k is 2,11 *kN* and the design value R_d is 1,53 *kN* in the medium-term load-duration class with service classes 1 and 2. MNC tests with these nails and with the nail spacings of Figure 2 have been carried out. According to the tests over a series of different width and length joints, the average load-carrying capacity R_m was 2,7 *kN* per nail and the characteristic value R_k calculated from test results is 2,4 *kN*. This comparison shows that EC5 is suitable for estimation of the load-carrying capacity of the MNCs but it is somewhat conservative with these types of special nail. In this case the number of nails could be reduced by 15% if design is based on test results.

Analysis of MNC LVL trusses

The analysis model of a MNC Kerto-LVL truss is simple, because the connections are designed without eccentricity, so that all systemlines of members coincide with the member centre line and in the node they meet each other always at the same point at the centre of the chord. Fictitious beam elements may be needed only to model the eccentric supports (see EC5: Part 1-1: 5.4.1.1). The joints in compression have the same rigidity as in tension because any timber-to-timber contact between external and compression members is neglected.

The use of a simplified analysis (EC5: Part 1-1: 5.4.1.3) is also normally possible. The axial forces in the members are determined assuming that every node is pin-jointed. The bending moments in the chords are determined as if the member was a beam with a simple support at each node. The effect of deflection at the nodes and partial fixity at the joints may be taken into account by a reduction of 10% in the node bending moment. The reduced node moments should be used to calculate the span bending moments.

Trusses should be analysed as framed structures in general analysis, where the deformations of the members and joints, the influence of support eccentricities and stiffness of the supporting structure are taken into account in the determination of the member forces and moments (EC5: 5.4.1.2). The analysis should be carried out using the appropriate values of modulus of elasticity given for Kerto-LVL in STEP lecture A9 and the joint slip defined below. The fictitious beam elements should be assumed to be as stiff as the adjacent elements. Joints may generally be assumed to be rotationally pinned, but the moment capacity and the rotational stiffness of MNC joints are taken into account in the chord splices and with other eccentric joints by modelling the nail group of a MNC with elastic theory.

The joint slips of MNCs may be estimated by the slip modulus of a single MNC nail. The instantaneous slip modulus K_{ser} per shear plane per fastener under service load is given in EC5: 4.2. The nail slip modulus K_{ser} for Kerto-LVL with $\rho_k = 480$ kg/m^3 is $420d^{0.8}$ in N/mm. The final joint slip is calculated by k_{def} values given for calculation of creep deformation of plywood (STEP lecture A9). For MNCs the instantaneous slip modulus K_u per nail for the ultimate limit state design should be taken as:

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

The final slip modulus $K_{u,fin}$ is given by

$$K_{u,fin} = K_u / (1 + k_{def}) \tag{4}$$

Strength verification of members

The cross section of an internal LVL element is designed for the member force $F_d/2$ using the design strength of Kerto-LVL given in STEP lecture A9. The external members are designed according to EC5 at the most critical point for the design load combination of the moment $M_d/2$, normal force $N_d/2$ and shear force $V_d/2$. It is dangerous to design the cross-section using the sum dimensions of parallel compression members where lateral buckling is possible. The standard thicknesses of Kerto-LVL are shown in STEP lecture A9, and the heights of members may be freely determined so that the cross-section will be fully utilized.

The same values as with glued laminated timber may be used in the design of compression members of Kerto-LVL assuming the straightness limits: $\beta_c = 0,1$. For internal members in compression, the effective length for in-plane strength verification is usually taken as the distance between the centroids of the MNC nail group areas. Also the influence of the rotational stiffness in these semi-rigid connections may be taken into account in a more sophisticated analysis (see STEP lecture B7). The effective length for chords in compression should generally be taken as the distance between two adjacent points of contraflexure (EC5: Part 1-1: 5.4.1.4). When a simplified analysis has been carried out, the effective lengths of the top chords may be simply assumed to be a certain factor times bay lengths, but then the calculated axial forces should be increased by 10% for the strength verification of members in compression and also in the connection design. The bay-length-factors are given in EC5: Part 1-1: 5.4.1.4(3).

The buckling lengths of the internal members for the lateral (out-of-plane) strength verification can be assumed to correspond to the distance between the braces that are often at the outer edges of the top and bottom chord (STEP lecture B7). The separate design of the parallel compression members is a conservative method in the case of lateral buckling, because the MNCs connect the ends of members to each other. If lateral buckling is the critical factor and no additional brace is wanted, the theory of mechanically jointed columns may be utilized, but then usually additional MNCs are needed so that the shafts are connected at the ends and at the third points (EC5: Part 1-1: Annex C).

Joint strength verification

EC5: Part 1-1: 2.3.3.2

The cross-section of steel plates are designed according to the structural steel codes for the maximum loads of internal members using the material safety coefficient γ_M = 1,1. The width of the steel plate parallel to chord is designed for the force component of the chord direction in the joint node. When the plate has been cut so that each member part of the steel plate has a constant width, the centre lines of each part coincide with the centre line of the truss members. These centre lines meet in the node point at the centre of the chord. Thus the capacity of the steel plate in the joint line between the chord and the internal members will not be a critical factor.

The number of nails for each nail group of internal members is designed to resist half of the member force $F_d/2$ using the design strength of the nail ($n > F_d/2R_d$). The truss member force is divided by two because the MNC has the same nail groups on both sides. The numbers of nails for the chord is calculated from the difference in forces of all internal members meeting at the node.

In the strength verification of chord splices or other eccentric joints where a loading combination of N_d, V_d and M_d is acting on the MNC plate at the centroid of the nail group area, the following condition (5) should be satisfied for every nail:

$$\sqrt{F_{ix,d}^2 + F_{iy,d}^2} \leq R_d \quad or \quad \left(\frac{F_{ix,d}}{R_{x,d}}\right)^2 + \left(\frac{F_{iy,d}}{R_{y,d}}\right)^2 \leq 1 \tag{5}$$

where

$$F_{ix,d} = \frac{N_d}{2n} \pm \frac{M_d}{2I_p} y_i \quad and \quad F_{iy,d} = \frac{V_d}{2n} \pm \frac{M_d}{2I_p} x_i \tag{6}$$

$$I_p = \sum_{i=1}^{n} (x_i^2 + y_i^2) \tag{7}$$

R_d	is the design load-carrying capacity of round or square nails,
$R_{x,d}$ and $R_{y,d}$	are the design values of rectangular nails in x- and y-axis directions,
n	is the number of nails and
x_i and y_i	are the nail coordinates from the centroid of the nail group area when x-axis is parallel to the normal force N_d and y-axis is parallel to the shear force V_d.

Use of MNC Kerto-LVL-trusses

The MNC Kerto-LVL-truss is an economical alternative when long spans (18 to 50 *m*), high loads (> 10 *kN/m*) or fire resisting requirements (R30, R60) are needed. The MNC joints have such a high load-carrying capacity and rigidity that they are not the critical factors in the dimensioning of members or in the deflection of rafters. Unnecessary wastage of Kerto-LVL material with its high strength and stiffness values is avoided because the height of every member may be optimised to the force in the element.

The most common Kerto-LVL truss type has been made from 75 *mm* thicknesses of Kerto-LVL with members jointed together with MNCs using nails and nail spacings as shown in Figures 1 and 2. Thus the total width of the rafter is 160 *mm* when a steel plate thickness of 10 *mm* is used. Typical Kerto-LVL-trusses have a span of 20 to 40 *m* with truss spacings of 4,8 to 7,2 *m*. Normally, long rafters over 23 *m* have been made from two parts jointed together on the building site by chord splices as shown in Figure 6. Two examples of site joints between Kerto-LVL-trusses and columns are shown in Figure 7.

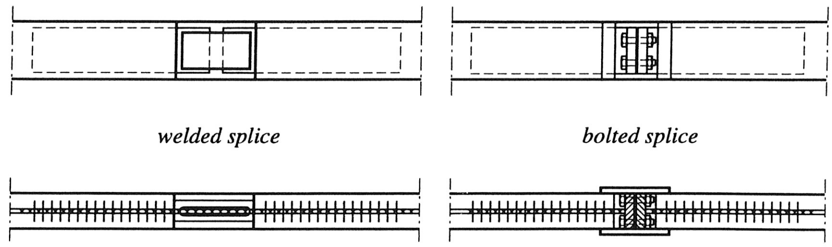

Figure 6 *The building site splices of MNC Kerto-LVL-trusses.*

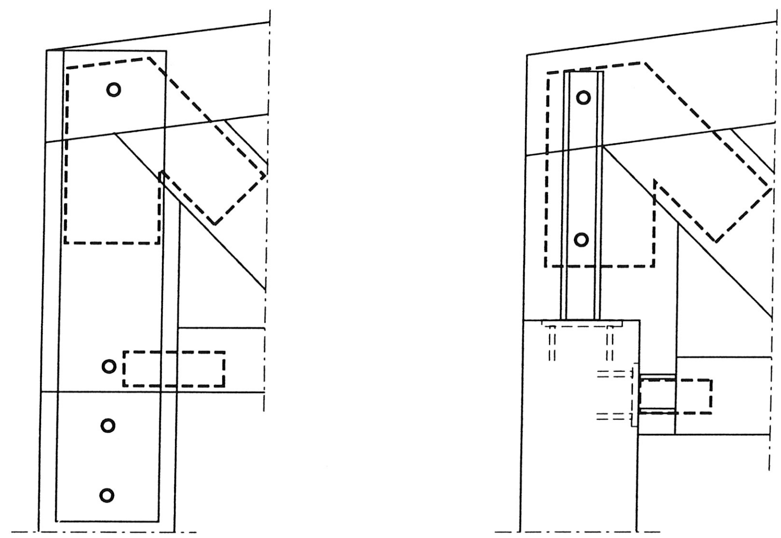

Figure 7 *Examples of joints between MNC Kerto-LVL trusses and columns.*

References

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