# Bracing - Structural detailing

STEP lecture D9
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## Objectives

To provide advice on the use and behaviour of bracing. The lecture includes examples of bracing as well as the necessary detailing and joints.

## Summary

The behaviour of bracing is discussed and simplified design rules are provided to assist design engineers. Some advice on structural modelling and detailing of the joints is provided.

## Introduction

It is essential that principal structural members which are liable to buckle are connected to walls, columns, beams or bracing structures which are able to resist the forces involved, in order to ensure local and overall structural stability. The bracing elements prevent large lateral displacements which will otherwise occur perpendicular to the principal axis/plane of the structural element. At the same time, they can be used as structural elements for resisting external forces such as wind loading. If main structural elements are perfectly straight and the external loads are applied only in their principal planes, i.e. without any eccentricity, then deflections will occur only in the principal plane without inducing any reactions onto the bracing. However, in practice, it is necessary to allow for the lack of straightness due to imperfections in the production process and which can occur during the erection process. Bucking forces will also occur if wind or other external loads occur in the plane of the bracing, resulting in lateral deflections.

## Uses of bracing

Structural bracing can be used to resist *external forces* which do not arise from the behaviour of the structure but are applied onto the structure and have to be transmitted to the foundations. Examples are wind loads or horizontal loads e.g. lateral shocks, crane braking forces and seismic loads.

The second type of forces are *internal forces* which result from deviations of the main structural element from its intended position. These forces can be balanced within the structure which is correctly detailed and therefore do not have to be transmitted to the foundations. Examples are

- forces due to the lateral displacements of frames and columns,
- forces arising from supporting beams and the compression chords of trusses which are liable to buckling,
- forces at the intermediate supports of compression members,
- forces at the lateral supports of tension chord nodes in trussed members.

Examples are given in Figures 1 to 7.

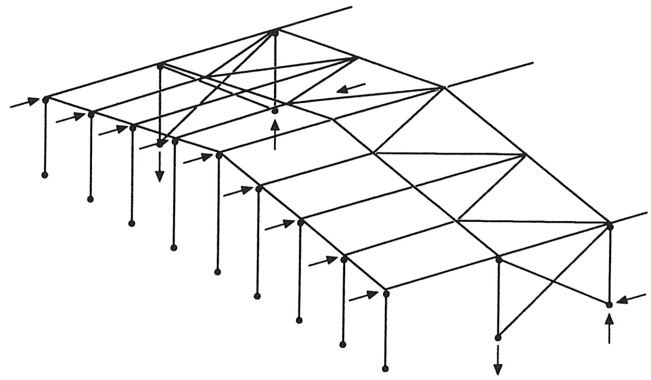

*Figure 1* *Transfer of wind loads from gable columns through roof and wall bracing.*

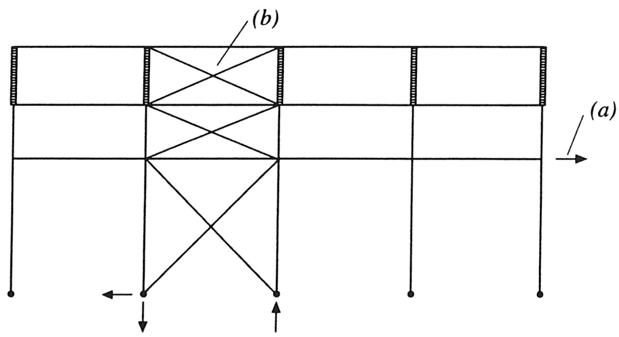


*Figure 2* *Transfer of external loads through bracing into the foundation. (a) braking force from crane, (b) bracing to provide torsional resistance at beam ends.*

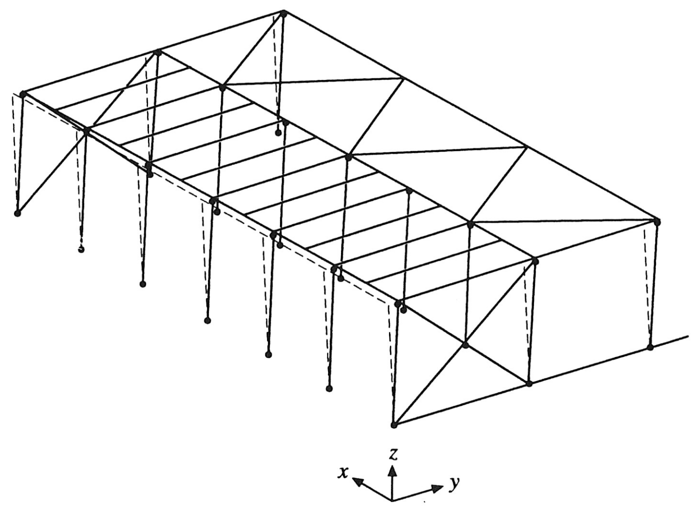


*Figure 3* *Transfer of P-Δ forces from inclined columns through roof and wall bracing.*

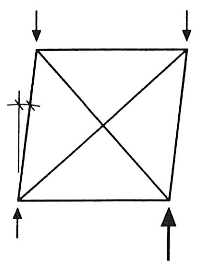

*Figure 4* *Support reactions for inclined structures and vertical actions.*

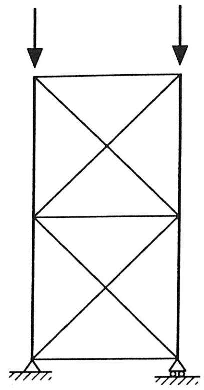

*Figure 5* *Lateral intermediate support to decrease column lengths.*

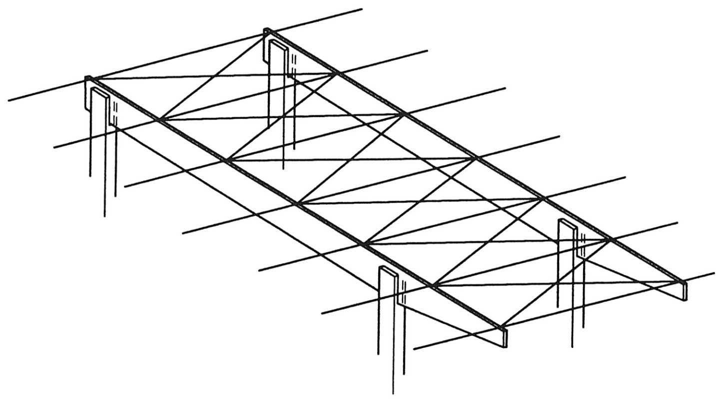

*Figure 6* *Lateral bracing of beams.*

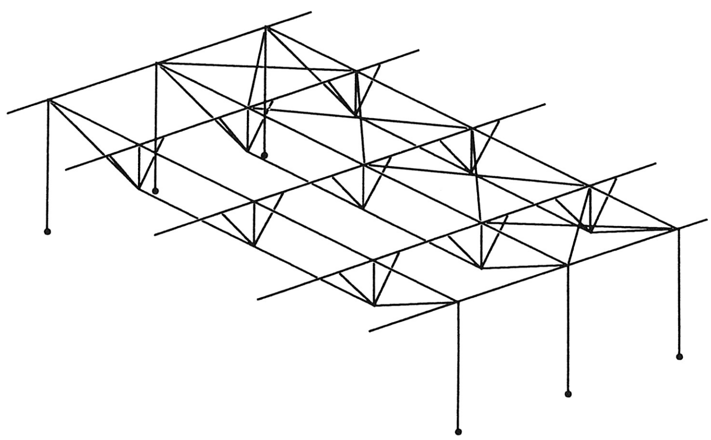

*Figure 7* *Lateral support of tension chords using knee-bracing against purlins.*

In a structure, the main load bearing elements have to transmit the vertical forces e.g. self-weight and snow loads on roofs whilst the bracing elements have to resist horizontal wind loads and buckling forces from the main element. The designer usually considers these actions separately and the design of the main elements and bracing is carried out in two steps. In reality, however, structures are three-dimensional systems such as the simple truss, shown in Figure 8, with upper and lower purlins. In this case two diagonal bracing elements, which together with the purlins acting as chords form a truss system in the plane of the roof, to ensure lateral stability of the simple truss. There are eight support reactions. One of these is needed to prevent the four structural elements at eaves level from forming a rectangular mechanism, thus leaving seven support reactions, with six possible equilibrium conditions in space. Thus the system is statically indeterminate to one degree.

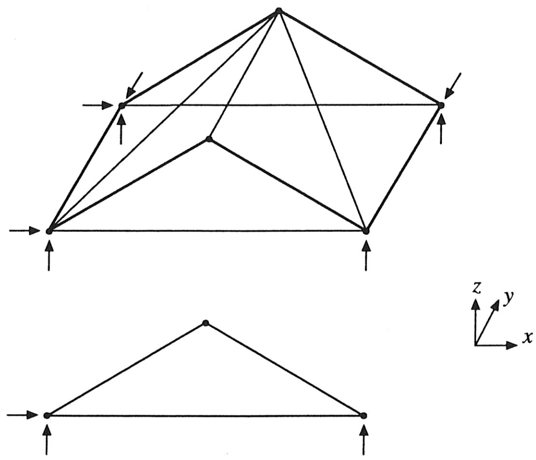


*Figure 8* *Support reactions of three-dimensional braced system.*

For design purposes, the design may be simplified by neglecting one of the support reactions in the *x*-direction (see Figure 8) and assigning the horizontal bracing forces to the two supports in the *y*-direction. This simplification is only possible if the displacements of the supports (assumed as fixed in the *y*-direction) are nearly the same; otherwise the "omitted" support will have to resist forces in the *x*-direction resulting from the rotation of the structure in plan. This approach is also only valid if the deformations of the chords (purlins) are small enough to be negligible but would only cause displacements in the *y*-direction.

Due to the extensions in the internal members of the truss and movements in the joints, shear deformation as shown in Figure 9 will occur. Hence the vertical element at the support will remain vertical without causing any horizontal reaction at the top of the truss.

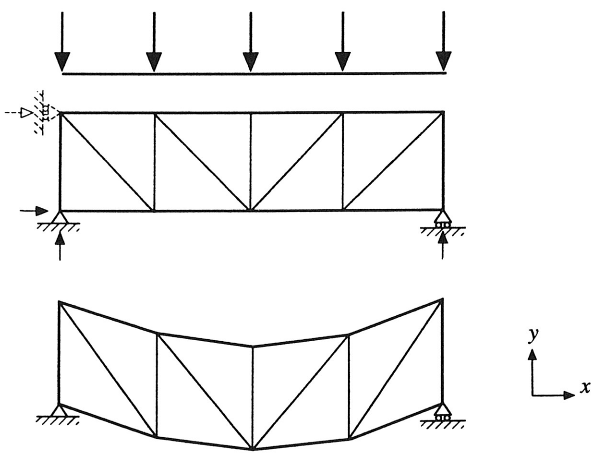


*Figure 9* *Deflection of a bracing structure.*

In sloping roofs, the span of the bracing system is assumed to be equal to the length of the roof plane and is a plane structure. The three-dimensional load carrying behaviour leads to inclined forces (see Figure 10) which should be taken into account. This is a practical calculation model. For roofs with large slopes, it is sensible not to consider the transfer of shear forces along the apex of the roof resulting in two cantilever beams, as shown in Figure 11.

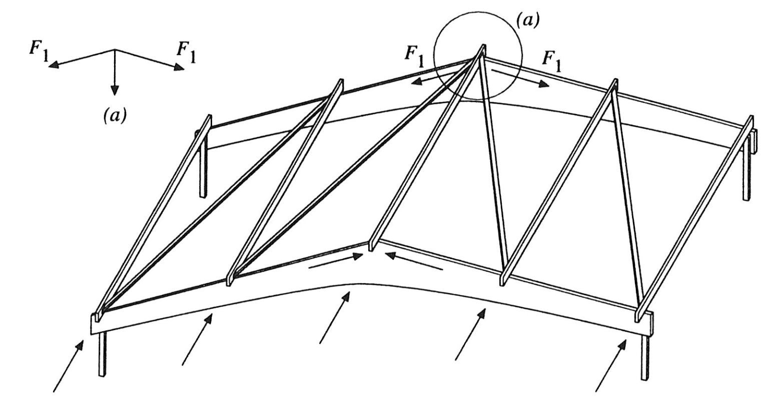


*Figure 10* *Vertical forces at the top of the structure caused by horizontal actions.*

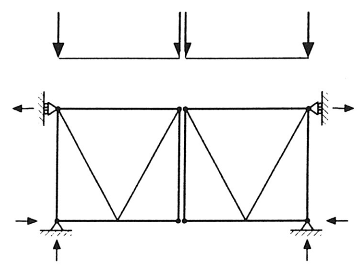

*Figure 11* *Support reactions of cantilevered system.*

If the structural system and the loading are symmetrical and the deformations of the chords are not considered, the horizontal displacement of the apex is the same for both bracings. Thus there would be no forces along the apex but there would be two horizontal support reactions in the *x*-direction which have to be considered.

It is also advisable to support the bracing system at the apex and/or at intermediate locations. These support forces should be transferred to structural strong points, say at the eaves - see Figure 12. In such cases, where the stiffness of the support system is sufficiently high, small deformations of the bracing system would occur, resulting in smaller lateral forces.

In general this is a sensible approach, however, with nailed plate trusses which are usually narrowly spaced, it is impossible to provide such a bracing systems with sufficient depth and hence stiffness.

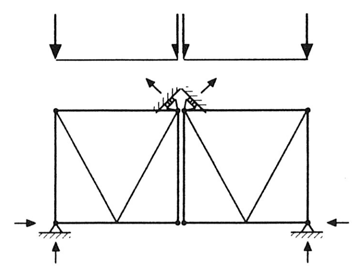

*Figure 12* *Support of bracing truss at apex.*

## Bracing details

### *Types of bracing*

Bracing systems are mostly formed by adding diagonal members to the main structural elements (e.g. beams and purlins) to form trusses. Prefabricated trusses which are placed in between the members to be braced can also be used. In this lecture only trusses are considered although beams, shear walls or single members can also be used for bracing purposes.

In most cases, the main structural elements also form the chords of the bracing system. In the case of trusses, the compression cord which needs to be braced should also be part of the bracing system. Where beams have to be braced, the bracing system should be placed in the compression zone. For roof structures with purlins, the purlins can be used as part of the bracing system. This is achieved by adding diagonal members. The characteristics of the different possible forms are described below.

### *Crossed diagonals resisting only tensile forces*

- usually made of steel e.g. steel rods with turn buckles for tightening purposes;
- ease of erection;
- the purlins will be subjected to the additional stresses arising from being part of the bracing system.

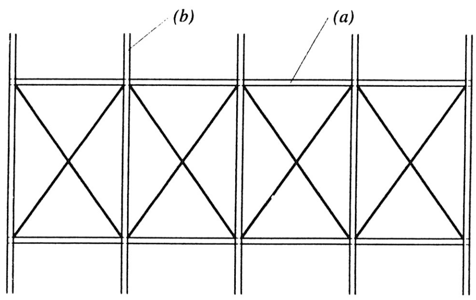


*Figure 13 Crossed diagonals. (a) Braced beam, (b) purlin.*

### *W-trusses*

- no additional forces in the purlins;
- all diagonals have to transmit both tensile and compressive forces due to reversal of forces, thus timber members are recommended;
- where the diagonal members are fixed to the purlins, the buckling lengths of the diagonals can be reduced.

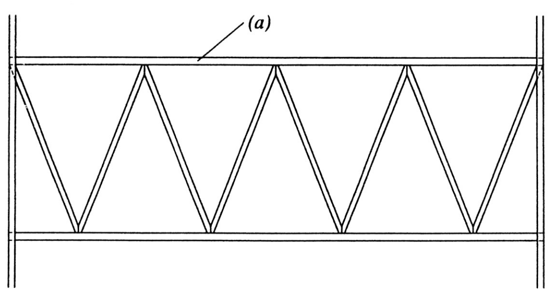


*Figure 14 W-truss. (a) Braced beam.*

*N-trusses*

- this system is only sensible if the external loading in one direction produces relatively higher forces;
- the vertical internal members, if in compression, have shorter buckling lengths.

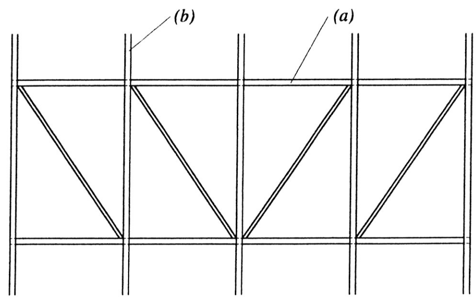


*Figure 15 N-truss. (a) Braced beam, (b) purlin.*

*K-trusses*

- the forces in the internal members are reduced by up to 50%;
- buckling lengths are relatively shorter;
- offers larger openings when used as a vertical wall bracing system, see Figure 17;
- the diagonals support the purlins at midpoint, thus reducing the buckling length in the plane of bracing.

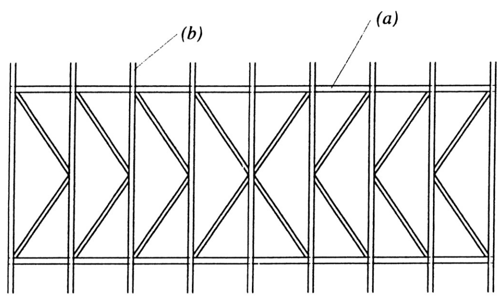


*Figure 16 K-truss. (a) Braced beam, (b) purlin.*

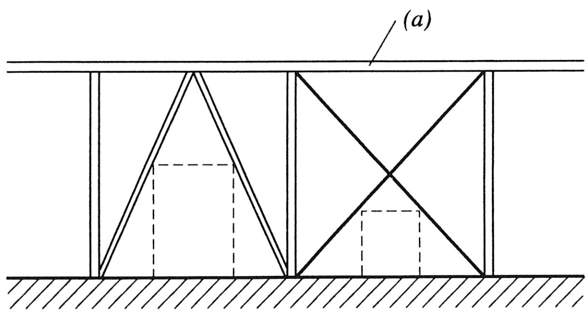


*Figure 17 Wall bracing.*

*Trussed beam*

- ease of erection e.g. screwing or nailing steel members onto the purlins;
- the use of a parabola shape for the tension chord is optimal as it results in a constant tensile forces;

- only applicable where the loading is in one direction;
- non-uniform external loading must be considered.

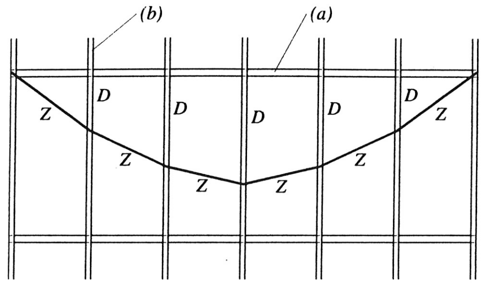


*Figure 18 Trussed beam. (a) Braced beam, (b) purlin.*

### *Connections*

Connections can be detailed in a number of ways and the examples shown in Figures 19 to 21 have worked well in practice. Timber diagonals can be connected with steel plates (Figure 19) and nails or dowels. Slotted steel plates should be predrilled together with the timber since the required spacings are smaller and the connections are stiffer and more effective when compared with non-predrilled nailed connections. For small forces, thin steel plates on one side are sufficient. The connection area required for non-predrilled nailed connections is four times larger than that required for predrilled connections with slotted steel plates. The diagonals have also to be designed for the bending moments resulting from the eccentricity of the steel plates.

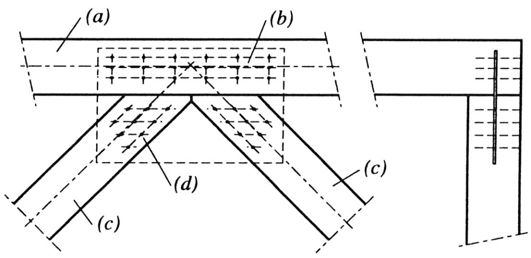


*Figure 19 Timber diagonals connected by slotted steel plate. (a) Braced beam, (b) slotted steel plate, (c) timber diagonals, (d) predrilled nailed connection.*

The diagonals can be connected through specially designed steel connections such as those shown in Figure 20. This kind of joint can be assembled easily.

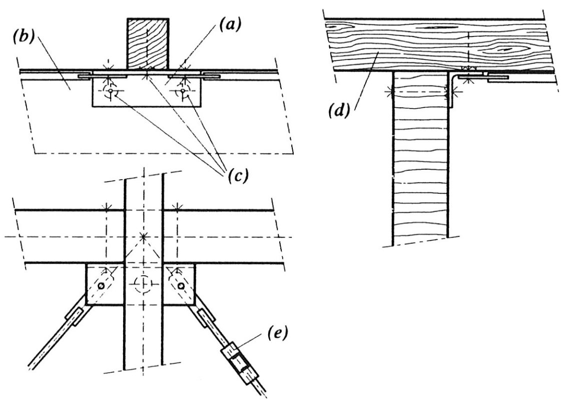


*Figure 20 Connection of steel diagonals with wedge formations and flat bars. (a) Steel angle, (b) braced beam, (c) connectors, (d) purlin, (e) turnbuckle.*

Steel rods which penetrate the chords can be connected at the other side as shown in Figure 21. Special steel connections which allow for a wide range of diagonal angles are available.

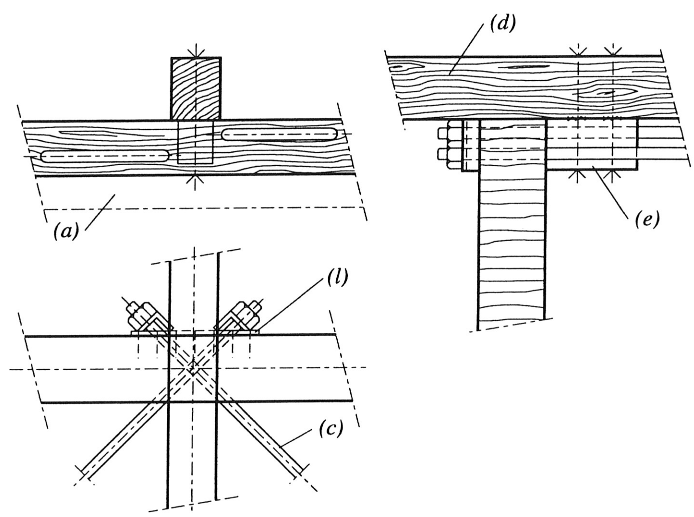


*Figure 21* *Connection of steel diagonals on the back side of the chords. (a) Braced beam, (b) nailed steel fitting, (c) steel bar, (d) purlin, (e) joint using timber block and connectors.*

## Example

In STEP lecture B15, the forces on the bracing members due to the buckling of the bending members shown in Figure 22 were determined as

$q_{d,br}$ = 5,04 *kN/m*

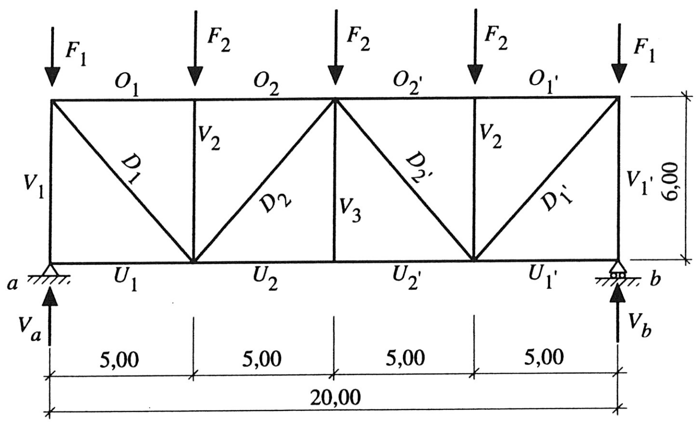


*Figure 22* *Bracing structure.*

Assuming a uniformly distributed wind load of

$w_d$ = 3,96 *kN/m*

and two bracing trusses, the following forces are obtained.

$q_d$ = 4,5 *kN/m*; $F_1$ = 11,25 *kN*; $F_2$ = 22,5 *kN*
$V_a$ = $V_1$ = -45 *kN*; $V_L$ = $F_2$ = -22,5 *kN*
$D_1$ = 43,9 *kN*; $U_2$ = 37,5 *kN*

The existing purlins need to be designed for the forces $V_1$ and $V_2$. The additional timber diagonals are designed for forces $D_1$ and $D_2$. The connection details are as shown in Figure 19 and the following points should be considered:

- the lowest purlin should be designed for the bending moments due to the vertical actions and a compressive force $V_1 = 45\ kN$. This compressive force is to be transferred to the main truss;
- the purlin subjected to a compressive force $V_2 = 22{,}5\ kN$ is to be designed as a column;
- the purlin $V_3$ is to be designed for a compressive force of 22,5 $kN$ to allow for load reversal;
- the top rafters of the main truss which form the chords of the bracing truss should be designed for the force $U_2 = 37{,}5\ kN$ which is compressive when the loading acts in the opposite direction;
- the vertical component of the force $F_v$ for a roof slope of $\alpha$ is $F_v = 2U_2\ sin\alpha$
- the diagonal members should be designed for a compressive force $D_1 = 43{,}9\ kN$;
- it is recommended that all members are connected with the same number of nails, rather than designing the joint in accordance with the shear force diagram for the truss. This is because designing the joints for the actual shear forces would result in identical joint displacements when the bracing is loaded which, however, is not realistic. By using the same number of nails per joint, and thus having the same joint stiffness for the entire truss, realistic differential joint slips are achieved;
- the requirement to limit the deflections to $l/700$ for lateral buckling loads or $l/500$ for the combination of wind loads and buckling loads is not part of the serviceability limit state design. These limits are given because they were used in the assumptions for the development of the EC5 equations. These limits can be exceeded if a more exact calculation for the buckling loads is carried out in which case, the actions should be increased by $\gamma_F$ and 5%-values for material properties modified by $\gamma_M$ and $k_{mod}$ should be used. The slip modulus $K_u$ should be taken as 2/3 $K_{ser}$;
- it is not necessary to limit the deflections when the span to depth ($l/h$) ratio of the bracing is less than 6. However, accurate design and good detailing is particularly important. The deflections should be calculated in accordance with appendix C of EC5. The elastic deformations of the internal members as well as the deformations of the joints have to be taken into account.

## Concluding summary

- Bracings are in general three dimensional structures although for design they are often considered as plane trusses.

## References

Brüninghoff, H. (1988). Verbände und Abstützungen, Grundlagen und Regelnachweise In: Informationsdienst Holz, Bericht der Entwicklungsgemeinschaft Holzbau in der Deutschen Gesellschaft für Holzforschung.