Learning from failures II

STEP lecture E28
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Objective

To describe cases of disorders and accidents caused by production, design or installation errors.

Summary

The pathologies ot traditional framework, lightweight structures and glulam structures are examined, photographs and sketches are shown, and short comments are given.

Traditional structures

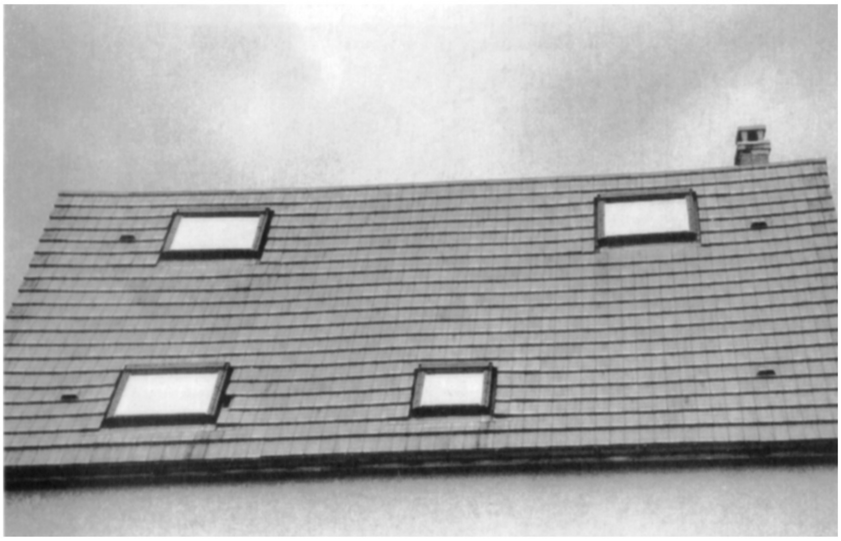

Figure 1 *Roof deformation.*

The carpentry supporting the roof in Figure 1 is of a classical type: rafters, purlins, supported by gable walls and a central truss. The ridge beam of the roof shown in Figure 1 has become concave, and rows of tiles have slipped to the bottom of the roof planes.

This very common situation is the result of the absence or inadequacy of blocking of rafters at the base of the planes, allowing the purlins placed obliquely to become deformed by transverse bending.

The trussed rafter shown in Figure 2 has broken because of the presence of a large-sized knot. The timber was obviously not graded properly.

The ridge purlin shown in Figure 3 has broken because of the steep slope of the grain of the timber, which causes local transverse stresses, resulting in breakage. The timber was obviously not graded carefully enough.

The opening of the assembly of a king post on the tie bar of a traditional truss is shown on Figure 4. It may be seen that the king post is cracked more or less on the plan of the bolt, and that the metal suspender is embedded in the bottom ot the tie bar. The fracture process is in progress.

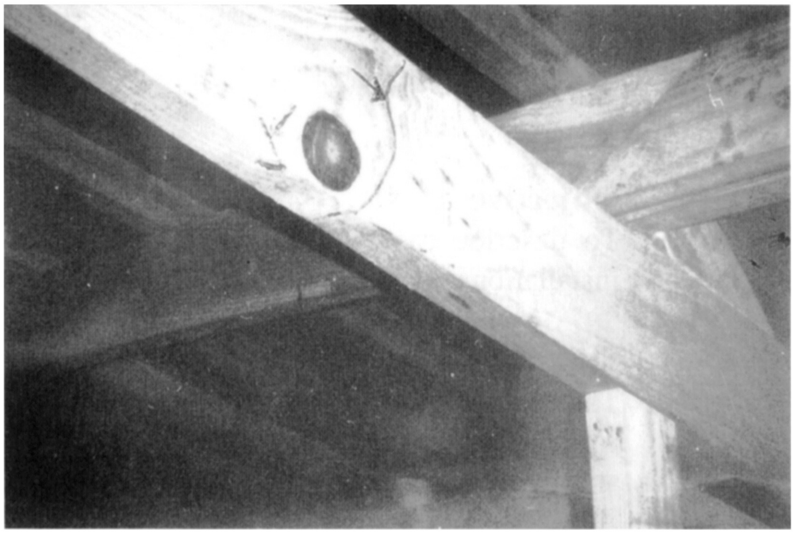

Figure 2 *Fracture caused by a knot.*

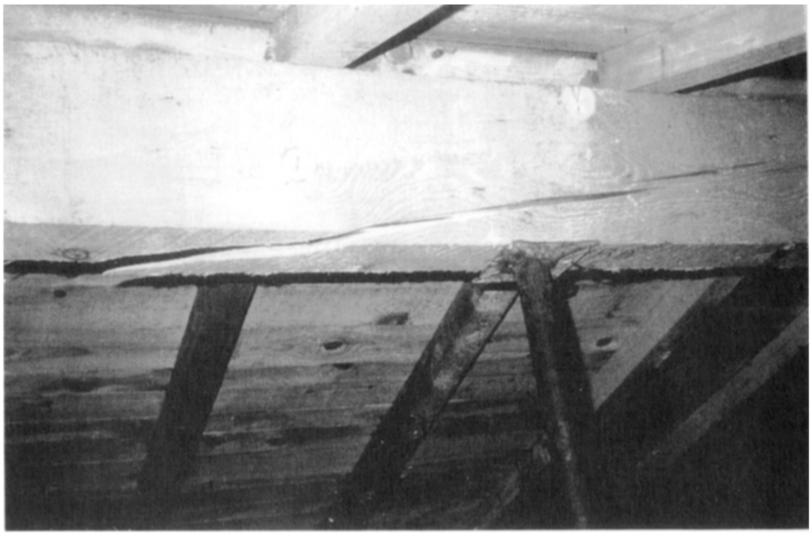

Figure 3 *Fracture caused by the slope of the grain.*

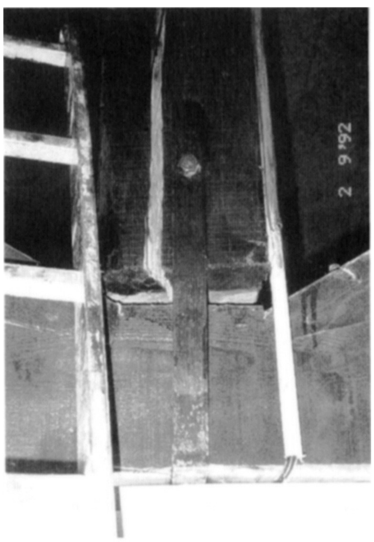

Figure 4 *Assembly of king post on tie bar.*

This case involves a design error in the assembly of the central diagonals, which are blocked on the tie bar with the result that the metal suspender and bolt are overloaded. A good design would tie the diagonals to the king post.

Figure 5 *Serious damage by fungus.*

The structure shown in Figure 5 is about fifty years old. Infiltrations of water caused by gaps in the waterproofing of the roof created conditions favourable to the growth of fungus. This structure is very seriously damaged at places where infiltrations took place. Proper maintenance of the roofing is needed to avoid, or reduce, the risk of fungus attack on the supporting timber structure.

Lightweight structures

Figure 6 *Buckling of trussed rafters.*

Cases of buckling of trussed rafters, as shown in Figure 6, are rather common. They are caused by over estimation of the transverse rigidity of the framework, resulting from the idea that the length of transverse buckling for trussed rafters would be equal to the distance between batten lines. This idea is an illusion because the lateral restraint given by the tile battens and the bracing is not sufficiently rigid. The numerous nailed joints which are involved may slip and drag, as shown on Figure 7.

The design of continuous bracing bars under the roof planes, with girtrails and torsional blocking of truss bases, as well as the adoption of reasonable design buckling lengths, are essential precautions needed to prevent the risk of lateral buckling of trussed rafters.

Figure 7 Slipping and dragging of batten nailing.

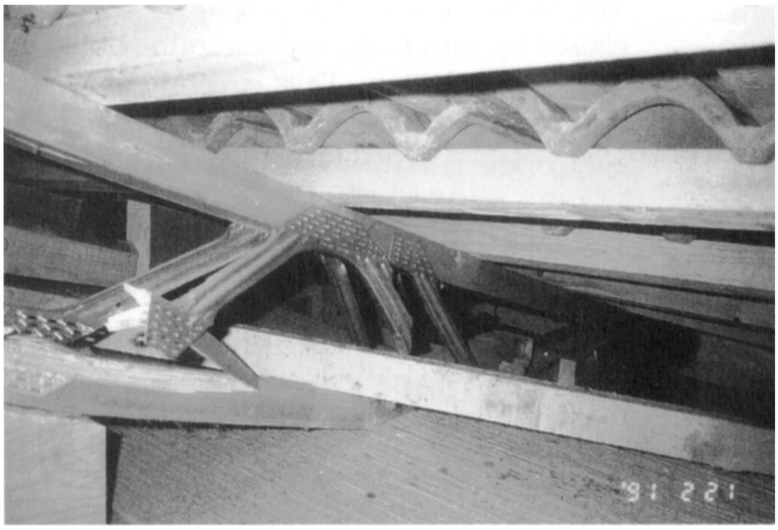

Figure 8 Failure of timber girder.

The broken girder shown in Figure 8 is used as a rafter. The end of its lower flange has broken, and its metal diagonals have torn away. The support of this girder is not properly designed: offsetting the supporting point from the triangulation node causes a secondary moment, which has resulted in the failure. Attention must be paid in the design of supports with respect to the calculation hypothesis in order to avoid secondary moments.

Figure 9 Warping of LVL frame.

The frame shown in Figure 9 consists of two thicknesses of 36 *mm* LVL, side by side for the crossbeam and forming a coffer for the columns. Warping is due to insufficient lateral and torsional stiffness, caused here by a loose nailing of the LVL sheets together. The specification of adequate nail densities in the design documents is necessary to avoid this instability.

Figure 10 *Instability of timber frame walls.*

The timber frame house shown in Figure 10 is supported by props. The ground floor walls slope outwards, probably because the connections between floor and walls are absent or inadequate. Design, fabrication and erection should be done by professionals, preferably.

Glulam structures

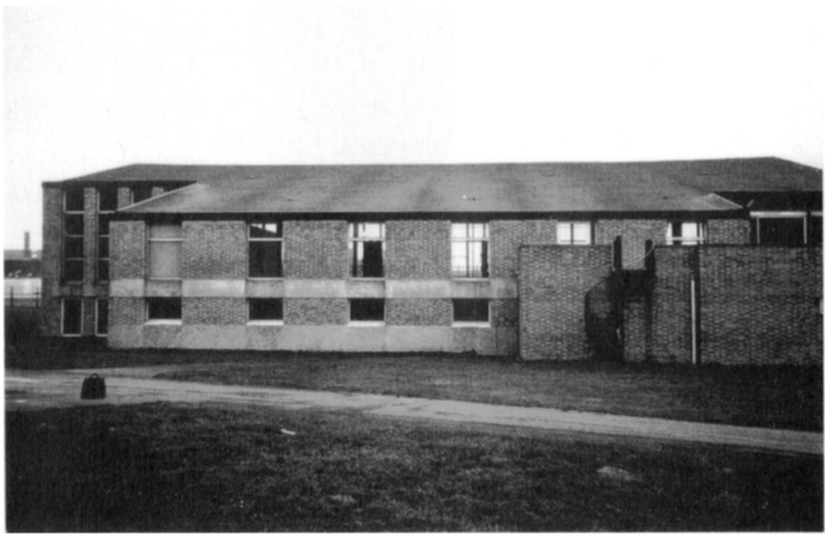

Figure 11 *Ridge deformation.*

The ridge of this sports centre (Figure 11) has subsided about 300 *mm*, following an increase in the curvature of the flanks of the frames that form the main structure. This increase in curvature is not caused by any extra load on the frames, nor by creeping, but results from the transverse shrinkage as the wood dries out.

Shrinkage moves the soffit and back of the curved flanks of the arches closer together, while their respective lengths remain approximately the same, which means an increase in their curvature, and consequently subsidence of the key point as indicated in Figure 12. Control of drying conditions with regard to the service condition, and anticipation of the possible deformation will prevent this problem.

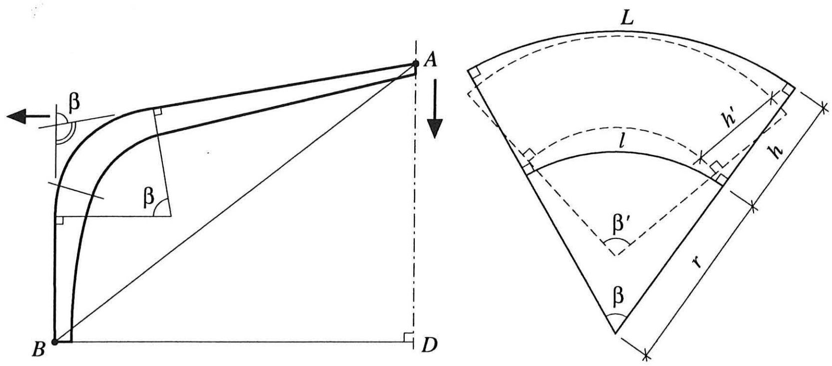

Figure 12 Increase in curvature and deflection due to shrinkage.

Curved beams are subject to transverse tensile stresses accompanying bending forces. This is a cause of serious cracking. Many cases have been recorded of cracking similar to the case shown in Figure 13. They are generally the result of over-optimism in the transverse tensile strength. Consideration of the influence of curvature on the transverse tensile stress (see STEP lecture B8) as well as the influence of service conditions on shrinkage and surface cracking is needed in the design of curved tapered beams. The use of reinforcements made of glued in bolts or glass fibre is recommended (see STEP lecture E4).

Figure 13 Cracking of tapered curved beam.

Another case of cracking caused by transverse tensile stresses is shown on Figure 14 and 15. These steeply tapered glulam columns are situated outside. Their exposure to climatic changes helps cracking. A good design would need a smooth taper, and inside location, which is, in most cases, an architectural concern.

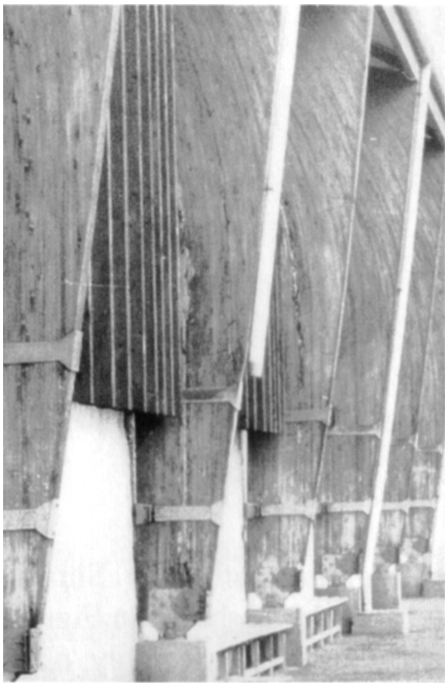

Figure 14 *External uprights with cut-off strips.*

Figure 15 *Detail view of cracking.*

Waterponding may occur on flat roofs. It is responsible for many cases of collapse, the beam in Figure 16 is one example. Beam deflection under water ponding loads increases beam loading. In case of insufficient beam stiffness, this process leads to instability, gluing defects (Figure 17) and finger jointing defects (Figure 18) may reduce the stiffness and the resistance of beams, increasing dangerously their susceptibility to water ponding loads. Special care is needed for beam design in the case of flat roofs, the stability under water ponding loads must be checked. Prevention of gluing and finger jointing defects needs quality control in the manufacturing process.

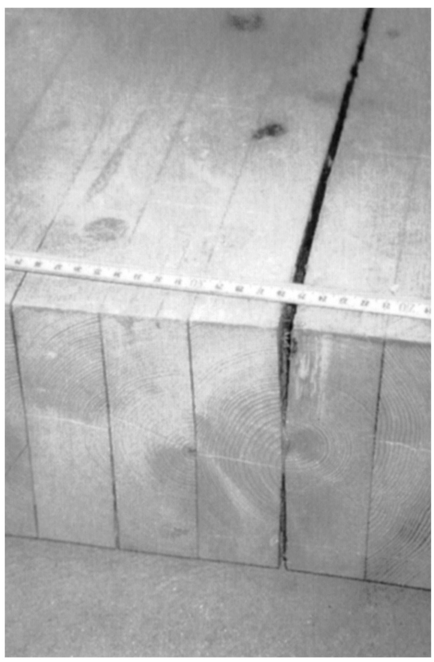

Figure 16 *Beam collapse.*

Figure 17 *Defective gluing.*

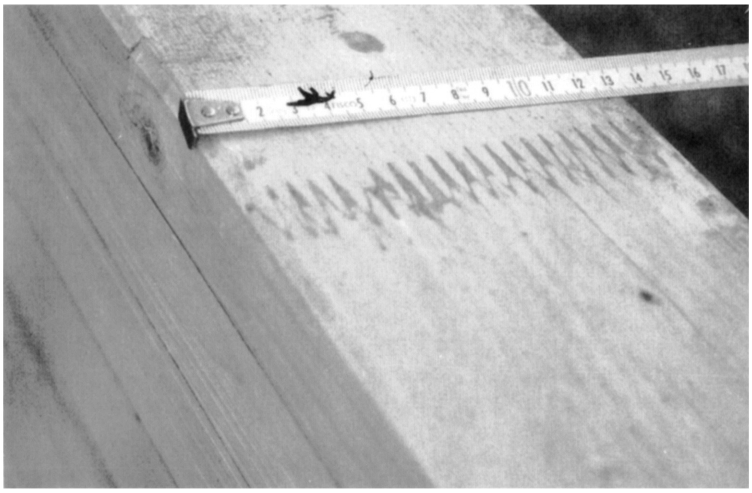

Figure 18 Finger jointing defects.

Joints play an important part in glulam pathology. Shrinkage of beams and columns at frame corners often result in cracks as shown in Figure 19. This can be prevented by adequate drying of the glulam prior to assembly, associated with gluing process control. The designer must bear in mind that the risk increases with the depth of beams and columns. Reduction of design stresses may be recommended in particular cases.

Figure 19 Cracked frame corner.

Insufficient rotational capacity of joints may create problems for glulam structures. This is the cause of the collapse shown in Figure 20.

Figure 20 Failure of cantilever joint.

The beam had two bays, a cantilever joint was located at a short distance from the central support, see Figure 21.

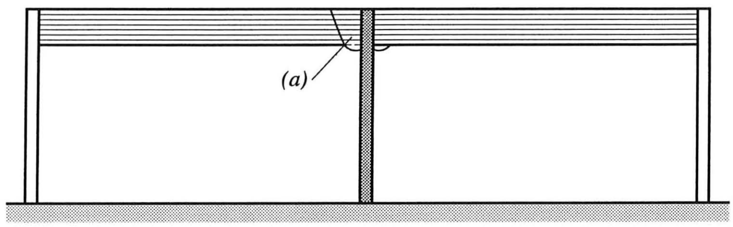

Figure 21 Two bays beam and cantilever joint (a).

The design of the cantilever joint shoe shown on Figure 22 does not allow the rotational possibility required by the position of the joint, which is different from the zero moment point.

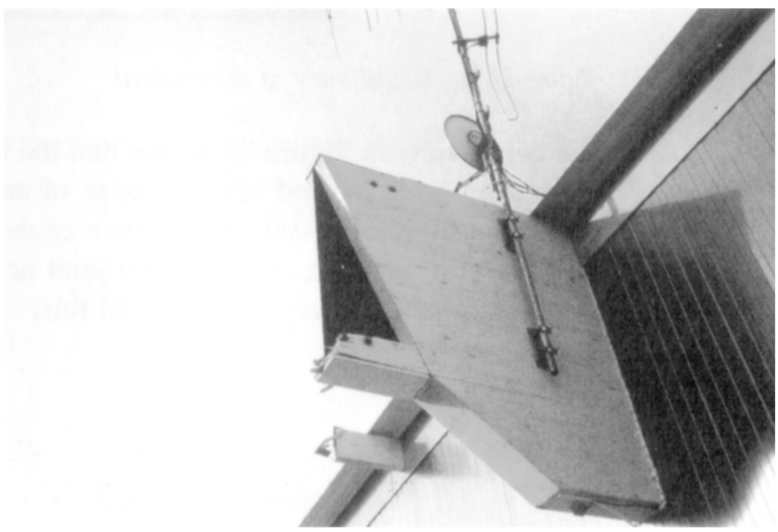

Figure 22 Detail view of cantilever joint.

The canopy of the stadium stand shown in Figure 23 has been almost entirely carried away by an ordinary gust of wind.

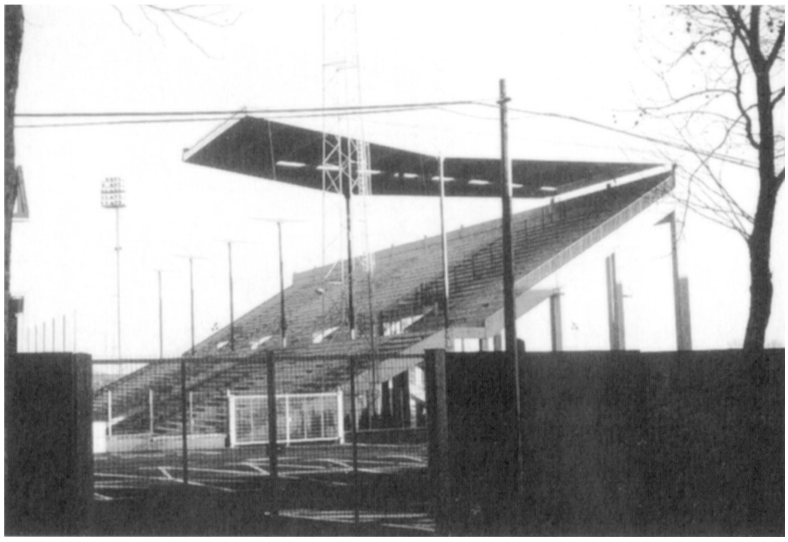

Figure 23 *Attachment failure.*

Figure 24 *Detail view of attachment.*

The detail view in Figure 24 shows that the beams were attached to the tops of the column by bolts located near the edge of each beam. This arrangement generates transverse tensile stresses, which have caused cracks to cut the beams at the level of the upper bolt. The design of the joint according to the provisions described in STEP lecture C2 is required to avoid this.