FAILURES OF TIMBER STRUCTURES IN SLOVENIA

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Abstract

In Slovenia in last thirty years only few failures of timber structures occurred. According to our knowledge two typical modes of failure have been observed: the reason of one was bad design of curved and tapered laminated beams where too high perpendicular to-grain-stresses caused splitting of the beams, and the second was local failure of roof truss elements connected with punched metal plates. Problems of perpendicular to grain tension were noticed also on three hinged arch, luckily when tested in laboratory. The last case was not a complete failure - an improper use of glue (not durable glue used in the industrial premise) caused cracks in long straight beams. The bigger problem is noticed on historical structures: some of old roof and floor beams failed or were heavily damaged because of bad maintenance. In old buildings even heavy timber floors can collapse - one failure happened just recently. It is very important to detect which are potential weak points of old roof and floor beams, so some inputs for inspection manual of installed elements are mentioned.

Introduction

The tradition of timber structures in Slovenia is quite old, although in the recent century more concrete and steel structures have been built. In past timber was generally used for bending structural elements (beams, floors, roof structures), but not for walls - they were mainly made from massive materials (stone, bricks).

Main timber structures were roofs and floors: roof structures were classical in-situ built structures and sometimes prefabricated truss beams, and floors were hollow or heavy timber structures. Nowadays timber is used mainly for roof structures and the widely used material is glued laminated timber. Prefabricated timber houses are also quite popular but they represent only 3 - 4 % of housing and we are not aware of any major structural mistakes so far.

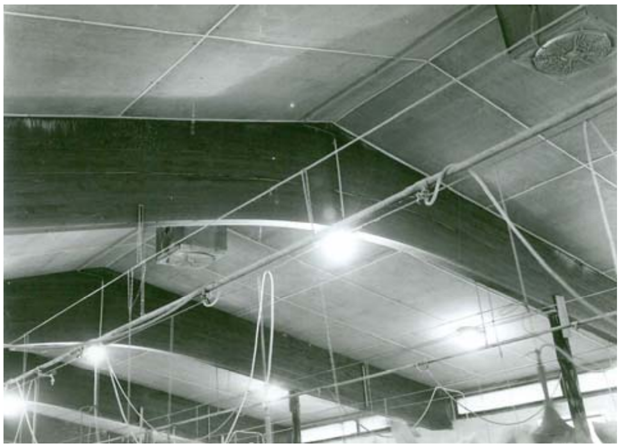
Failures of timber structures in Slovenia can be divided into two types: one are contemporary structures (glulam elements, trusses with nail plates) which fail mainly of bad design or improper use of material (glue), and another are old buildings where the main causes of failure is sometimes a bad detailing, and above all, a lack of maintenance.

Examples

Contemporary structures

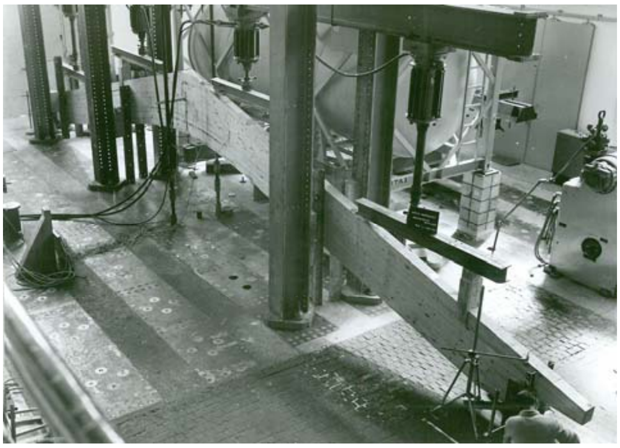
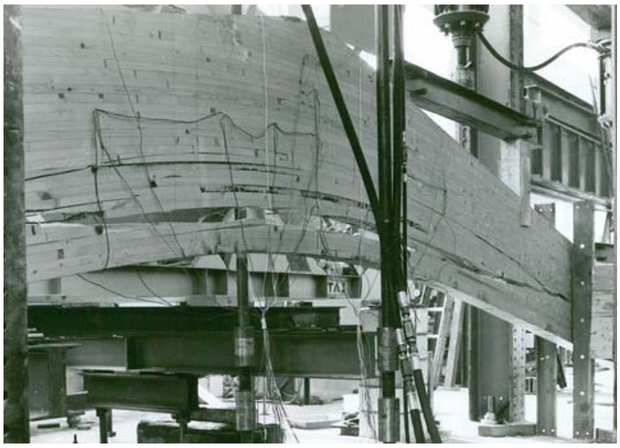
In the autumn 1979 in Markovec, 60 km from Ljubljana, 15 roof beams in one building of the chicken farm collapsed, and some elements in other two buildings cracked. The beams were curved and tapered glued laminated beams with relatively small radius of curvature.

The type of failure was so called "tension perpendicular-to-grain failure" which was in 70-ties quite often and well known, but recently, according to our knowledge, no more such failures are noticed. The reason is improvement of design: in Eurocode 5 (and in national codes before that) for these types of structures precise formulas for controlling stresses in radial direction are introduced.

Figures 1, 2: Failed and cracked curved and tapered beams

We like to point out that also in the mentioned case failure was partly caused by the bad gluing and the additional "trigger" for the failure was exposure to the changing climatic conditions. An influence of friction on supports also played a certain role because the same type of element, produced after failure to be tested in laboratory, carried much higher load.

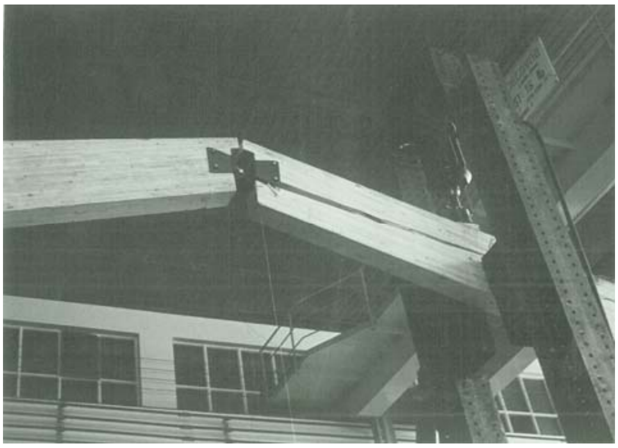



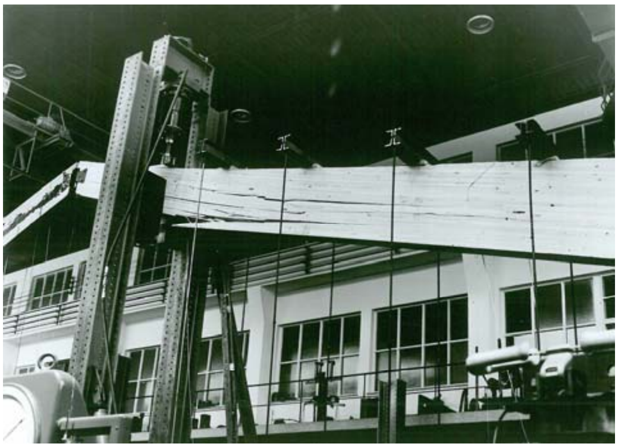
Figures 3, 4: Laboratory test of new beam with the same geometry

Being warned by this failure an on-site investigation of the same type of elements has been performed. The result was failure of roof element during the on-site loading test. The sudden failure happened at 1.16 x design load, just one step before we wanted to finish the loading. After the test beam was removed and brought to laboratory to study possibilities of strengthening (glued-in rods, tensile tie...).


Figures 5, 6: Failure of beam during in-situ loading test

Another problem with tension perpendicular-to-grain was noticed in 1982 when three-hinged arch was tested in laboratory. Proposed solution of fixing the middle hinge with two dowels caused the unfavourable failure: splitting the wood below the dowel (Figure 7). Changing the detail - fixation of hinge with three dowels, additional transverse dowels - improved the load bearing capacity for almost 100% and also changed a mode of failure (Figure 8).





Figures 7, 8: Unfavourable tension failure and changed mode at redesigned hinge of arch beam

In 1983 cracks was noticed on big Gerber hinged straight beams (length: 17.5 m + 21 m + 17.5 m, height 0.92 m). On some of 21 beams cracks were noticed and an investigation was taken to find out the residual strength of beams. Also tests of shear strength of glueline were performed to find out if the proper glue was used. The results of investigation showed that beams had no sufficient bending strength - the reason was non adequate design and improper use of glue (not durable glue was used in the industrial premise).

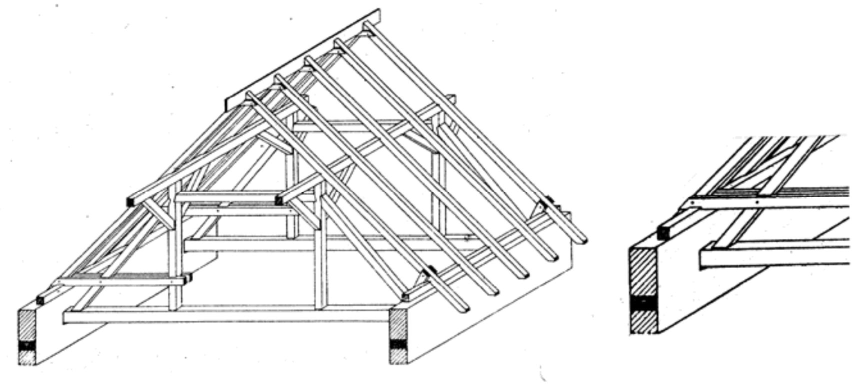
In 1987 failure was noticed on roof trusses where connections were made by metal nail plates. As seen from the pictures, the plates were situated out of centre lines of upper chords and transverse stresses were higher then perpendicular to tension strength of timber (Figures 9, 10).

Figures 9, 10: Failure details of roof trusses connected with nail plates

As mentioned, practically all failures of contemporary timber structures in Slovenia was caused by tension perpendicular to grain which is, obviously, for our type of wood (spruce/fir) a most problematic property. Experienced designers are aware of that but for young designers who regularly design e.g. steel structures and are not familiar with low perpendicular-to-grain tensile strength of wood, it could be a problem. Perpendicular to grain tensile strength is also very sensitive to moisture - whereas for other properties reduction factor at 20% MC is 10 - 15%, for perpendicular to grain tension it is ca 30%.

Historical structures

Classical roof structures were made from solid wood and mostly used structural systems were strutted and suspension frames. Strutted structures have supports on outer walls which are sometimes in the attics floor level but most commonly they are raised on so called gable walls to achieve the bigger height of the attics. Transfer of load from poles to the lower chord is made through vertical struts, which are usually built into gable wall. Because they are closed in the brick or stone walls and therefore not ventilated, deterioration of wood is very often observed. Typical roof with gable wall and detail of the support is presented in Figure 11 and typical deteriorated strut in Figure 12.



Figures 11, 12: Typical detail of roof structure support and deteriorated strut

As seen from Figures 13 - 18 old roof structures have several potential deterioration weak points.

Figures 13, 14: Failed lower chords of roof beams

Figures 15, 16: Destroyed supporting beams of roof structures

Figures 17, 18: Typical wetting points of roof structures

Usually the problems are spotted during the inspections performed before restoration works, but failures sometimes can occur also during the use. As we can see from Figures 19 and 20 they are mainly connected with constant wetting of timber. Whereas in some cases floor beams are only damaged (e.g. under the water tank placed in attics- Figure 19), in second case three floor beams totally collapsed (Figure 20). The reason was heavy constant wetting caused by bad drainage details under the later constructed terrace.

Figures 19, 20: Wetting of floor beams and failed floor

What to check?

Two principles for checking designed and installed timber structures should be taken into account: one for contemporary structures where a quality of material has (usually) been proofed, and other for old structures.

To assure that structures will have adequate reliability, thorough check of design has to be performed (this check is also necessary for already installed modern structures). As seen from our examples, special attention should be paid to controlling tensile stresses perpendicular to grain. In design check also very important point is to verify if the proposed service class corresponds to the real one, and how the duration of load is taken into account. Besides the control of static calculation check of construction details is necessary. There is common knowledge that wetting of wood is not dangerous if the structure can be later dried. The real danger is constant presence of moisture mainly on supports or in other details. Very bad solution is also installation of waterproofing membranes on both sides of timber elements which can cause deterioration of wooden element is just few years. Many problems a condensation on timber elements can cause.

As seen from Bad Reichenhall case, especially roofs on ice halls are subjected to really hard conditions and special attention should be paid on the proper ventilation of the roof elements.

By inspection of installed modern timber structures check of design should include also control of materials used (wood, glued, laminated timber, connectors...). This "paper check" should be followed by on site inspection of a structure. Firstly we have to control if structure is able to behave as it was supposed in design (e. g. if free movements of supports and free rotation in middle hinge of arches is enabled). All possible wetting points should be detected and critical details (supports, connections...) should be checked. We propose the same principle as by bridges: regular controls should be performed every second year, and after 6 years so called "main inspection" should be performed - the rule of it is "touch the structure". If damage is noticed, "detailed inspection" with taking samples for further investigations should follow.

Somehow different approach is proposed for historical structures. Design of such a structure is usually not available and, in principle, we do not recalculate the structure. There are two reasons for that: we can measure the geometry of structure but we can not define the characteristics of connectors (nails, dowels...) so the accurate control is impossible. On the other hand we suppose that if structure survived 50 - 100 years (in these times roof structure survived probably heavy snow loads) and structure is not damaged if no additional load is foreseen there is no reason for reducing load bearing capacity. But we strongly recommend a check of all construction "improvements" made during the life cycle. These changes are quite often by renovation of attics where some roof elements are cut or replaced (Figures 21, 22)


Figures 21, 22: "Professional" construction measures

Conclusion

As mentioned before, the majority of failures in Slovenia have happened ca 30 years ago and since then no major collapses of timber structures have been reported. Bad design is now well prevented by controls in EC 5, although some could be hidden and can show up in winters with substantial amount of snow. Nevertheless, the check of design - which is now in Slovenia not obligatory - is highly recommended, especially for demanding structures. Regular checks of installed structures, especially structures with large spans or heights, and structures where people are gathering (schools, sport halls, commercial buildings...) should be prescribed as it is the case with bridges.

Inspection of historical buildings usually performed before or during the reconstruction works, should comprise checking of structural changes which could essentially reduce the strength, and assessing the quality of timber. Special attention should be focussed to critical points where wetting of timber could be expected (supports, built-in elements, connections of roof planes, details at the gutters, chimneys, antennas, ventilation channels, etc.).