Design of safe timber structures –

How can we learn from structural failures in concrete, steel and timber?

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The presentation reports on research performed in a subtask for the joint Swedish-Finnish project "Innovative design, a new strength paradigm for joints, QA and reliability for long-span wood construction (InnoLongSpan)", conducted 2004–2007. The project dealt with two main issues: (1) design of joints used in long span timber structures and (2) documenting reliability and developing quality assurance of large and demanding timber structures. The present part documents the results of the subtask dealing with reliability, where the objective has been to obtain in-depth information about causes for failures in wood structural systems. The purpose is to learn from such experience in order to improve control systems and education of timber engineers.

It is clear that collapses in timber structures are quite negative for the competitiveness of timber on the construction market. The question is what can be done to reduce the risk for failure in timber structures in the future. The main hypothesis for the present work has been that quality assurance, control systems and improved training may be necessary, since the unwanted events are primarily related to human errors, ignorance and carelessness. To provide a basis for training and quality assurance of design and construction of buildings with wood as a structural material, a survey of failures in timber structures has been made. This report presents the results from this survey with an analysis of the underlying causes and associated conclusions and recommendations.

More specific, the objectives for undertaking the survey of building failures are to get a picture of

- the underlying reasons for observed failures
- which type of components are most prone to failure
- which failure modes are most frequent
- what can be done to avoid or reduce failures.

In the present report an investigation of failures in buildings with timber as a primary structural material is presented. The concept of failure considered here is mainly related to the ultimate limit state and is defined as events which have or could have implied risk for human lives.

A total of 127 failure cases were included in the survey. The data material used in the project was collected partly from direct information on failure cases provided by project participants who had been assigned to investigate failures and partly from cases documented in literature. The case reports were analysed and causes behind the failure event were classified with respect to the following nine categories:

1. Wood material performance
2. Manufacturing errors in factory
3. Poor manufacturing principles
4. On site alterations
5. Poor design/lack of design with respect to mechanical loading
6. Poor design/lack of design with respect to environmental actions
7. Poor principles during erection
8. Overload in relation to building regulations
9. Other/unknown reasons

The most common cause of failure found in the investigated cases is poor design or lack of strength design (41%). Other important failure causes are poor principles during erection (14.1%), on-site alterations (12.5%) and insufficient or lacking design with respect to environmental actions (11.4%). In total, about half of the failures are related to design. About one fourth of the failures are caused at the building site (on-site alterations, poor principles during erection). This means that wood quality, production methods and principles only cause a small part (together about 11%) of the failures. The problem is therefore not the wood material, but engineers and workers in the building process. This picture is similar to that found from other failure investigations for other types of structures (mostly steel and concrete), where human errors were found to be the dominating cause behind failure events.

The types of structural element or joint involved in the failures were recorded. Beams, trusses and bracing are the most frequent structural elements used in roof structures and also most frequent in the failure cases studied. Especially in the case of failure of trusses, almost all failures are caused by insufficient or absent bracing and poor principles during erection. Beams, especially curved beams and double-tapered beams with loads generating tension stresses perpendicular to the grain but also to a large extent straight beams, are dominant in the list of failures. Joints were involved in the failure event in 23 % of all cases. Dowel-type joints are dominant, both in terms of their use in structures and among the failure cases.

Among the studied cases instability is a very dominant failure mode. This means that the collapse/failure was caused by insufficient/absent bracing, which led to buckling or material failure. Bending failures and tension perpendicular to grain failures are also common.

The study more or less confirms the conclusion drawn by other researchers that for structures of all types of materials, the vast majority of failures occur due to human error. Failures due to human errors can not be counteracted by increased safety factors or safety levels in structural codes. As also found in many other investigations almost no failures were caused by unfavourable combinations of random events. Thus, there is no evidence from the present investigation that the chosen safety level for timber in structural codes is inadequate.

It is more or less impossible to eliminate the risk of human errors completely but their frequency can be reduced by improving building process management, where an important element is to assign or commission personnel with adequate experience and education as well as with the right attitude to the tasks at hand. Training, education and control measures should be especially focussed on those technical aspects found to be the most common causes of failures. Some of the issues which should be emphasised are

- Bracing to avoid instability problems both in the finished structure and during construction.
- Situations with risk for perpendicular to grain failure
- Consideration of moisture effects
- Design of joints

An important task for future research in timber engineering should be to develop methods to design robust structural systems, which are less sensitive to failure of single elements in the system and where the consequences of unforeseen events such as human errors and accidental loading are reduced.