Engineering Structures 33 (2011) 3113–3117

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Robustness of large-span timber roof structures — Two examples

Jørgen Munch-Andersen [a], Philipp Dietsch [b,*]

[a] Danish Timber Information, Lyngby Kirkestræde 14, DK-2800 Kgs. Lyngby, Denmark

[b] Chair for Timber Structures and Building Construction, Technische Universität München, Arcisstr. 21, D-80333 Munich, Germany

ARTICLE INFO

Article history:
Available online 6 May 2011

Keywords:
Timber
Structure
Large span roof
Failure
Robustness
Redundancy
Indeterminacy

ABSTRACT

This paper discusses the robustness of large-span timber roof structures, based on findings from failures of two roof structures. One is the Siemens arena in Ballerup, Denmark and the other the Bad Reichenhall ice-arena in Germany. The structures are described as well as the flaws that are believed to have caused the failures. The two cases serve as examples of different design strategies for large-span timber roof structures and the consequences of such strategies for robustness. It is demonstrated that robustness is not a straightforward concept because the best strategy depends on the cause of the failure — which is obviously not known during planning and design.

1. The structures and their failures

1.1. Siemens arena

The cycling arena was built in 2001. The main roof structure consisted of 12 trusses, each truss composed of two glulam timber arches with vertical connectors, see Fig. 1. The upper arch was mainly exposed to compression, the lower arch to tension. The horizontal components of the tension and compression forces were neutralised at the corner connections, realised with concealed steel plates which were connected to both arches by embedded dowels and a few bolts, see Fig. 2. The structure appeared as an elegant slim construction with a free span of 73 metres across the arena. The distance between the trusses was 12 metres. The secondary structure consisted of simply supported purlins.

Two of the trusses collapsed without warning at a time with almost no wind and only a few millimetres of snow. The partial collapse happened just a few months after the inauguration of the arena. No people were present in the arena during the collapse.

An investigation, see [1], showed that the cause of the failure could be localised to one critical cross-section in the tension arch near the support, where the load bearing capacity was found to be between 25% and 30% of the required capacity, see Fig. 3. By mistake, this cross-section was not considered at all in the design. Three critical design errors were identified:

- The design strength used for the timber part was almost 50% too high.
- The reduced height of the cross-section near the ends of the arches, see Fig. 2, was not considered.
- The reduction of the timber cross-section due to steel plates, bolts and dowels, see Fig. 3, was not considered.

The expected short term load-carrying capacity at the critical cross-section happened to be only slightly larger than the loads from the self-weight of the structure. Because the strength of timber is reduced over time when it is loaded (the k_{mod}-effect), it is likely that the collapse took place when the strength was reduced to the stresses caused by the self-weight. According to Eurocode 5 [2] and confirmed by Hoffmeyer and Sørensen [3], the reduction factor for medium duration loads (1 week to 6 months) is $k_{mod} = 0.8$. Such a reduction is enough to explain how the collapse could take place at a time with no special external load.

The investigation also revealed that the stability of the trusses was not ensured sufficiently and that the quality of the gluing of the glulam was not as specified. These problems, nevertheless, did not contribute to the actual failure.

The collapse did not occur due to an unknown phenomenon. The design of the trusses was not checked by the engineer responsible for the entire structure due to unclear specification of the responsibility and duties of that engineer. This might explain why such a vital error could pass the quality assessment of the design. The demands to the quality assessment of such structures in the Building Regulations have been increased after the incident. An independent third party control is now required.

* Corresponding author.
E-mail addresses: jma@traeinfo.dk (J. Munch-Andersen), dietsch@bv.tum.de (P. Dietsch).

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.03.015