COST E 55

The Siemens Arena collapse in a robustness perspective

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The structure

On one morning two trusses in the roof of Siemens Arena suddenly collapsed, see Figure 1. It happened just a few months after the inauguration of the arena and a few days before a major event should have taken place.

Each truss was composed by two glulam timber arches with vertical connectors, see Figure 1. The upper arch was mainly exposed to compression and the lower to tension. The horizontal component of the tension and compression forces were neutralised at the corner connections by concealed steel plates connected to both arches by embedded dowels and a few bolts, see Figure 2. The structure appeared as an elegant slim construction with a free span of 73 metres across the arena. The distance between the trusses were 12 m.

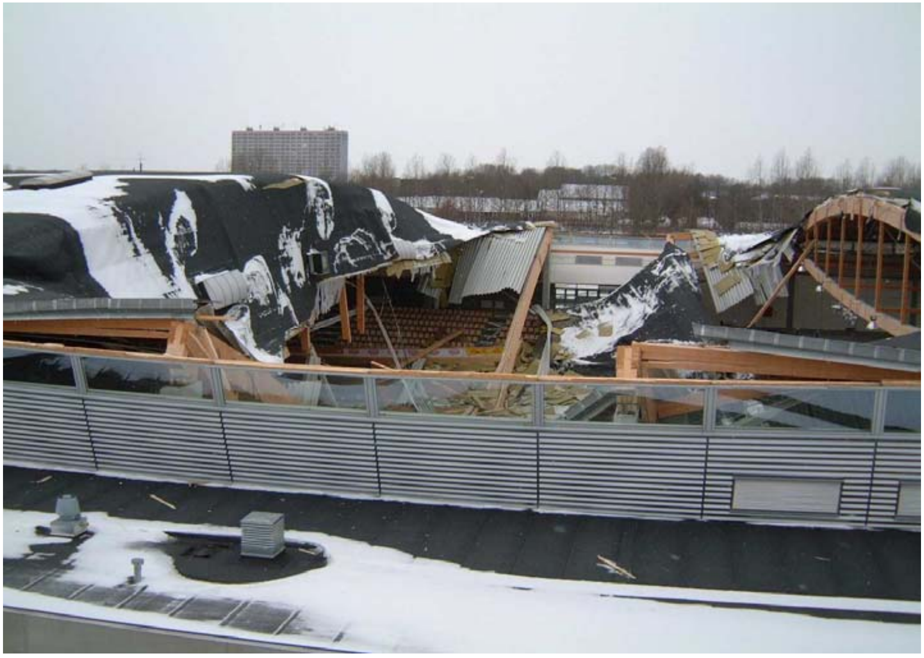

Figure 1. The roof of Siemens Arena after the collapse of two trusses. An intact truss is seen to the right.

The failure

The failure occurred without warning at a time with almost no wind and only a few millimetres of snow.

An investigation [1] showed that the problem could be localised to one critical cross-section at the corner in the tension arch where the strength was found to be between 25 and 30% of the required strength, see Figure 3. By mistake, this cross-section was not considered at all in the design.

Three critical design errors were identified:

- A 48% too high design strength was used for the timber part
- The reduced height of the cross section near the ends of the arches, see Figure 2, was not considered
- The reduction of the cross section due to holes in the timber for steel plates, bolts and dowels, see Figure 3, were not considered

The expected short term capacity at the critical cross section happened to be only slightly larger than the force from the self weight of the structure. Therefore the collapse could take place at a time with no special external load, just due to the decreasing strength over time (i.e. k_{mod})

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

The collapse did not reveal any unknown phenomenon, so the main question is how such a vital error could pass the quality assessment of the design.

Figure 2. The corner has concealed steel plates which connects the timber parts. Between the visible bolts numerous dowels are placed.

Figure 3. Rupture at the critical cross section in the corner connection. Note the dowels and steel plates.

Robustness strategies

The 12 m long purlins between the trusses were only moderately fastened, such that a failure of one truss should not initiate progressive collapse. This strategy proved to work fairly well as only two of the 12 trusses collapsed. As all trusses had much lower strength than required it might be fair to conclude that the extent of the collapse was *not* disproportionate to the cause.

Another and more expensive strategy against progressive collapse could have been to design the trusses, the purlins and their fastening such that a failed truss and the roof could hang in the purlins and transfer the load to the neighbour trusses (when considered an accidental load case).

Had the cause of the failure been a huge load on one truss or a lone standing mistake this strategy would have been preferable because it significantly reduces the risk of injuries. The strategy would also have worked if a leaking roof had degraded one truss because it is likely that the other trusses are unharmed.

But given the cause of the actual collapse this strategy would most likely have caused a total failure as the neighbour trusses could not have withstood the extra load.

The bracing in the longitudinal direction was ensured by two systems, one at each gable. This ensures stability of the remnant part of the building when one truss has failed, no matter which truss. This strategy also proved successful, even though there was no wind or snow to call for big demands to the bracing system. If insufficient stability of the trusses had caused a failure the division of the bracing into two systems might also help, especially if both systems can sustain the entire load. With only one system there will most likely be key-elements for which failure will cause a total collapse.