Robustness considerations from failures in two large span roof structures, Part 2

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Træinformation

Case: Siemens Arena, Ballerup, Denmark

Træinformation

Structure

- 12 ‘cigar’-shaped glulam trusses with concealed steel plates
- 73 m span with 12 m between trusses
- Simply supported purlins between trusses

Failure

- Two trusses collapsed without warning a few months after the inauguration of the arena
- Almost no wind and a few millimetres of snow
- No people was present in the arena during the collapse

Causes

- Failure in tension arch near to support
- This cross-section was not considered in the design
- Strength between 25 and 30% of the required strength
- Close to stresses from permanent load

3 critical design errors

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

Robustness assessment

- Strategy: Purlins was only moderately fastened to the trusses to avoid progressive collaps if one truss should fail
- Two separate bracing systems – one at each end
- This strategy proved to work fairly well
  - 'only' two of the 12 trusses collapsed
- Considering the size of the design error it might be fair to conclude that the extent of the collapse was *not* disproportionate to the cause
- Each truss becomes a key element

Robustness - alternative

- Strategy: Trusses, purlins and connections designed to permit for a failed truss to hang in the neighbour trusses (when considered an accidental load case)
- This strategy would have caused progressive collapse with the present design errors
- If the cause of failure had been a huge load on one truss or a lone standing weakness this strategy if preferable because it significantly reduces the risk of injuries
- Large deformations would occur, giving a warning
- The trusses are *not* key elements

Comparing the two collapses

Collapse can be attributed to

1. errors in design
2. errors during construction
3. lack of maintenance
4. unforeseeable incidents

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Siemens Arena (statically determined):

- Design errors

Ice-Arena (many times statically undetermined):

- Design errors
- Construction errors (eg. faulty gluelines)
- Unforseeable incident (condensation)

Siemens Arena:

- very severe weakness
- present from erection
- similar magnitude for all trusses
- robustness strategy worked

Bad Reichenhall Ice-Arena:

- smaller weakness
- increasing with time but at different rate over the roof
- local failure not revealed due to stiff secondary system

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- but minimum damage for local incident = one truss falls down ~ 2000 m^2
  => damage might not be proportional to the cause
- strong purlins avoids risk for local incident – but causes total collapse for systematic errors

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Bad Reichenhall Ice-Arena:

- smaller weakness
- increasing with time but at different rate over the roof
- local failure not revealed due to stiff secondary system
- softer secondary system would issue a warning
- a systematic error as severe as in Siemens Arena would eventually cause total collapse
- but a soft secondary system might have given a warning

Conclusions

- No strategy can ensure robustness in all cases
- When deciding on robustness strategy different scenarios must be considered
  – especially systematic error or unforeseeable incident

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- Systematic human errors causes most collapses
- Independent checking of design and construction needed
- Only if human errors are eliminated it is possible to choose a robustness strategy which is unambiguously beneficial
- (Neither of the projects for the two structures had undergone an independent checking. The concept was introduced in Denmark as a direct consequence of the collapse of Siemens Arena)