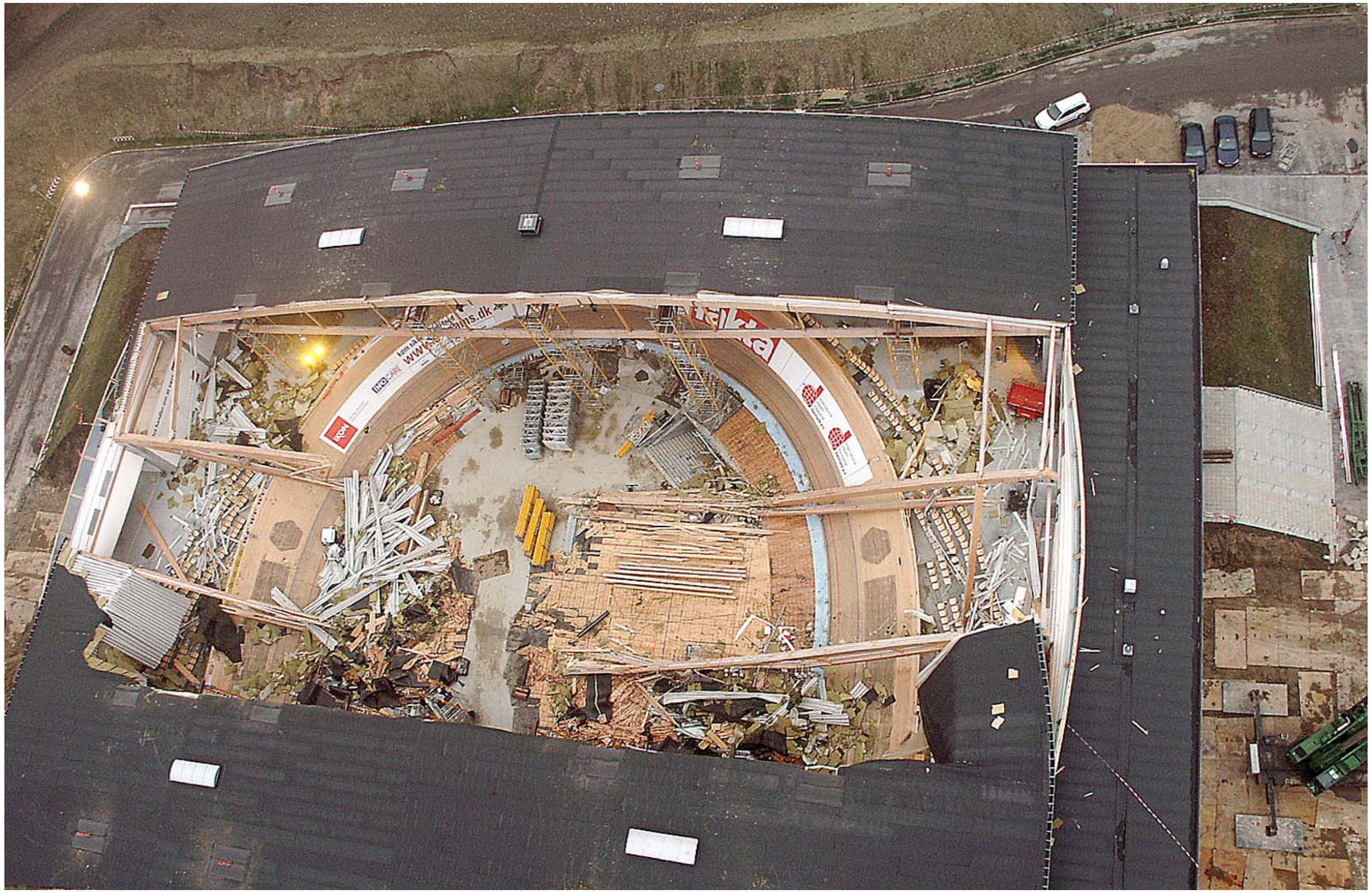

Robustness evaluation of failed timber structures

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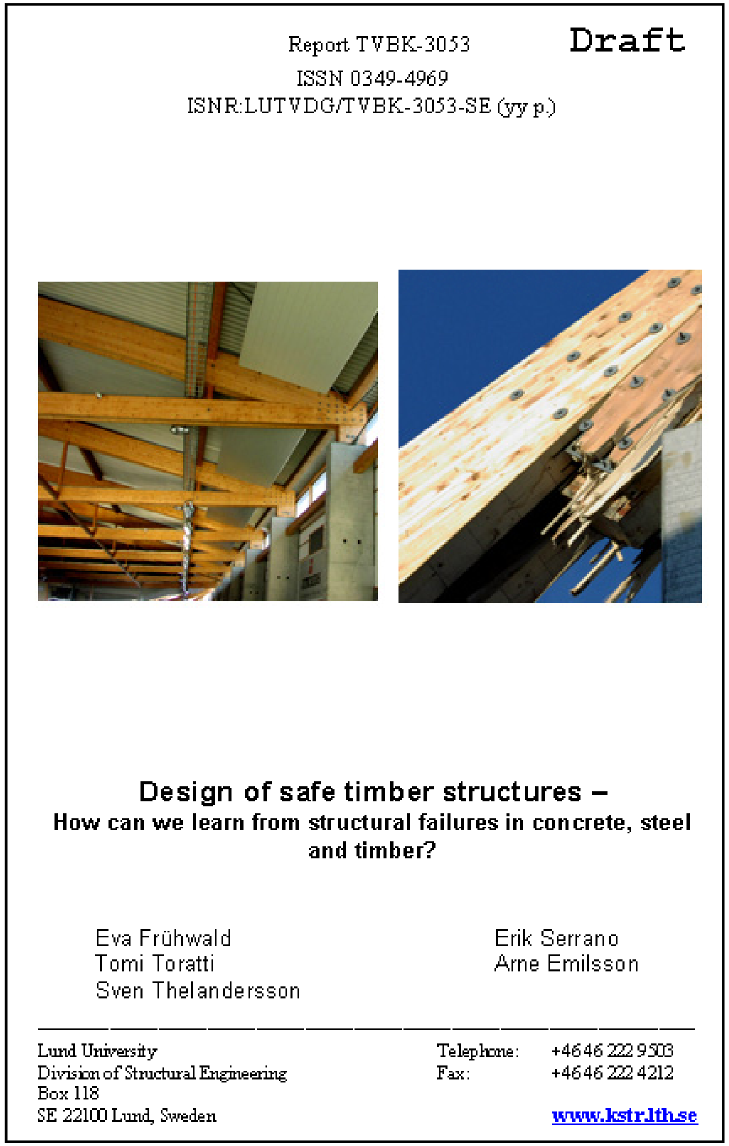
Background

A broad survey of failures in timber structures was made in a Swedish-Finnish project 2005-2007.

Original research questions:

- Is the level of safety adequate for timber structures compared to other materials?
- What can be done to avoid such failures?



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Design of safe timber structures –

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

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Investigation of robustness

The existing database was used to investigate robustness characteristics.

Outline

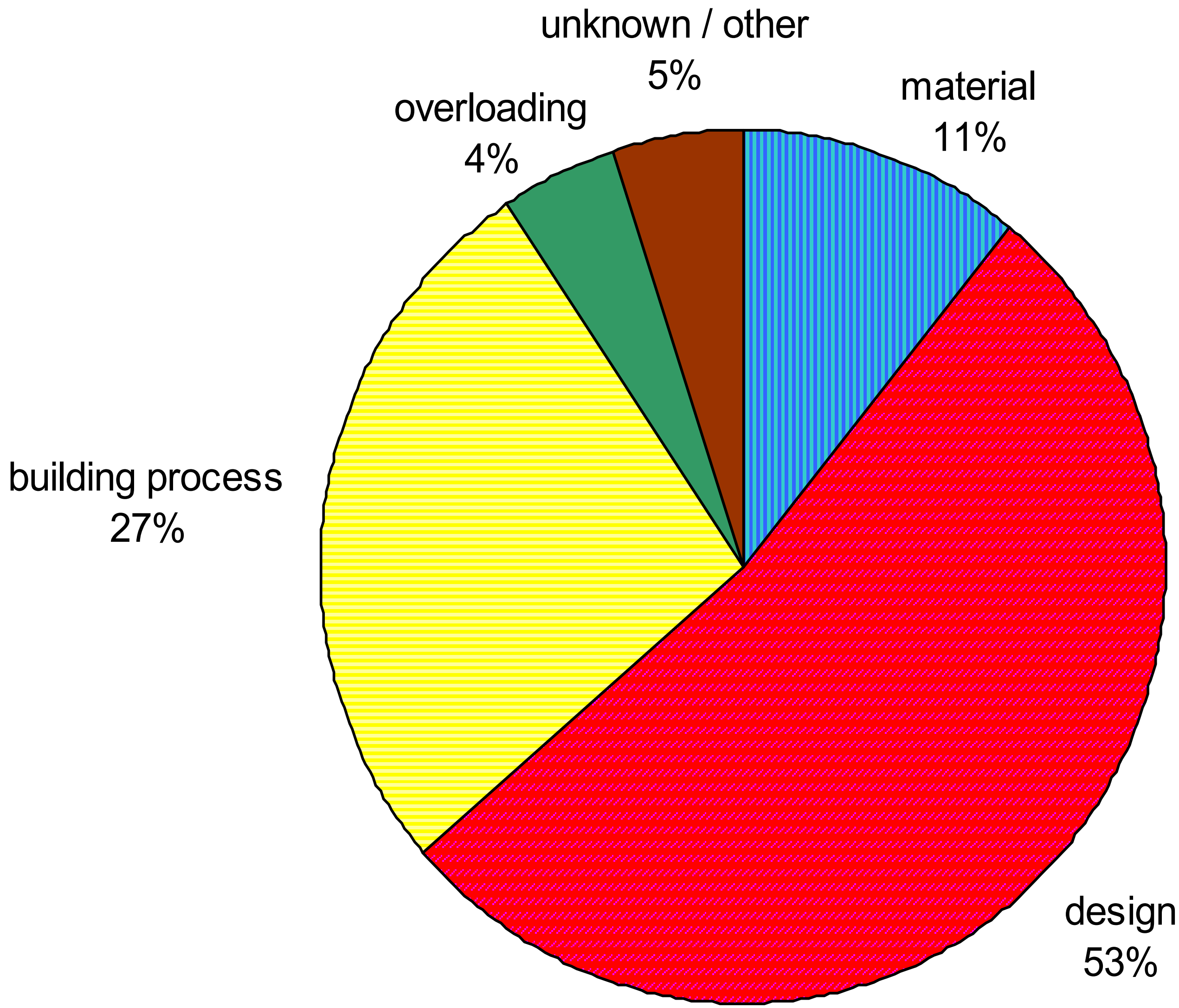
- **Characteristics of structures in the database**
- **Methodology for robustness assessment**
- **Results from assessments**
- **What can we learn about robustness?**
- **Conclusions**

Type of buildings (total 127)

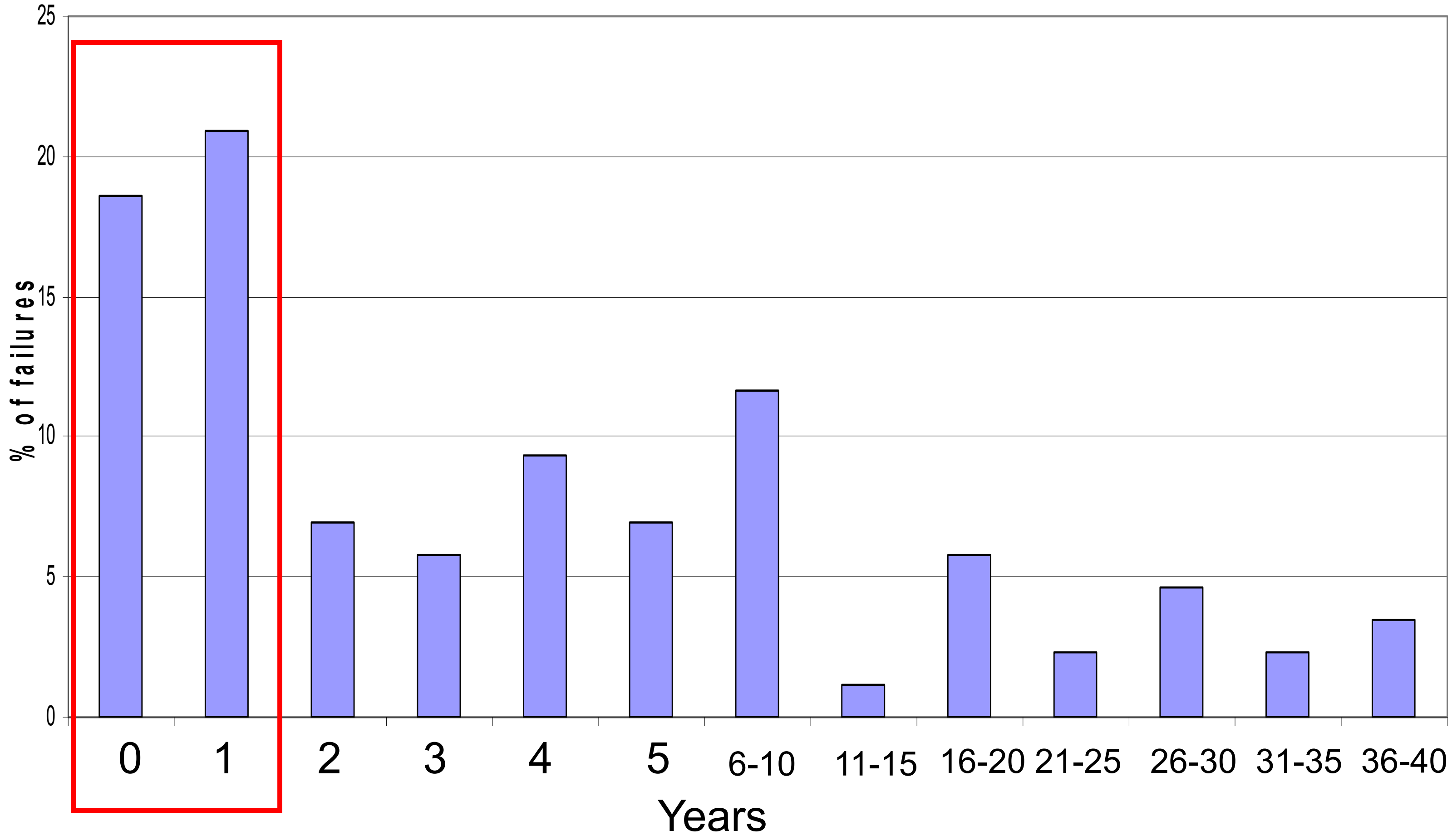
	in % of cases
public	51
industrial	23
agricultural	7
apartment	8
other / unknown	11

- Many long-span structures (mostly one storey buildings)
- Only cases implying risk for human lives included (ULS)
- Failure surveys in general can not be seen as representative for the general population of structures (cover up of mistakes is common, random sampling is impossible)

Cause of primary failure (127 cases)



Age at failure



Assessment methodology

The cases were evaluated with respect to:

1. **Collapse/no collapse**
2. **Progressive nature of collapse/ Secondary damage**
3. **Consequences**
4. **Nature of warning**
5. **Degree of proportionality between consequences and cause**

6. **Subjective assessment of robustness**

1. Collapse/no collapse

Collapse = at least one structural element falls down

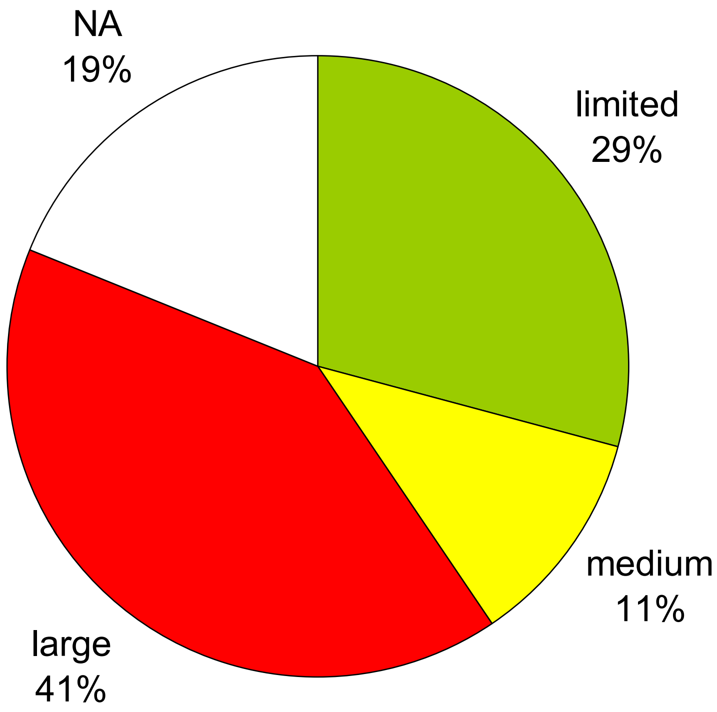
- 62 % of the cases exhibited collapse (79 cases)
- 38% no collapse (48 cases)

Collapse (one of the 79 cases)

No collapse (not in the 79)

2. Secondary damage (from 79 cases)

- Large secondary damage (> ≈ 3 times primary ”area”)
- Medium/intermediate secondary damage
- Limited secondary damage (<≈ 50% of primary)



3. Consequences?

- Consequences at structural level (important to occupants)?
- Consequences to society?
- Or ***potential*** consequences to occupants?

2500 m^2 of roof fell down:

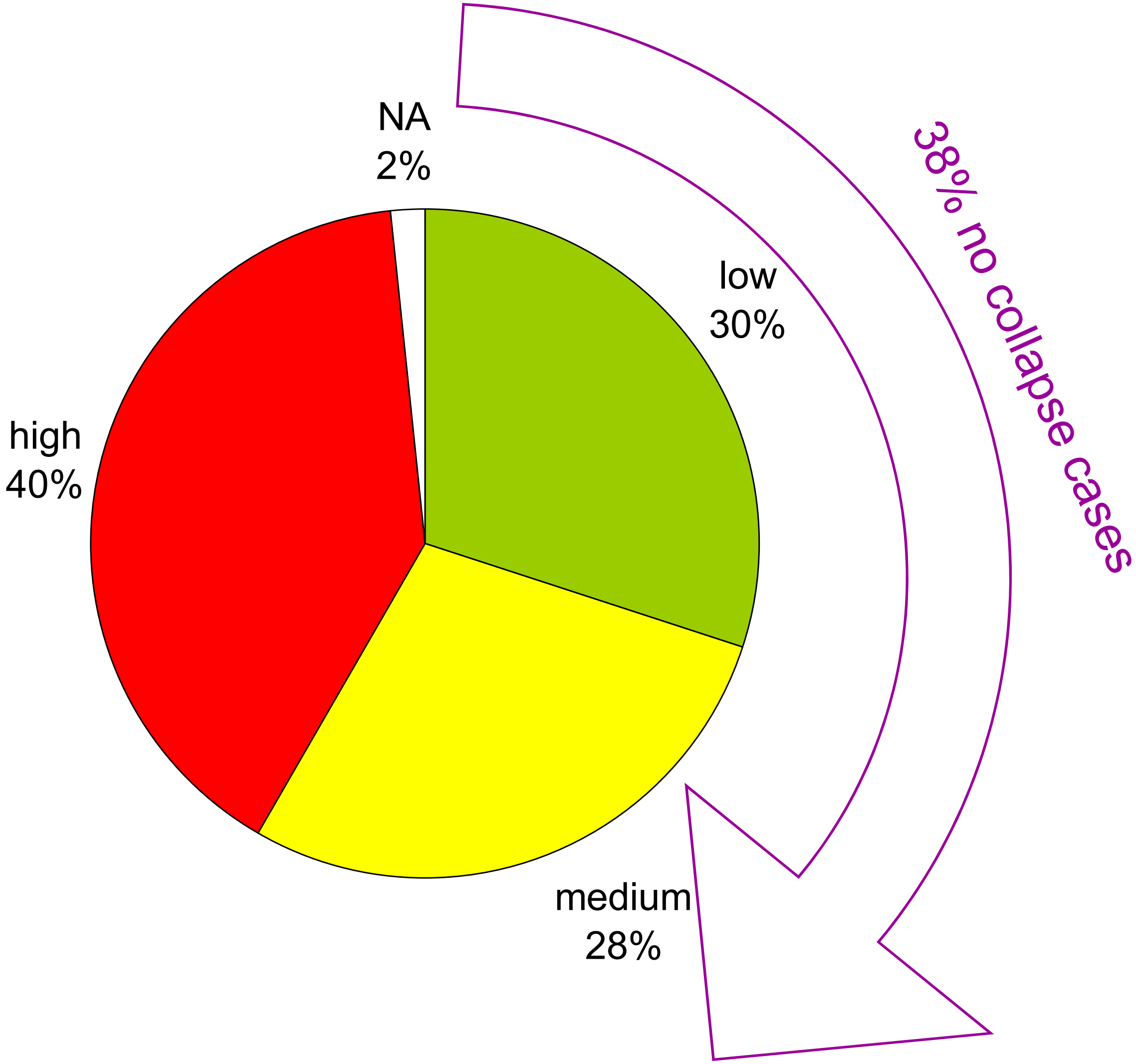
Typically **high** consequence

Crack in glulam arch

Typically **low** consequence

Consequences (127 cases)

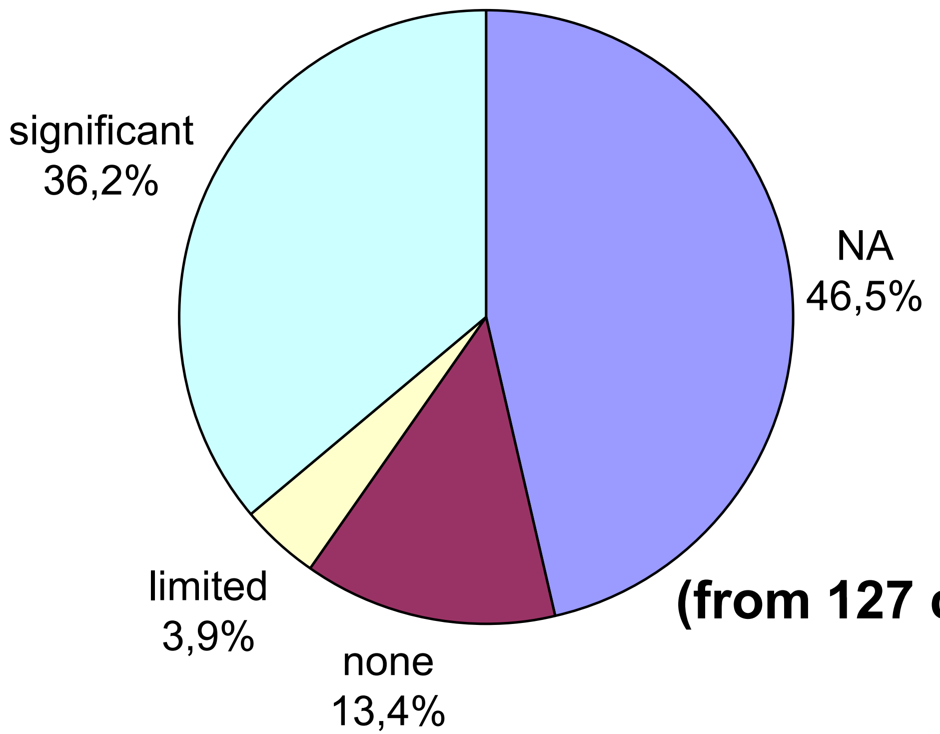
- High
- Medium
- Low



4. Nature of warning

Time lag between initial failure and collapse:

- None (order of seconds)
- Allowing evacuation (order of minutes)
- Allowing temporary strengthening/repair

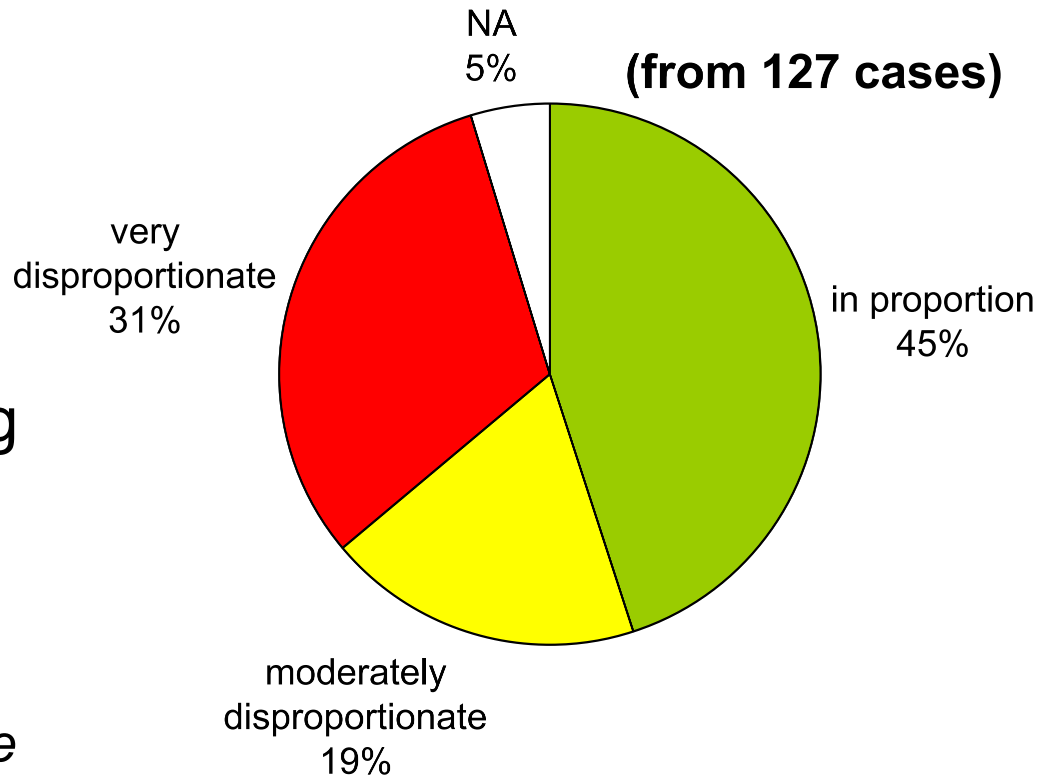


(from 127 cases)

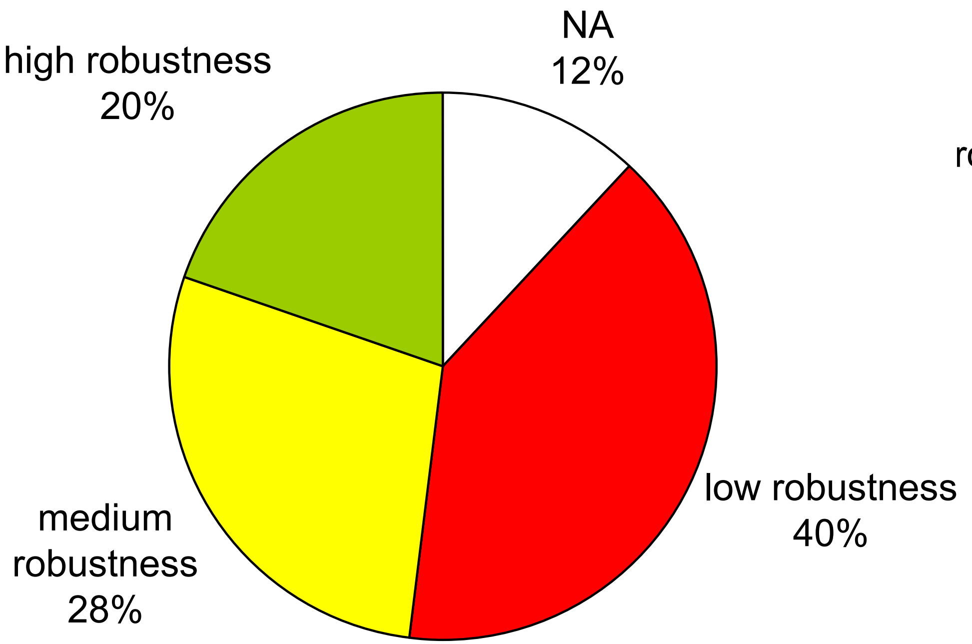
5. Degree of proportionality

- Very disproportionate
- Moderately disproportionate
- Consequences in proportion to the triggering event

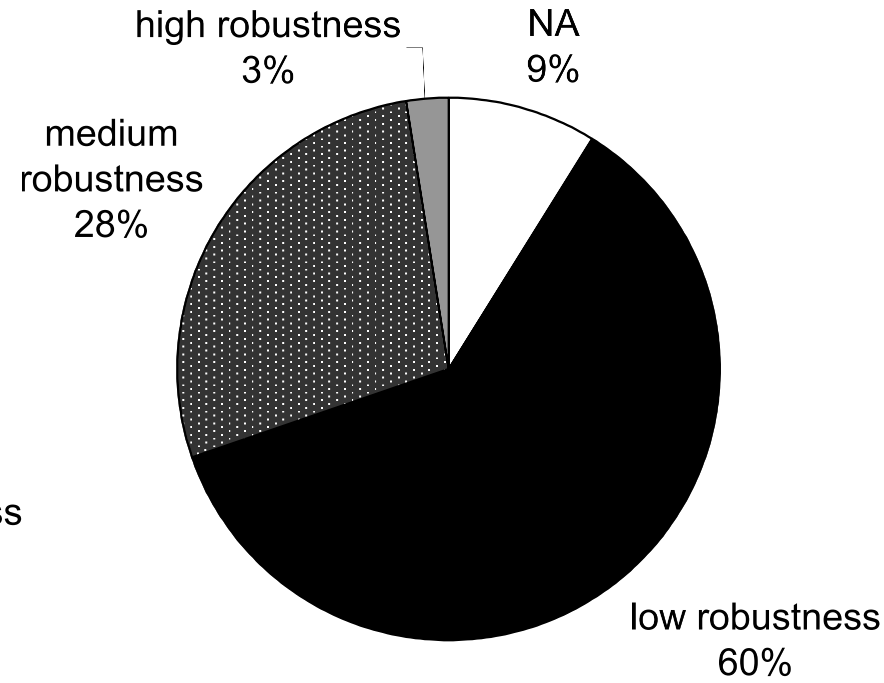
Difficult to evaluate the ”magnitude/extent” of the cause (mainly human errors in design/construction)



6. Subjective assessment of robustness



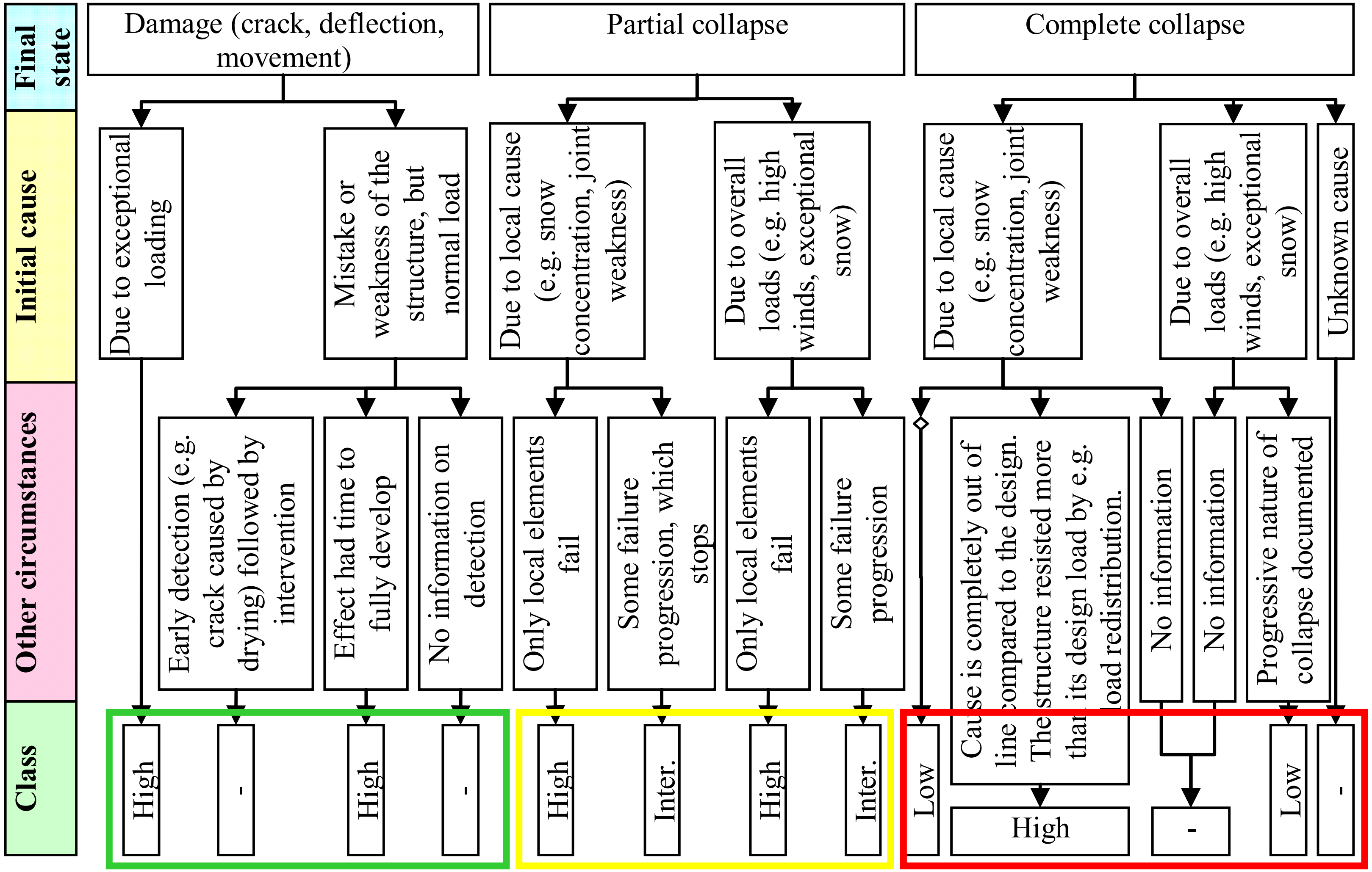
All 127 cases



79 collapsed cases

Parallel assessment by two persons showed reasonable agreement

Approximate evaluation scheme



What can we learn about robustness from investigations of failures?

Vulnerable typologies/structure groups can be identified.

Limitations of the present study in this respect:

- limited structural typologies
- limited hazard type

Insight can be learned about post-failure response and expected consequences.

Conclusions related to timber structures

- Better design methods for robustness of long span structural systems for one storey applications
- Systematic investigation and documentation of the system response to possible element failure scenarios should be required for public buildings
- Improved quality control of design for overall stability during erection and in finished buildings

General conclusions

- Data on failed structures give valuable information for practical implementation of robustness concepts.
- Such data can give insights about post-failure behavior and consequences
- Human errors are quite common in the building process, yet the specific ”exposure” from this hazard is unknown
- Consequences can be reduced if the structural system is designed for robustness

Ideas for debate…

Implement capacity design?

- Failure of a flat roof because of water overload (Case 10).
- After initial deflections of the beams, the flat roof was punctured and the water came into the building, unloading the roof. (i.e. failure did not progress, due to the unloading of the roof).
- Should the design aim for this?
- E.g. the roof sheeting weaker than the main girders and purlins in order to facilitate failure of the sheeting under snow, but protect the structure. (Capacity design)

Tie together and partition?

- (1) Too much integrity of the ceiling system caused the water from a sprinkler pipe failure to accumulate in the ceiling. This caused a roof beam to fail. This could be avoided with capacity design measures.

- (2) Ceiling elements dragging each other, after one failed due to concentrated load.

- In these cases partition would have been better than tying together.

- We have to tie together and/or partition, both at the same time? Will this not be confusing?

Is there a plural for “robustness”?

- Flat roof overloaded with water because a sink was not working (Case 13). In order to get to the second sink, the water level had to reach 25cm.

- A second sink would result in “redundant” water elimination. Would this increase the robustness of the structural system?

- Sure! The indirect consequences of the malfunctioning of the first sink would be I_{ID}=0. But no effect on robustness in case of snow load.

- Redundant water-sink increases robustness? Is there more than one robustness?