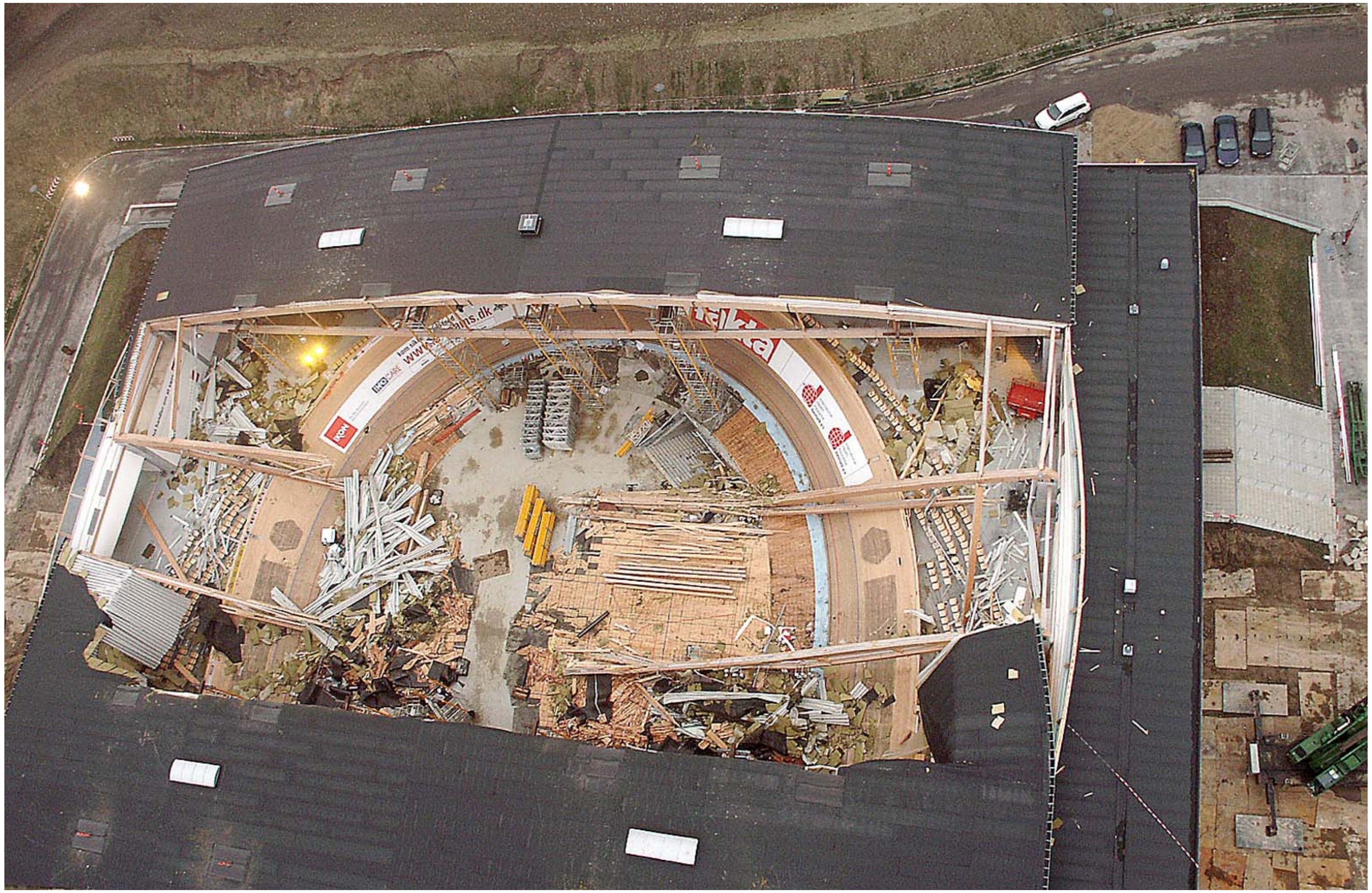

Robustness evaluation of failed timber structures-

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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 we do to avoid such failures?

Full report

Contents

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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 of failed structures is used to investigate robustness characteristics.

Outline

- **Characteristics of data material**
- **Methodology for robustness assessment**
- **Results from assessments**
- **What can we learn about robustness?**
- **Conclusions**

Database of failure cases

- survey
  - literature (L)
  - own investigations (I)

- partners — number of cases
  - Limträteknik AB, Falun (I) — 12
  - LTH (L) — 67
  - SP (I) — 18
  - VTT (I,L) — 30

→ total of **127 cases**

Only cases implying risk for human lives are included (ULS)!

Type of buildings

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

many of them are long-span structures (mostly one storey buildings)

- NOTE: 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)

failure modes

in decending order of importance…

	in percentage of cases
• **instability**	**30**
• bending failure	15
• tension failure perp. to grain	11
• shear failure	9
• drying cracks	9
• excessive deflection	7
• tension failure	5
• corrosion of fasteners / decay	4
• withdrawal of fasteners	3
• compression (buckling)	2
• other / unknown	21

Classification of error types causing failure

1. wood material performance
2. manufacturing errors in factory
3. poor manufacturing principles

Materials & products

4. on-site alterations
5. poor principles during erection

Construction work

6. poor design / lack of design with respect to mechanical loading
7. poor design / lack of design with respect to environmental actions

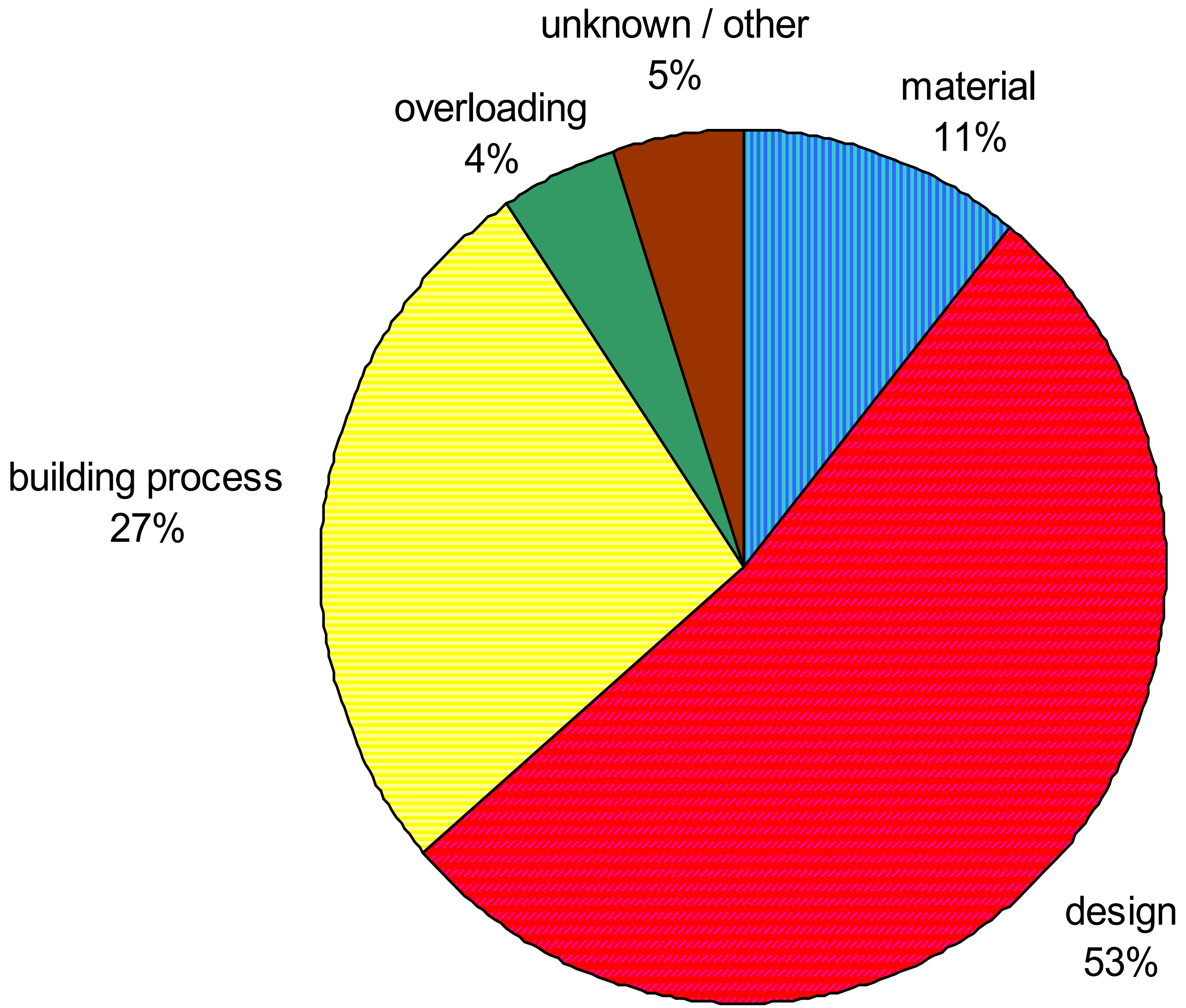
Design/planning

8. overload in relation to building regulations

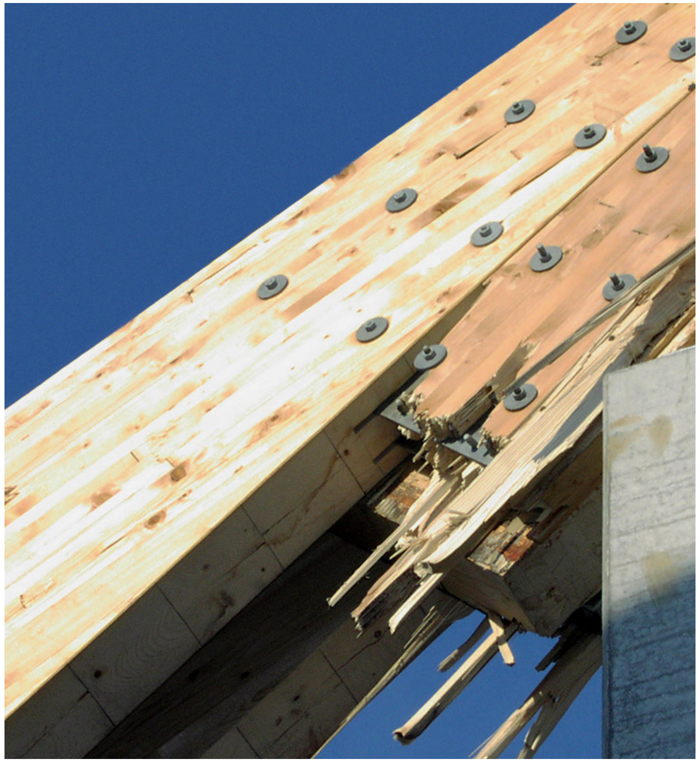
Codes

9. other / unknown reasons

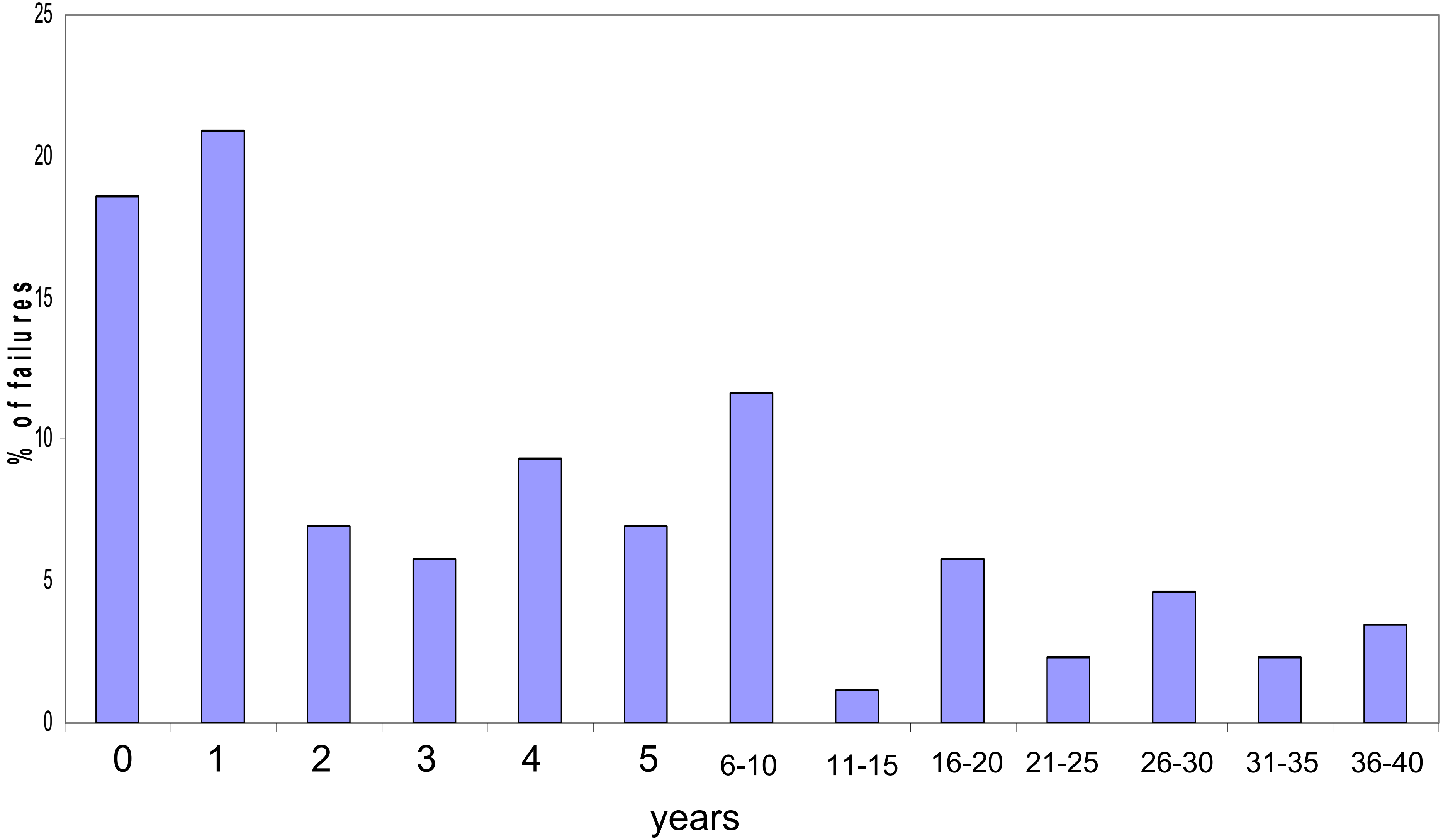
failure cause (127 cases)



Example: Failure in dowel type joint due to gross design error



age at failure



Robustness assessment - methods

The cases were evalauted with respect to

- **Collapse/no collapse**
- **Progressive nature of collapse**
- **Consequences**
- **Nature of warning**
- **Degree of proportionality between consequences and cause**

General

Subjective assessment of robustment in general

Collapse

Collapse = at least one structural element falls down

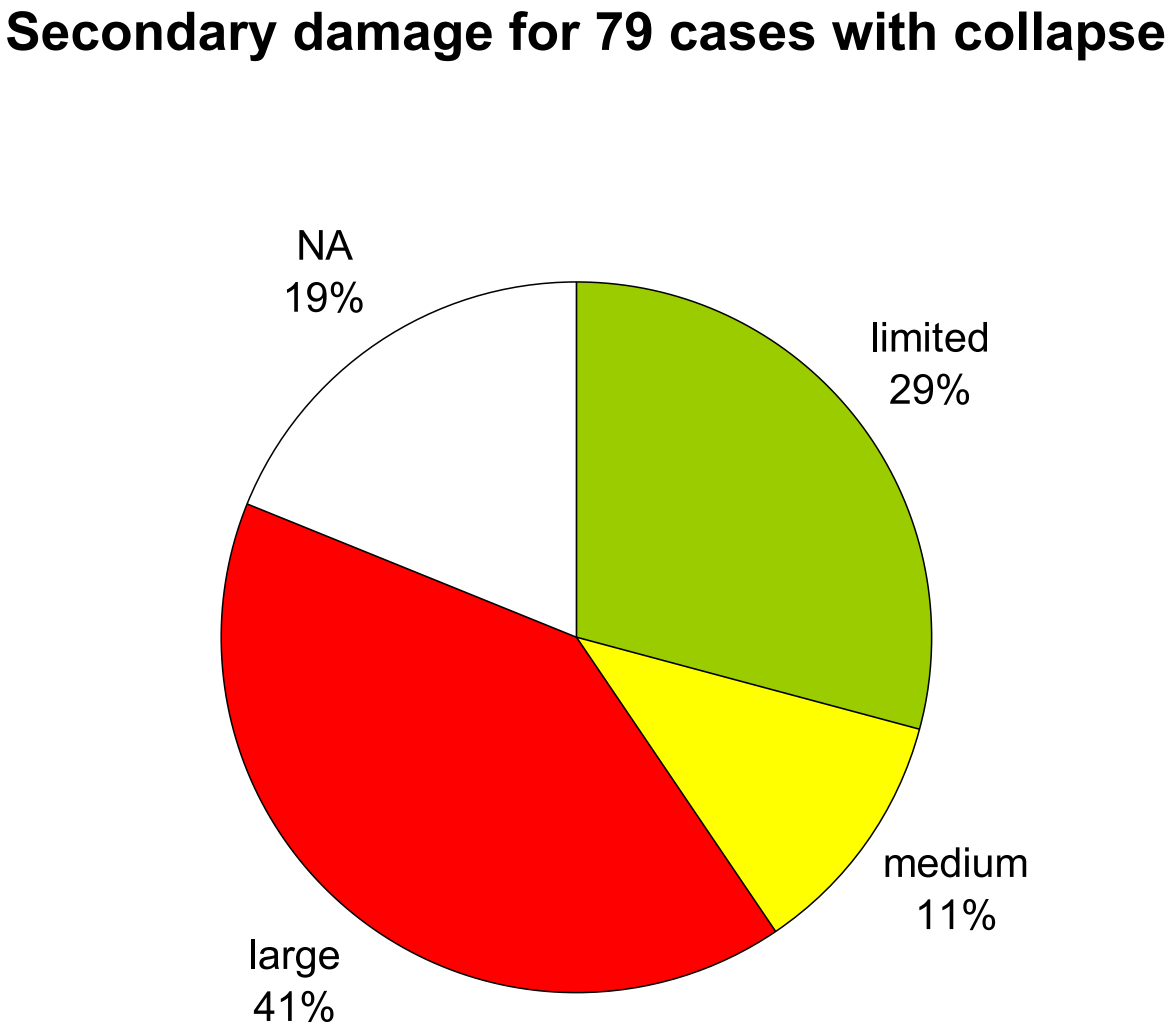
62 % of the cases exhibited collapse (79 cases)

<u>Progressive nature of collapse – classification levels</u>

- Large_secondary damage (> ≈ 3 times primary ”area”)
- Intermediate secondary damage
- Limited secondary damage (<≈ 50% of primary)

Large

Limited


Secondary damage for 79 cases with collapse
NA
19%
limited
29%
medium
11%
large
41%

Consequences- classification levels

- High
- Medium
- Low

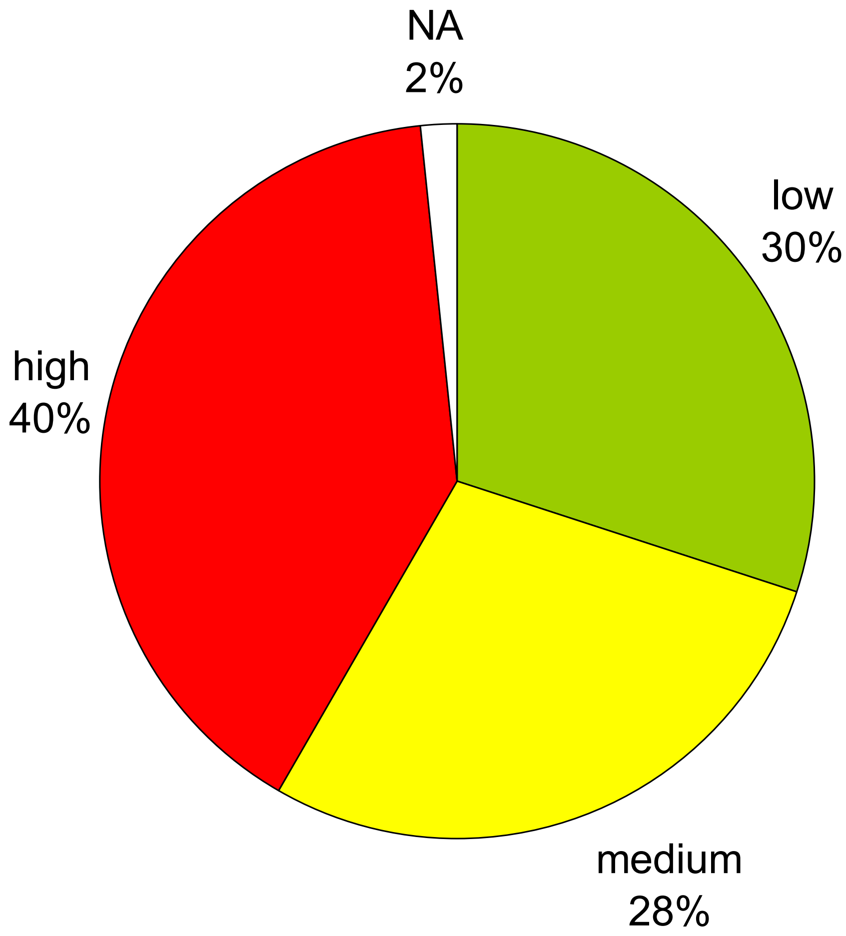
2500 m^2 of roof fell down:

Typically **high** consequence

Crack in glulam arch

Typically **low** consequence

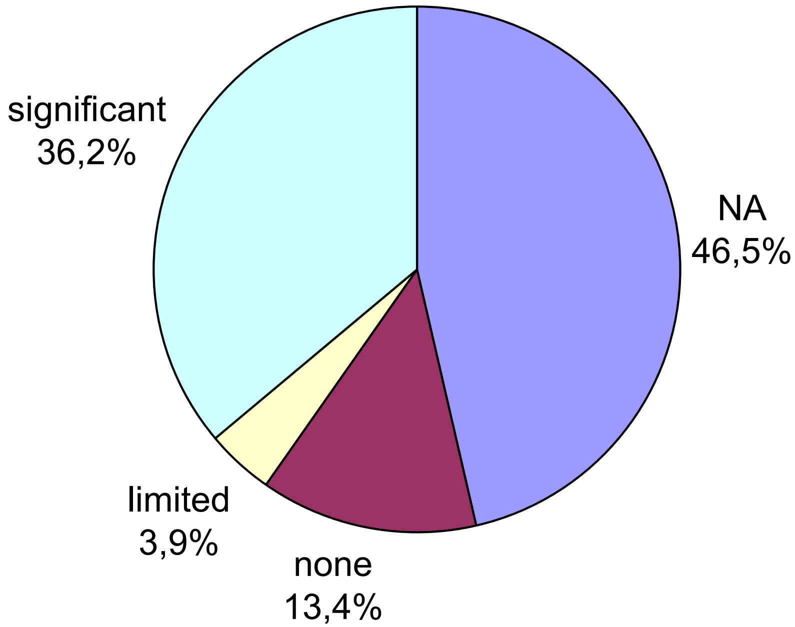
Consequences rated for 127 cases



Nature of warning- levels

Time lag between initiation and collapse:

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



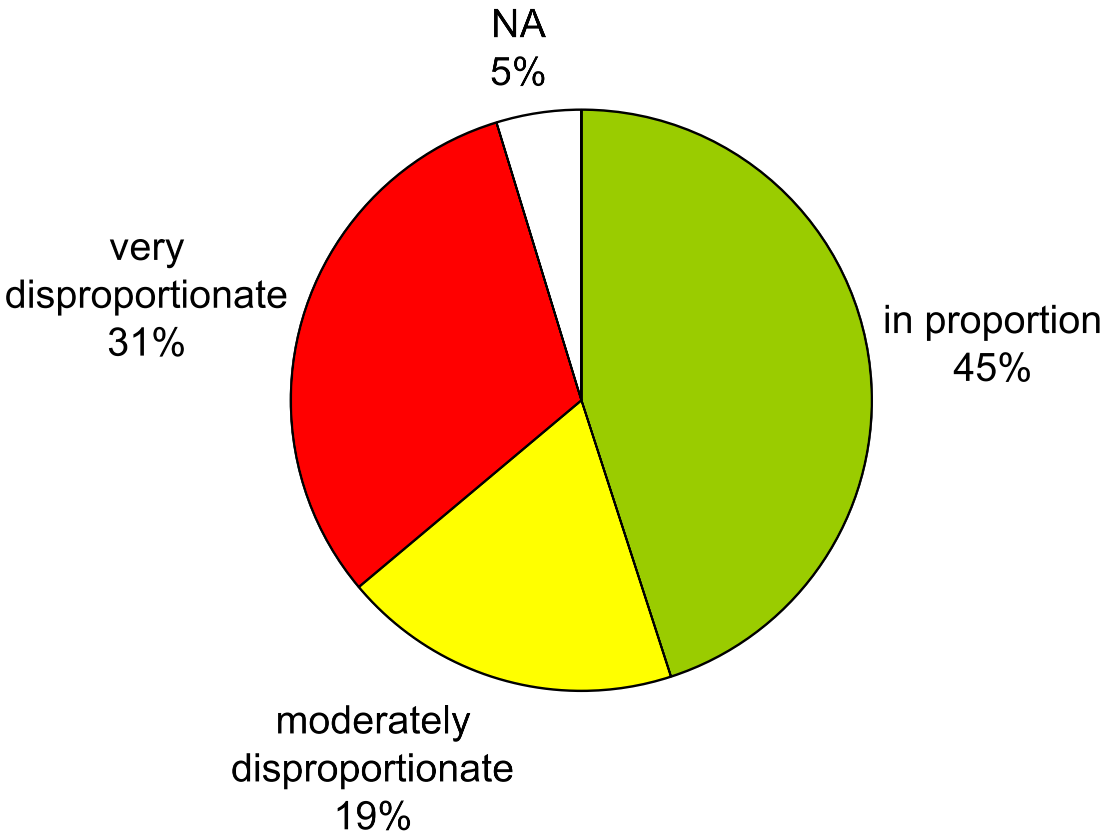
127 cases

Degree of proportionality in relation to the cause – classification levels

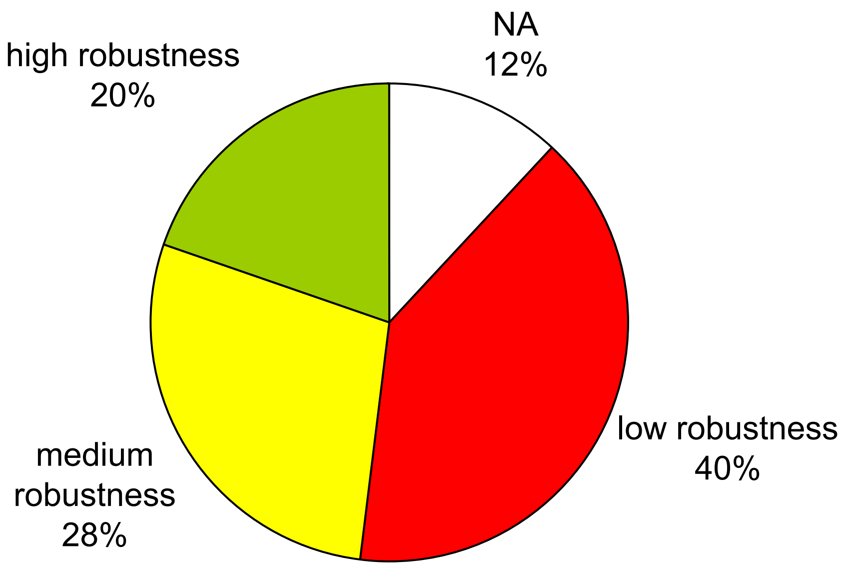
- Very disproportionate
- Moderately disproportionate
- Consequences in proportion to the triggering event

Difficulty in many cases: To determine the ”magnitude/extent” of the cause (mainly human errors in design/construction)

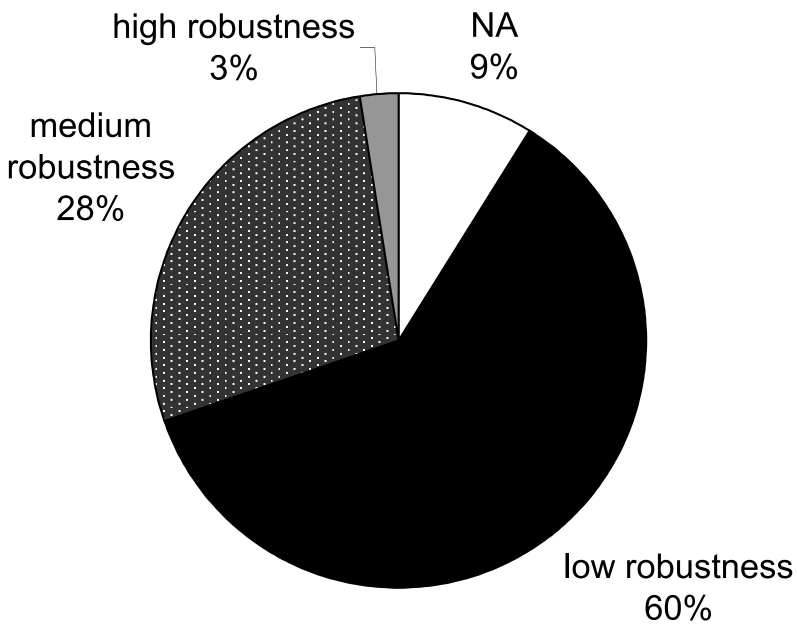
Degree of proportionality in relation to the cause (127 cases)



Overall assessment of robustness



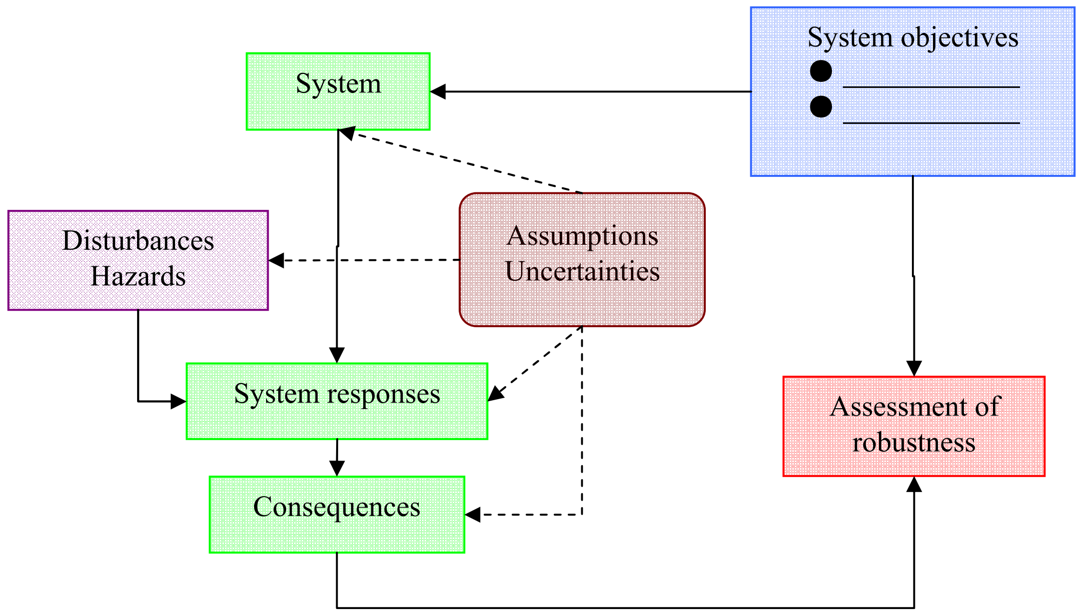
All 127 cases



79 collapsed cases

Parallel assessment by two persons showed reasonable agreement

What can we learn about robustness from investigations of failures in real life?



Scheme presented by Maes et al (2005)

Mainly insight about post-failure response and expected consequences

Limitations in present study:

<u>Type of :</u>

- **system**
- **hazard**

Conclusions related to timber structures

- Better design methods for robustness of long span structural systems for one storey applications are needed
- 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
- Evaluation of such data can give insights about post-failure behaviour and consequences
- Human errors in the building process are quite common, yet the specific ”exposure” from this hazard is unknown
- Consequences can be reduced if the structural system as such is designed for robustness

Possible scheme for evaluation