Robustness evaluation of failed timber structures-

Eva Frühwald, S. Thelandersson, Lund University
Ludovic Fülöp, Tomi Toratti, VTT

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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

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2. Experience from previous failure investigations
3. Survey of failure cases – methodology
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Appendix

Design of safe timber structures – How can we learn from structural failures in concrete, steel and timber?

Eva Frühwald
Tomi Toratti
Sven Thelandersson
Erik Serrano
Arne Emilsson

Lund University
Division of Structural Engineering
Box 118
SE 22100 Lund, Sweden

Telephone: +46 46 222 9303
Fax: +46 46 222 4212

www.kstr.tth.se
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
  – 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>public</td>
<td>51</td>
</tr>
<tr>
<td>industrial</td>
<td>23</td>
</tr>
<tr>
<td>agricultural</td>
<td>7</td>
</tr>
<tr>
<td>apartment</td>
<td>8</td>
</tr>
<tr>
<td>other / unknown</td>
<td>11</td>
</tr>
</tbody>
</table>

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 descending 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

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

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

8. overload in relation to building regulations

9. other / unknown reasons

Materials & products
Construction work
Design/planning
Codes
failure cause (127 cases)

- Design: 53%
- Building process: 27%
- Material: 11%
- Overloading: 4%
- Unknown / other: 5%

Total: 100%
Example: Failure in dowel type joint due to gross design error
age at failure

![Bar chart showing age at failure distribution. The x-axis represents years: 0, 1, 2, 3, 4, 5, 6-10, 11-15, 16-20, 21-25, 26-30, 31-35, 36-40. The y-axis represents the percentage of failures. The chart shows a peak in failures during the 1-year period, with a gradual decrease as the years increase.](chart)
Robustness assessment - methods

The cases were evaluated 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 robustness in general
Collapse

Collapse = at least one structural element falls down
62 % of the cases exhibited collapse (79 cases)

Progressive nature of collapse – classification levels

• Large secondary damage (> ≈ 3 times primary "area")
• Intermediate secondary damage
• Limited secondary damage (<≈ 50% of primary)
Secondary damage for 79 cases with collapse

- NA: 19%
- Limited: 29%
- Medium: 11%
- Large: 41%
Consequences - classification levels

- High
- Medium
- Low

2500 m² of roof fell down:
Typically high consequence

Crack in glulam arch
Typically low consequence
Consequences rated for 127 cases

- High: 40%
- Medium: 28%
- Low: 30%
- NA: 2%
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)

- In proportion: 45%
- Moderately disproportionate: 19%
- Very disproportionate: 31%
- NA: 5%
Overall assessment of robustness

- High robustness: 20%
- Medium robustness: 28%
- Low robustness: 40%
- NA: 12%

All 127 cases

Parallel assessment by two persons showed reasonable agreement
What can we learn about robustness from investigations of failures in real life?

Mainly insight about post-failure response and expected consequences

Limitations in present study:

Type of:
- system
- hazard

Scheme presented by Maes et al (2005)
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

Final state

Damage (crack, deflection, movement)
- Due to exceptional loading
- Due to local cause (e.g. structural weakness)
  - Mistake or weakness of the structure, but normal load
  - Effect had time to fully develop

Partial collapse
- Due to overall loads (e.g. high winds, exceptional snow)
- Due to local cause (e.g. snow concentration, joint weakness)
  - Only local elements fail
  - Some failure progression, which stops

Complete collapse
- Due to overall loads (e.g. high winds, exceptional snow)
- Due to local cause (e.g. snow concentration, joint weakness)
  - Only local elements fail
  - Some failure progression

Other circumstances

Early detection (e.g. crack caused by drying)
- Effect had time to fully develop

No information on detection
- Effect had time to fully develop

Robustness

High
- High
- High
- High
- High
- High
- High

Inter.
- Inter.
- Inter.
- Inter.
- Inter.
- Inter.
- Inter.

Low
- Low
- Low
- Low
- Low
- Low
- Low
- Low

Unknown cause