# Failures of Roofs under Snow Load: Causes and Reliability Analysis

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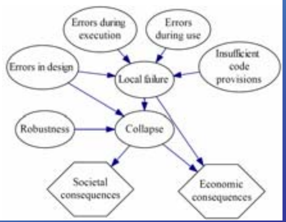
## Introduction

- ***Number of collapses*** of timber and steel roofs during the winter 2005/06 in Austria, Czech Republic, Germany and Poland
- Forensic assessments:
  - What were major ***causes of failures***?
  - Were observed ***snow*** loads ***exceptional***?
  - Is the ***reliability*** of structures designed according to standards ***sufficient***?
- Presented overview of 249 investigations in the Czech Republic focused on ***main causes***, ***consequences*** of failures and analysis of ***code provisions***



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## Causes of structural failures

- ***Errors in design*** (inconsistencies with code provisions, incorrect loading widths, numerical errors) – severe consequences
- ***Errors during execution*** (low-quality materials for timber structures, inappropriate details)
- ***Errors during use*** (incompetent interventions, installation of new facilities, insufficient maintenance) - most frequent errors
- ***Insufficient code provisions*** (low reliability of light-weight roofs, underestimation of load effects, influence of high-quality heat insulation, combination of snow and ice) - the most common cause
- In many cases ***multiple causes*** observed
- Errors in design and execution ***not identified*** due to inadequate ***quality control***



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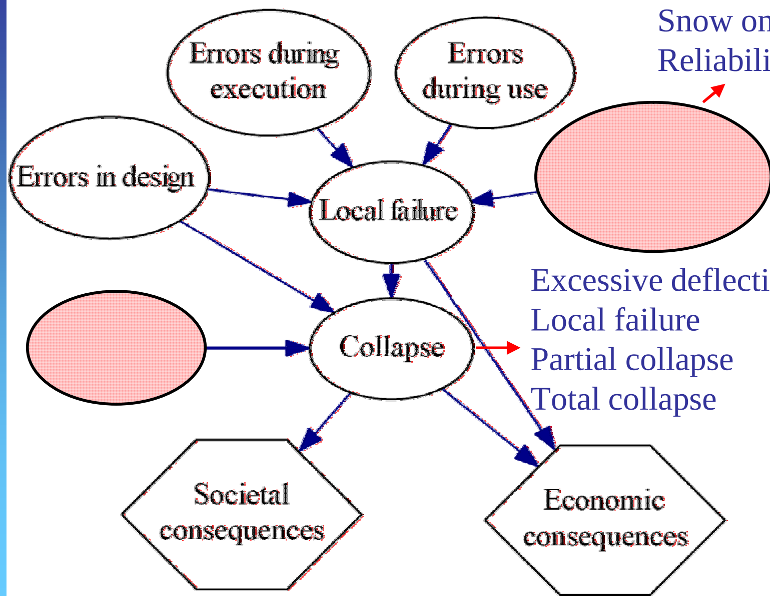
## Consequences of structural failures

Snow on the ground
Reliability analysis

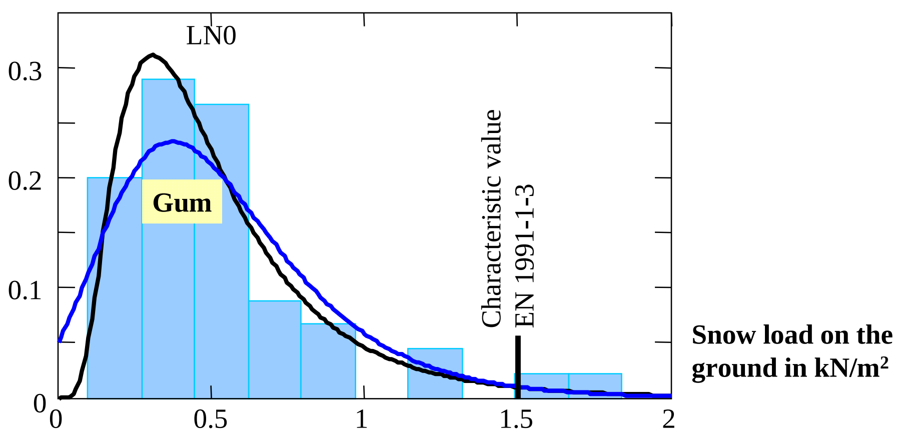



Excessive deflection ~5 %
Local failure ~ 25 %
Partial collapse ~ 15 %
Total collapse ~ 55 %

# Probabilistic model for the snow load on the ground

- ***Annual maxima*** – sample size 40-50 (no trends considered)
- ***Coefficient of variation*** about 0.7, ***skewness*** between 1.0 and 2.0

**Relative frequency, probability density function**








# Probabilistic reliability analysis

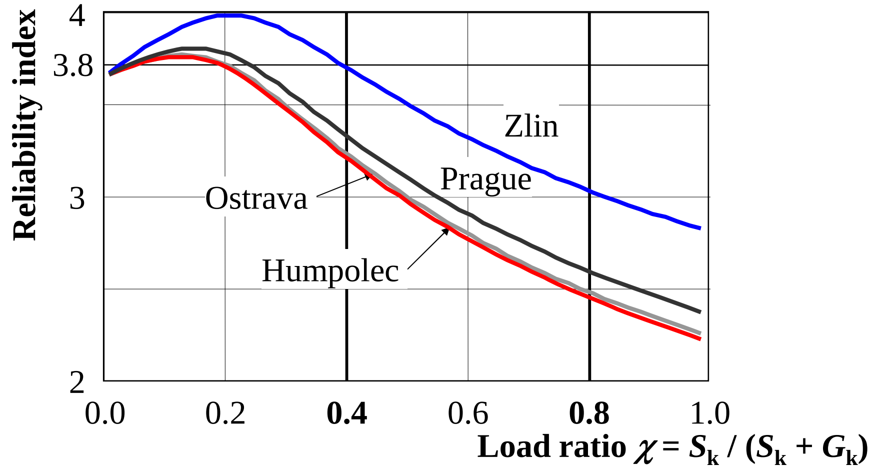
- Design of a ***generic steel member*** exposed to permanent and snow loads according to EN 1990 (2002)
- ***Limit state function***: $g(\mathbf{X}) = K_R\, R - K_E\, (G + \mu\, S_{50})$

| Variable | Symb. | Distr. | Partial factor | Mean | CoV |
|---|---|---|---|---|---|
| Resistance | $R$ | LN | 1 | $1{,}17R_k$ | 0.08 |
| Permanent load | $G$ | N | 1.35 | $g_k$ | 0.10 |
| Shape coefficient | $\mu$ | N | - | 0.8 | 0.15 |
| Snow on ground (50 years) | $S_{50}$ | Gum | 1.5 | $\mathbf{s_k}$ | **0.22** |
| Resistance uncertainties | $K_R$ | LN | - | **1.15** | 0.05 |
| Load effect uncertainties | $K_E$ | LN | - | 1.0 | 0.10 |





# Results of reliability analysis




- The recommended partial factors lead to a ***significant variation*** of the reliability index.
- For the load ratio 0.4 – 0.8 the reliability index decreases ***below the target value*** 3.8 recommended in EN 1990 (2002).





# Conclusions

- The main observed causes of structural damage may be subdivided into ***errors*** and ***insufficient code provisions***.
- In some locations ***snow loads*** slightly exceeded characteristic values and may ***hardly*** be considered as ***exceptional***.
- ***Reliability*** of roofs designed in accordance with the Eurocodes is ***lower than*** the ***target level*** recommended in EN 1990 (2002).
- Proper code provisions alone do not prevent collapses. ***Systematic quality control*** of design and execution needs to be applied.
- ***Robustness*** should be considered in design to ***reduce*** possible damage due to snow loads.