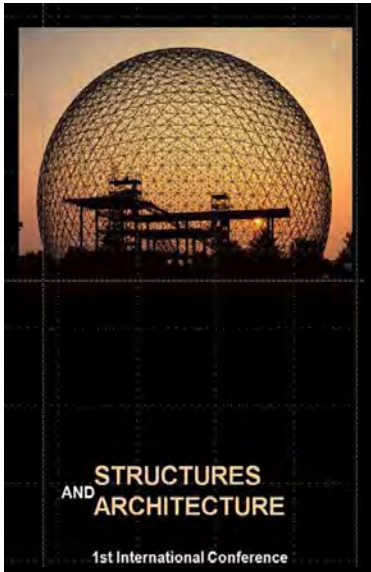


Structural robustness as an innovative design concept

M. Sykora & M. Holicky
Czech Technical University in Prague

Introduction
Definitions
Assessment of robustness
Design principles
Numerical example
Conclusions

Introduction

• Developments of high-performance materials, construction technologies and methods of structural analysis - design of ***complex*** and ***slender structures*** vulnerable to extreme events

• Robust structures - significantly reduced ***consequences***

• ***Requirements*** and methods for assessment of robustness in codes - ***vague*** and ***insufficient*** for practical use

• COST Action TU0601 Robustness of Structures

• The present contribution attempts to:
- promote ***discussion*** between architects and civil engineers
- ***review*** available findings
- provide numerical example on ***decision making*** about robustness measures

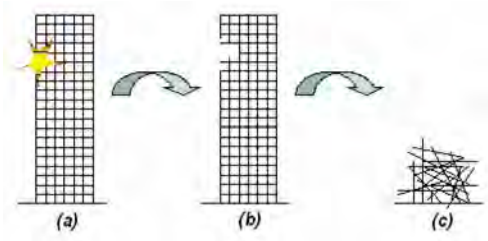
Definitions

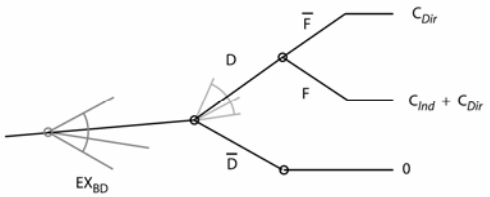
• EN 1990 - sufficient structural reliability can be achieved by suitable measures such as ensuring an appropriate degree of robustness (***structural integrity***)

• EN 1991-1-7 - ability of a structure to withstand extreme events without being damaged to an extent ***disproportionate*** to the original cause

• Useful definitions - indicator of the ***ability of***:
- ***structure*** to perform adequately under accidental situation
- ***system*** containing a structure to perform adequately under accidental situation of the structure

Assessment of robustness





a) Exposures — Models of exposures *EX*

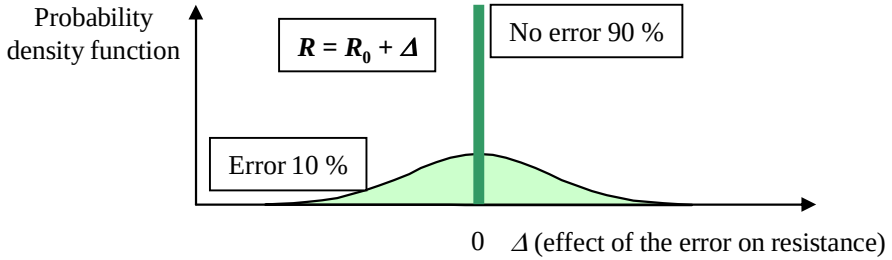
b) Local damage (direct consequence) — Damage *D*, or undamaged state $\tilde{D}$

c) Collapse (indirect consequence) — Collapse *F*, or structural survival $\tilde{F}$

Robustness index: $I_{rob} = \frac{R_{Dir}}{R_{Dir} + R_{Ind}}$

Exposures

- Probabilistic characteristics of exposures:
  - Known and dealt with (normal loads, some accidental actions)
  - Known in principle, but unrecognized or ignored (accidental actions, human errors)
  - Unknown (lack of knowledge of the profession) or unforeseeable (some human errors)



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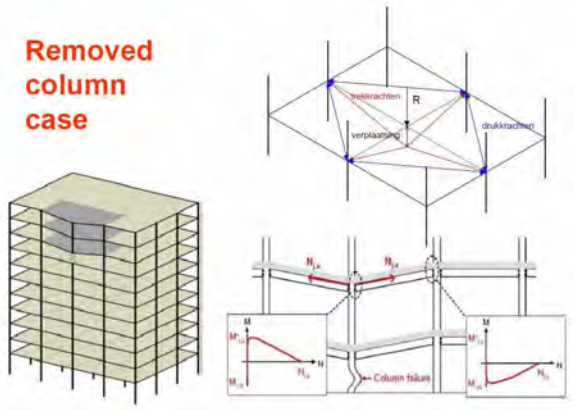
Structural models

- Structural models – analysis of various ***damage scenarios***, estimation of the ***probability of the collapse***:
  - partly damaged structure
  - large cracks and/or plastic deformations
  - catenary or membrane actions
  - high temperatures
  - dynamic effects

- ***Validation*** with available experimental data

- For selected cases ***simplified design rules***



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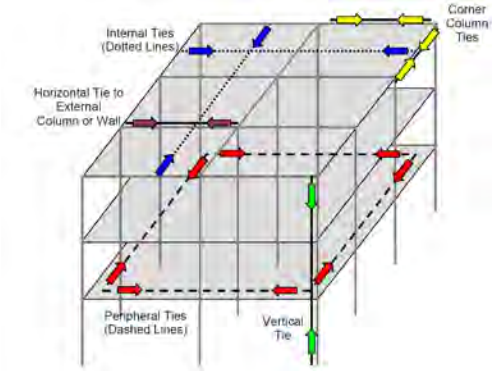
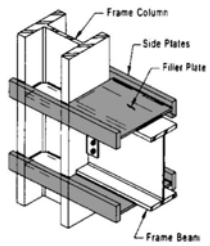
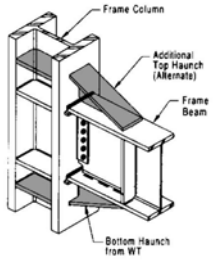
Design principles

- No universal approach

- Reduction of the ***probability of collapse***:
  - Redundant load paths
  - An integrated system of ties
  - Ductility of structural members and connections
  - Resistance to brittle failure
  - Exterior columns and walls capable to bridge over several stories
  - Increased reliability of key structural elements
  - Maintenance







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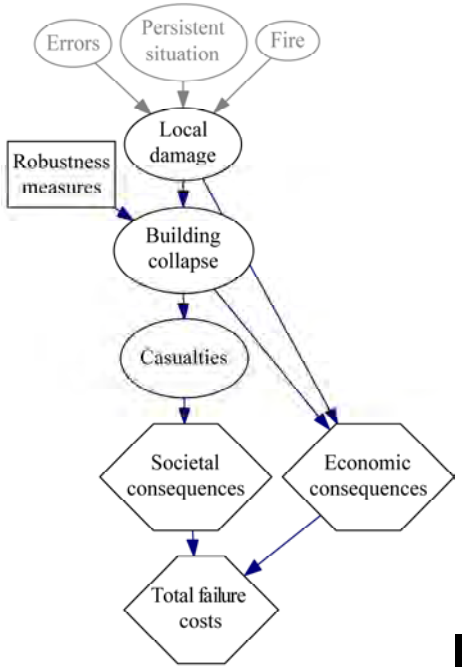
Numerical example

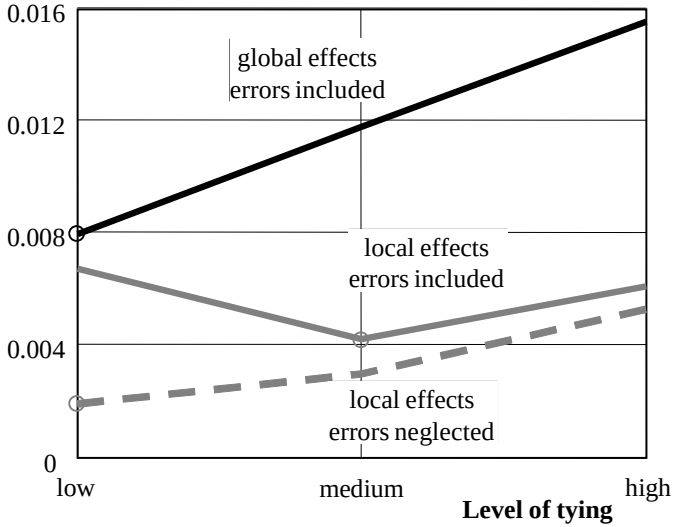
- Decisions concerning robustness - ***optimisation of cost and consequences***

- Robustness measures – level of tying for an ***office building***



Cost optimisation

Standardised total costs $(C_{tot} - C_0) / C_0$ (low level of tying)



Conclusions

- ***Robustness*** is a key property of new ***modern structures***.
- Robustness is ***not understood uniformly***.
- Quantification of robustness and ***methods*** of assessment are ***insufficiently developed***.
- A crucial issue is the ***definition*** of robustness and consequences that should be included in the assessment.
- The ***risk-based approach*** provides a useful tool for decision making concerning robustness measures.
- The numerical example indicates that it may be important to distinguish between ***local and global effects*** of exposures.
- ***Assessment*** of direct and indirect ***consequences*** of failure/collapse is essential for practical applications.

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Thank you for your attention.