



Robustness - key property of modern structures

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Introduction

Definitions

Assessment of robustness

Design principles

Lessons from structural failures

Conclusions



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1

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**, **increased safety** of occupants
- Requirements and methods for assessment of robustness in **codes** - **vague** and **insufficient** for practical use
- The **contribution** summarises:
 - achievements of **COST Action TU0601** Robustness of Structures (2006-2011)
 - experiences from recent structural failures



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2

Definitions of robustness

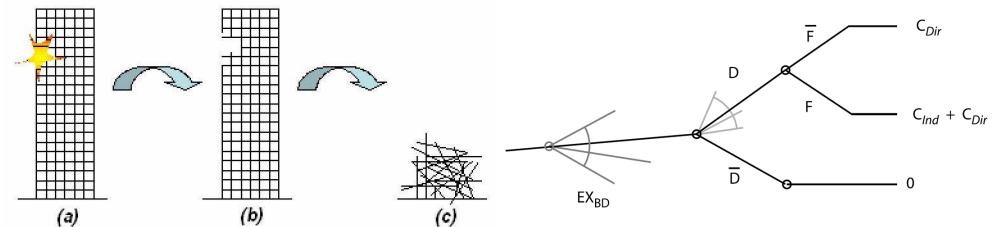
- **EN 1990** - sufficient structural reliability can be achieved by suitable measures such as ensuring an appropriate degree of **robustness** (structural **integrity**)
- **EN 1991-1-7** - ability of a structure to withstand extreme events without being damaged to an extent **disproportionate** to 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



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3

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}**

- An example of **indicator**:
$$I_{\text{rob}} = \frac{R_{\text{Dir}}}{R_{\text{Dir}} + R_{\text{Ind}}}$$

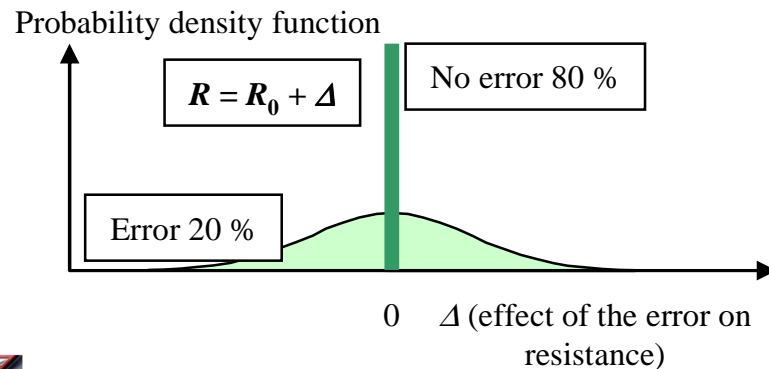


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4

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)

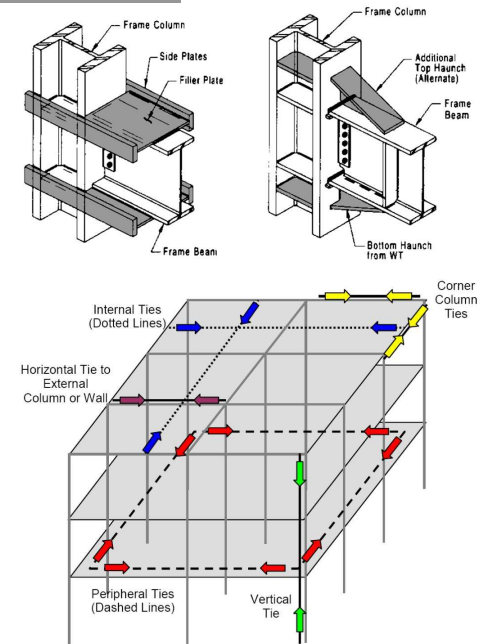


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5

Design principles for new structures

- **No universal approach**
- **Direct** or **indirect** design
- **Common measures**:
 - Event control
 - Reduction of vulnerability
 - Increased local resistance
 - Alternative load paths
 - Segmentation



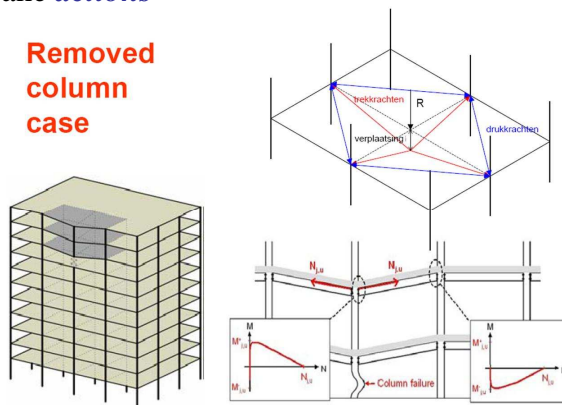
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7

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

Removed column case



- **Validation** with available experimental data
- For selected cases **simplified design rules**



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6

Existing structures

- **Reduction** of exposures, local **strengthening** and improvements of the **redundancy**
- Relatively **simple measures**, **acceptance** of the present conditions and/or orderly measures until major rehabilitation for other reasons



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8

Case studies from the Czech Republic - floods



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9

Gas explosions



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11

Snowfalls



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10

Collapse during repair



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12

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.
- *Assessment* of direct and indirect *consequences* of failure/collapse is essential for practical applications.



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13

Milan Holicky, Jana Markova & Miroslav Sykora
Robustness - key property of modern structures



Thank you for your attention.