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Robustness of existing structures

(modelling, robustness measures)

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WG2

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Introduction

- ***Uncertainties*** in modelling of existing structures ***different*** from those considered in design
- Some ***less significant*** (modelling uncertainties, deviations from dimensions and strengths), the other ***more significant*** (inaccessible parts)
- ***Information*** - original design, construction and history data, visual inspections, measurements
- ***Satisfactory past performance*** – reduced influence of errors
- Present contribution:
  - principles of ***modelling*** and ***assessment*** of robustness of existing structures
  - overview of applied ***measures***
  - ***experience*** from structural failures

Actions and environmental effects

- Load effects should correspond to the ***actual situation*** (permanent actions, actual use)
- Unfavourable ***environmental effects*** (changes in structural parameters, maintenance)
- ***Overloading*** may be important (industrial structures and bridges)

Geometry

- When no deviations evident, ***nominal design dimensions*** can be used
- Verification of ***irreversible deformations*** (past overloading)

Material properties

- No deterioration, defects and errors – properties in accordance with the ***original design*** (or testing + previous experience)
- Actual material strengths usually greater than the nominal values – ***testing*** may be ***useful***

Connections

- Modelling of connections ***important*** - significant contribution to structural ductility, load redistribution and ultimate strength
- ***Survey*** and ***evaluations*** necessary for identification of differences between design assumptions and as-built conditions
- Representation of connection needed to prove actual ***rotational*** and ***tensile capacity*** of as-built connections

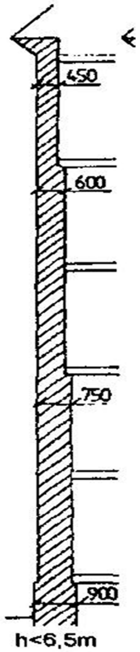
Structural modelling

- ***Lack of experimental data*** for behaviour under extreme events - difficult specification of structural properties
- Effects of robustness measures indicated by ***analyses*** (performance before and after rehabilitation)
- Level of analysis increased ***step-by-step*** (computational expenses justified by repair cost savings)
- Limited knowledge on structures that withstood extreme events, structures to be demolished – ***calibration*** of advanced analyses

Structural testing

- Analytical approaches may be ***conservative*** due to neglected system effects
- Proof, diagnostic (service loads) and dynamic ***tests***

Requirements on robustness in standards



- Original standards ***country-specific***
- Regulations of the Czech standards:
  - ***empirical construction rules***
  - specific emphasis on ***tying*** at each floor and roof level
- Present standards (USA):
  - rehabilitation to improve structural robustness should ***wait*** for other ***major rehabilitation*** (seismic upgrade)
  - alternatively, the decision based on a ***cost-benefit analysis***

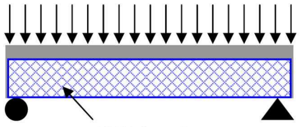
Robustness measures

- Constrained by ***as-built conditions*** (existing geometry, materials) and ***demands of users*** (economics, aesthetics) - increased costs
- ***Reduction of exposures***:
  - ***barriers*** to reduce effects of explosions or prevent impacts
  - ***not constrained*** by detailing, little disruption to functioning
- ***Redundancy of the structure*** - ***rotational*** and ***tensile capacity*** in ***connections*** or new alternate ***load paths***
  - secondary trusses, Vierendeel action, cables to resist horizontal loads

Robustness measures

- ***Local strengthening***:
  - members locally strengthened to withstand a ***specified exposure***, prevent failing connections and/or support others members
  - additional ***moment connections*** of simply-supported beams, ***tying*** of friction-based connections
  - techniques similar to those used for ***seismic upgrades***, but:
    - -- earthquake involves the entire structure whereas for progressive collapse, the initial event may be ***localized***
    - -- seismic loads mostly horizontal and temporary; for progressive collapse, the ***loads*** are ***vertical*** and mostly ***permanent***

Examples - concrete and masonry structures



Ellingwood et al. 2007. *Best Practices for Reducing the Potential for Progressive Collapse in Buildings*, US National Institute of Standards and Technology

Taghdi et al. 2000. Seismic Retrofitting of Low-Rise Masonry and Concrete Walls Using Steel Strips. *Journal of Structural Engineering*

Case studies from the Czech Republic - floods

Snowfalls

Gas explosions

Conclusions

- The ***actual structural conditions*** including deterioration and past overloading should be considered.
- ***As-built material properties*** should be determined since design values may be conservative.
- ***Realistic models of connections*** should be applied (structural ductility, ultimate strength, load redistribution).
- Advanced models can be often justified by ***considerable repair cost savings***.
- Proof, diagnostic or dynamic load ***tests*** may help update information on structural properties.
- The rehabilitation to improve structural robustness should be ***postponed until other major rehabilitation***.

Conclusions

- A ***cost-benefit*** analysis provides a basis of decision-making concerning robustness measures.
- Robustness should be assured in ***all phases*** of ***rehabilitations***.

Thank you for your attention.

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