1921-2011
90 YEARS OF KLOKNER INSTITUTE

Robustness of existing structures

(modelling, robustness measures)

Milan Holicky, Karel Jung, Jana Markova
and Miroslav Sykora
Czech Technical University in Prague, Klokner Institute
WG2

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

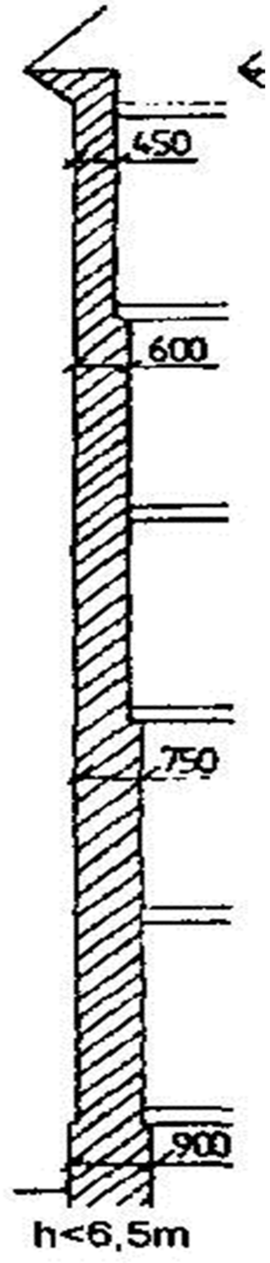
- Original standards ***country-specific***
- Regulations of the Czech standards:

  - ***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

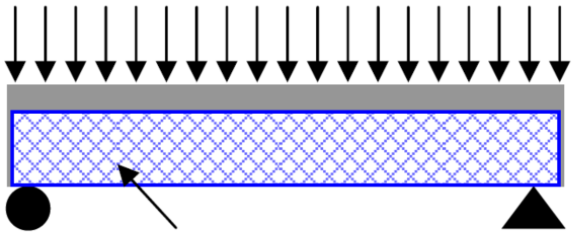
  - additional ***moment connections*** of simply-supported beams, ***tying*** of friction-based connections

  - 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***.

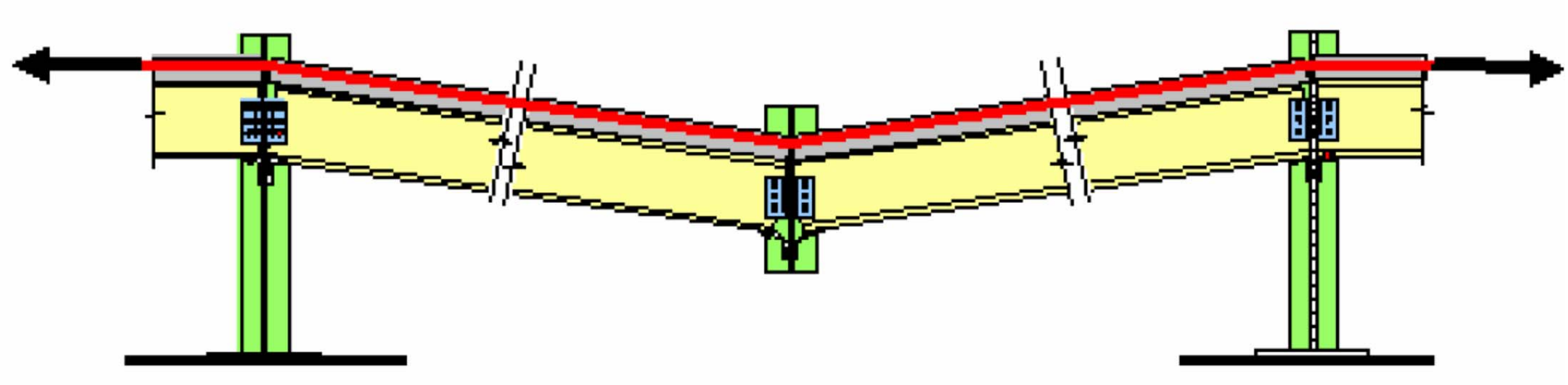
1921-2011
90 YEARS OF KLOKNER INSTITUTE

Thank you for your attention.

Robustness of existing structures

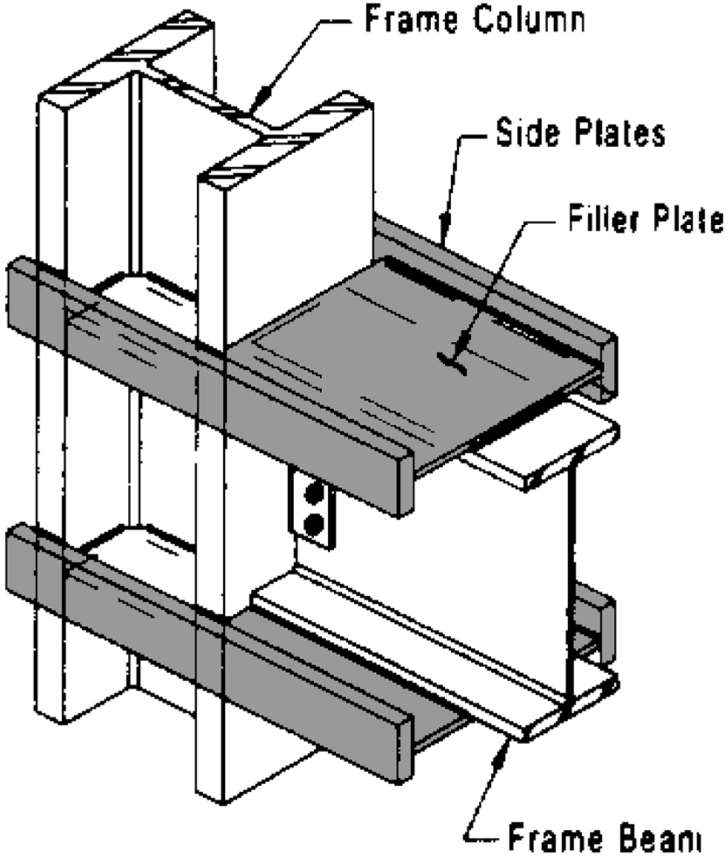
Milan Holicky, Karel Jung, Jana Markova and Miroslav Sykora
Czech Technical University in Prague, Klokner Institute

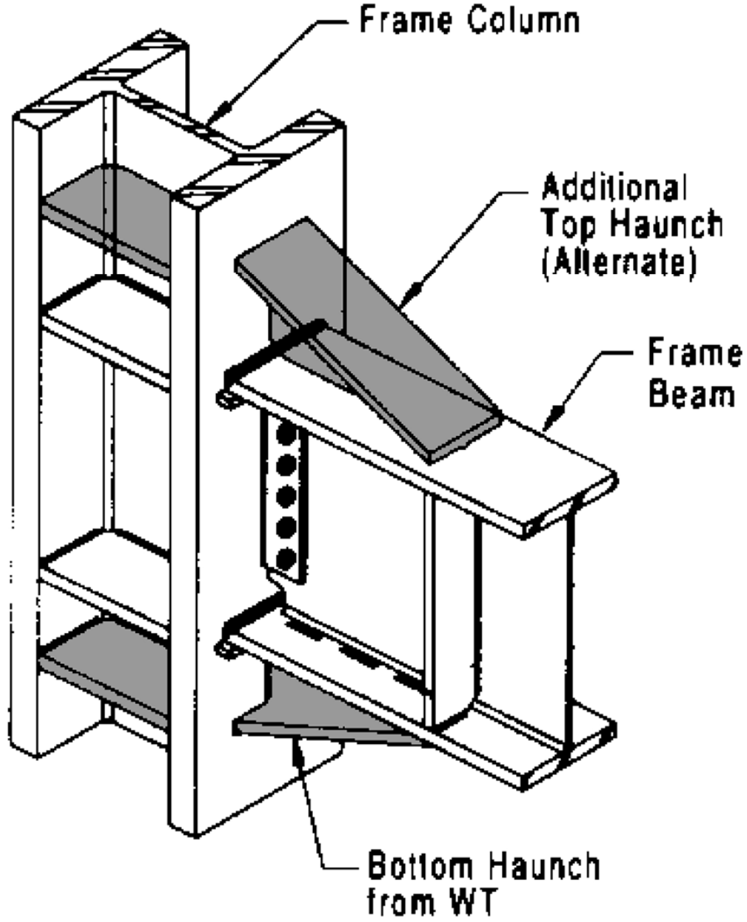
Examples - catenary cables



Astaneh 2003. Progressive Collapse Prevention in New and Existing Buildings. *Proc. 9th Arab Structural Engineering Conference*

Steel connections





Case studies from USA and Saudi Arabia

- ***Collapses*** often develop due to:

  - ***insufficient*** structural ***integrity***

  - ***lack of*** alternate ***load paths*** (e.g. statically determinate systems).

- ***Successful*** robustness ***measures***:

  - special ***detailing*** (seismic regions)

  - alternate ***load paths***

  - ***continuity*** of bottom ***reinforcement*** through supports

  - ***conservative design*** for persistent design situations

Collapses of structures under execution