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Earthquakes and robustness for timber structures

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Introduction

- Common concepts in seismic engineering and robustness analysis
- Prescriptions used in one verification can be adapted to the other
- Lessons that can be learned from seismic analysis
- Seismic design $\Leftrightarrow$ Robust structures ?

Common concepts

- Buildings classified in terms of importance
- Redundancy and ductility are key factors for both seismic design and robustness analysis
- Both, robustness and seismic design, are system based (rather than single element) and assume that damage can occur in the structure
- Unexpected and seismic events are both extremely rare and consequently difficult to quantify

Definition of importance classes

Importance class	Buildings
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.
II	Ordinary buildings, not belonging in the other categories.
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.

Robustness affects one building and earthquake affects a region

Guiding principles

- structural simplicity;
- uniformity, symmetry and redundancy;
- bi-directional resistance and stiffness;
- torsional resistance and stiffness;
- diaphragmatic behaviour at storey level;
- adequate foundation.

Timber seismic design

In view of the limited ability of timber to behave nonlinearly, energy dissipation should be mostly in connections and timber elements should respond linearly.

Timber is not the ideal material for achieving redundancy and load redistribution

Ductility classes

Design concept and ductility class	Examples of structures
Low capacity to dissipate energy - DCL	Cantilevers; Beams; Arches with two or three pinned joints; Trusses joined with connectors.
Medium capacity to dissipate energy - DCM	Glued wall panels with glued diaphragms, connected with nails and bolts; Trusses with doweled and bolted joints; Mixed structures consisting of timber framing (resisting the horizontal forces) and non-load bearing infill.
	Hyperstatic portal frames with doweled and bolted joints (see **8.1.3(3)**P).
High capacity to dissipate energy - DCH	Nailed wall panels with glued diaphragms, connected with nails and bolts; Trusses with nailed joints.
	Hyperstatic portal frames with doweled and bolted joints (see **8.1.3(3)**P).
	Nailed wall panels with nailed diaphragms, connected with nails and bolts.

Ductility

Limitations on design of connections exist to guarantee ductility

Overstrength

- [8.6.(4)] In order to ensure the development of cyclic yielding in the dissipative zones, all other structural members and connections shall be designed with sufficient overstrength.

  This overstrength requirement applies especially to:

  – anchor-ties and any connections to massive sub-elements;

  – connections between horizontal diaphragms and lateral load resisting vertical elements.

Redundancy

- [4.2.1.2(5)] The use of evenly distributed structural elements increases redundancy and allows a more favourable redistribution of action effects and widespread energy dissipation across the entire structure.
- [5.2.3.5(1)] A high degree of redundancy accompanied by redistribution capacity shall be sought, enabling a more widely spread energy dissipation and an increased total dissipated energy.
- Consequently structural systems of lower static indeterminacy shall be assigned lower behaviour factors.

Continuity

- All parts of the structure between separation joints shall be interconnected to form a continuous path (ASCE 7-05)

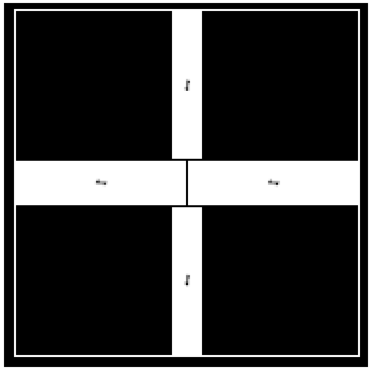
- Smaller portion of the structure shall be tied to the remainder of the structure

Improving robustness

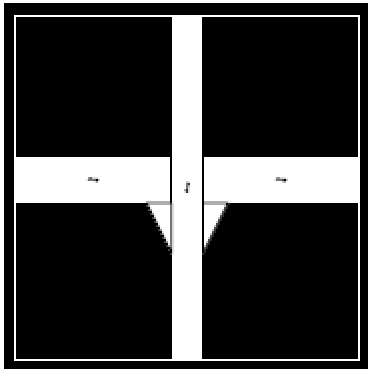
- by selective "overstrength" (strong column/weak beam concept);
- by ductility of response (eg by adopting members and connections that can absorb significant strain energy without rupture or collapse);
- By provision of redundancy (eg by providing alternative paths for loads shed from damaged elements);

Column slab system

(Munch-Andersen)



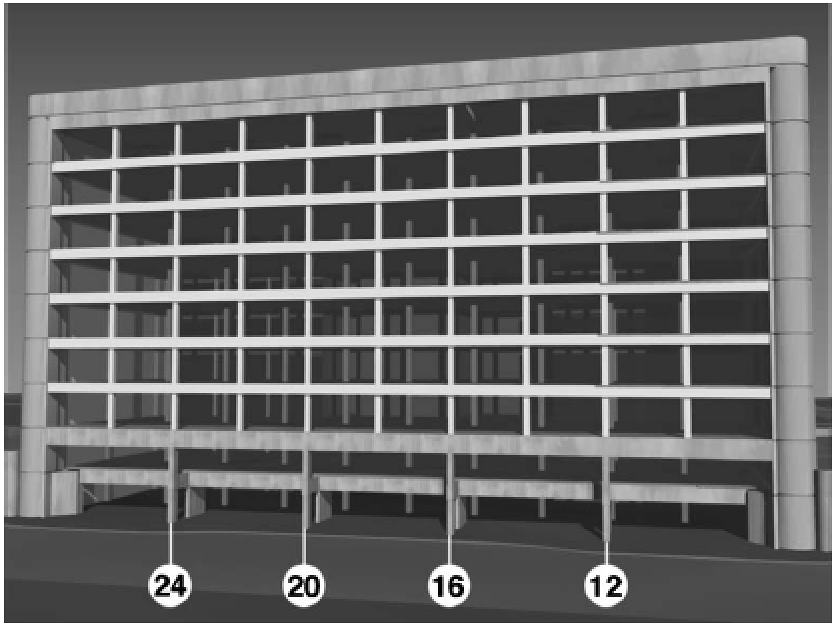
Traditional slab-column arrangement

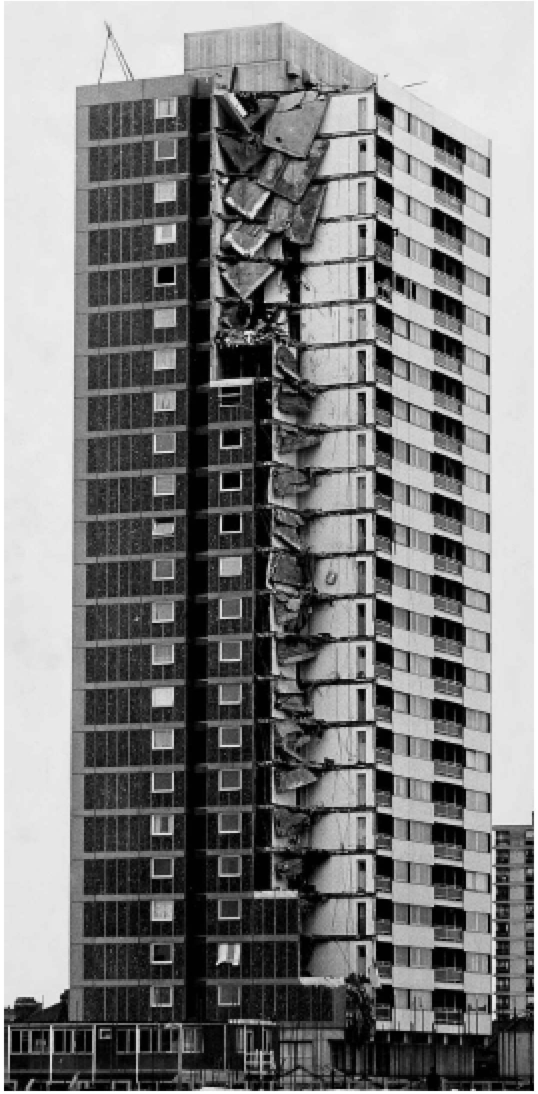


Seismic resistant slab-column arrangement

Alfred P. Murrah Federal Building

In multi-storey buildings formation of a soft storey plastic mechanism shall be prevented, as such a mechanism might entail excessive local ductility demands in the columns of the soft storey





Ronan Point

Poor workmanship of critical connections between the panels led to the fatal partial collapse

Under a seismic event, the consequence could also be catastrophic.

Siemens Arena

Seismic design would not have improved robustness

Increase tying and transversal stiffness would have increased consequences

At best, more attention to connections might have avoided errors

Bad Reichenhall Ice-Arena

The same is true for the
Bad Reichenhall Ice-Arena

Increase transversal stiffness
increased consequences

Strategies to improve robustness

- Reduce exposures =
- Limit local damage = ↓
- Reduce extensive damage/collapse ↓↓
- Reduce direct/indirect consequences ↑

Conclusions

- The effect of seismic design on robustness is comparable to that of robustness prescriptive rules
  - Useful in many cases (buildings)
  - Harmful in some cases (long span structures)

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