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ROBUSTNESS OF TIMBER STRUCTURES IN SEISMIC AREAS

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Outline

- Motivation
- Earthquake design
- Timber structures under seismic loads
- Seismic design and robustness
- EC8 and robustness prescriptive rules
- Examples
- Case study – Large span roof
- Conclusions

Common concepts

Buildings classified in terms of importance

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.

NOTE Importance classes I, II and III or IV correspond roughly to consequences classes CC1, CC2 and CC3, respectively, defined in EN 1990:2002, Annex B.

Common concepts

✓ Redundancy and ductility are key factors for both seismic design and robustness analysis

Seismic design promote the dissipation of energy through plastic hinges distributed in the structure

✓ Both 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

Statements

✓ Prescriptions used in one verification can be adapted to the other

✓ Lessons that can be learned from seismic analysis

Seismic design ⇔ Robust structures ?

Earthquake design

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

Diaphragmatic action of the horizontal load bearing systems and the connection to the vertical load bearing components in order to transfer the seismic forces to the most rigid ones and tie the whole building.

Timber structures under seismic loads

- ✓ Satisfactory performance = wood + lightness and high redundancy of most wood-based structural systems
- ✓ Lateral redundancy plays an important role
- ✓ Detailing of connections is crucial

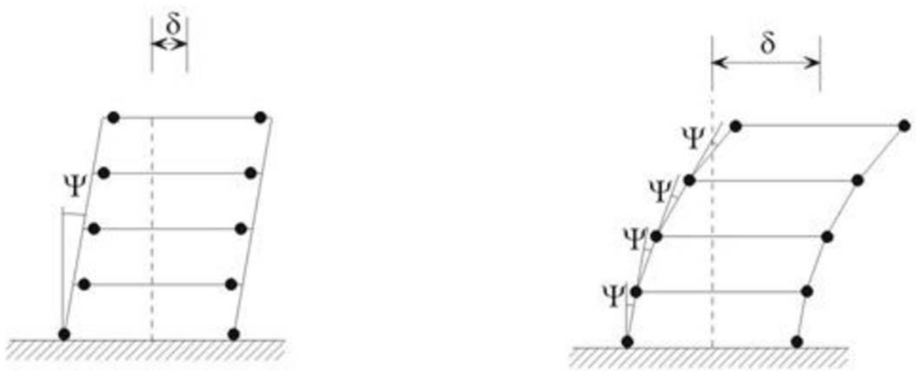
Seismic design and robustness

- ✓ Structural simplicity, uniformity, symmetry and redundancy are crucial in the existence of alternate load paths, a key concept in robustness design
- ✓ Seismic design leads to an improvement in ductility and redundancy, as well as ensuring the interconnection of the structure
- ✓ However, the increased redundancy and removal of weak links between elements and parts of the structure will allow damage to propagate through the structure, leading to higher costs in the event of failure

Seismic design and robustness

✓ Closer attention to detailing of connections can enhanced robustness

✓ Consideration of earthquakes has led to a significant evolution of engineering practice



a) Weak beams b) Strong beams

EC8 and robustness prescriptive rules

(i) selective ‘‘overstrength’’ (strong column/weak beam concept);

(ii) redundancy (e.g. by providing alternative paths for loads shed from damaged elements);

(iii) ductility of response (e.g. by adopting members and connections that can absorb significant strain energy without rupture or collapse).

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 favorable 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 behavior factors.

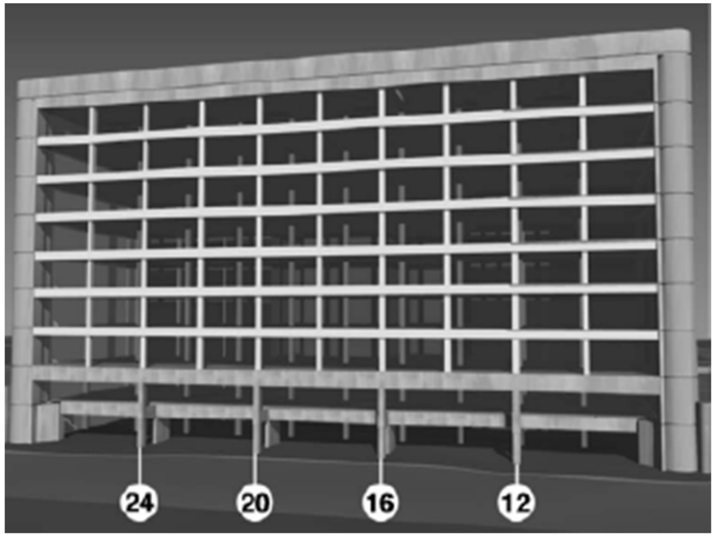
Ductility

[2.2.4.1(2)P] In order to ensure an overall dissipative and ductile behavior its is necessary the hierarchy of resistance of the various structural components and failure modes necessary for ensuring a suitable plastic mechanism and for avoiding brittle failure modes - Capacity design

In timber structures the ductility is concentrated in the joints whereas the timber elements must be regarded as behaving elastically

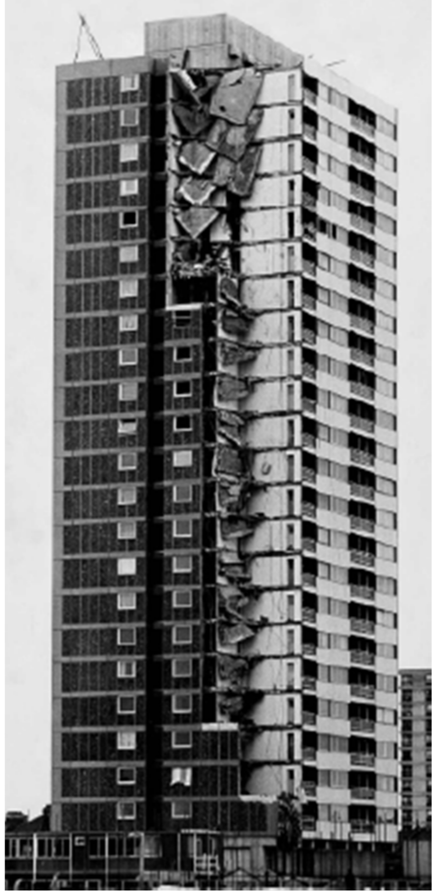
Examples - Alfred P. Murrah Federal Building

The building had a structural system composed of regular frames, but, at the ground level, the number of columns was reduced. The soft first story failure is prevented by the seismic design



Examples – 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.

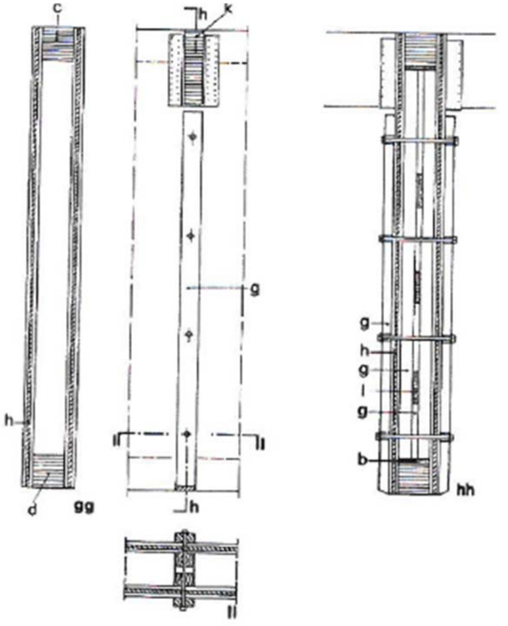


Examples – Siemens Arena

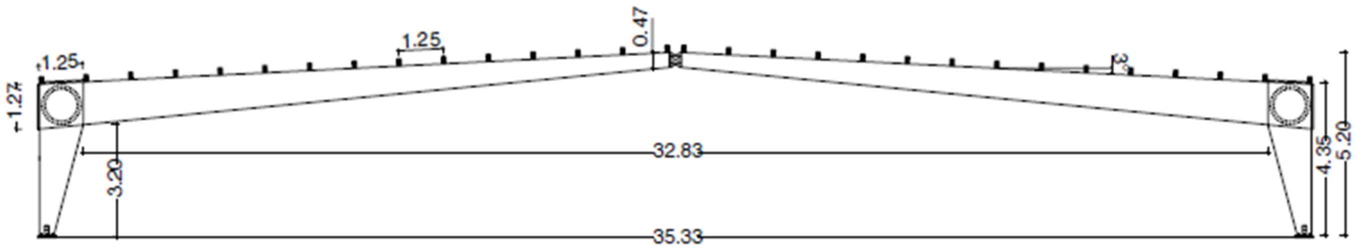
Seismic design would not have improved robustness. Increase tying and transversal stiffness would have increased consequences At best, more attention to connections might have avoided errors

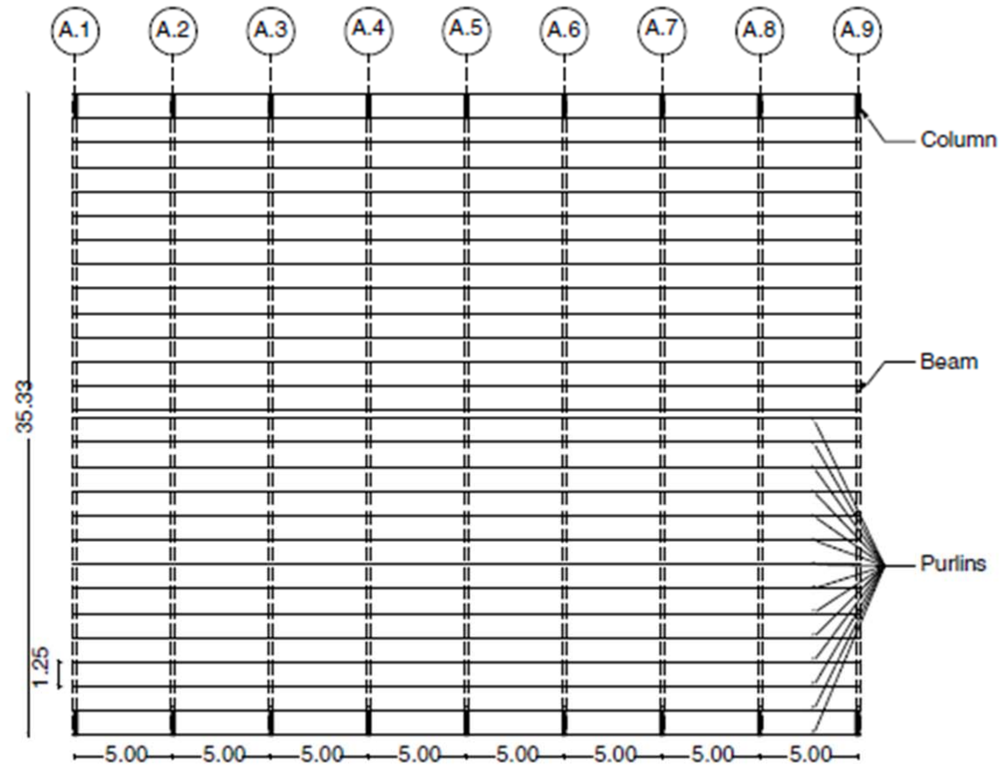
Examples – Bad Reichenhall Ice-Arena

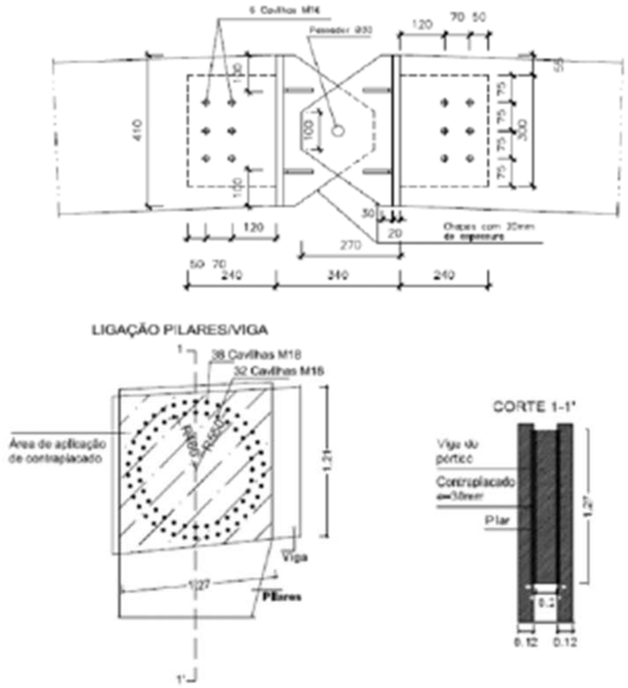
Increase transversal stiffness increased consequences



Case study


1.25
1.25
0.47
1.27
3.20
32.83
35.33
4.35
5.20


A.1
A.2
A.3
A.4
A.5
A.6
A.7
A.8
A.9
Column
Beam
Purlins
35.33
1.25
5.00
5.00
5.00
5.00
5.00
5.00
5.00
5.00


LIGAÇÃO PILARES/VIGA
CORTE 1-1'
Viga
Pilares
Plar

Case study

Case study

1st step: different damage scenarios

(S1) failure of one column;

(S2) failure of the central hinge-joint;

(S3) stiffness a reduction of 75%.

2 hypotheses were considered for the purlins:

- simple supported beams with 5 m length;

- double span with 10 m.

Frame	Section	Undamaged	S1 (Column)	S2 (Central hinge-joint)	S3 (0,25 joint stiffness)
2	1	0.28	0.45	0.53	0.58
	2	0.05	0.09	0.10	0.07
	3	0.31	0.56	0.58	0.42
	4	0.31	0.86	1.02	0.54
	5	0.31	0.86	1.02	0.54
	6	0.34	0.74	0.63	0.46
	7	0.48	1.06	0.89	0.66
	8	0.39	0.93	0.71	0.80
3	1	0.30	0.65	0.91	0.64
	2	0.46	0.52	0.39	0.66
	3	0.32	0.35	0.26	0.46
	4	0.25	0.12	***	0.39
	5	0.25	0.12	***	0.39
	6	0.35	0.00	0.29	0.50
	7	0.50	0.00	0.44	0.71
	8	0.41	0.01	0.73	0.86
4	1	0.29	0.46	0.54	0.63
	2	0.45	0.82	0.85	0.65
	3	0.32	0.57	0.59	0.46
	4	0.25	0.72	0.89	0.39
	5	0.25	0.72	0.90	0.39
	6	0.35	0.75	0.64	0.50
	7	0.49	1.07	0.91	0.71
	8	0.40	0.93	0.72	0.85

*** - section where damage is assumed

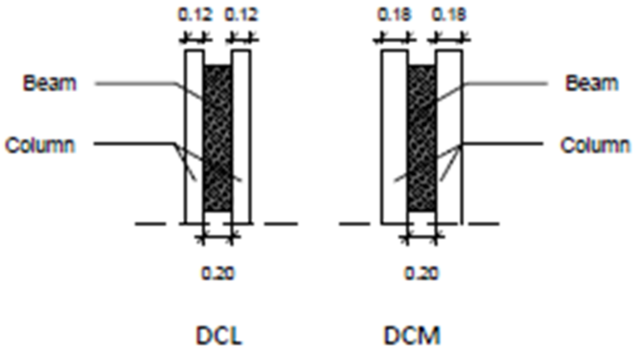
Case study

These results show that very stiff and resistant purlins cause the progression of damage to the adjacent frames, resulting in progressive collapse of the overall structure.

On the other hand, if less resistant or simple supported purlins are considered, the failure of frame 3 is unavoidable.

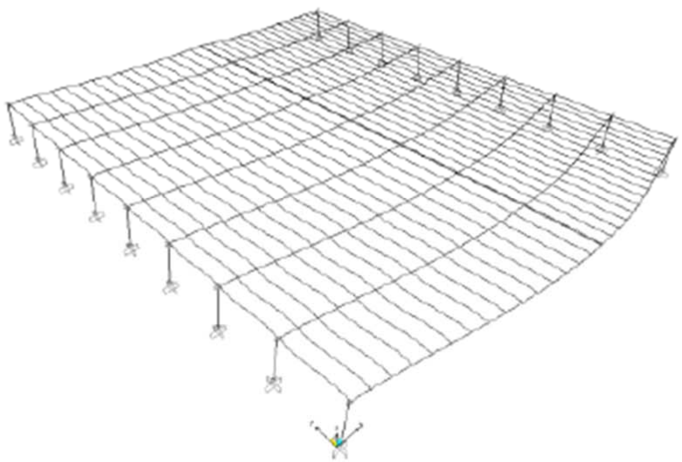
However, damage will not progress, and the consequences will be rather limited.

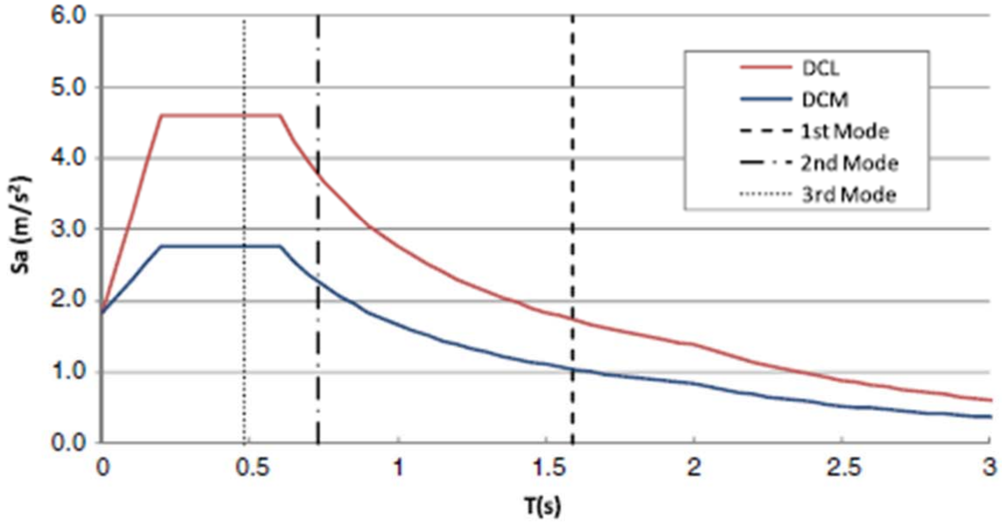
Case study



Mode shape	DCL				DCM			
	Period (s)		Frequency (Hz)		Period (s)		Frequency (Hz)	
1	1.66	1.76	0.60	0.57	1.59	1.68	0.63	0.59
2	0.75	0.75	1.33	1.33	0.73	0.73	1.37	1.37
3	0.49	0.49	2.03	2.04	0.48	0.48	2.05	2.05
Purlins	D	S	D	S	D	S	D	S

D – Double span purlins; S – Single span purlins.





Conclusions

Prescriptions for an adequate seismic performance tend to improve robustness (redundancy and ductility).

Requirements for ductility for timber structures are relatively simplistic, and limited to the joints.

Several examples of failures associated with disproportionate consequences were analyzed and the potential benefits of a seismic design were highlighted.

Conclusions

Seismic design tends to improve robustness.

However, increased redundancy can also lead to an increase in failure cost as a result of a localized damage.

This is particularly true for long span timber roof structures.

As shown in the case study, a more redundant roof structure is safer during a seismic event but more prone to progressive collapse.

Thank You for the attention

Obrigado!