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Robustness Design of Timber Structures – Secondary Structures – Purlin Systems

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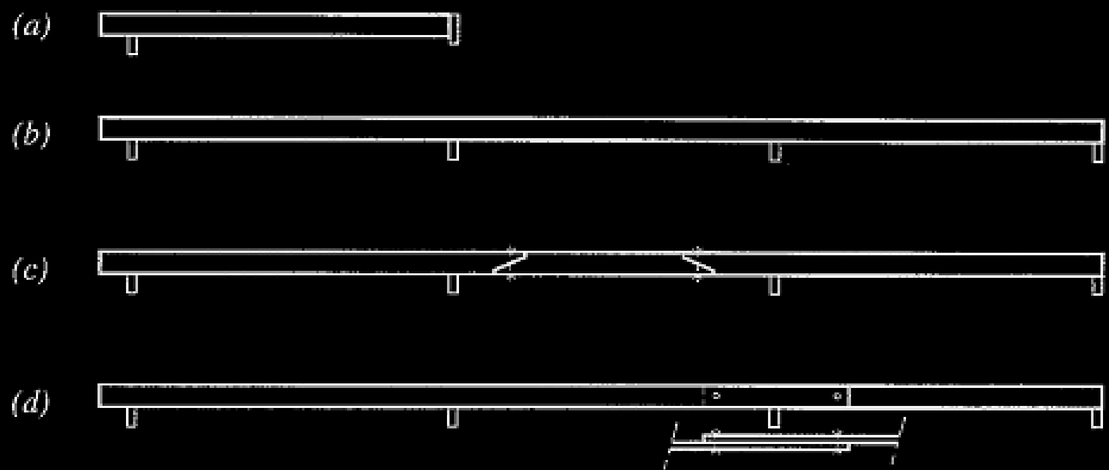
General Robustness Requirements

- Structure shall be insensitive to local failure
- Progressive collapse shall be prevented

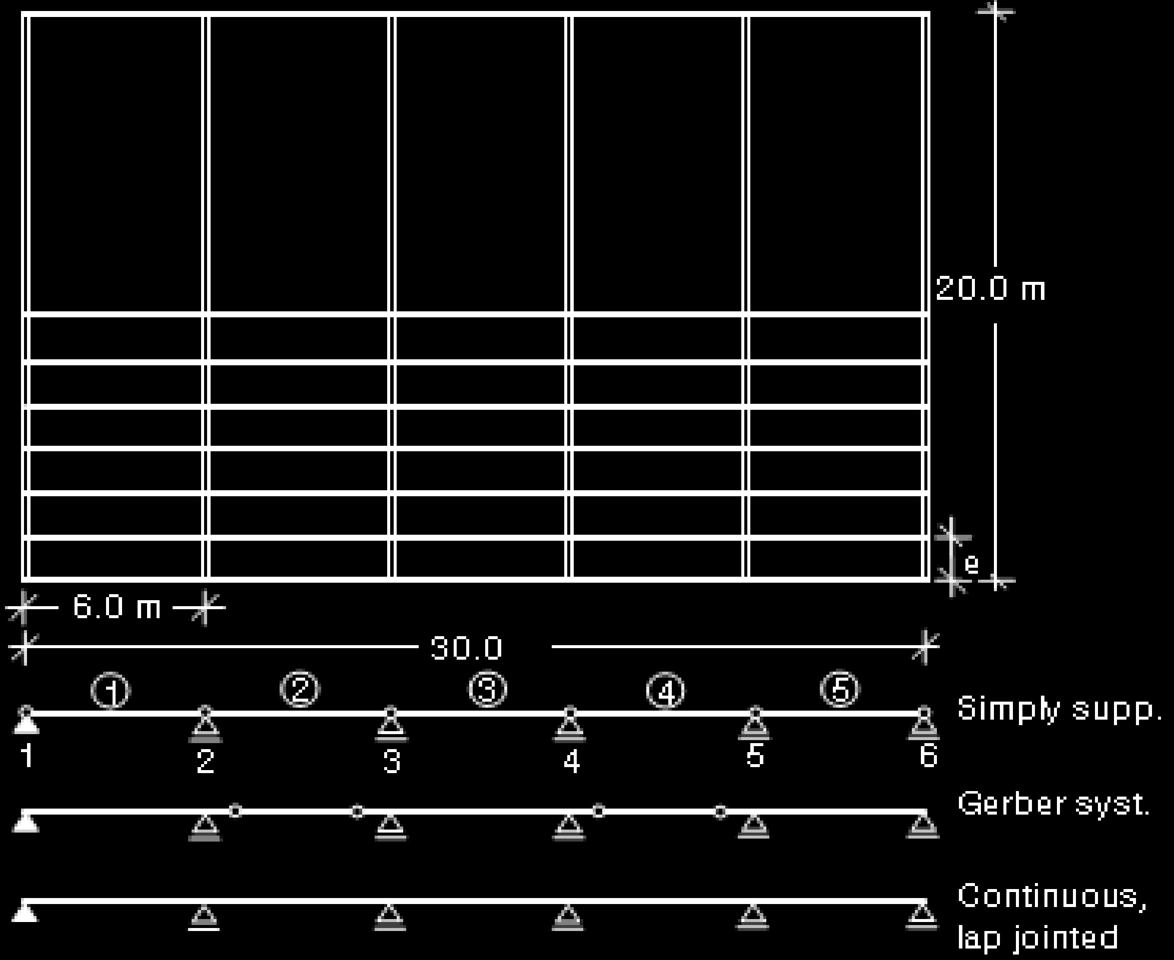
→ Possibility of verification by load case “removal of a limited part of the structure”

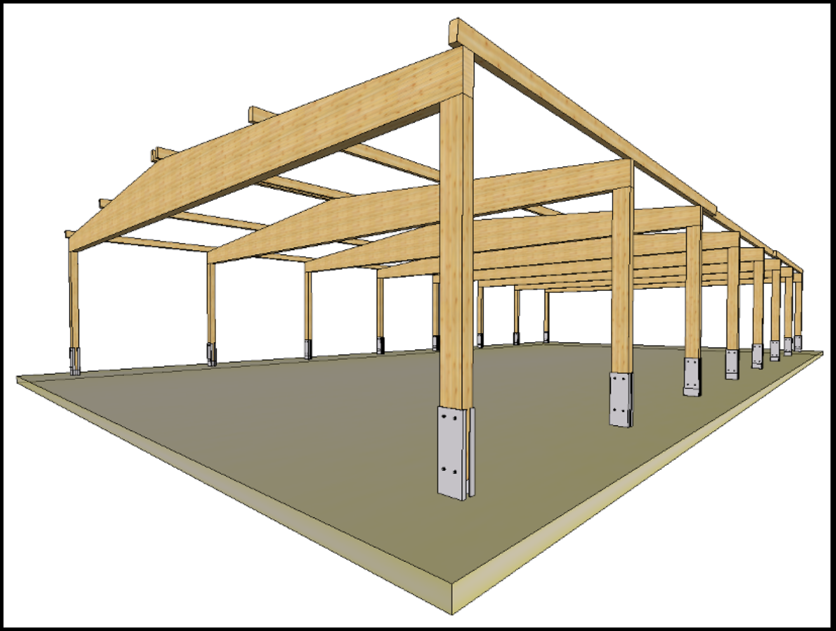
Structural Elements for wide-span Timber Structures

- Primary structure (e.g. trusses, pitched cambered beams)
  - Mainly determinate systems (simply supported beams, trusses)
- Secondary structure - purlins
  - simply supported beams (a)
  - continuous beams (b)
  - gerber beams (c)
  - lap-jointed purlins (d)



Scheme of evaluated Structure





Structural Information of Evaluated Structure

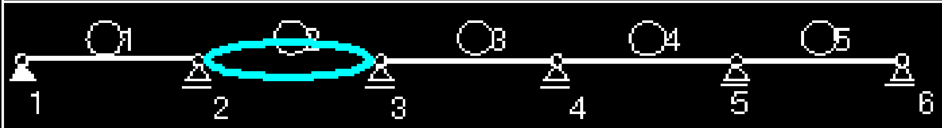
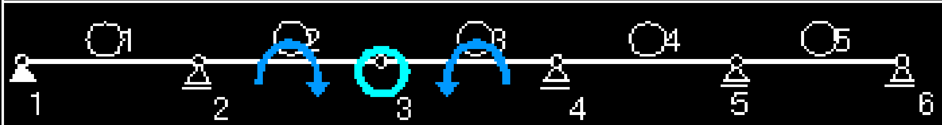
- Roof area ℓ/w = 30.0/20.0 m², roof angle = 10°
- 6 primary beams, e = 6.0 m, assumed utilization factor $\eta \sim 0.95$.
- $g_k = 0.5$ kN/m², $s_k = 0.8$ kN/m², wind (suction) is neglected.
- purlins, C24 b/h = 100/200 mm²
- utilization factor (ULS) of $0.9 < \eta < 1.0 \rightarrow$ spacing e

Purlin system	Spacing *e*	Purlin System	Spacing *e*
Simply supp. beam	1.0 m	Continuous beam	1.3 m
Gerber beam	1.3 m	Lap jointed purlin	1.6 m

Load case: Removal of a limited part of the Structure

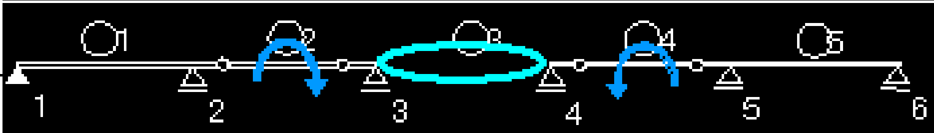
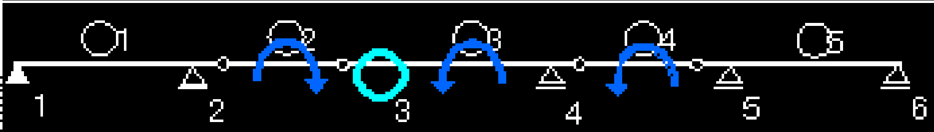
- Removal of a purlin between two supports (equivalent to the failure/rupture of one purlin)
- Removal of one support (equivalent to the failure of one main beam).
- Deterministic analysis: Comparison of load increase on remaining purlins and main beams incl. utilisation factors in the accidental load case ($\gamma_G = \gamma_Q = 1.0$; $\psi_{2,snow} = 0$; $k_{mod,acc}$).

Removal of a limited part of the Structure – simply supp. beam

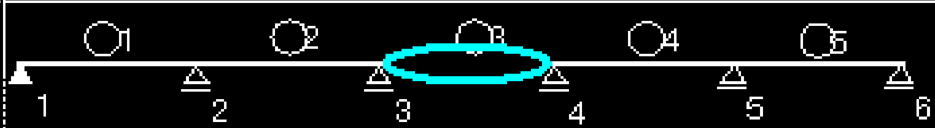
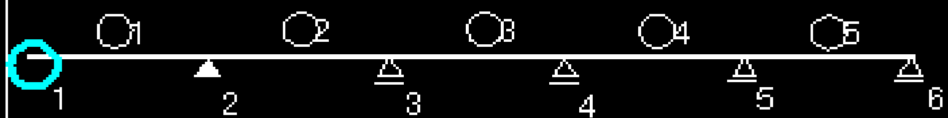
	1	2	3	4	5	6
1	Purlin system / removed member	Removed Member Additional failing members due to system instability	Max. stress incr-ease	*Max. utili-sati-on η*	Max. stress incr-ease	*Max. utili-sati-on η*
2			for remaining purlins		for remaining main beams (supports)	
3	Simply supp. beam					
4	a) Removal of purlin	 – no additional purlins failing due to system instability	--		--	
5	b) Removal of supp.		--		--	

Removal of a limited part of the Structure – gerber beam

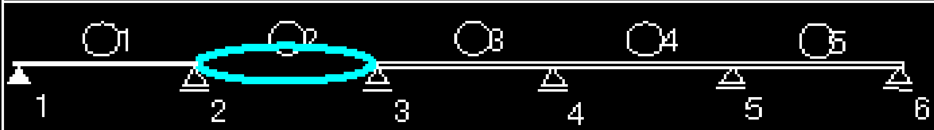
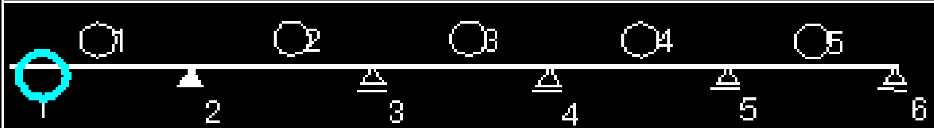
	1	2	3	4	5	6
1	Purlin system / removed member	Removed Member Additional failing members due to system instability	Max. stress incr-ease	*Max. utili-sation η*	Max. stress incr-ease	*Max. utili-sation η*
2			for remaining purlins		for remaining main beams (supports)	

6	Gerber beam				
7	a) Removal of purlin (worst case)		25% (field 1)	*57%*	--
8	b) Removal of supp. (worst case)		25% (field 1)	*57%*	--

Removal of a limited part of the Structure – continuous beam

	1	2	3	4	5	6
1	Purlin system / removed member	Removed Member Additional failing members due to system instability	Max. stress incr-ease	*Max. utili-sati-on η*	Max. stress incr-ease	*Max. utili-sati-on η*
2			for remaining purlins		for remaining main beams (supports)	
9	Continuous beam					
10	a) Removal of purlin (worst case)	 - no additional purlins failing due to system instability	19% (supp. 2)	*54%*	10% (supp. 2)	*50%*
11	b) Removal of supp. (worst case)	 - no purlins failing due to system instability, - possible failure due to significant overloading of remaining purlins	475% (supp. 2)	*228 %*	82% (supp. 2)	*83%*

Removal of a limited part of the Structure – lap jointed beam

	1	2	3	4	5	6
1	<u>Purlin system</u> / removed member	Removed Member Additional failing members due to system instability	Max. stress incr-ease	*Max. utili-sati-on η*	Max. stress incr-ease	*Max. utili-sati-on η*
2			for remaining purlins		for remaining main beams (supports)	
12	<u>Lap jointed beam</u>					
13	a) Removal of purlin (worst case)		60%	*77%*	10%	*50%*
			(field 1)		(supp. 4)	
14	b) Removal of supp. (worst case)	 - no purlins failing due to system instability, - possible failure due to significant overloading of remaining purlins	520%*	*250 %**	82%	*83%*
			(field 1)		(supp. 2)	

* beams designed for field moment, assumed overlap of 0.10*?, resp. 0.17*?.

Removal of a limited part of the Structure – Results

- Determinate Secondary Systems
  - Failure of one member will not result in substantial overloading of remaining members (depending on connection stiffness)
- Redundant Secondary Systems
  - Failure of one purlin will lead to stress increase in remaining purlins of up to 50%
  - Failure of one main member will result in an additional load on remaining main members of up to 82% (depending on purlin strength and stiffness)

Causes for Failure in Timber Structures

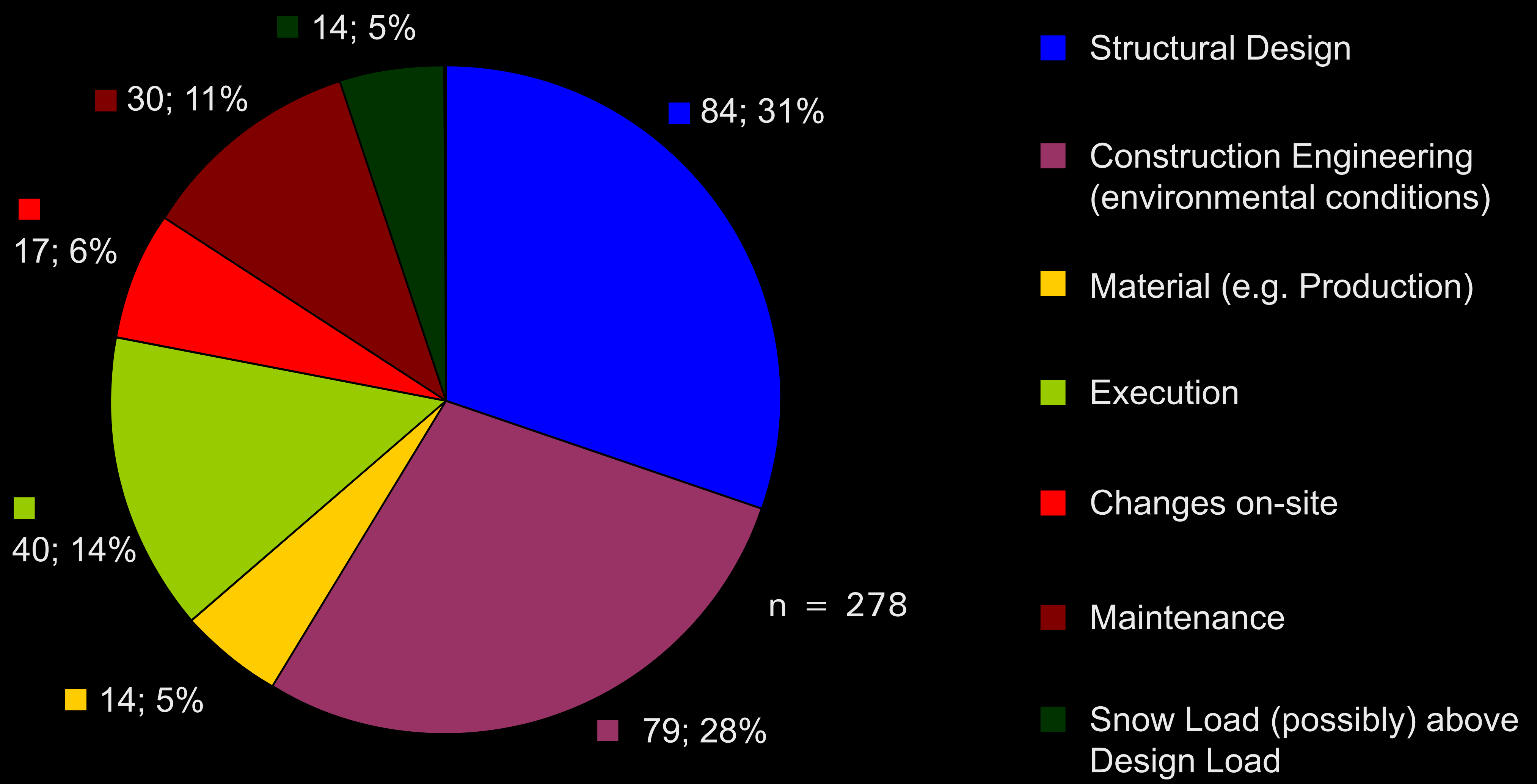
- numerous studies on failures in timber structures (Blaß, Frese; Frühwald et al.; Dietsch, Winter) have shown that the majority of failures were not due to local effects or statistically random occurrences, but – in the vast majority – due to systematic mistakes or global deterioration

- Reason is: structures are usually composed of repetitive elements, connected by analogical construction principles

→ mistakes during planning or construction phase, will most likely repeat itself in all identical elements (e.g. Bad Reichenhall, Siemens Arena)

→ structures containing global defects (systematic mistakes or global deterioration) will not be able to withstand a large load increase due to load distribution from one failing member, meaning they are more fragile to collapse progressively

Evaluation of failed Timber Structures - Accountabilities for Failure



Dietsch, P.; Winter, S.: "Assessment of the Structural Reliability of all wide span Timber Structures under the Responsibility of the City of Munich" 33rd IABSE Symposium Proceedings, Bangkok, Thailand, September 9-11, 2009

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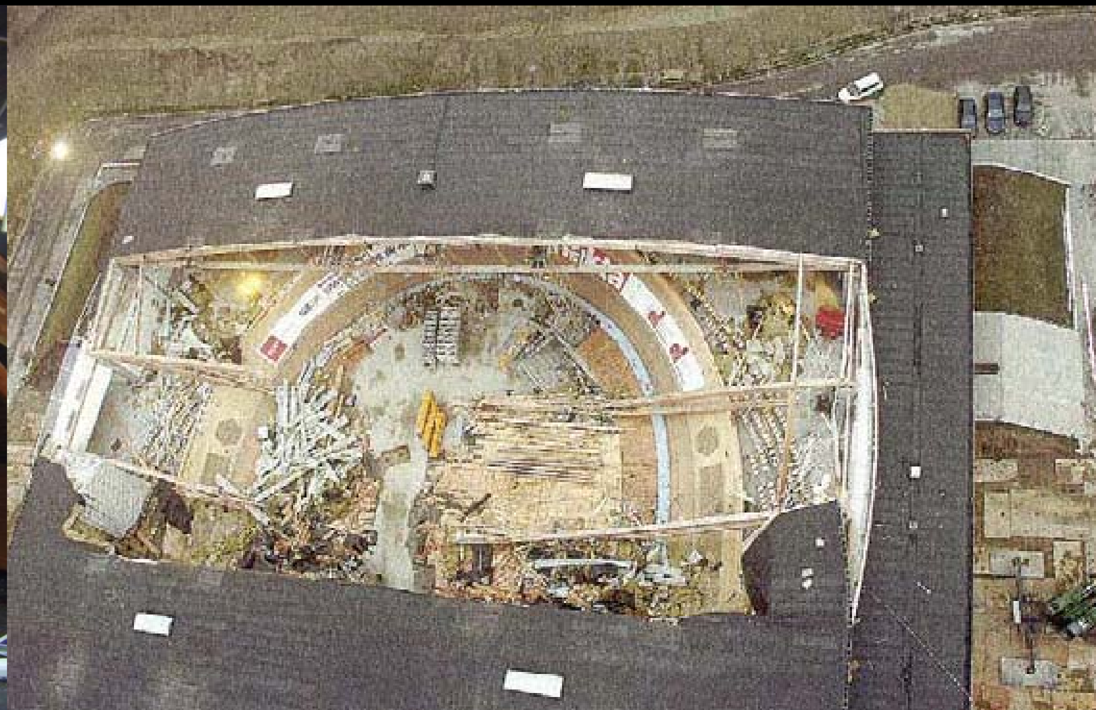
Examples – redundant secondary systems

Bad Reichenhall

Reithalle Grafling, MPA BAU/TUM

Examples – determinate secondary systems


Messe Salzburg, MPA BAU/TUM


Siemens Arena, Hansson, Larsen

Conclusion: Robustness Requirements for Timber Structures

Local effects – local failures, e.g.	Global effects, e.g.
• Local detioration of element from e.g. local water ingress • Local weakening of element from e.g. holes • Local overloading from e.g. local snow accumulation	• Global weakening of structural elements due to systematic mistakes • Global detioration of elements from e.g. wrong assumption of ambient climate • Global overloading from e.g. addition of green roof without structural verification
Robustness Approach:	**Robustness Approach:**
• Redistribution of loads to adjacent (undamaged) elements by e.g. redundant secondary system	• Limiting failure to local level by e.g. determinate secondary systems with “weak/flexible” connections • Compartmentalization / Segmentation

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