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Robustness experiences from two failed Timber Structures

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Two Cases:

- Bad Reichenhall Ice-Arena, Germany
- Siemens Arena, Ballerup, Denmark

Relevance:

- Examples of different design strategies
- Consequence of strategy for robustness
- Robustness is not an unambiguous concept
- The best strategy for robustness depends on the cause of the failure - which is (obviously) not known during planning and design

Robustness experiences from failed Timber Structures - The Bad Reichenhall Ice-Arena Collapse

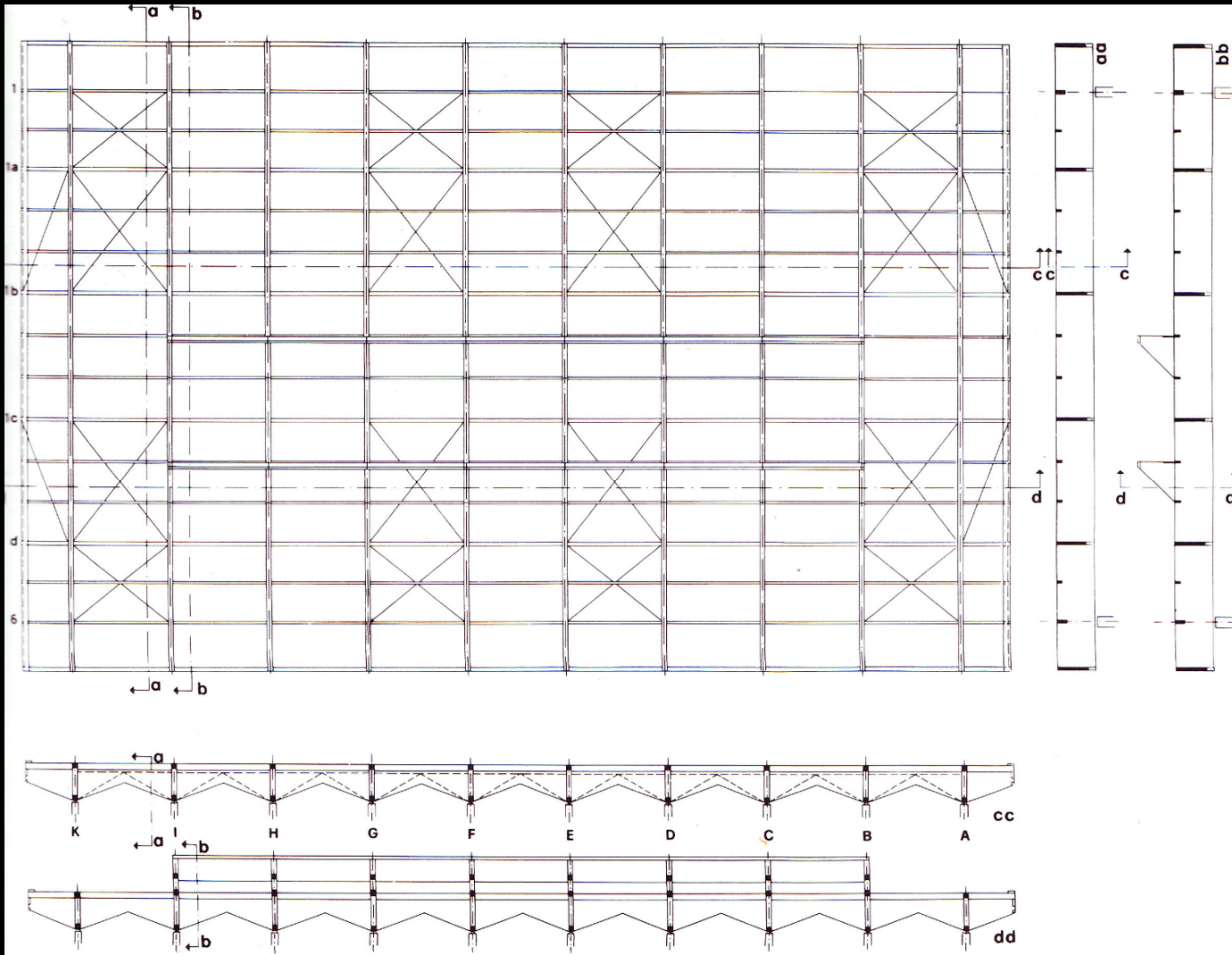
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The Bad Reichenhall Ice-Arena – Front View



Eishalle Bad Reichenhall – Year of Construction 1971/72

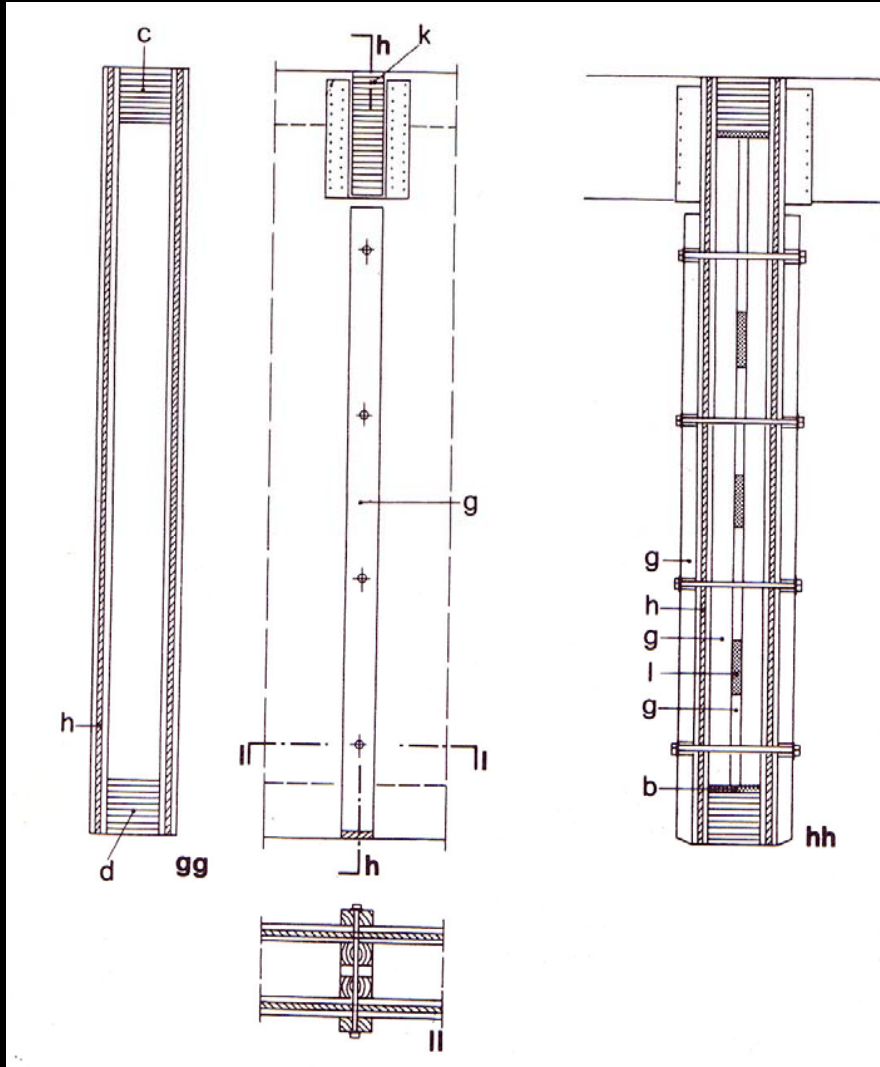
The Bad Reichenhall Ice-Arena – Layout and side-view of girders



$b = 48 \text{ m}$

$l = 75 \text{ m}$

The Bad Reichenhall Ice-Arena – Cross-section of girders



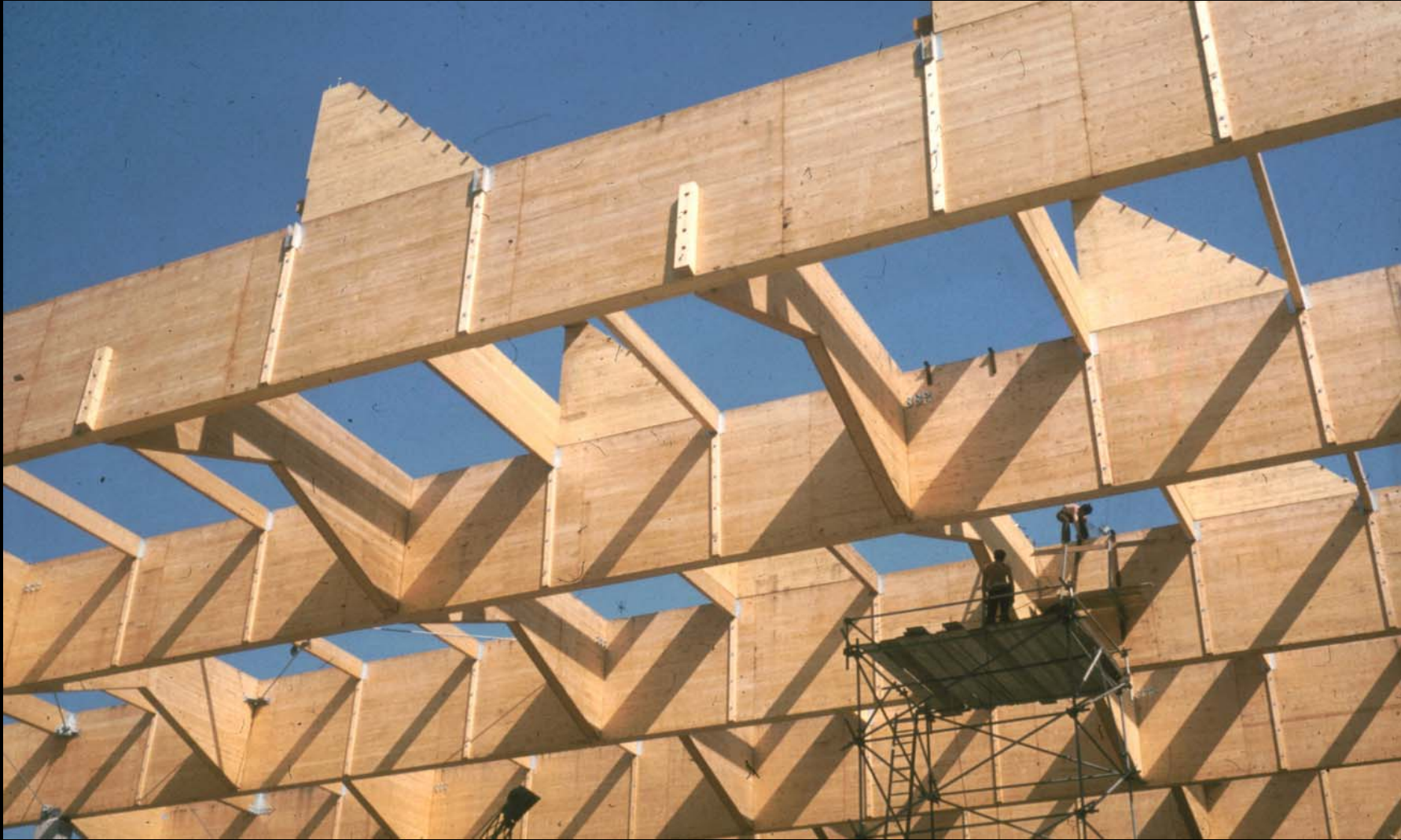
c-upper girder, d-lower-girder, h-Kämpf web-board,
k-purlin, g-reinforcement (to avoid buckling)

The Bad Reichenhall Ice-Arena – Construction



Eishalle Bad Reichenhall – Year of Construction 1971/72

The Bad Reichenhall Ice-Arena – Primary and Secondary System



Eishalle Bad Reichenhall – Year of Construction 1971/72

The Bad Reichenhall Ice-Arena – Collapse on 2. Jan. 2006



Eishalle Bad Reichenhall – Progressive collapse under char. snow load

The Bad Reichenhall Ice-Arena – Contributions to failure

- Errors in structural calculations – reduction of safety factor to ≈ 1.5
- “Kämpf”-web boards – not compliant with technical approval (limit 1.20m)
- Gluing process between girder parts not reliable
- Urea-formaldehyde glue used is not permanently moisture-resistant (high ambient humidity and thermal radiation between ice and roof)
- Repeated cases of water penetration as a result of leaks in the roof
- No professional examination of structural integrity during service life

- Winter, S., Kreuzinger, H. (2008): “The Bad Reichenhall Ice-arena collapse and the necessary consequences for wide span timber structures”. Conference Proceedings WCTE 2008 , Miyazaki, Japan.

The Bad Reichenhall Ice-Arena – General finger joints



General finger joints – Loss of adhesive effect of UF-glue

The Bad Reichenhall Ice-Arena – Progressive Collapse



Eishalle Bad Reichenhall – Collapse initiated in one of the three main girders on the east side

The Bad Reichenhall Ice-Arena – Progressive Collapse

- Stiff cross bracing – redistribution of loads from failing girder to neighbouring girders
- All girders suffered from the same systematic mistakes and degradation processes – no ability to sustain additional load
- Progressive collapse within seconds



The Bad Reichenhall Ice-Arena – Robustness Considerations

- Strong and stiff cross bracing – shifting of loads without warning through deformations
 - Possible amelioration:
 - Partition between secondary system and bracing against lateral torsional buckling
 - Use of statically determinate secondary system with more flexible connections
 - K-bracing not in every field - compartmentalization
- possibility of one girder failing without inducing progressive (total) collapse



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