# ENGINEERING FAILURES

# LESSONS TO BE LEARNT

## IN MODERN TIMBER DESIGN

**June 2024**

engineering new zealand
te ao rangahau

# CONTENTS

This case study summarizes a webinar by Dr Daniel Moroder, the immediate past president of the Timber Design Society. Daniel is a Technical Director at PTL Structural & Fire in Christchurch, New Zealand and has extensive experience in timber engineering. The webinar is presented by the Timber Design Society and Daniel is introduced by Lisa Oliver, the current president of the society, and a structural engineer with Holmes Group based in Christchurch.

In this webinar, Daniel provides valuable insights into the challenges and opportunities in modern timber design and construction, reflecting on lessons learned from his own and overseas timber construction projects.

# INTRODUCTION

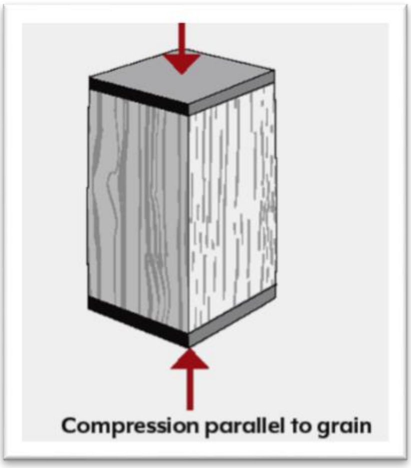
The New Zealand Timber Design Society is a volunteer society operating as a collaborating technical society of Engineering New Zealand. With approximately 500 members, mostly designers focused on timber structures, the society's work is supported by its member and industry sponsors. Recently, the Timber Design Society has shifted its focus from promotion of the use of more timber to promotion of the "good" design and use of timber in construction.

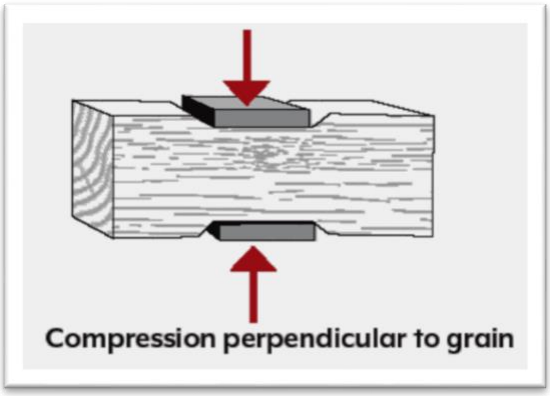
### Timber as a material

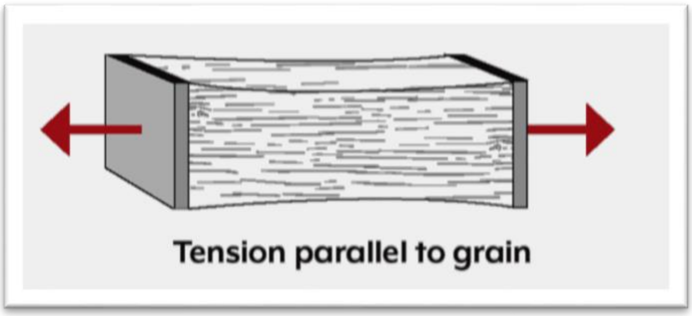
Timber, as a natural material, has unique properties that need to be understood for effective design:

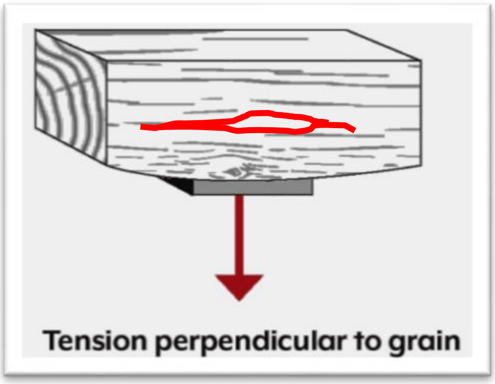
The structure of wood can be idealized as parallel tubes

1. It is anisotropic, meaning it has different properties in different directions.



## Reinforcement

www.timbermedia.co.uk

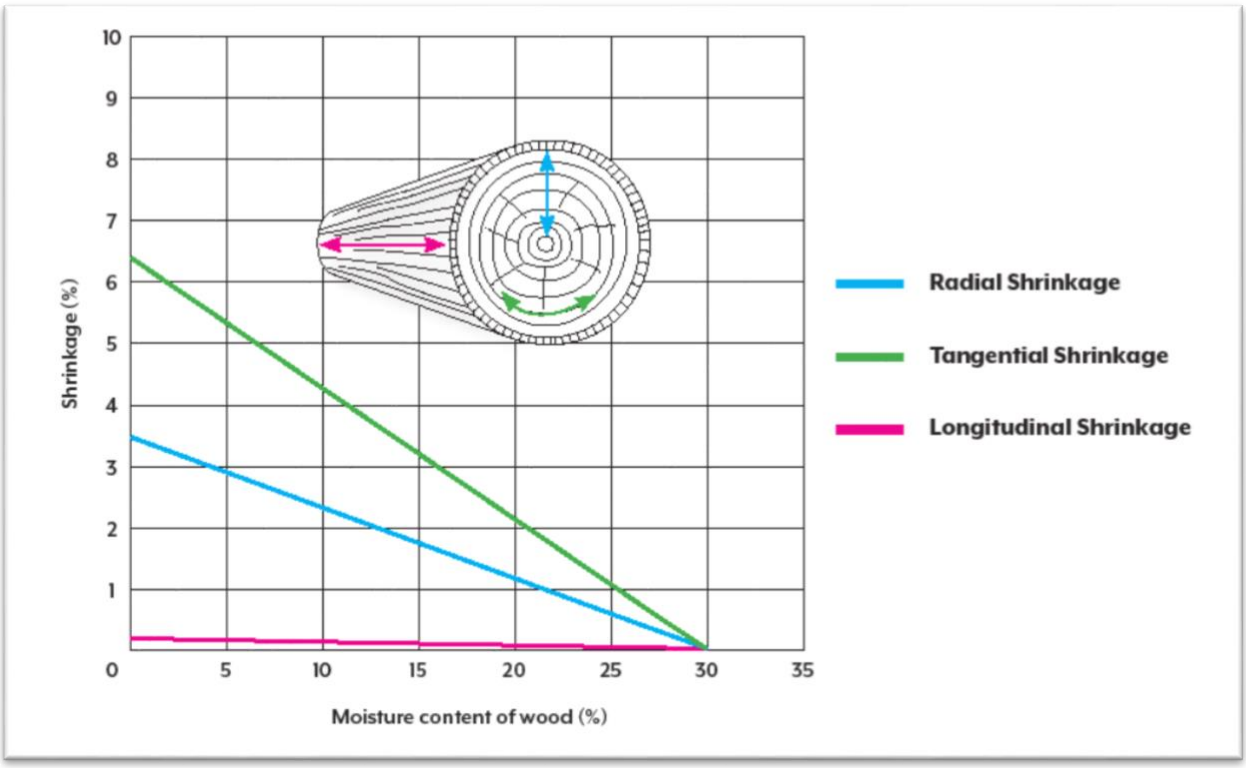
## Reinforcement

www.dreamstime.com

With limited tensile strength (perpendicular to grain) it can be reinforced similarly to concrete design.

2. Timber is hygroscopic, able to absorb and release moisture, which can lead to dimensional changes in the different directions.

## Shrinkage (and swelling)




*NZ Wood Design Guide. Trees, Timber, Species and Properties, Chapter 1.2*

3. It can be susceptible to mould and rot if moisture content remains elevated for extended periods.

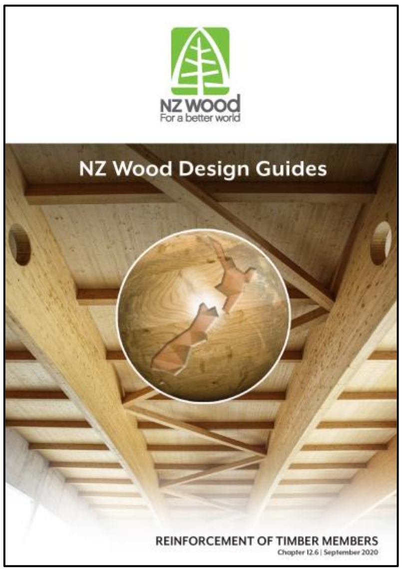
**Mould**

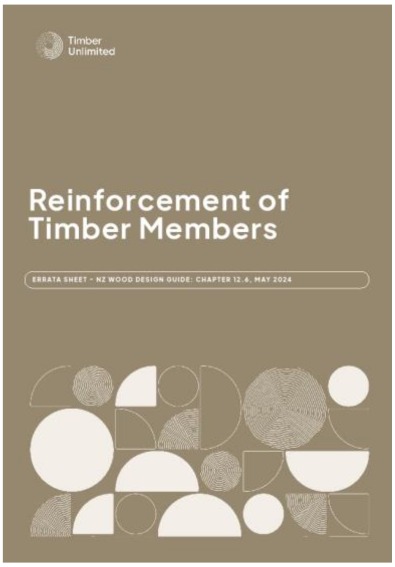
*www.bowens.com.au*

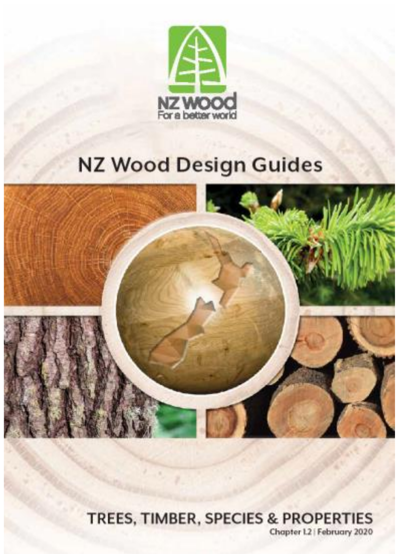
**Rot and decay**

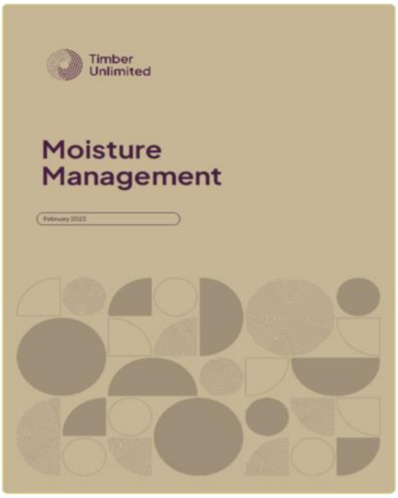
*www.trac-structural.co.uk*

These properties present both challenges and opportunities in timber construction, particularly in the use of mass timber in building projects increases. The following sources can be used to learn more about timber properties and guidance on how to design timber members and connections.




# CASE STUDIES

This section explores three case studies

## CASE STUDY 1: MULTI-STORY MASS TIMBER BUILDING IN NEW ZEALAND

This project involved the construction of a 5-story multi-residential timber building using prefabricated wall panels (with cladding installed) and prefabricated floor cassettes.

Components of this multi-storey timber building were exposed to the rain for weeks before installation due to poor storage. Due to timber swelling, some building components did not fit into the structure anymore, requiring remediation.

Once installed, the contractor did not follow the moisture management plan and the timber assemblies were further exposed to the weather. Also, no moisture meters were initially used on site.

Unfortunately, the site was left exposed to the rain for a further two months during the Covid 19 lockdown and the OSB flooring remained under high moisture content for a long time.

### Key Issues:

1. Moisture Damage:
   - Floor panels swelled due to improper storage before installation, causing fitment/tolerance issues.
   - COVID-19 lockdowns left the structure exposed to rain for weeks, leading to extensive water damage.
   - Superficial mould growth occurred on timber elements and plasterboard.
   - Some timber members began splitting and deforming due to excessive moisture.
2. Construction Challenges:
   - Contractors initially failed to follow moisture management instructions.
   - Plasterboard installation began prematurely, leading to water damage and mould growth.
3. Drying Issues:
   - Rapid drying and high temperatures after the initial remediation caused further additional problems, including cracking of plasterboard and separation of timber elements.

### Outcomes:

- The building was initially deemed a potential write-off.
- Extensive remediation was required, including testing and assessment of water damaged materials, implementation of forced ventilation and heating for controlled drying and constant measurement of the moisture content.
- The project was delayed by approximately one year.

### How it could have been avoided:

- Specify measures to keep the timber dry
- Require the implementation of a moisture management plan
- Talk the contractor through the issues and do not allow for a business as usual approach typically applied to concrete and steel construction.

- For sensitive structures
    - cover them up
    - Use membranes and/or tape floors and roofs
    - Tape floor and roof panels
    - Remove ponding water

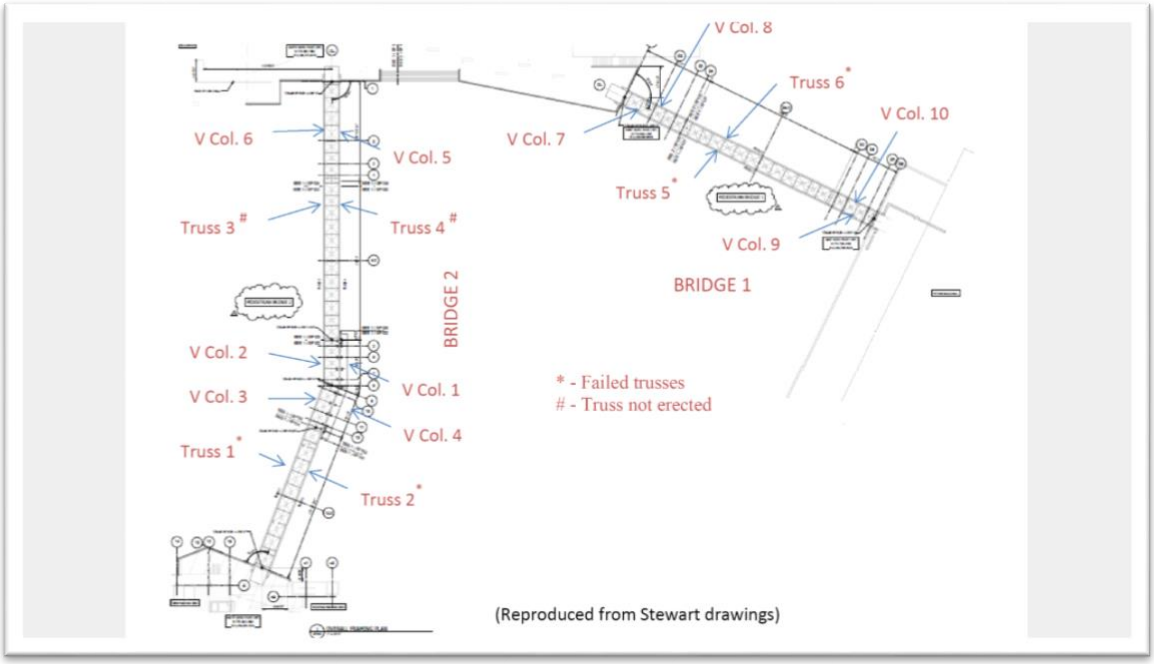
It is also important to remember that chemical treatment is no silver bullet when it comes to moisture management during construction and in-service. Mould can still grow on H1 or H3 treated timber. It only limits structural decay in the short to medium term and should not be considered an alternative to proper detailing for durability.

Refer to NZ Wood Guideline “CONSTRUCTION GUIDANCE FOR TIMBER BUILDINGS” or manufacturer’s literature for more information.

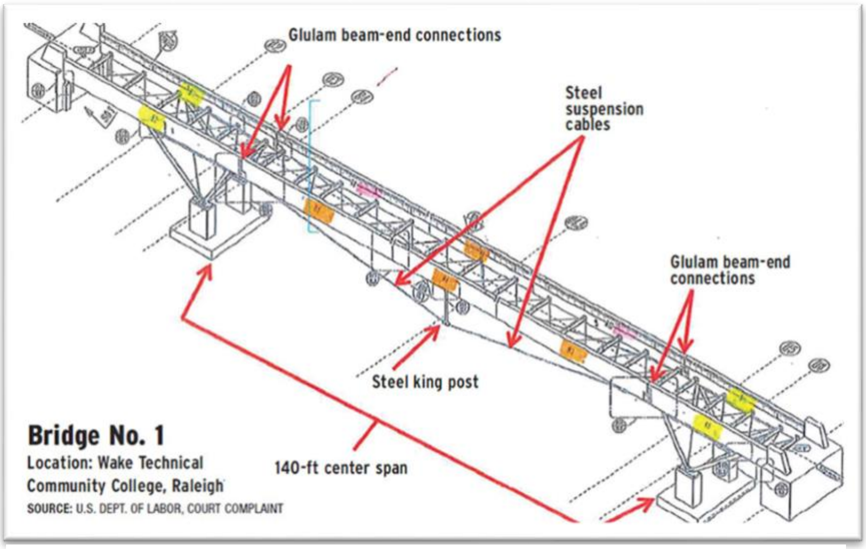
## CASE STUDY 2: PEDESTRIAN BRIDGE COLLAPSE IN NORTH CAROLINA, USA

This project involved the construction of two timber pedestrian bridges on a community college campus. On November 2014, during the concrete pour one bridge collapsed, killing one person and injuring 4. 14 hours later the second bridge collapsed, luckily it was midnight and no one was on site.

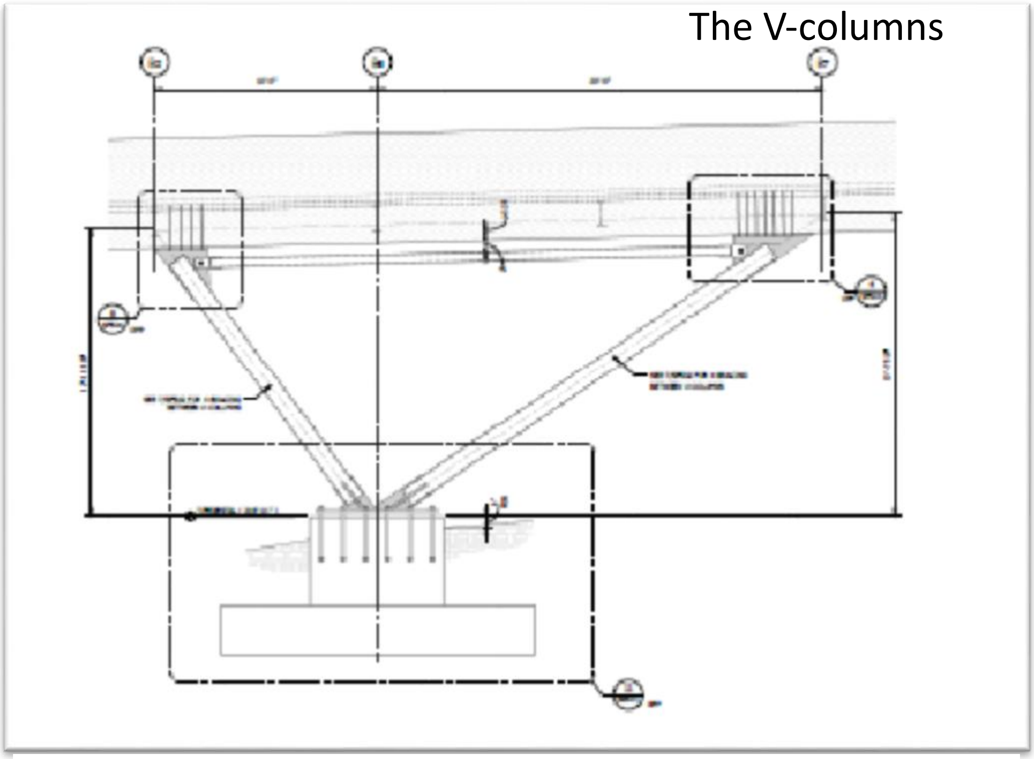
Two bridges had been erected, one with a 42.3 m length and one with a 39.6 m length. Beams were supported on concrete supports, with suspension cables and a central king post as well as V-shaped steel columns. Glulam beams were 340mm wide and 1.5 meter deep. The deck of the bridge consisted of poured-in-place concrete over a metal deck supported over steel beams.




*Reproduced from Stewart drawings*

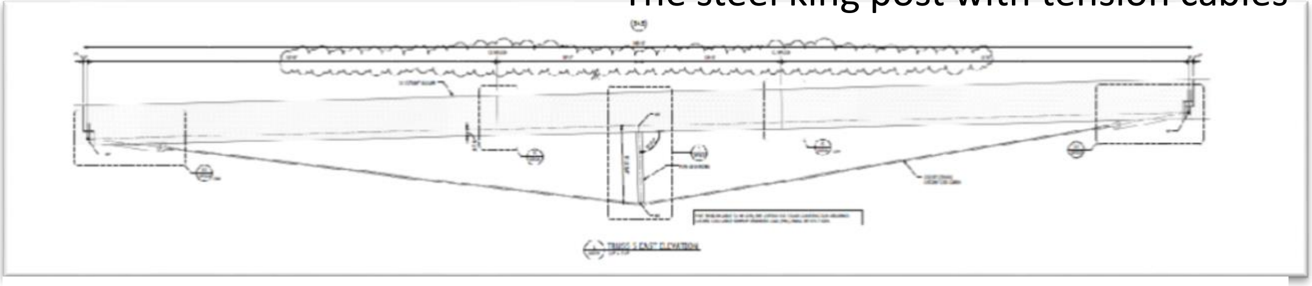



*U.S. Dept of Labor, Court Complaint*

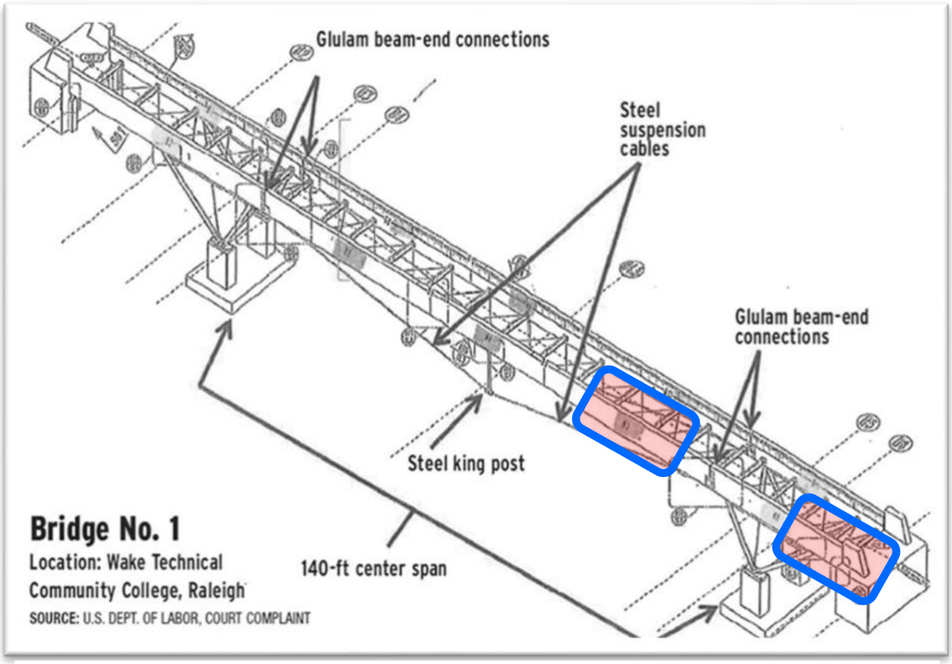



*U.S. Dept of Labor, Court Complaint*

The steel king post with tension cables



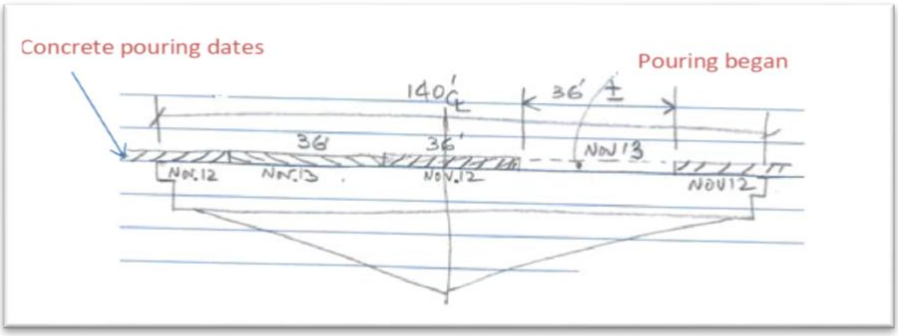
*U.S. Dept of Labor, Court Complaint*




*U.S. Dept of Labor, Court Complaint*

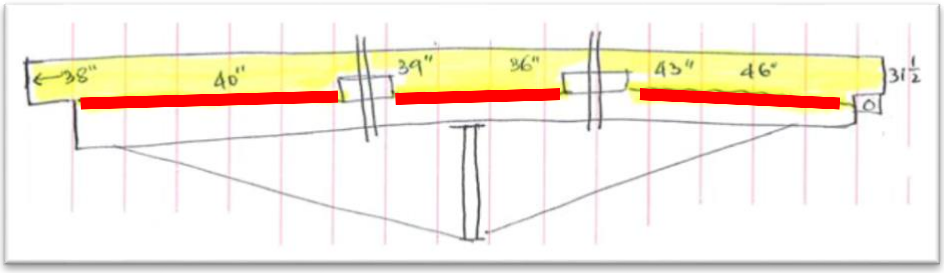
The glulam girders were too long to be shipped in one piece. Two splices were designed 11 metres apart along the span – see left hand rectangle in red.

## The Failure Bridge 1



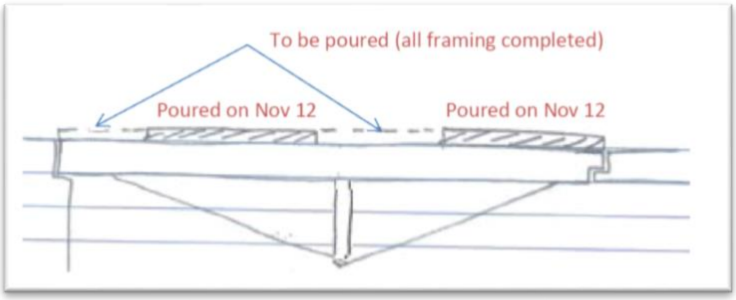

*U.S. Dept of Labor, Court Complaint*

The failure initiated at the splices and supports, which all had unreinforced notched supports.



*U.S. Dept of Labor, Court Complaint*

## The Failure Bridge 2




*U.S. Dept of Labor, Court Complaint*

*U.S. Dept of Labor, Court Complaint*

### Key Issues:

1. Design flaws:
   - Inadequate design of notched connections in glulam beams, failing to account for tension perpendicular to grain.
   - During the shop drawing process it was agreed to introduce camber to the beams by tensioning the cables
   - The tension in the cables introduced tension stressed into the notches
   - The deck was attached at the bottom of the beams, pulling down the underside of the beams
2. Construction and quality control:
   - Lack of proper reinforcement at notched connections, the design engineer ignored the design standards and did not design/check the notches.
   - Inadequate site supervision and quality control.
3. Regulatory oversight and peer review:
   - Although the design was reviewed and checked at several stages by different entities, including the glulam manufacturer, the notches were never flagged as a potential design issue.

### Outcome:

- One bridge collapsed during concrete deck pouring, resulting in one fatality and four injuries.
- The second bridge collapsed two days later under its own weight.

### Conclusion:

- The cause of the failures was the structural design flaw from the notched glulam girders
- The notches were not in compliance with the applicable ANSI/AF&PA NDS-2005
- Several consultants did not notice the presence of the notches or neglected the opportunity to raise concern

- Consultants/contractors failed in their professional responsibility to share their knowledge and expertise with the structural engineer
- The bridges otherwise were adequately designed

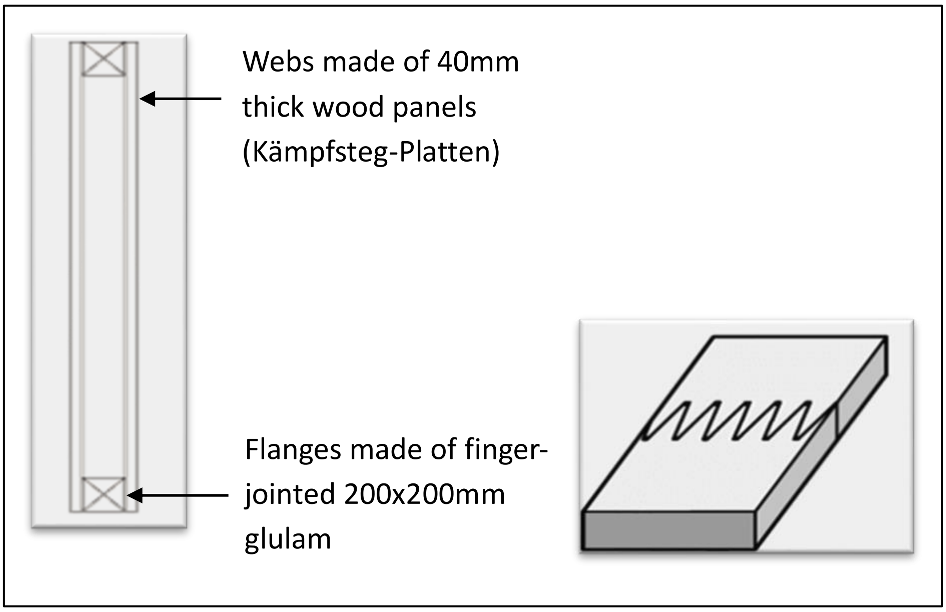
## CASE STUDY 3: ICE RINK ROOF COLLAPSE IN BAD REICHENHALL, GERMANY

This case involved the collapse of a timber roof structure over an ice rink, built in 1972 with a span of 48 meters. During a winter day in 2006 the roof collapsed.

Youtube video summary of the collapse.

*www.idowa.de*

**Structure:**




Structure was 75m long and 48m wide.

Box beams were spanning 48m and were spaced at 7.5m centres.

Cross beams every 9.2m, creating a tri-dimensional grid system.

**Key Issues:**

1. Design and Material Selection:
   - Mistakes in design calculations.
   - Use of finger-jointed timber sections without considering net section properties.
   - Box girders were higher than allowed in appraisal (2.87 meters instead of 1.20 meters).
   - Use of box beam sections that trapped moisture over time. Inadequate consideration of long-term moisture effects on the structure.

*buildingfailures.files.wordpress.com*

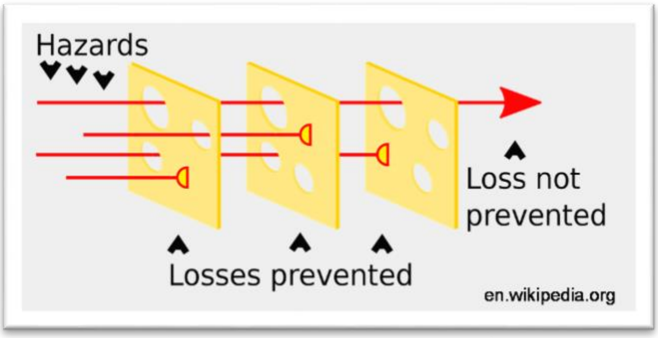
2. Construction and Manufacturing:
   - Improper gluing techniques in the manufacture of box beams, the gluing between flanges and webs was not carried out according to the state of the art.
   - Inappropriate use of urea-formaldehyde adhesive in a high-moisture environment.
   - Water damage further weakened the finger joint.
3. Maintenance and Environmental Changes:
   - Lack of regular inspections and maintenance.
   - The rink was enclosed with a glass façade at a later stage, changing the in-service conditions and therefore affecting the moisture content of the timber members.
   - Moisture and condensation accumulated inside the hollow beams (due to cold radiation from ice)
   - Known roof leaks were not adequately addressed.
4. Regulatory and Oversight Issues:
   - No peer review of the original design despite its complexity.
   - Inadequate inspection processes failed to identify developing structural issues. An inspection in 2003 did not discover any construction issues and the moisture content of the beams were not checked.

○

**Multiple point of failures (Swiss cheese model):**

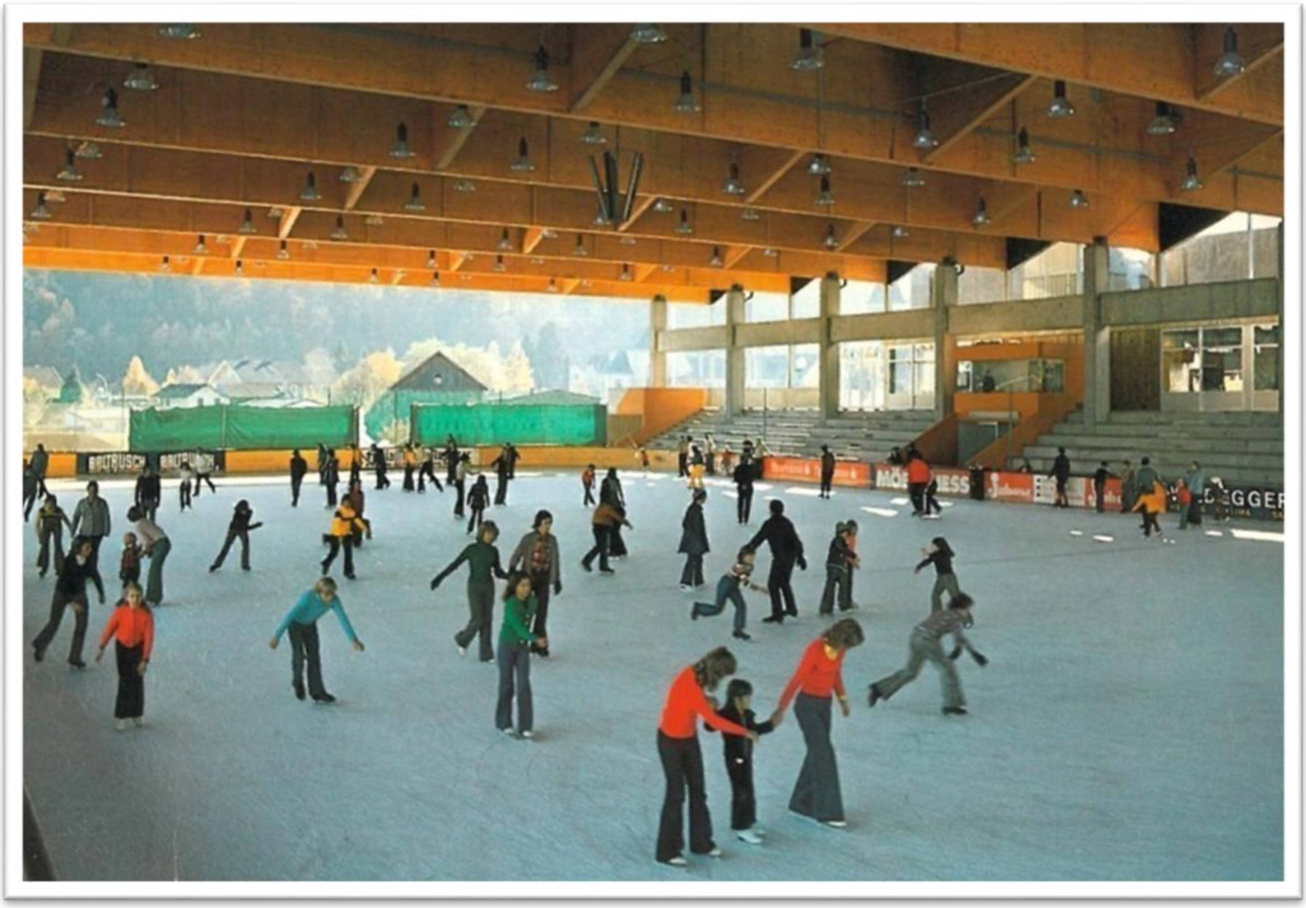
- Design mistakes
- Formal/regulatory failures
- Manufacturing/Construction failures
- Maintenance failure

Leading to a progressive failure mechanism




**Outcome:**

- The roof collapsed in 2006, 34 years after construction, resulting in 15 fatalities and 34 injuries.
- The collapse occurred under snow load, though the load was within design parameters.



*www.tab.de*

# LESSONS LEARNED

1. Moisture management is critical:
   - Proper storage and protection of timber elements during construction is essential.
   - Ongoing moisture monitoring and management throughout construction and the building's lifecycle is crucial.
2. Design must account for timber's unique properties:
   - Anisotropic behaviour, particularly tension perpendicular to grain, must be considered in design.
   - Long-term effects of moisture on timber strength and durability should be factored into design.
3. Quality control and supervision are essential:
   - Rigorous quality control during manufacturing and construction is necessary.
   - Regular site supervision by knowledgeable professionals is critical.
4. Change of use and maintenance must be considered:
   - Any change of use of the building which could impact loadings or environmental conditions need to be considered, as they might affect the performance of the building.
   - Regular inspections and maintenance are crucial for ensuring long-term structural integrity.
5. Innovative solutions can enhance performance:
   - New technologies and design approaches can improve the resilience and durability of timber structures.

# SOLUTIONS

1. Moisture Management:
   - Develop comprehensive moisture management plans for the construction phase of timber buildings.
   - Educate contractors and workers on the importance of moisture control in timber construction.
2. Design Considerations:
   - Properly account for timber's anisotropic properties in structural designs.
   - Use reinforcement techniques where necessary, especially for tension perpendicular to grain.
   - Avoid closed sections that can trap moisture in long-span structures. If closed sections are used, building physics principles should be applied to estimate the likely environmental conditions in the beam cavity.
   - Consider climate change impacts and design for increased resilience.
3. Quality Control and Supervision:
   - Implement strict quality control processes during manufacturing and construction.
   - Ensure regular site supervision by knowledgeable professionals.
   - Conduct thorough site investigations and verify existing conditions.
4. Long-Term Performance:
   - Design for ease of inspection and maintenance.
   - Provide clear guidance to building owners on long-term care of timber structures.

- Implement regular inspection and maintenance programs for timber structures to be carried out by knowledgeable professionals.

5. Education and Training:
    - Promote better understanding of timber properties and design considerations among engineers and architects.
    - Provide ongoing training for professionals in the latest timber design and construction techniques.
6. Collaborative Approach:
    - Encourage collaboration between architects, engineers, contractors, and timber suppliers throughout the project.
    - Engage with regulatory bodies to ensure appropriate standards and guidelines are in place for timber construction.

By implementing these solutions and learning from past experiences, the timber construction industry can continue to innovate and expand the use of mass timber while ensuring the safety, durability, and performance of timber structures.

## EXAMPLES OF RECENT GOOD DESIGNS

Nelson Airport


*c/o Studio Pacific*

Kaikoura District Council Building

*c/o Xlam*