The Behaviour Of Round Timber Sections Notched Over The Support On The Tension Face

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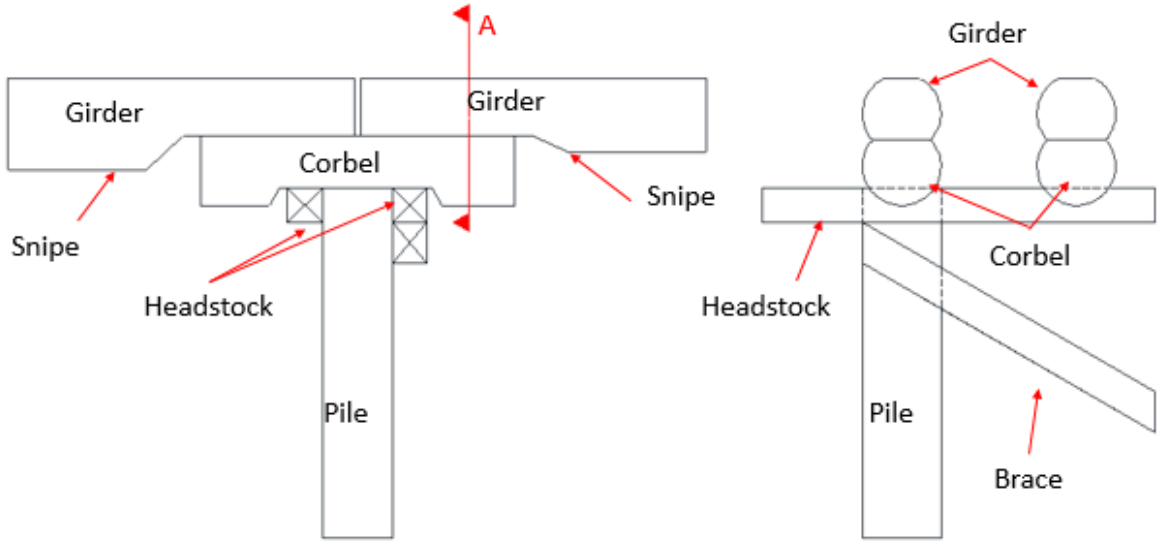
Need for research

- In Queensland there are approximately 400 timber bridges still in use.
- Very little research or knowledge about notches
- Tapered notches have never been verified in round timber sections

Sniped girders

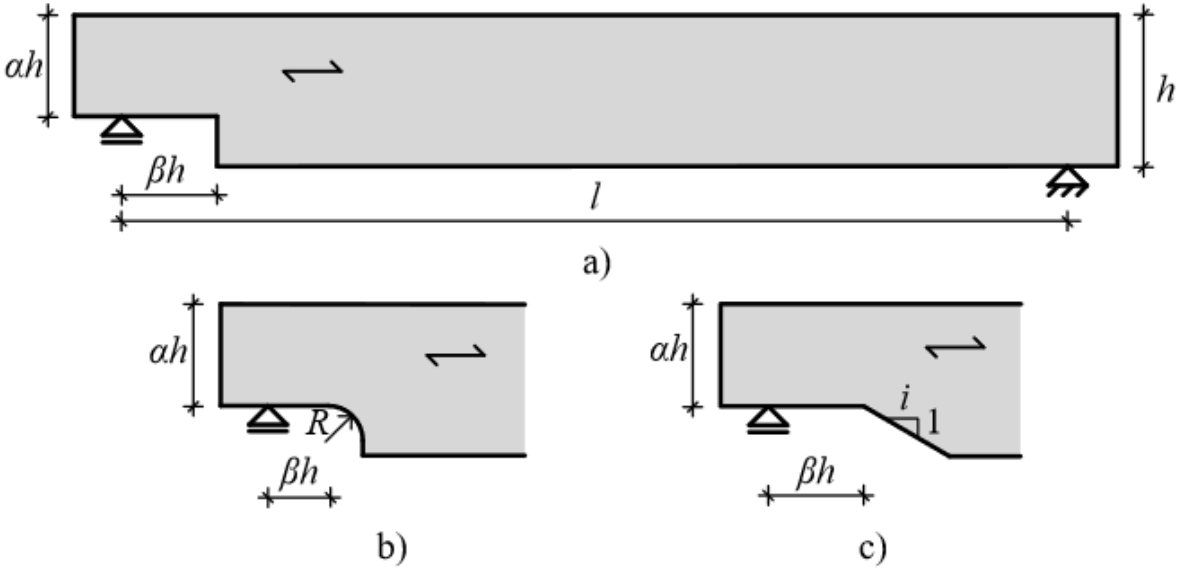
Notch Types

- Notching is required to create flat seating onto the corbel and is usually cut on site with chainsaws
- Different profiles
  - Stepped notch - Square cut notch
  - Tapered notch – Raking slope away from re-entrant corner
  - Rounded notch – internal corner is drilled prior to the notch being cut
- Tapered and Round end notches developed to minimise stress concentration.
- Square end notch has been shown to have the least structural capacity
- Sniping is limited to 15% of depth after top seating is formed. Larger than this requires bolted strengthening



Bridge section

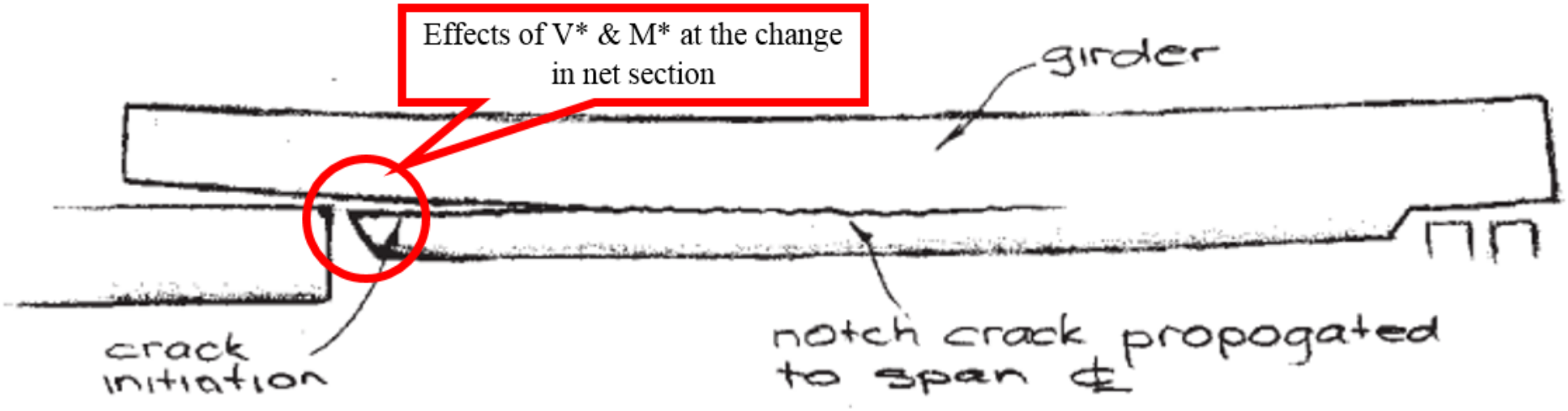
Section A



Notch profiles: a) Stepped. b) Round. c) Tapered

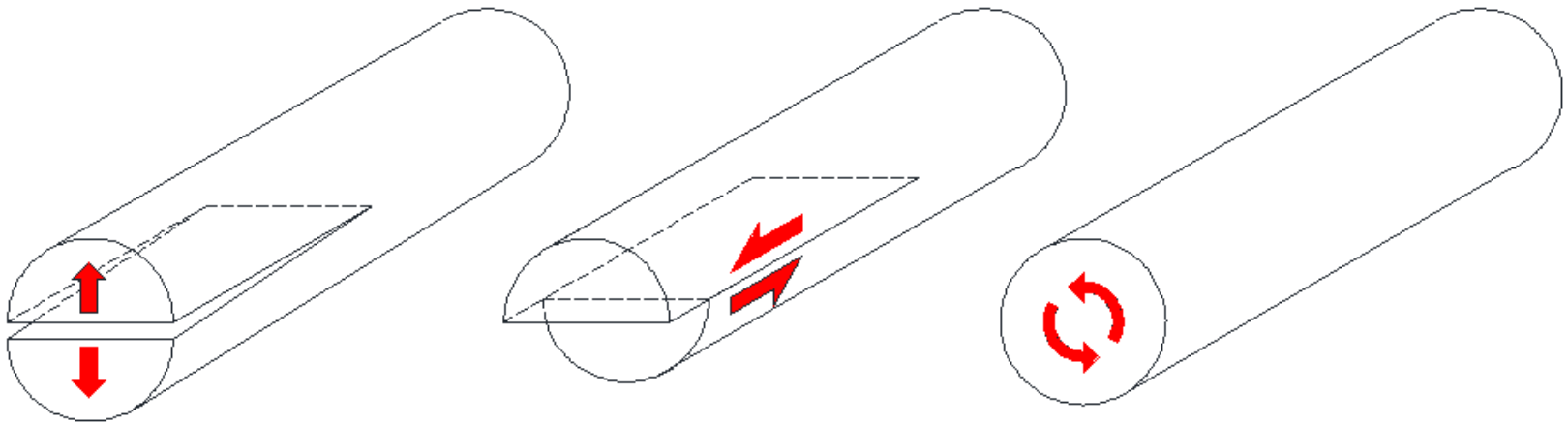
Effects of snipes on timber girders

- Notches or snipes are used to create a flat surface for seating onto the corbel. This reduces the net section in a critical region.
- At the sharp re-entrant corner, high localised stress concentrations occur due to a combination of normal stress perpendicular to the grain and shear stress parallel to the grain.
- AS1720 states that these adverse effects due to notching may be minimized by increasing the opening angle of the notch.



Round girder showing the effects of load at the notch corner

Three Potential Notch Failure Modes



Mode 1: Tension perpendicular to the grain

Mode 2: Shear parallel to the grain

Mode 3: Torsion/Rolling shear

- Mode 1: Tension failure perpendicular to the grain
- Mode 2: Shear stress inducing sliding of the fibres parallel to the grain
- Mode 3: Torsional – not an issue in round sections due to their inherent stability

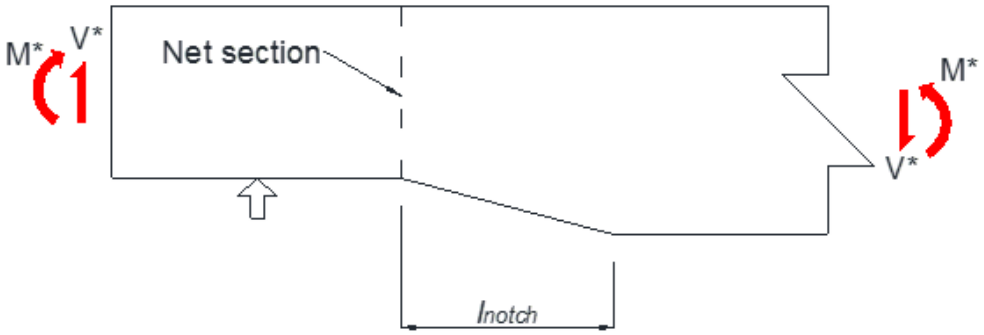
AS1720.1-2010 Notch design for timber

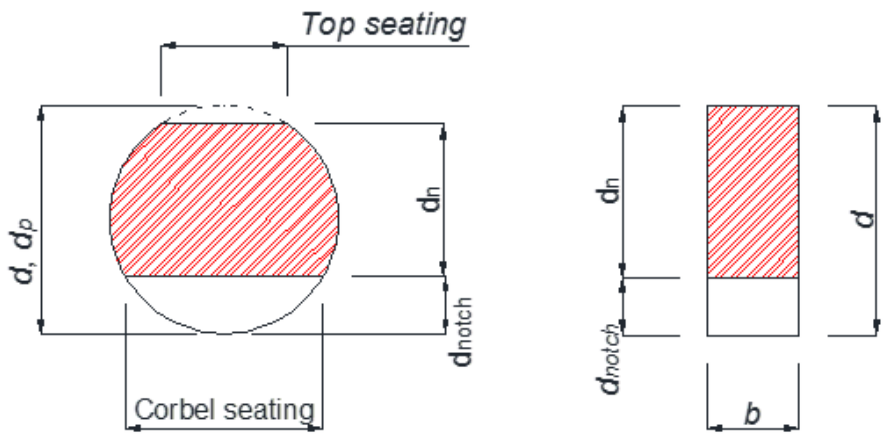
- There are currently no design methods that allow specifically for the strength of round sniped sections to be determined.
- AS1720 uses linear elastic fracture mechanics to design for notches in rectangular sections using the equation below. This assumes the timber is isotropic.

$$\frac{6\,M^*}{bd_n^2} + \frac{6\,V^*}{bd_n} \leq \emptyset\, g_{40} k_1\, k_4\, k_6\, k_{12}\, f'_{sj}$$

- The bending stress at the net section and four times the shear stress at the net section are used to determine a design load

$$f_b + 4 \cdot f_s \leq \emptyset\, g_{40} k_1\, k_4\, k_6\, k_{12}\, f'_{sj}$$





Notch notation

AS1720.1 Notch design for timber

- k_1 to k_{12} refer to reduction factors for timber
- $F_{s\,j}^{'}$ refers to the shear strength parallel to the grain
- The coefficient g_{40} is used to account for a taper cut away from the re-entrant corner

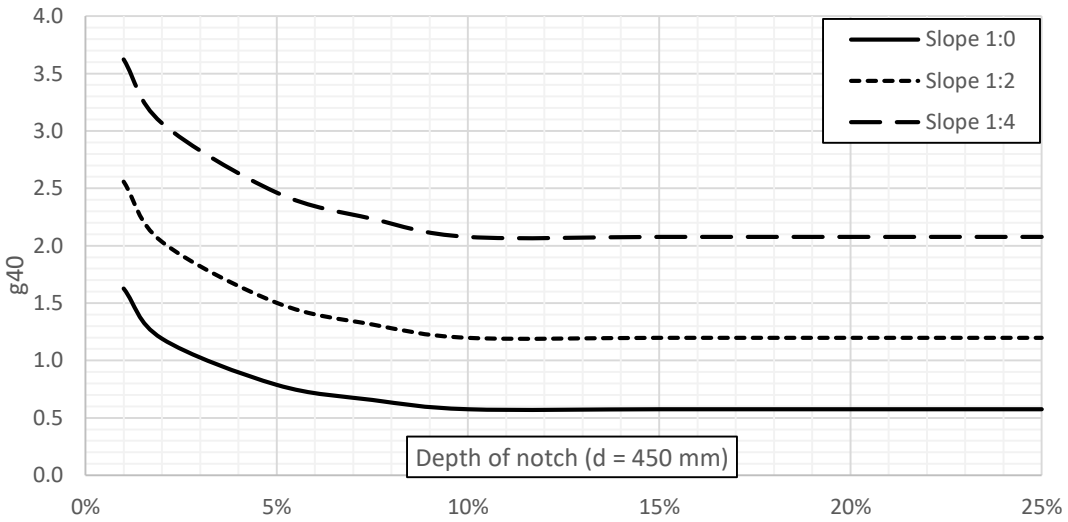
TABLE E8

COEFFICIENT g_{40} FOR SAWN NOTCH ON BEAM EDGE

Notch angle slope (see Figure E8)	g_{40}	
	$d_{notch} \geq 0.1d$	$d_{notch} < 0.1d$
$l_{notch}/d_{notch} = 0$	$9.0/d^{0.45}$	$3.2/d_{notch}^{0.45}$
$l_{notch}/d_{notch} = 2$	$9.0/d^{0.33}$	$4.2/d_{notch}^{0.33}$
$l_{notch}/d_{notch} = 4$	$9.0/d^{0.24}$	$5.2/d_{notch}^{0.24}$

NOTE: l_{notch}, d_{notch} and d are to be stated in millimetres (see Figure E8).

AS1720.1-2010

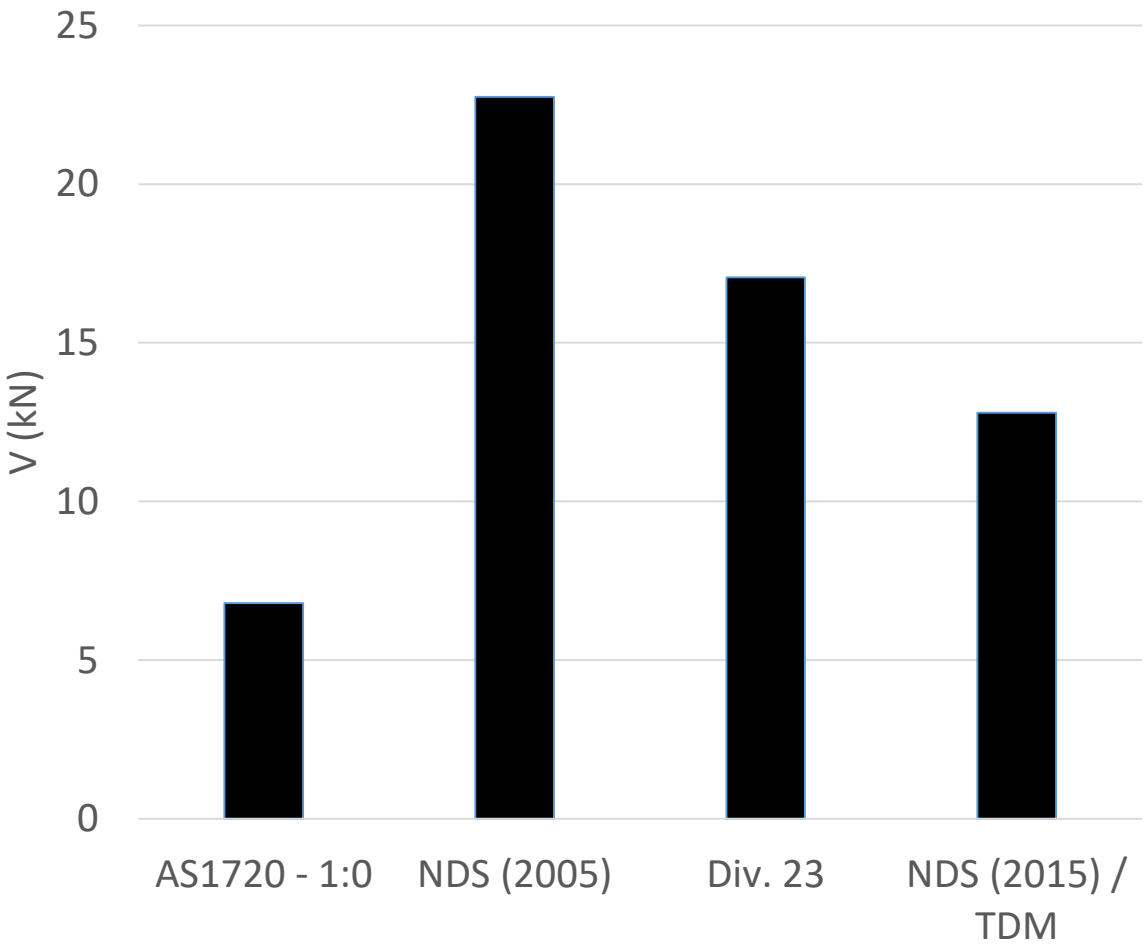


Coefficient g_{40} for a 450 mm round girder

Other methods for round notched sections

AS1720.1-2010**	$f_b + 4 \cdot f_s \leq \emptyset\, g_{40}\, f'_{sj}$
National Design Specifications (2005)	$V = \frac{2}{3} A \cdot f_v$
Division 23 Building Regulations	$V = \frac{2}{3} \cdot A_n \cdot f_v \left(\frac{d_n}{d}\right)$
National Design Standards (2015) / Timber Designers Manual	$V = \frac{2}{3} F'_v A_n \left(\frac{d_n}{d}\right)^2$

***Assumes notch hard against corbel*



Design loads for a 100 mm round section with a stepped notch of 25 % depth

Aim of current research

- To determine the behaviour of round notched timber sections with different slope profiles exposed to the effects of flexure and shear.

- To determine the efficiency of design procedures experimentally for notched round sections with and without tapers

- Creation of accurate numerical models to be able to determine the effects of different notch slopes and strengthening schemes.

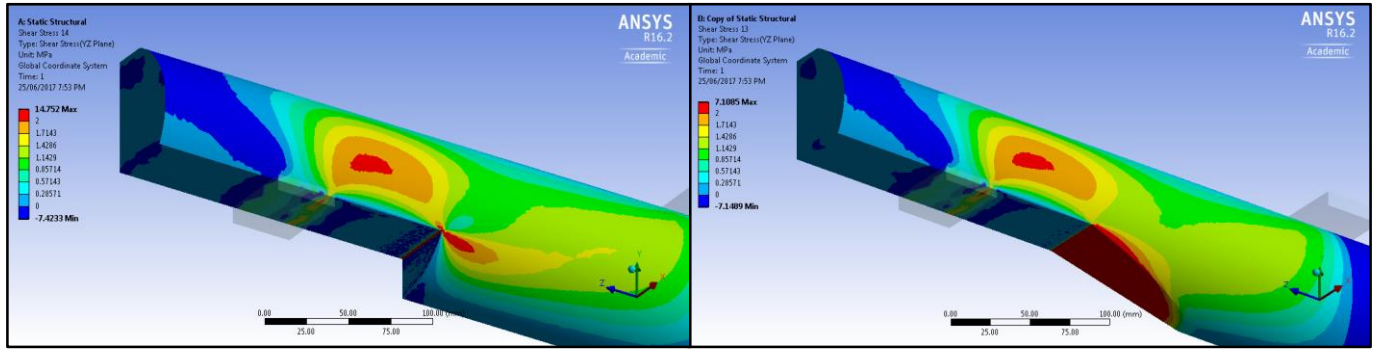
Methodology

Phase 1

- Experimental program of testing involving rectangular and round notched timber members of different slope profiles.

Phase 2

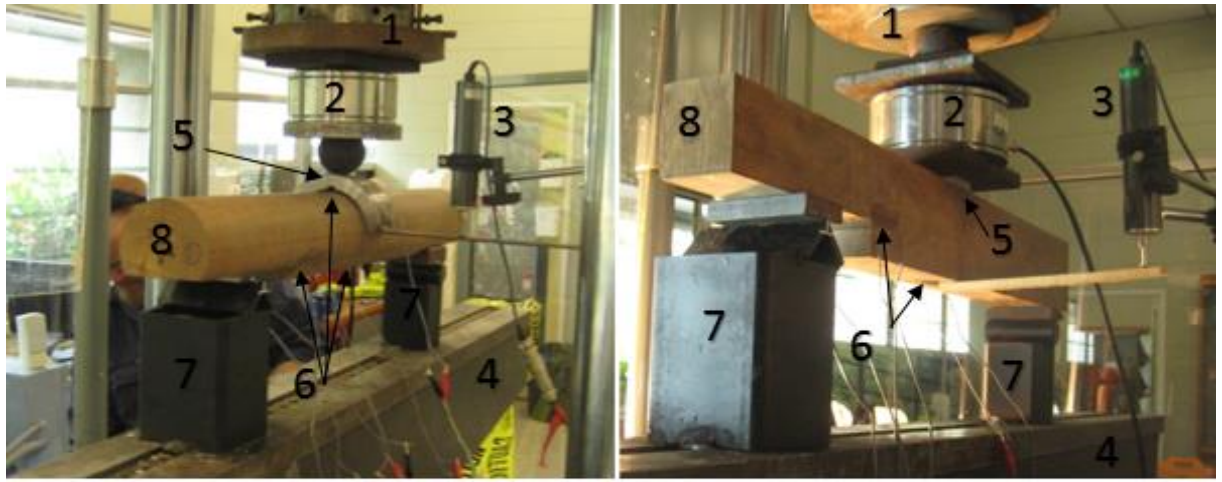
- Finite Element Analysis using ANSYS modelling software to create an orthotropic model for further parametric study.



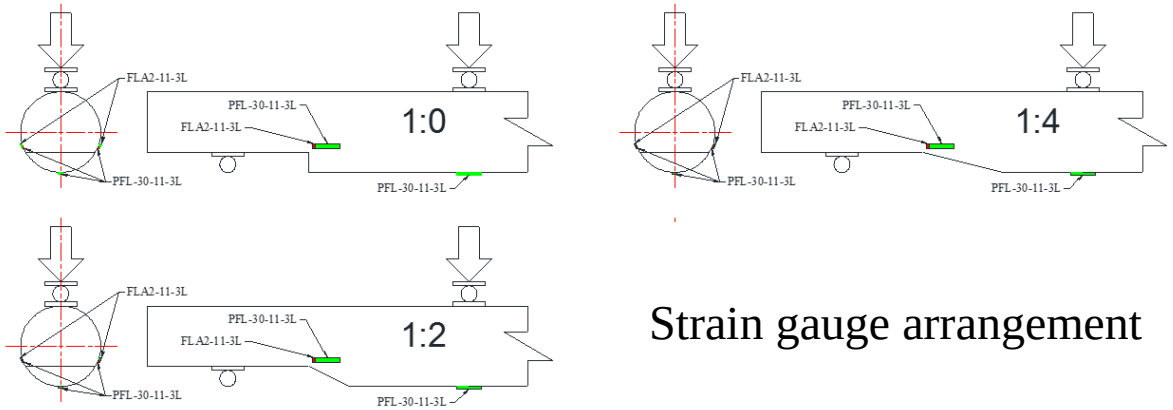
Experimental program

Materials and apparatus

- 3 Point load test similar to that found in AS4063.1-2010 to determine beam shear strength
- LVDT's at mid span to measure deflection
- Strain gauges were used to clarify time of failure
- Load rate of 10 kN/min



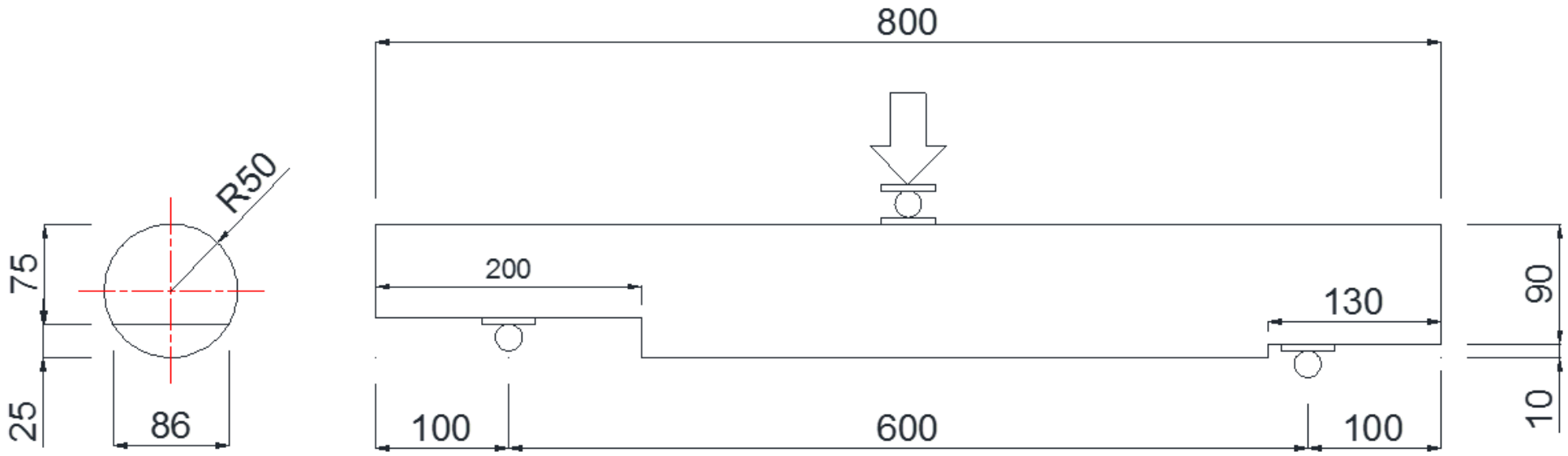
1. MTS
2. Load cell
3. LVDT
4. Reaction frame
5. Loading plate
6. Strain gauges
7. Supports
8. Specimen



Strain gauge arrangement

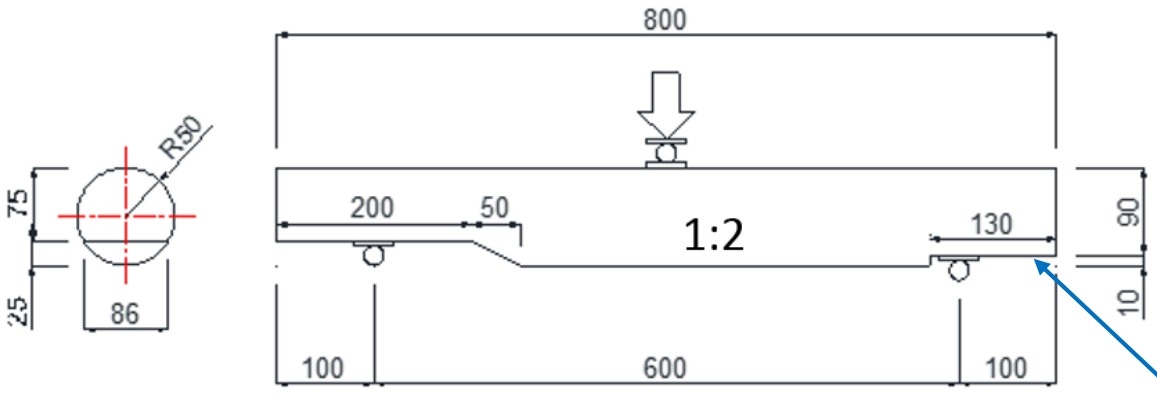
Experimental program: Control tests

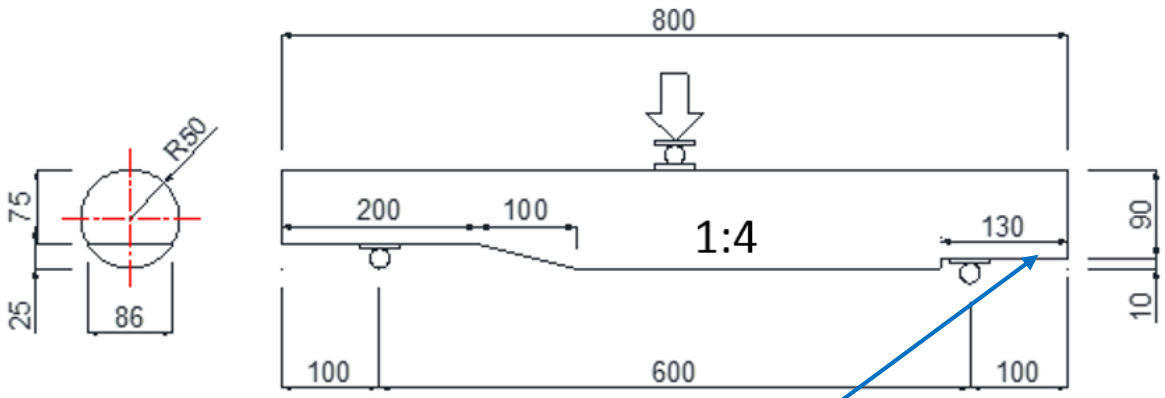
- All specimens Corymbia maculata (Spotted Gum)
- 7 round specimens, 4 rectangular specimens
- Purchased in a box heart profile and turned round on a timber lathe. Notches were created using a milling machine



Tapered notch 1:2 & 1:4

- Tapers of 1:2 and 1:4 were created for study for both rectangular and round profiles
- 4 specimens of each profile





Small notch for seating purposes

Experimental results: Failure types

Failure stages

Mode 1: Initial notch cracking

- Due to tension perpendicular to the grain
- Not very obvious when not under load. Any cracks virtually disappear when not under load

Mode 2: Notch shear failure

- Sudden brittle rupture
- Sudden increase in deflection
- Sudden opening at notch

Ultimate failure of remaining section

- Compressive
- Flexural
- Shear

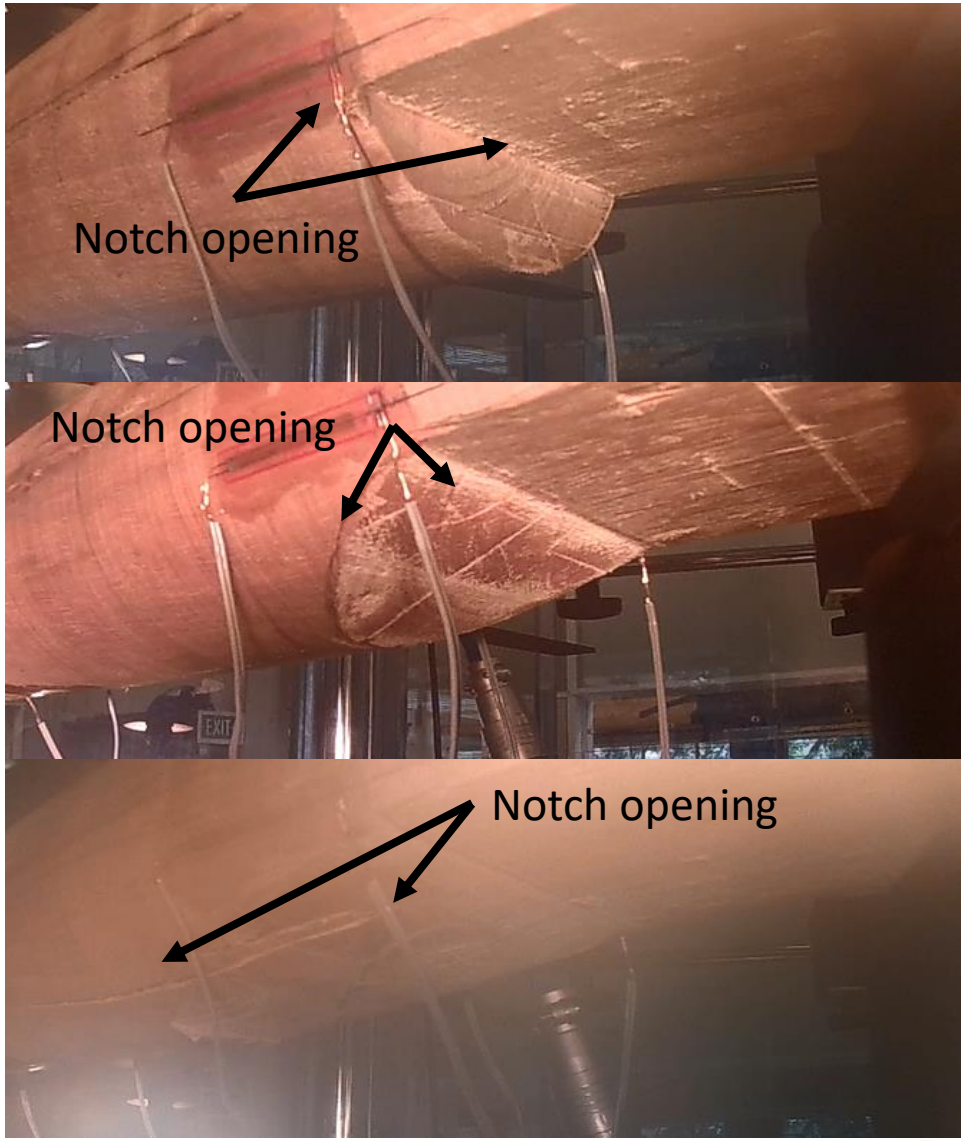
Mode 1 failure: Initial notch cracking

Stepped notch

- Hairline crack which always followed the reentrant corner
- Was difficult to visually observe tension failure but very obvious on the strain plots

Tapered notch 1:2 & 1:4

- Sometimes occurred at reentrant corner but quite often occurred on sloping face
- Was often not visually observed and often occurred simultaneously with mode 2 shear failure



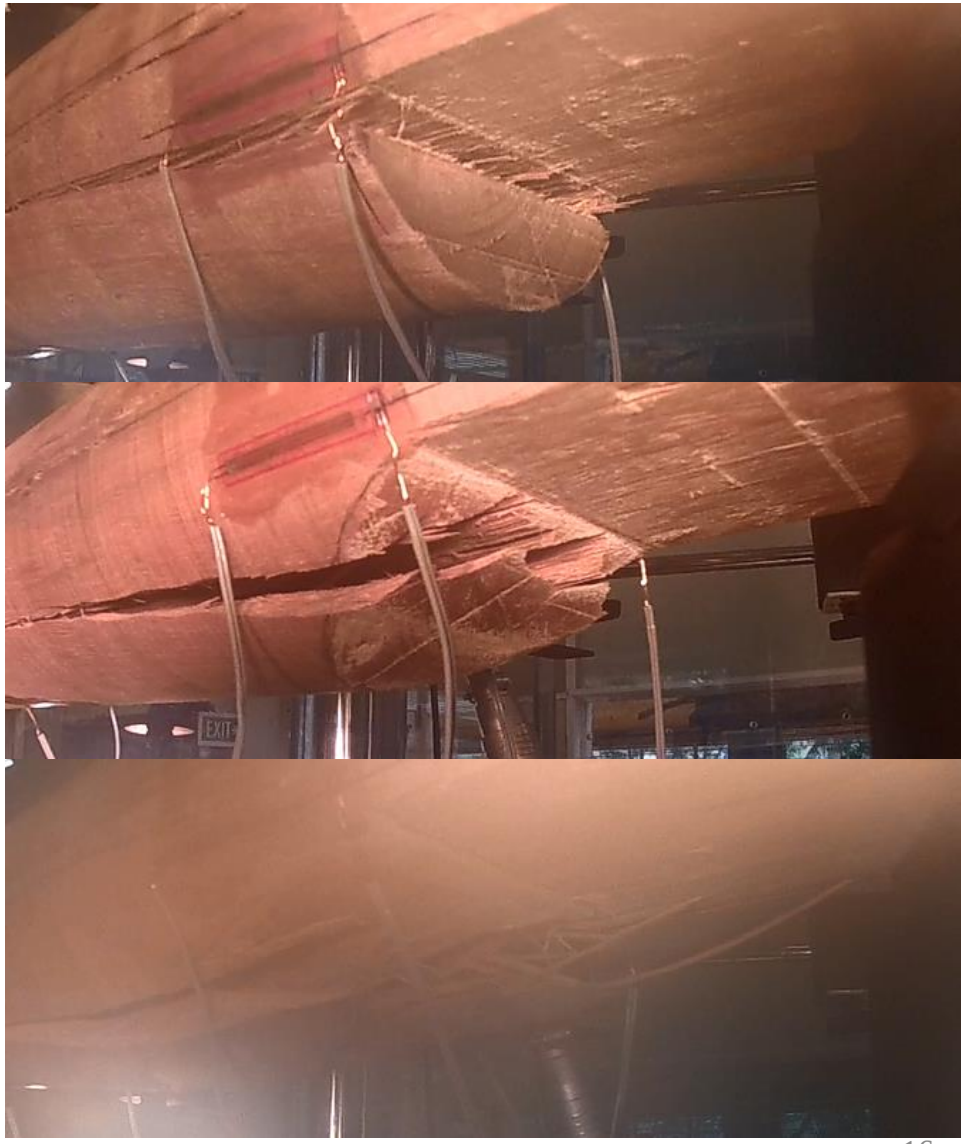
Mode 2 failure: Shear notch failure

Stepped notch

- After hairline crack had propagated shear sliding would occur in a plane directly in line with the notch
- Sudden brittle crack extended to a point below the load point

Tapered notch 1:2 & 1:4

- Very sudden brittle failure often simultaneously with initial mode 1 failure with the crack extending to a point below the load.
- Sometimes occurred at reentrant corner but quite often occurred on sloping face radially from below the heart



Load vs. Deflection

Stepped notch 1:0

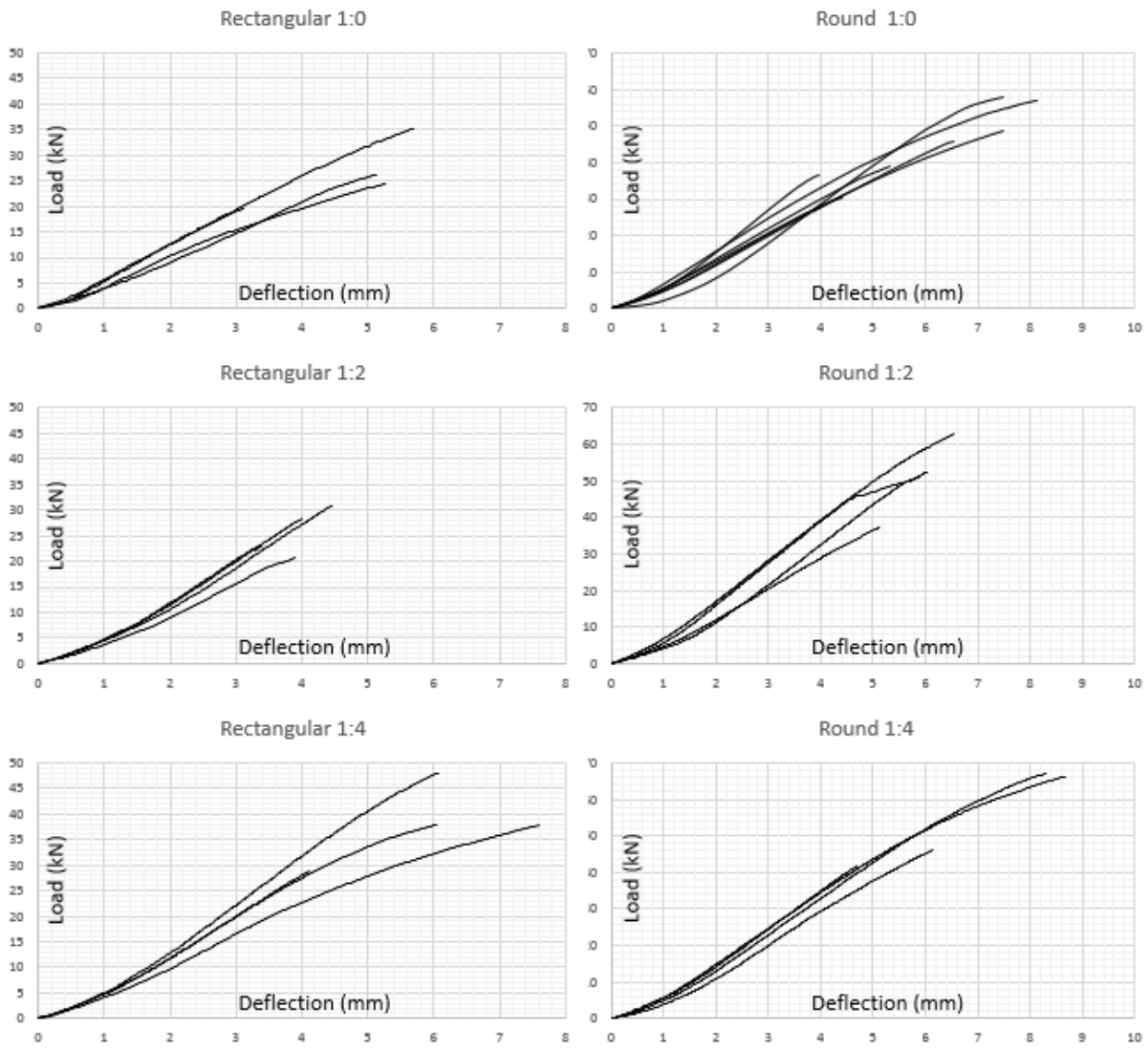
- Lowest average member capacities for both rectangular and round profiles.
- Commonly a two stage failure with an initial mode 1 followed by a sudden brittle mode 2 failure.

Tapered notch 1:2

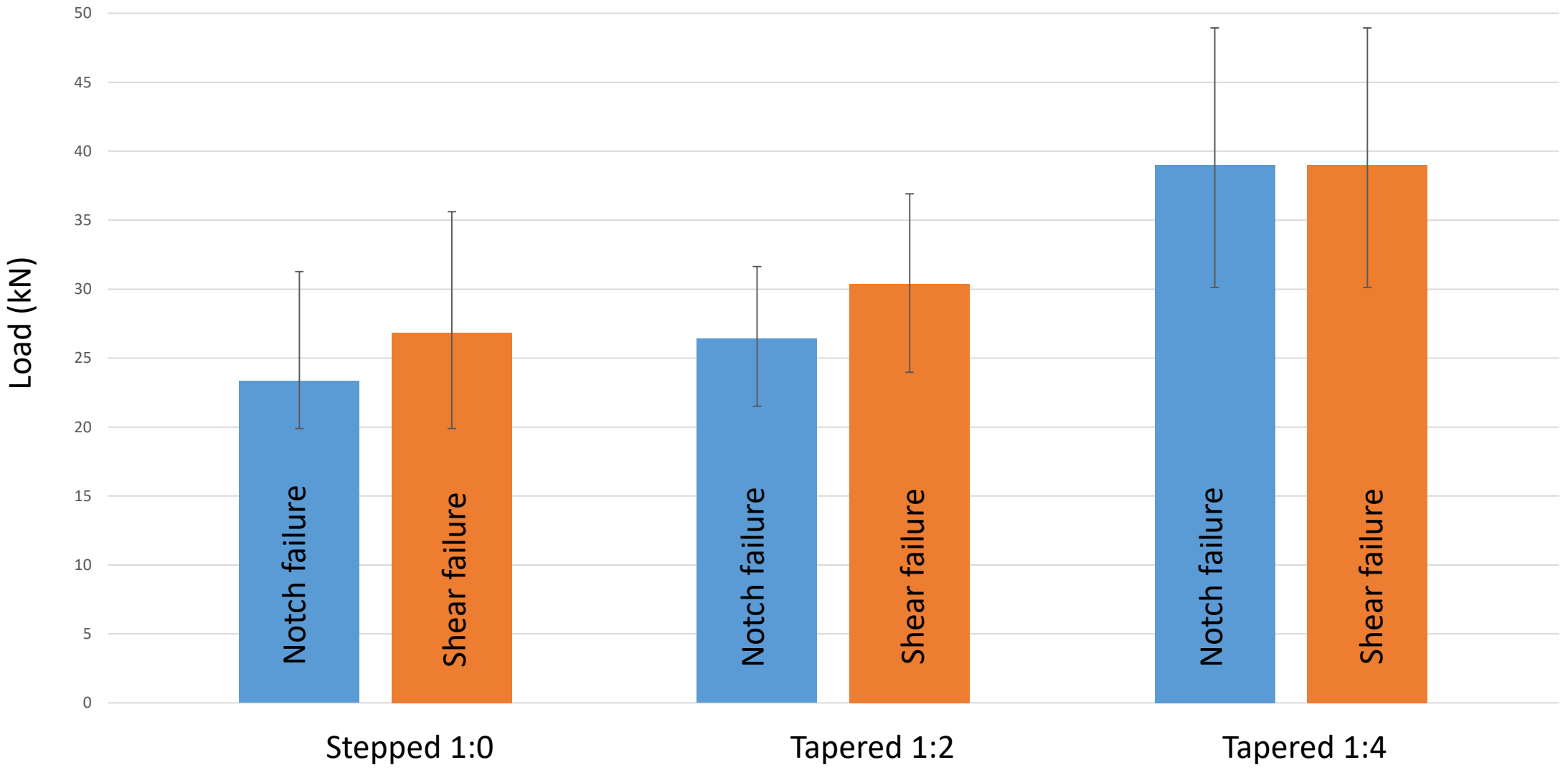
- No yield in this profile indicating sudden brittle mode 2 shear failure
- Some mode 1 crack propagation prior to mode 2 shear failure
- Failed higher on the cut face than the 1:4

Tapered notch 1:4

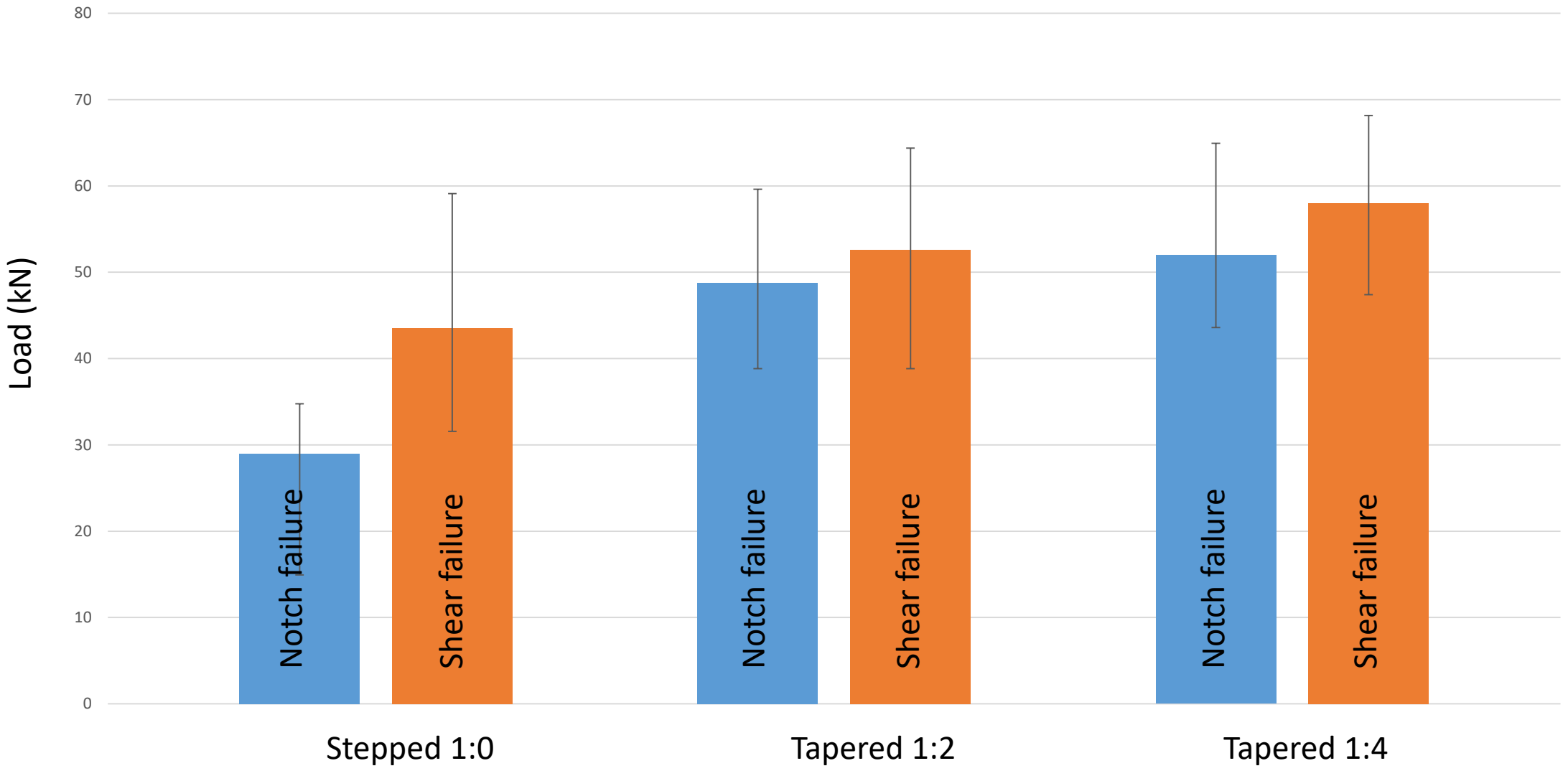
- Very little load difference in load between Mode1 and Mode 2 failure
- Delayed both mode 1 and mode 2 failure
- Commonly failure site was on the sloping cut face away from the re-entrant corner



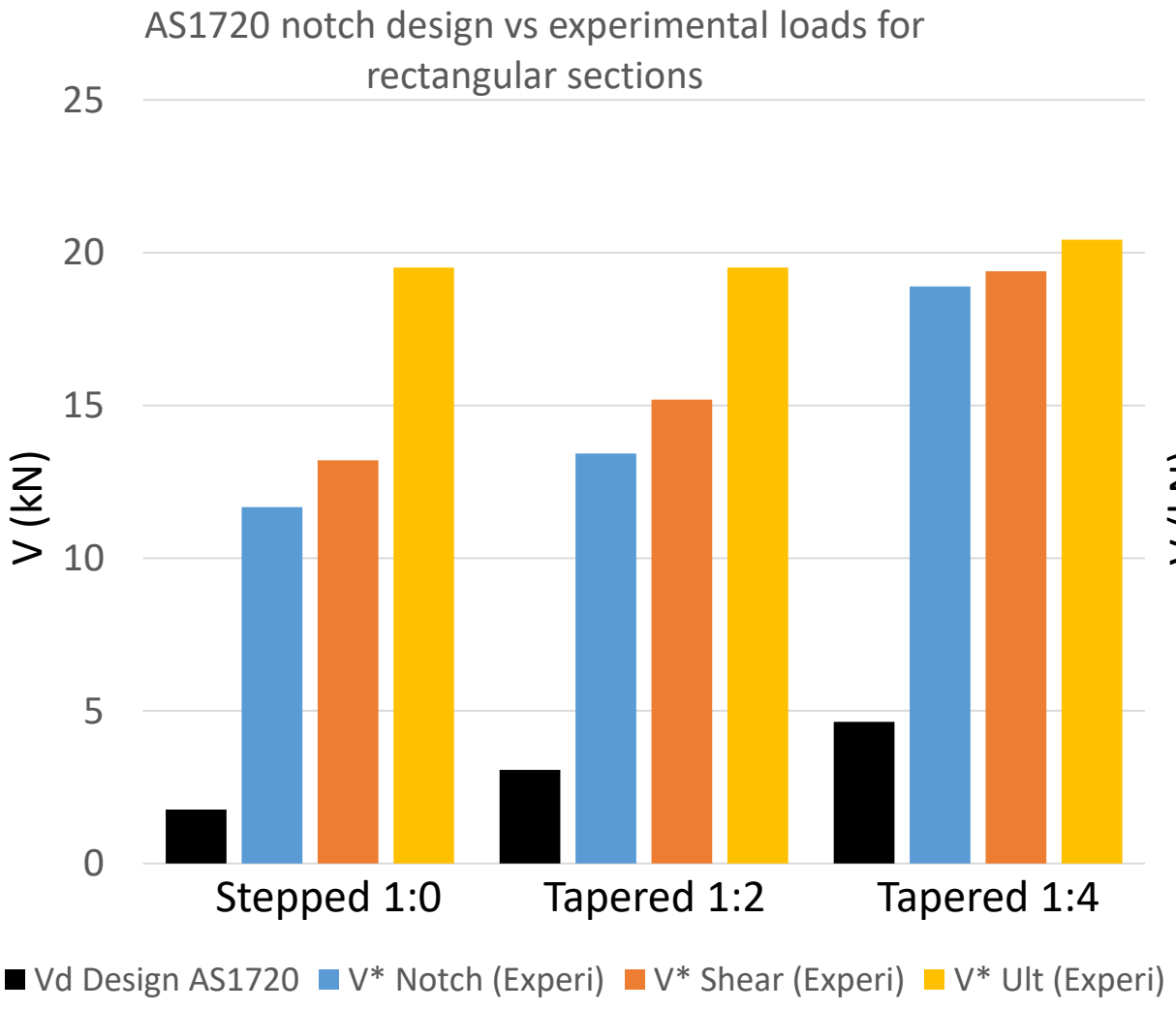
Rectangular experimental capacities

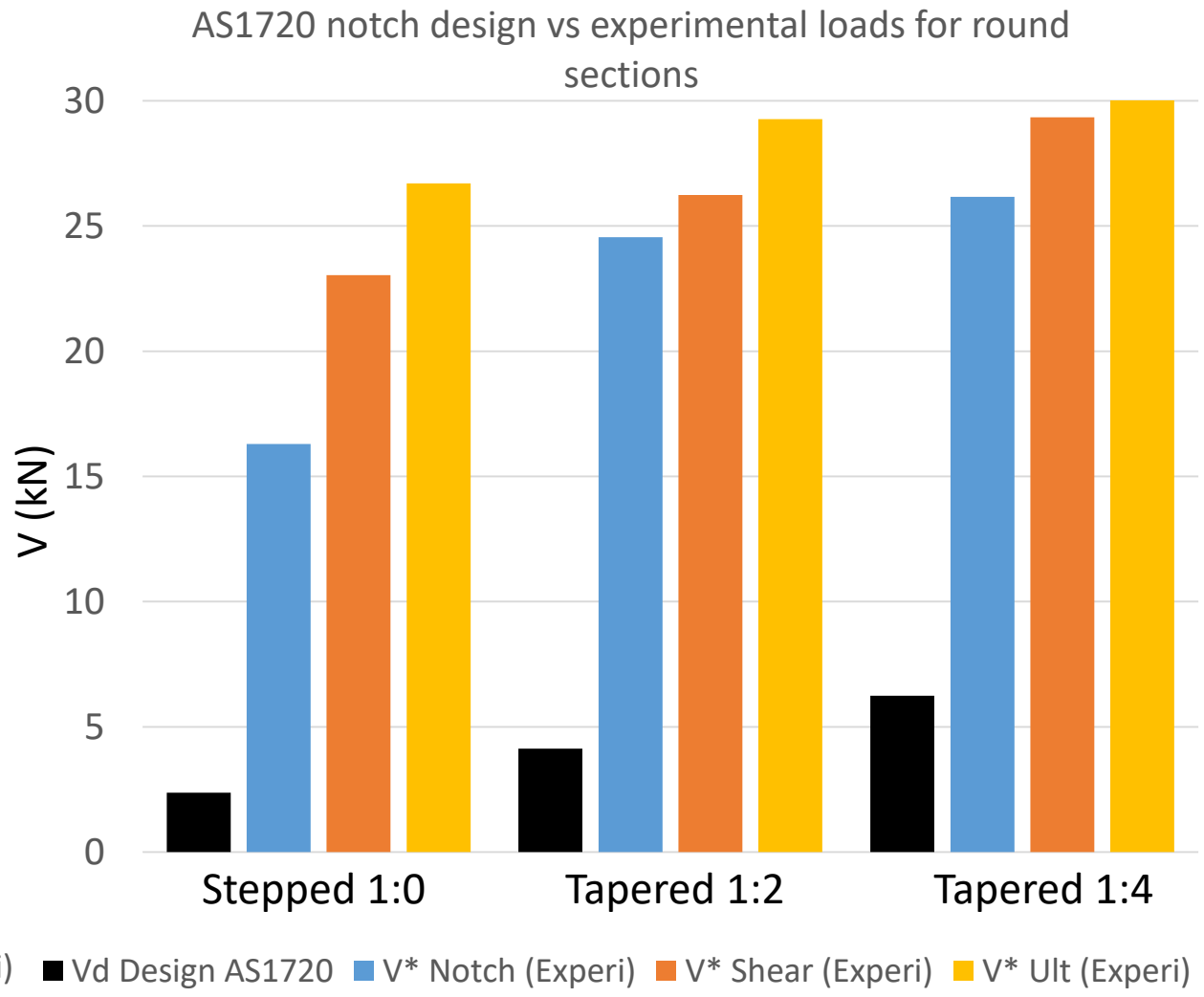


Round experimental capacities

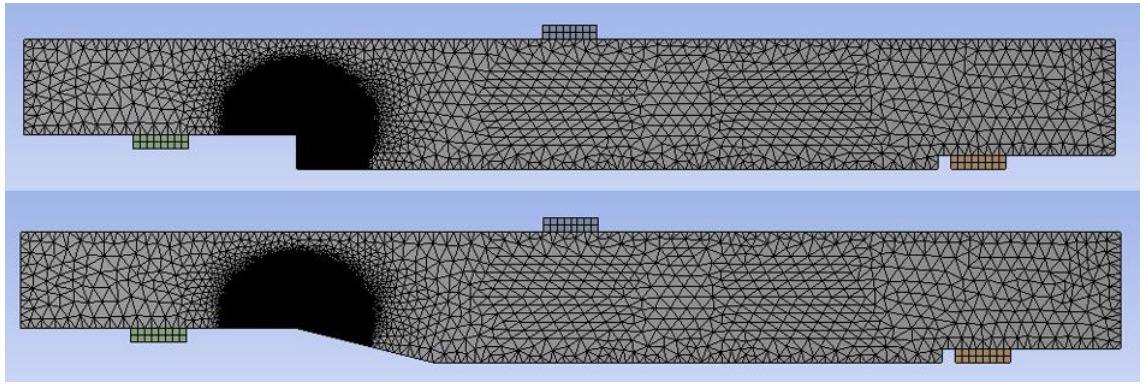


Comparison of capacities





FEA Program (ANSYS)



Models

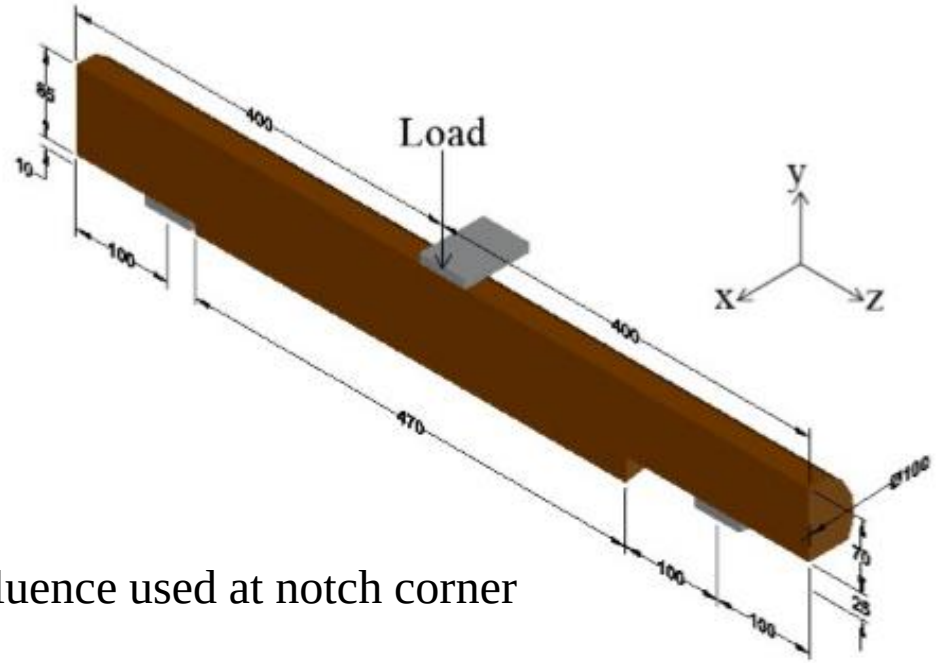
- Both rectangular and round sections in the same profiles as those used experimentally (Stepped 1:0, Tapered 1:2, Tapered 1:4)
- Mode 1 average failure load **32 kN**
- Mode 2 average failure load **46.5 kN**

Material properties

- Spotted gum material properties
- Modeled as an orthotropic material
- Assumed no defects and homogenous

Contact details

- Timber as deformable material
- Frictional contacts between timber and steel



Mesh

- Sphere of influence used at notch corner

Boundary conditions

- Roller and pin simulated at supports
- Frictionless supports for cross-section

Mode 1 FEA model verification

Loads determined experimentally

- Avg. mode 1 notch opening for stepped notches: 32.0 kN

Experimentally observed:

- **Stepped notch** displayed hairline cracks at the re-entrant corner
- **Tapered notch** mode 1 failure did not always occur before mode 2 failure. When mode 1 was observed it occurred lower on the sloping face

Numerically observed:

- **Stepped notch** displayed stress concentrations (shear, tension perp) in the same regions as those seen in the experimental study being confined to the re-entrant corner
- **Tapered notches** still displayed tension perp at the notch but magnitude was significantly reduced. Tension perp was also distributed over a much larger region of the sloping face

Mode 2 FEA model verification

Loads determined experimentally

- Avg. mode 2 shear sliding for stepped notches: 46.5 kN

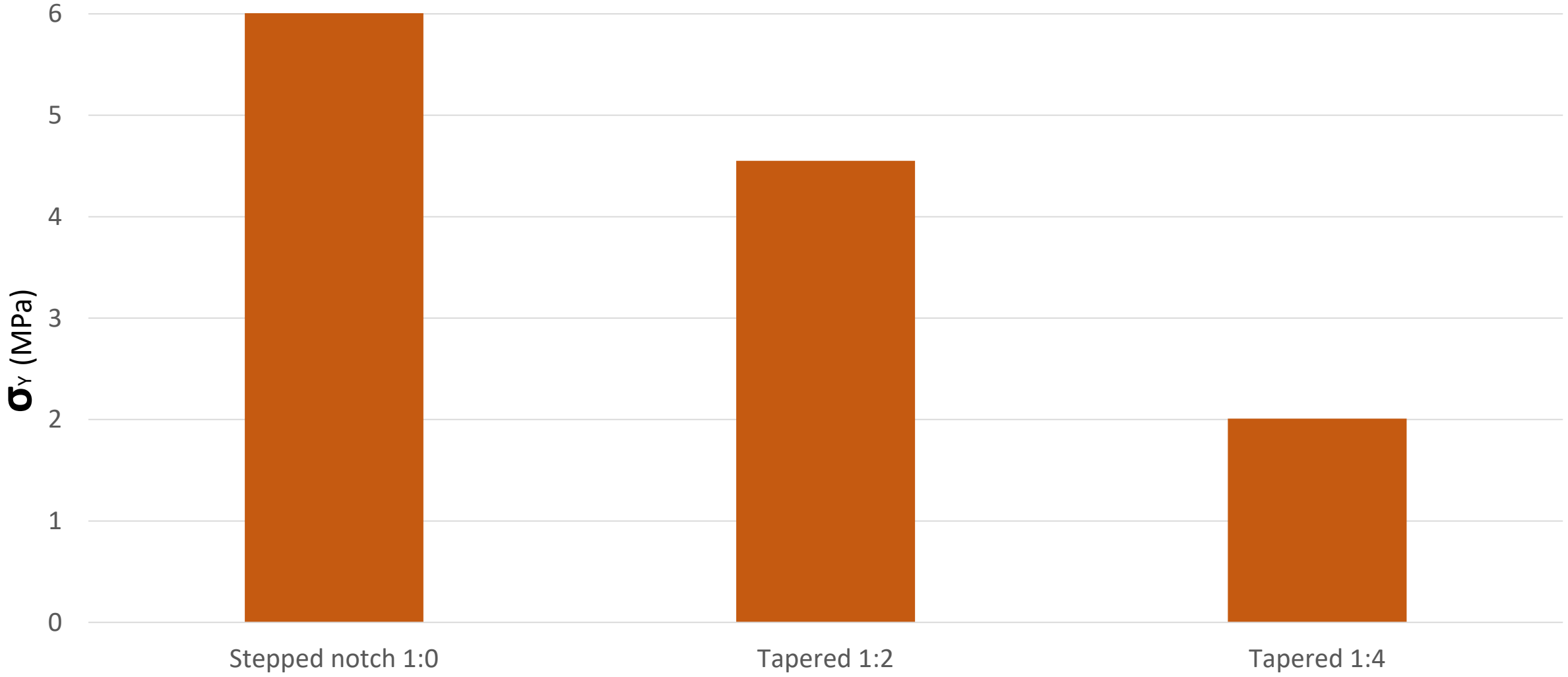
Experimentally seen:

- **Stepped notch:** Shear sliding and tensile failure occurred in a brittle manner for stepped notches always starting from the hairline crack at the re-entrant corner in the same plane as the seating cut
- **Tapered notch:** Mode 2 shear sliding was delayed in tapered notches. Shear failure occurred lower on the sloping face and followed the grain to below the load point in a sudden manner

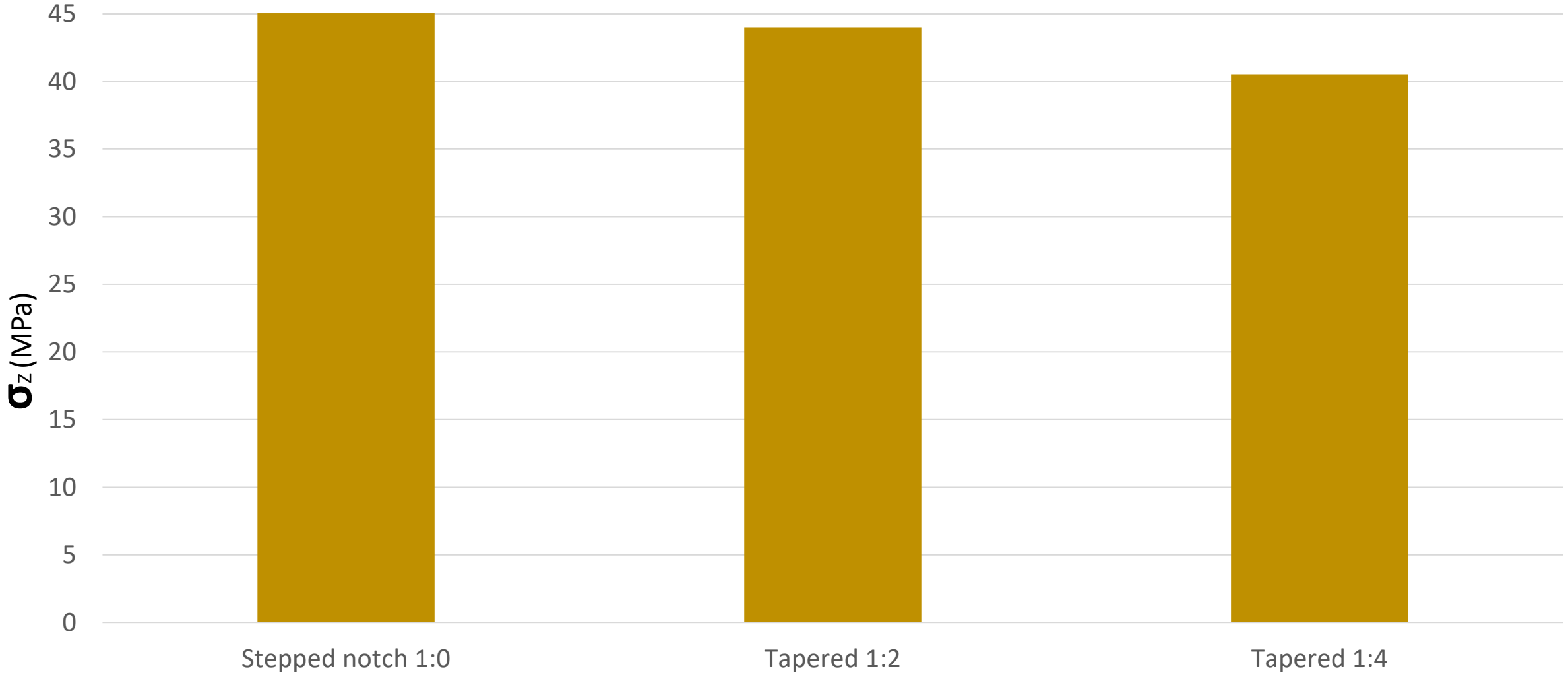
Numerically seen:

- **Stepped notch** developed high shear stresses propagating from the notch to the centre along the plane of the seat cut
- **Tapered section** displayed slower shear stress development
- **Tapered section** showed a reduction in the magnitude of stress concentrations

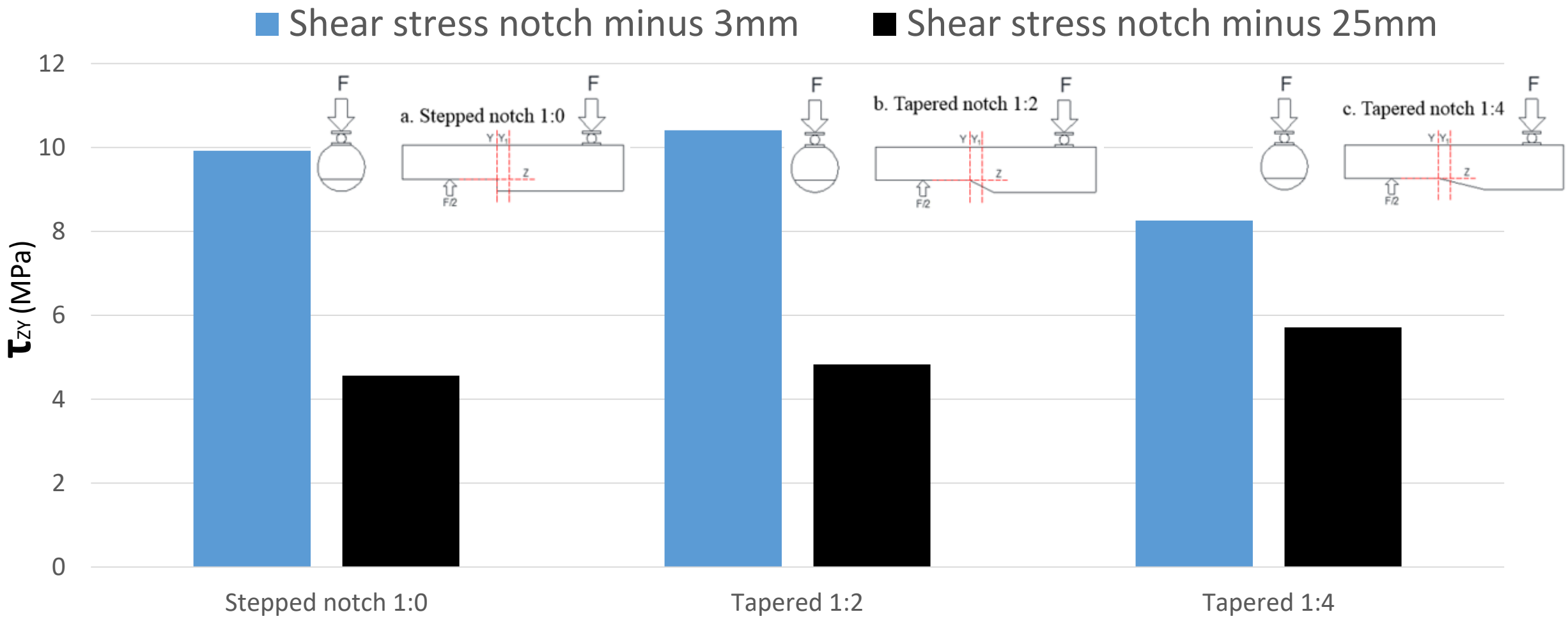
Tension stress perpendicular to the grain at notch



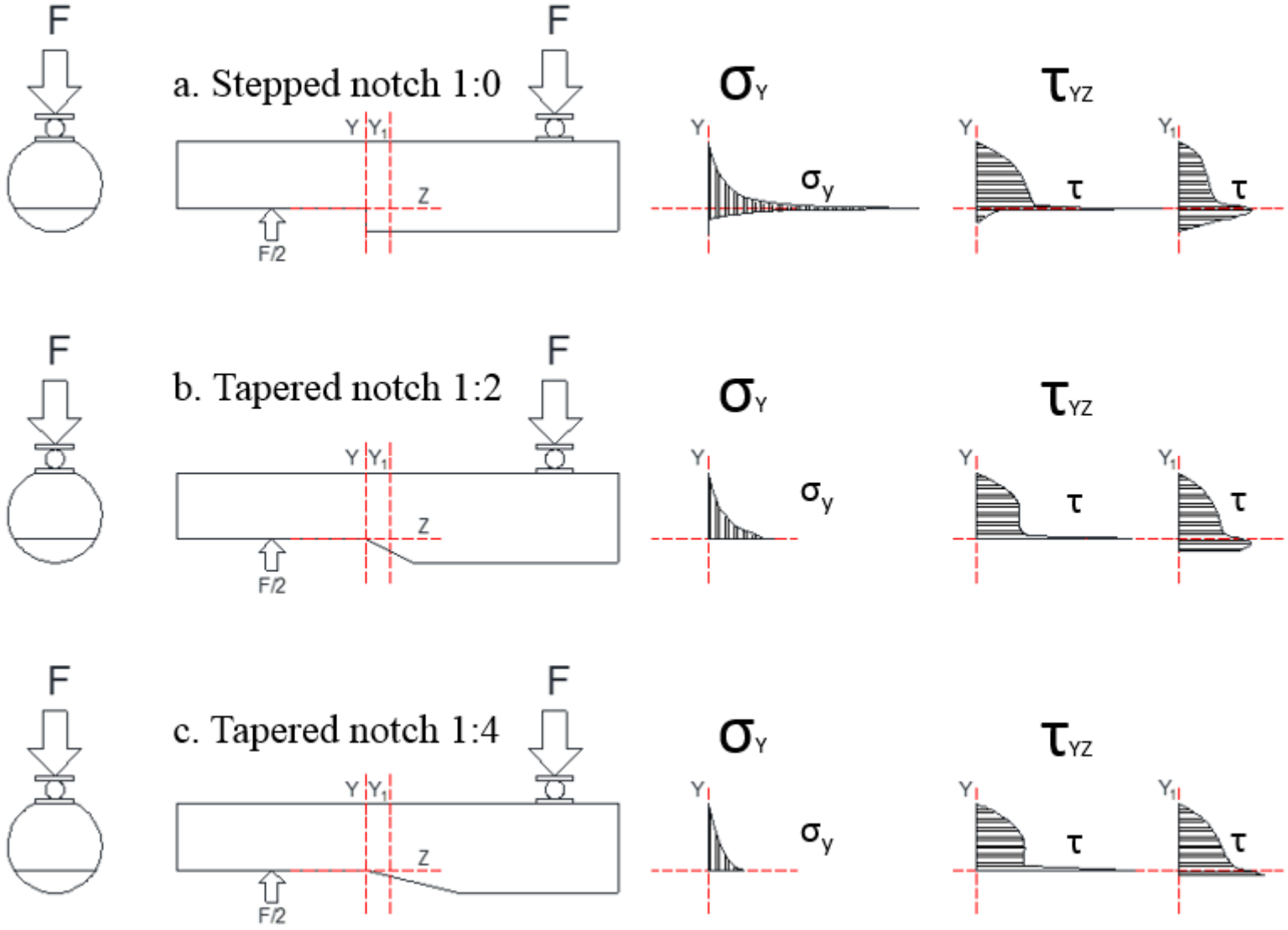
Tension stress parallel to the grain at Notch



Shear stress parallel to the grain

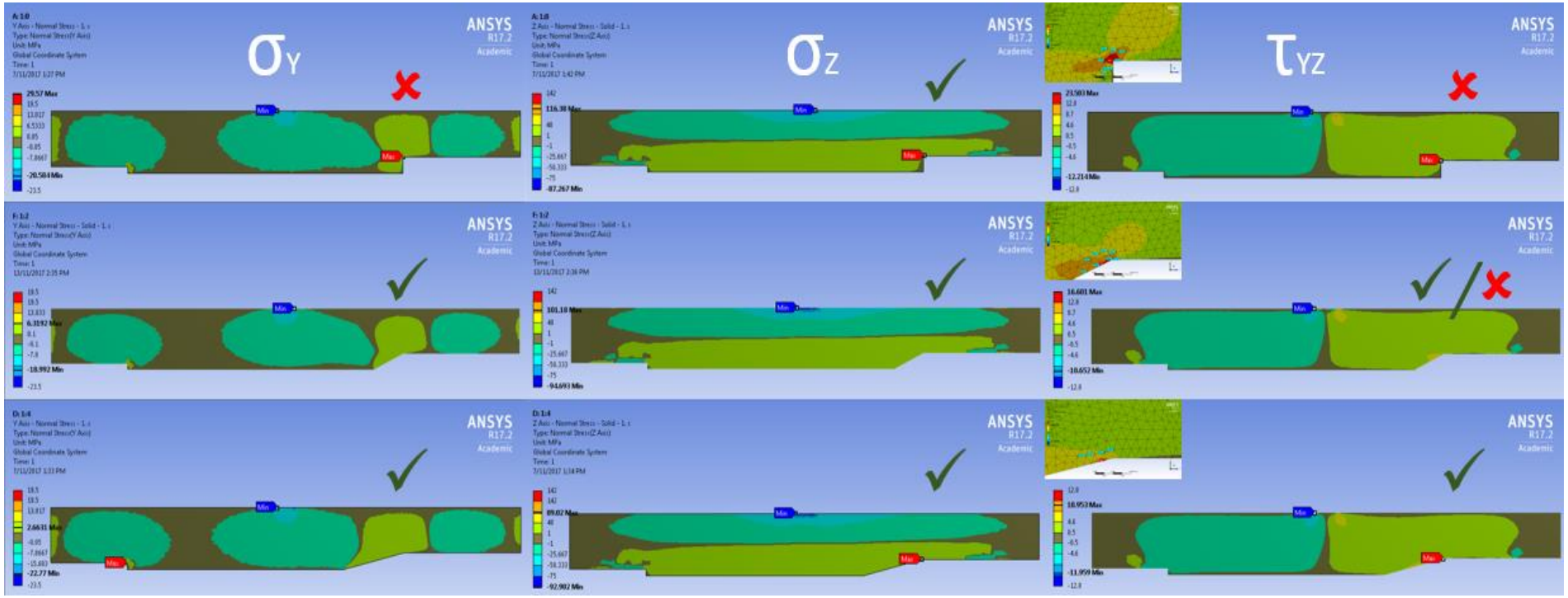


Stress profiles at mode 1 notch failure (32 kN)



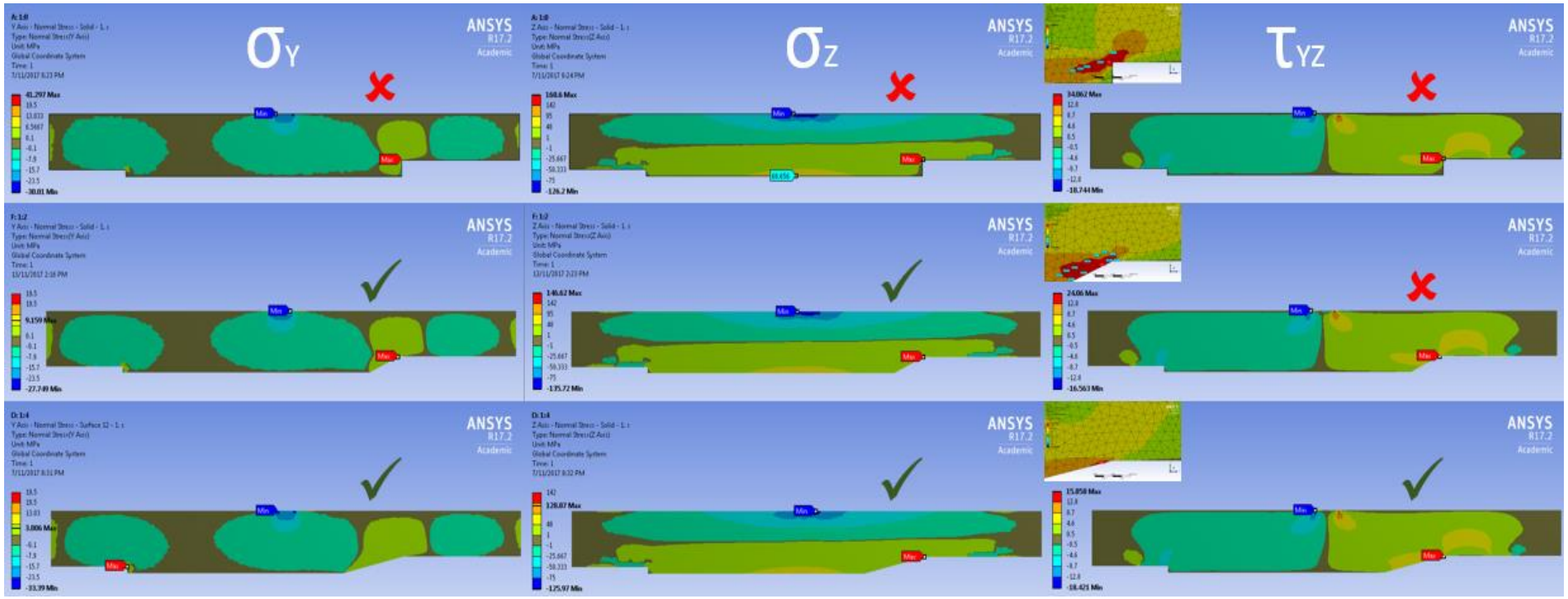
FEA findings at notch opening load (32.0 kN)

- Both tension perp and shear exceed values in a stepped notch for Spotted gum indicating failure
- Shear parallel is exceeded in the 1:2 profile while tension perp is under failure values
- Parallel to the grain tension stress does not appear to be a cause of failure in any profile at loads that cause mode 1 failure opening



FEA findings at shear failure load (46.5 kN)

- A 1:0 slope fails in all stress profiles at the mode 2 failure load
- At a slope of 1:2, shear stress exceeds failure values but tension perp is under failure values
- At a slope of 1:4 all stress values are under failure stress indicating successful negation of stress concentrations



Conclusion and findings

- Tapering of the notch at 1:4 reduces the tension stress perpendicular to the grain at the notch allowing the section to potentially reach its full shear capacity
- From experimental analysis, AS1720.1-2010 using round section properties is the most conservative design method for round notched sections
- Tapered notch profiles delayed initial notch cracking due minimising the effects of tension perpendicular to the grain
- Tapered notches significantly increase mode 2 shear capacity
- Numerical modelling of round orthotropic timber sections is possible and shows where failure is likely to occur

Acknowledgements

- Dr Rabin Tuladhar (Supervisor)
- Scott Anderson from Rockfield for creating the round sections
- QR for their continuing support