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
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.
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 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 snipped 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.

\[
\frac{6 M^*}{bd_n^2} + \frac{6 V^*}{bd_n} \leq \phi g_{40} k_1 k_4 k_6 k_{12} f_{sj}
\]

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

\[
f_b + 4 \cdot f_s \leq \phi g_{40} k_1 k_4 k_6 k_{12} f_{sj}
\]
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**

<table>
<thead>
<tr>
<th>Notch angle slope (see Figure E8)</th>
<th>$g_{40}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$d_{notch} \geq 0.1d$</td>
</tr>
<tr>
<td>$l_{notch}/d_{notch} = 0$</td>
<td>9.0/d$^{0.45}$</td>
</tr>
<tr>
<td>$l_{notch}/d_{notch} = 2$</td>
<td>9.0/d$^{0.33}$</td>
</tr>
<tr>
<td>$l_{notch}/d_{notch} = 4$</td>
<td>9.0/d$^{0.24}$</td>
</tr>
</tbody>
</table>

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

Depth of notch (d = 450 mm)
### Other methods for round notched sections

<table>
<thead>
<tr>
<th>Standard/Manual</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AS1720.1-2010</strong></td>
<td>$f_b + 4 \cdot f_s \leq \varnothing g_{40} f_{sj}$</td>
</tr>
<tr>
<td>National Design Specifications (2005)</td>
<td>$V = \frac{2}{3} A \cdot f_v$</td>
</tr>
<tr>
<td>Division 23 Building Regulations</td>
<td>$V = \frac{2}{3} A_n \cdot f_v \left( \frac{d_n}{d} \right)$</td>
</tr>
<tr>
<td>National Design Standards (2015) / Timber Designers Manual</td>
<td>$V = \frac{2}{3} F'_v A_n \left( \frac{d_n}{d} \right)^2$</td>
</tr>
</tbody>
</table>

**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
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
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 Mode 1 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

- Stepped 1:0
  - Notch failure: 25 kN
  - Shear failure: 24 kN

- Tapered 1:2
  - Notch failure: 30 kN
  - Shear failure: 32 kN

- Tapered 1:4
  - Notch failure: 40 kN
  - Shear failure: 40 kN
Round experimental capacities

- Stepped 1:0
  - Notch failure
  - Shear failure

- Tapered 1:2
  - Notch failure
  - Shear failure

- Tapered 1:4
  - Notch failure
  - Shear failure
Comparison of capacities

AS1720 notch design vs experimental loads for rectangular sections

- Vd Design AS1720
- V* Notch (Experi)
- V* Shear (Experi)
- V* Ult (Experi)

Stepped 1:0, Tapered 1:2, Tapered 1:4

AS1720 notch design vs experimental loads for round sections

- Vd Design AS1720
- V* Notch (Experi)
- V* Shear (Experi)
- V* Ult (Experi)
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 $32 \text{ kN}$
- Mode 2 average failure load $46.5 \text{ kN}$

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
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

- Stepped notch 1:0
- Tapered 1:2
- Tapered 1:4

\( \sigma_Y \) (MPa)
Tension stress parallel to the grain at Notch

σ_z (MPa)

- Stepped notch 1:0
- Tapered 1:2
- Tapered 1:4
Shear stress parallel to the grain

- Stepped notch 1:0
- Tapered 1:2
- Tapered 1:4

Shear stress notch minus 3mm
Shear stress notch minus 25mm
Stress profiles at mode 1 notch failure (32 kN)

a. Stepped notch 1:0

b. Tapered notch 1:2

c. Tapered notch 1:4
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

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