
Scott Munter – Steel Reinforcement Institute of Australia
Mark Patrick – MP Engineers
Vijay Rangan – Curtin University of Technology
Recent Australian Bond Test Results

Overview

- New Design Rules in AS 3600–2009
  - Straight D500N bars
  - Tensile development lengths
  - Tensile lap lengths

- Recent Australian Bond Test Series
  - University of New South Wales
  - University of Queensland
  - Curtin University of Technology (SRIA)

- Australian Bond Test Results
New Design Rules in AS 3600–2009

- D500N Bars to AS/NZS 4671

**Stress**

- Tensile-to-yield-stress ratio $f_u/f_{sy}$
- Tensile Strength $f_u$ (Onset of Necking)

**Yield stress** $f_{sy}$

**Uniform strain** $\varepsilon_u$

**Fracture**

**Strain**
# Recent Australian Bond Test Results

## New Design Rules in AS 3600–2009

- **D500N Bars to AS/NZS 4671**

<table>
<thead>
<tr>
<th>Property</th>
<th>D500N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal diameter (mm)</td>
<td>10 to 40</td>
</tr>
<tr>
<td>Characteristic yield stress (MPa)</td>
<td></td>
</tr>
<tr>
<td>lower</td>
<td>500</td>
</tr>
<tr>
<td>upper</td>
<td>650</td>
</tr>
<tr>
<td>Tensile-to-yield-stress ratio, min.</td>
<td>1.08</td>
</tr>
<tr>
<td>Uniform strain (%) , min.</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Estimate upper characteristic tensile strength = 1.15x650 = 750 MPa = 1.5\(f_{sy}\)
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New Design Rules in AS 3600–2009

**Basic Tensile Development Length:**

\[
L_{sy.tb} = \frac{50k_1 \left[(1.0 - 0.15(c_d - d_b) / d_b\right] f_{sy} d_b}{(132 - d_b)\sqrt{f_c}} \geq 29k_1d_b
\]

\[c_d = \min. (c_1, c_2, a/2)\]

and \(d_b \leq c_d \leq 3d_b\)

**Refined Tensile Development Length:**

\[
L_{sy.t} = [1.0 - K(\sum A_{tr} - \sum A_{tr.min}) / A_s ] [1.0 - 0.04\rho_p] L_{sy.tb} \geq (0.7/k_3)L_{sy.tb}
\]

*Transverse reinforcement term, \(k_4\)*  
*Transverse pressure term, \(k_5\)*
Recent Australian Bond Test Results

New Design Rules in AS 3600–2009

**Basic Tensile Lap Length:**

\[ L_{sy.t.lap} = k_7 \frac{50k_1 \left[ (1.0 - 0.15(c_d - d_b) / d_b \right] f_{sy} d_b}{(132 - d_b)\sqrt{f'_c}} \geq 29k_1d_b \]

- \( c_d = \min. (c_1, c_2, a/2) \)
- \( d_b \leq c_d \leq 3d_b \)

**Refined Tensile Lap Length:**

\[ L_{sy.t.lap} = \left[ 1.0 - K(\sum A_{tr} - \sum A_{tr.min}) / A_s \right] \left[ 1.0 - 0.04\rho_p \right] L_{sy.t.lap} \geq \max. [\left( \frac{0.7}{k_3} \right) L_{sy.t.lap}, 29k_1d_b] \]

*Transverse reinforcement term, \( k_4 \)*

*Transverse pressure term, \( k_5 \)*
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New Design Rules in AS 3600–2009

What minimum tensile stress should anchored or spliced bars be capable of reaching before failure occurs?

In design, it is assumed that the nominal yield stress, \( f_{sy} = 500 \text{ MPa} \), will be reached before the anchorage or splice fails……
but what about in the real structure?
Clause 13.2.6 Welded or mechanical splices

“Welded or mechanical splices formed between Class N reinforcing bars should not fail prematurely in tension or compression before the reinforcing bars, unless it can be shown that the strength and ductility of the concrete member meet the design requirements.”
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New Design Rules in AS 3600–2009

- Any form of splice can reduce bar strength
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New Design Rules in AS 3600–2009

<table>
<thead>
<tr>
<th>Diameter</th>
<th>$f_u$ MPa</th>
<th>$\varepsilon_u$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>664</td>
<td>10.0</td>
</tr>
<tr>
<td>15.1</td>
<td>620</td>
<td>4.5</td>
</tr>
<tr>
<td>14.8</td>
<td>607</td>
<td>3.5</td>
</tr>
<tr>
<td>14.5</td>
<td>590</td>
<td>2.0</td>
</tr>
<tr>
<td>13.9</td>
<td>550</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- 13.9mm notch diameter
- 14.5mm notch diameter
- 14.8mm notch diameter
- 15.1mm notch diameter
- Control Bar – N16

Stress (MPa) vs. Strain (%) graph
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Design principles

\[ 1.25 \times 500 = 625 \text{ MPa} \]
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- University of New South Wales

- 10 conventional slabs in flexure
- Small diameter, widely-spaced D500N12 or N16 bars representative of slabs or walls (min. clear distance 157 mm)
- No staggering
- No transverse reinforcement
- Short lap length (max. approx. 18\(d_b\)) for bond failure
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- University of Queensland

- Unconventional pull-out tests, without flexure to cause bar prying, etc.
- Small diameter, D500N16 bars representative of slabs or walls
- Contact lap splices
- No staggering
- Transverse bars present in 3 of these tests, but presence should be ignored in design since on wrong side of main bars
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests

4 N24 contact lap splices without transverse reinforcement
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests

Test lap length = 900 mm, while AS 3600–2009 design

\[ L_{sy.tb.lap} = 930 \text{ mm if use nominal } f'_{c} \text{ and } k_{7}=1.0 \]
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Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests
Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests

Face splitting & Edge side splitting
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests

6 N24 contact lap splices without transverse reinforcement
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests

Side splitting
Recent Australian Bond Test Results

Recent Australian Bond Test Series

- Curtin University of Technology – SRIA tests

Bar prying
Recent Australian Bond Test Results

Australian Bond Test Results

- American Concrete Institute (ACI) Database

![Graph showing recent Australian bond test results](image)

1.5$f_{sy}$ bar fracture
Recent Australian Bond Test Results

Australian Bond Test Results

- American Concrete Institute (ACI) Database

ACI DATA BASE - BOTTOM BARS, NO TRANSVERSE REINFORCEMENT

Ultimate Bond Stress / AS 3600-2009 Design Ultimate Bond Stress

1.5$f_{sy}$ bar fracture

5% Failure Rate
Australian Bond Test Results

- University of New South Wales

Recent Australian Bond Test Results

Graph showing ultimate bond stress compared to design ultimate bond stress for ACI 318-08 and AS 3600-2009. The graph highlights a fracture condition at 1.5 times the yield stress ($1.5f_{sy}$) bar fracture.
Recent Australian Bond Test Results

Australian Bond Test Results

- University of Queensland

![Graph showing bond stress results](image)
Australian Bond Test Results

- Curtin University of Technology – SRIA tests
Recent Australian Bond Test Results

Bond Test Results & Conclusions

- UNSW & UQ tests were designed to replicate slabs & walls incorporating small diameter bars (D500N12 & 16)
- Results of UNSW and UQ tests on small diameter (N12 & N16) bars, with very high mean AS 3600–2009 test/design ratios of $2.1 f_{sy}$ and $1.8 f_{sy}$, respectively, indicate that factor $k_2=(132-d_b)/100$ could possibly be increased
- SRIA tests on beams with D500N24 bars performed by Curtin University also indicate $1.25 f_{sy}$ is more realistic
- ACI database shows that $1.25 f_{sy}$ is a much more realistic target achieved using AS 3600–2009 under non-seismic conditions, which serves as a ductility criterion for spliced D500N bars generally

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