REINFORCEMENT

Manufacture, Processing, Quality & Welding

© SRIA 2020
SRIA promotes Good Design & Detailing

Detailing must allow fabrication

Detailing of reinforcement is the interface between the actual design of the concrete structure and what is to be constructed

Sufficient details must be shown on drawings

Designers must be aware of the practical limitations of construction
SRIA promotes Good Design & Detailing
Severely corroded and pitted steel should not be used unless the material has been checked for strength and cross-sectional area limitations (TN1).
Development and Lap Splice Lengths

New SRIA Technical Note TN7

Note: Basic Tables contained in Detailing Handbook
Development and Lap Splice Lengths

New design rules in AS 3600 – Section 13 Tensile development length

**Basic**

\[ L_{sy.tb} = \frac{0.5k_1k_3f_{sy}d_b}{k_2\sqrt{f_c'}} \geq 0.058f_{sy}k_1d_b \quad (f_c' \leq 65 \text{ MPa}) \]

×1.5 for epoxy-coated bars
×1.3 for lightweight concrete

**Importance of** \( k_1 \) (bar location), \( k_2 \) (bar size) and \( k_3 \) (bar spacing)

Anchorage forces create tension in concrete – which can result in splitting
Development and Lap Splice Lengths

New design rules in AS 3600 – Section 13 Tensile development length

**Basic**

\[ L_{sy.tb} = \frac{0.5k_1k_3f_{sy}d_b}{k_2\sqrt{f'_c}} \geq 0.058f_{sy}k_1d_b \]

×1.5 for epoxy-coated bars
×1.3 for lightweight concrete

**Refined**

\[ L_{sy.t} = k_4k_5L_{sy.tb} \]

When calculating \( L_{sy.t} \), minimum 0.058\( f_{sy}k_1d_b \) does not apply to \( L_{sy.tb} \)

**Tensile lap length (basic or refined)**

\[ L_{sy.t.lap} = k_7L_{sy.t} \geq 0.058f_{sy}k_1d_b \]

Clause 13.1.2.1 of AS 3600

\( L_{sy.t} \) shall be calculated from either:

- Clause 13.1.2.2 (basic) - \( L_{sy.tb} \), or
- Clause 13.1.2.3 (refined) - \( L_{sy.t} \)
## Technical Note 7 – Example of General Design Tables

### Stress Development and Lap Splicing of Straight D500N Tensile Reinforcing Bars to AS 3600-2009

#### Table G/20/1.0.100 – Tensile Development and Lap Lengths

<table>
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<th>N10</th>
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### Table G/20/1.0.100 – Minimum Refined Development Length

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</table>

Note: The tabulated theoretical values of minimum refined development length, \( L_{d \text{refinel}} \), and minimum refined lap length, \( L_{\text{refinel} \text{lap}} \), are minimum possible solutions, based on the values of \( \{k_dL_d\} \) in Table C.2. They are useful for indicating the lowest possible values achievable using refined design, but may not be appropriate for a particular design situation. Therefore, if they are less than basic development length, \( L_d \), or basic lap length, \( L_{\text{lap}} \), respectively, then refined design may be beneficial, but a designer must calculate the actual values of \( L_d \) (or \( L_{\text{lap} \text{min}} \)) and/or \( L_{\text{refinel} \text{lap}} \) (or \( L_{\text{refinel} \text{lap} \text{min}} \)).
Guide to Historical Steel Reinforcement in Australia

Available to order from sria.com.au home page

Written to address the volume of technical enquiries in this area

Covers reinforcement dating back to 1895
Past Reinforcement Types

Divided into Chapters based on Industry Developments

Plain round or square  
circa 1895 to 1957  
200 MPa

Square twisted 1957  
410 MPa

Twisted deformed 1963  
CW.60 – 410 MPa

Hot-rolled deformed (QST) 1983  
410 MPa

Microalloy (MA) 1983  
410 MPa

Hot-rolled deformed (QST) 2001  
500 MPa (D500N Bar)

Microalloy D500N 2001

Contistretch D500N 2001
Guide to Historical Steel Reinforcement in Australia

Chapters include:

- Reinforcement properties and developments
- Standards
- Industry Resources
- Concrete Design
- Background to Period
- Symbols Used
- Examples of Drawings
- Project examples

Table A.2 - Suggested Reinforcement Yield Strengths

<table>
<thead>
<tr>
<th>Period</th>
<th>Bars:</th>
<th>Fabric:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1895</td>
<td>International developments before first use of reinforced concrete in Australia.</td>
<td></td>
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<tr>
<td>1895 to 1920</td>
<td>If the proprietary system cannot be established, use 200 MPa unless samples tested.</td>
<td>Assume 380 MPa.</td>
</tr>
<tr>
<td>1920 to 1957</td>
<td>Locally manufactured Hot-rolled plain steel bars or for proprietary systems that cannot be identified, assume 200 MPa unless samples tested.</td>
<td>Assume 380 MPa.</td>
</tr>
<tr>
<td>1957 to 1963</td>
<td>Square Twisted, 410 MPa; Hot-rolled plain or deformed, use 200 MPa unless samples tested. If identifiable, Intermediate grade, 275 MPa and hard grade, 345 MPa.</td>
<td>Pre 1958, assume 380 MPa and Post 1958, assume 450 MPa.</td>
</tr>
<tr>
<td>1963 to 1983</td>
<td>Square Twisted or CW.60, 410 MPa; Hot-rolled plain or deformed, Pre 1965, use 200 MPa and Post 1965, use 230 MPa unless samples tested. If identifiable, Intermediate grade, Pre 1965, use 275 MPa and hard grade, Pre 1973, use 345 MPa.</td>
<td>Assume 450 MPa.</td>
</tr>
<tr>
<td>2001 to 2019</td>
<td>Hot-rolled plain round or deformed bars, use 250 MPa. If deformed high-strength bars are identifiable by the rib pattern, use either 400 MPa or 500 MPa. Note: At the beginning of the period as AS 3600 (2001) included both Grade 400 and 500 bars, it is essential to determine which Grade of bar was used from the design drawings.</td>
<td>Assume 500 MPa.</td>
</tr>
</tbody>
</table>
Billet casting
150 x 150 mm in size
Reinforcement made from recycled metal
Scrap melted in EAF
Billet casting
150 x 150 mm in size
Billets allowed to cool slowly
Steel strength 250 to 300 MPa
Stacked in yard
Manufacturing of Reinforcement - Bars
Straight Quenched and Self Tempered (QST) D500N (12 to 40 mm)

- Rolling to size
- Hot rolling ribbed profile
- Quenching process

Schematic diagram on a Time – Temperature Curve

Tempered Martensite
Ferrite - Pearlite
Microstructure of QST Reinforcing Bars
Coiled Reinforcement

Allows several kilometres of bar in continuous length

10, 12 mm, 16 mm and 20 mm sizes available
Manufacturing Smooth Rod

Hot rolling rod mill – turning billets into smooth rod (R250N)

‘Wild’ coils of smooth rod 5.5 to 16 mm
Cold rolled deformed bar

Produce ribbed bar from smooth round rod
 Increases yield stress to 500MPa

Coil ribbed bar
Mini cassette roller to deform smooth rod into ribbed bar
Coils of smooth rod

Ribbed bar used for mesh and fitments
Mesh Processing

Bars resistance welded into sheets of mesh

Typical mesh-making machine
Mesh Processing

Quality of welding and adequate lap are critical

- Each welded joint develops 50% of the bar’s yield stress
- Overlap mesh sheets a minimum of 2 cross bars

Figure 5.1 from AS 2870

NOTE: The wire orientation is illustrative only.
# Reinforcing Bar Classification

All reinforcing bar to comply with AS/NZS 4671 Steel reinforcing materials

<table>
<thead>
<tr>
<th>AS/NZS 4671 Designation</th>
<th>Yield Stress, MPa</th>
<th>Ductility Class</th>
<th>Description</th>
<th>Typical Size mm</th>
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<tr>
<td>D500N</td>
<td>500</td>
<td>N</td>
<td>Hot-rolled Deformed bar</td>
<td>Coil 10, 12, 16, 20 Straight 12 – 40 Special 50</td>
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<tr>
<td>R250N</td>
<td>250</td>
<td>N</td>
<td>Hot-rolled Plain round</td>
<td>6.5, 10, 12, 16, 20, 24</td>
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<td>N</td>
<td>Hot-rolled Deformed bar</td>
<td>12 (pool steel)</td>
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<td>L</td>
<td>Cold-rolled Deformed bar</td>
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<td>R500L</td>
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<td>L</td>
<td>Cold-drawn Round rod</td>
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# Mechanical Properties (from AS/NZS 4671)

<table>
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<th>Property</th>
<th>500L</th>
<th>500N</th>
<th>Probability of exceedance</th>
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<td>Nominal Diameter (mm)</td>
<td>5 to 12</td>
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<td>Characteristic Yield Stress (MPa), $R_{ek,L}$</td>
<td>500</td>
<td>500</td>
<td>95%</td>
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<td></td>
<td>$R_{ek,U}$</td>
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<td>5%</td>
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<td>Ratio: $\frac{\text{Tensile Stress}}{\text{Yield Stress}} = \frac{R_m}{R_e}$</td>
<td>≥ 1.03</td>
<td>≥ 1.08</td>
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<td>Uniform Elongation, $A_{gt}$ (%)</td>
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<td>≥ 5</td>
<td>90%</td>
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### Stress Strain Curve 500L

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<th>STRESS (MPa)</th>
<th>STRAIN (%)</th>
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### Stress Strain Curve 500N QST

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<td>200</td>
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# Mechanical Properties

**AS/NZS 4671:2019 Steel for the reinforcement of concrete**

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<th>Property</th>
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<th>Probability of exceedance</th>
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<tbody>
<tr>
<td>Characteristic Yield Stress (MPa), $R_{ek,L}$(\frac{R_{ek,U}}{R_{ek,U}})</td>
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<td>750</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>900</td>
<td>5%</td>
</tr>
<tr>
<td>Ratio: $\frac{\text{Tensile Stress}}{\text{Yield Stress}} = \frac{R_m}{R_e}$</td>
<td>≥ 1.08</td>
<td>≥ 1.04</td>
<td>90%</td>
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<tr>
<td>Uniform Elongation, $A_{gt} (%)$</td>
<td>≥ 5.0</td>
<td>≥ 4.0</td>
<td>90%</td>
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</tbody>
</table>

**Non-standard Grades**

Shall meet the ratio and uniform elongation requirements of the nearest lower grade for the applicable ductility class (Cl 7.2.1 of AS/NZS 4671)


Aligned with international standards where possible but as differences exist (eg earthquakes steels) published as AS/NZS 4671.
Clause 1.1.2 Application

This Standard applies to structures and members in which the materials conform to the following:

d) Higher reinforcing steel grades > 500 MPa to 800 MPa meeting the requirements of Table 3.2.1. For ultimate limit states the strength of the reinforcement in design models shall not be taken as greater than 600 MPa unless noted otherwise.

Note that for columns, in Clause 10.7.3.3 of AS 3600:2018:
The yield stress of the reinforcement used as fitments can be as high as 800 MPa.

800 MPa steel has been in AS 3600 since 2009.
# Chemical Composition

<table>
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<th>Type of analysis</th>
<th>Chemical Composition (%) Max</th>
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<td>Cast analysis</td>
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<td>Product analysis</td>
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<td>0.055</td>
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## Carbon Equivalence:

\[ C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \]
Correct Chemistry allows Welding to AS 1554.3
Ensuring Quality Reinforcement

Third Party/Independent Certification - ACRS or Equivalent

ACRS Mill Certificate Example

Required by processors as proof that quality reinforcement supplied by mill
Ensuring Quality Reinforcement

Third Party/Independent Certification - ACRS or Equivalent

ACRS Mill Certificate Example

Required by processors as proof that quality reinforcement supplied by mill

Reinforcing Bar Manufactured to AS/NZS 4671:2001

Bar approved under this certificate remains ACRS certified after processing only if cut, or bent, or welded by an ACRS certified processor. For processed bar approval, please refer to the bar processor’s ACRS certificate.
Ensuring Quality Reinforcement

ACRS Processor Certificate Example

Required by purchasers to prove quality reinforcement delivered to site

Processing and distribution of carbon steel bars and welded mesh in accordance with AS/NZS 4671, plus the requirements of the “material and construction requirements for reinforcing steel” clauses of AS 3600 Concrete structures and AS 5100.5 Bridge design – Concrete, or the “Reinforcement” clauses of NZS 3109 Concrete Construction
Ensuring Quality Reinforcement

ACRS Processor Certificate Example

Required by purchasers to prove quality reinforcement delivered to site
Ensuring Quality Reinforcement

Need for an ACRS or equivalent certificate?
Every project should specify one and obtain to guarantee quality
A Processor Certificate should be obtained for every project.
Scheduling from Design Drawings & Specifications

Develop electronic bar cutting/bending schedules
Each bar is assigned a code for processing
Cutting & Bending – Off Coil

Bar continually drawn from coil and bent around pin of specific diameter
Almost any shape possible – virtual bends
Cutting & Bending – Straight Bar

Shear line for efficient cutting of stock bar lengths
Cutting & Bending – Straight Bar

Larger bars also bent around pin of specific diameter
Bending Reinforcement
Clause 17.2.3.2 of AS 3600 – required pin diameters

Avoids excessive steel strain and crushing of concrete

**Fitments**
- 500L & R250N: $3d_b$
- D500N: $4d_b$

**General**
- D500N: $5d_b$
- Galvanised ≤16mm: $5d_b$
- Galvanised ≥ 20mm: $8d_b$

Stress Strain Curve 500N QST

- $R_m$ or $f_{su}$
- $R_e$ or $f_{sy}$
- Fail
Curved Reinforcement
Recent bending problems

Bar hit with sledge hammer

Clause 17.2.3.1
Bars shall not be bent using impact, such as with hammers.

AS 3600 Clause 17.2.3 contains requirements for bending reinforcement

Clause 17.2.3.1
Reinforcement partially embedded in concrete may be field-bent provided the bending complies with Clauses 17.2.3.1(a) Cold bending and (b) Hot bending
Bending Reinforcement
Correct Site Practices

Manual and electric bending equipment - preferred

Bends up to 180
Maximum D16 bar
63 mm bending roller

Bends of 90, 135 and 180
Maximum D20 bar
Roller diameter?
Bending Reinforcement
Incorrect Site Practices

Not bending around correct pin diameter

Over-heating
Maximum 600°C allowed Clause 17.2.3.1
If temp. exceeds 450°C, yield strength taken as 250 MPa
Recent bending problem

Galvanised N32 bars bent around 47 mm diameter pin

AS 3600 requires 8 bar diameters for galvanised bars – 256 mm dia. pin

Accept or reject?

Engineer prepared to certify?  YES

Authority prepared to accept?  NO
Scheduling & Processing

Stored ready for delivery – 2 to 3 day lead time required
Fabrication Tolerances
Clause 17.2.2 of AS 3600

Fitments (stirrups & ties):
Plain round bars and wire: \(-10\text{mm} \pm 0\text{mm}\)
Deformed bars & mesh: \(-15\text{mm} \pm 0\text{mm}\)
General (bar and mesh):
Length ≤ 600mm: \(-25\text{mm} \pm 0\text{mm}\)
Length > 600mm: \(-40\text{mm} \pm 0\text{mm}\)
Fixing Tolerance
Clause 17.5.3 of AS 3600

WHERE CONTROLLED BY COVER

- Beams, slabs, columns, walls: -5mm +10mm
- Slabs-on-ground: -10mm +20mm
- Footings: -10mm +40mm (less cover – more cover)

OTHER

- End of reinforcement: -50mm +50mm
- Spacing of reinforcement: greater of 15mm, or 10% of specified spacing

Note: Designer is responsible to ensure steel can be placed to within tolerances
Keeping Reinforcement in Place

**Bar Chairs - AS/NZS 2425 Bar chairs in concrete – Product requirements**

- Concrete
- Plastic
- Hurdles
- Plastic tipped wire
Support reinforcement at heights greater than normal chairs – typically 300 mm to 400 mm max.

Requirements determined by steel scheduler
Specify

- Bar chairs to comply with AS/NZS 2425 Bar chairs in concrete – Product requirements
- Type of bar chair - Depends on application

Marine or water retaining application?

Why concrete .......... and not plastic?
Specifying Bar Chairs

Specify

- Bar chairs to comply with AS/NZS 2425 Bar chairs in concrete – Product requirements
- Type of bar chair - Depends on application
- Load capacity - 60, 120, 200 or > 300 kg
- Spacing - To adequately support load
- Chloride permeability (if concrete)
  - Ensures suitability of concrete spacer for exposure

<table>
<thead>
<tr>
<th>Maximum charge passed (coulombs)</th>
<th>Chloride permeability class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 4,000</td>
<td>High</td>
</tr>
<tr>
<td>2,000 - 4,000</td>
<td>Moderate</td>
</tr>
<tr>
<td>1,000 – 2,000</td>
<td>Low</td>
</tr>
<tr>
<td>&lt; 1,000</td>
<td>Very low</td>
</tr>
</tbody>
</table>

Table 2 from AS/NZS 2425
BIM - 3D drafting ideal for complex shapes

Science Museum in Valencia, Spain
Architect: Santiago Calatrava

8 Chifley Square
Mirvac Property Trust
Arup
Welding of Prefabricated Reinforcement

Types of AS/NZS 1554.3 non-loadbearing welds in cage prefabrications:

- **Non-loadbearing welded joints** – in accordance with Section 3.3
  - These welds hold the cage during fabrication, transport & concreting
  - The welded joint strength does not contribute to the structure

- **Locational Welds** – in accordance with Clause 5.6
  - Used to hold parts of a weldment in alignment until final welds made
  - If left in place & included in prefabrication must meet Table 6.2.
    - Note 6 requirements ensure there is no loss of cross-sectional area or imperfections. If locational welds are too small they will change the bar metallurgy underneath causing insufficient strength when lifted.
    - Amdt 1 Nov 2017 – New Note 7: “Non-loadbearing welds shall not reduce the full load bearing capacity of the structural elements (see Note 6)”
  - If weld size does not meet Cl 5.6 requirements their limited heat affect and rapid cooling can lead to cracking
  - If removed properly – minimal (if any) impact.
Prefabrication of Reinforcement

- The number of welds to locate reinforcing steel shall be kept to a minimum

- **Locational Welds** - AS/NZS 1554.3:2008, Note 2 to 1.6.2 said “tack welds in bent sections of bars are permitted subject to Cl 3.3” ERROR AS DELETED IN 2014 PUBLICATION

- **Load bearing welds** are not permitted on a bend:
  - AS/NZS 1554.3, Clause 1.6.3 requires >2d_b from weld to start of bend
  - AS 3600, Clause 13.2.1 requires 3d_b from part of the bar that has been bent and restraightened

- Welding must be done by person qualified in AS/NZS 1554.3 welding procedures

Weld Images courtesy of Weld Australia, (WA)
Lifting of Prefabrication Reinforcement

Locational (non loadbearing) welds used for lifting

- Must be designed by a suitably qualified person
- Must be approved by Design Engineer prior to lifting
- Safe lifting points for fabricated cages shall be clearly marked on the drawings and fabricated cages
Prefabrication of Reinforcement

Lifting points need to be clearly marked

Bars set up in welding jig

Sydney Light Rail

Lifting points clearly marked
Prefabrication of Reinforcement

Reduces congestion on site and speeds up construction

Pile cages with spiral fitments typically prefabricated by machine welding

Good consistent weld quality with experienced operators in 3rd Party Processor Certified facilities
Welding of Reinforcement

- Often specified to be in accordance with AS 1554.3 Welding of reinforcing steels
- Contractors generally unaware of requirements
- Weld details should be specified by Engineer (refer Section 3)
- Need to study AS 1554.3 carefully
- Some recommendations:
  - Qualify procedure to AS 1554.3
  - Specify procedure/process
  - Do trials
  - Test weld to verify penetration and tensile capacity
  - Bend test if butt welded – for flexural tensile reinforcement
  - If insufficient penetration:
    May need to adjust gap between bars or procedure
  - Due diligence is required
Consider Mechanical Couplers

Various Types

Examples of couplers

- Tapered thread
- Sleeve extruded over bar end with parallel thread
- Parallel thread
- Proprietary bar couplers

Examples of coupling sleeves

- Mechanically bolted
- Grouted
Prefabrication of Reinforcement

Large prefabrications become temporary structures

Need to ensure stability – specify bracing if required

University of Nevada Report CCEER 10-07 & Presentation – Stability of Bridge Column Rebar Cages during Construction
Summary

- SRIA is here to help
- Historic structures require careful consideration
- Steel reinforcement is a high technology product
- Quality assurance is essential
- Bar chairs need to be specified
- Care required with welding
- Ensure stability of prefabricated reinforcement
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Thank you