Reinforcement Quality Issues

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Executive Director, SRIA
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Manufacturing of Billets - EAF

Reinforcement made from recycled metal

Chemical properties tested prior to billet casting

Scrap melted in EAF

Billet casting 150 x 150 mm in size
Manufacturing of Billets - EAF

Billets cut to length

Billets allowed to cool slowly
Steel strength 250 to 300 MPa

Billets moved to cooling beds

Stacked in yard
Hot Rolling Bar Mill

Turning billets into reinforcement

Billets reheated in oven and then rolled to required size
Hot Rolling Bar Mill

Straight Quenched and Self Tempered (QST) D500N (12 to 40 mm)

- Rolling ribbed profile
- Quenching process
- Self-tempering in cooling beds

Schematic diagram on a Time – Temperature Curve

Microstructure of QST Reinforcing Bars
- Tempered Martensite
- Ferrite - Pearlite
Coiled Microalloy D500N (12 and 16 mm) and D250N

Microalloy (MA) D500N coils -12 and 16 mm (alloy is vanadium and bars have constant metallurgical properties across their section)
Hot Rolling Rod Mill

Smooth Rod (R250N) and coiled deformed bar (D250N)

‘Wild’ coils of smooth rod 5.5 to 16 mm

Deformed bar coils
10, 12 & 16 mm

Typical labels
Cold rolled deformed bar

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

Rollers to straighten rod

Round rod
Deform bar
Straighten rod

Used for mesh and fitments

Plain round rod
# Mechanical Properties (from AS/NZS 4671)

<table>
<thead>
<tr>
<th>Property</th>
<th>500L</th>
<th>500N</th>
<th>Probability of exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Diameter (mm)</td>
<td>5 to 12</td>
<td>10 to 40</td>
<td>-</td>
</tr>
<tr>
<td>Characteristic Yield Stress (MPa), $R_{ek,L}$</td>
<td>500</td>
<td>500</td>
<td>95%</td>
</tr>
<tr>
<td>$R_{ek,U}$</td>
<td>750</td>
<td>650</td>
<td>5%</td>
</tr>
<tr>
<td>Ratio: Tensile Stress / Yield Stress</td>
<td>$\frac{R_m}{R_e}$</td>
<td>$\frac{R_m}{R_{sy}}$</td>
<td>$\geq 1.03$ / $\geq 1.08$</td>
</tr>
<tr>
<td>Uniform Elongation, $A_{gt}$ (%)</td>
<td>$\geq 1.5$</td>
<td>$\geq 5$</td>
<td>90%</td>
</tr>
</tbody>
</table>

**Stress Strain Curve 500L**

- **STRESS (MPa)**: 0 to 1000
- **STRAIN (%)**: 0 to 5.0
- **$R_m$ or $f_{sy}$**
- **Fail**

**Stress Strain Curve 500N QST**

- **STRESS (MPa)**: 0 to 1000
- **STRAIN (%)**: 0 to 20.0
- **$R_e$ or $f_{sy}$**
- **$R_m$ or $f_{su}$**
- **Fail**
# Chemical Composition

<table>
<thead>
<tr>
<th>Type of analysis</th>
<th>Chemical Composition (%) Max</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Steel Grades</td>
<td>Carbon Equivalent Value for Class</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Cast analysis</td>
<td>0.22</td>
<td>0.050</td>
</tr>
<tr>
<td>Product analysis</td>
<td>0.24</td>
<td>0.055</td>
</tr>
</tbody>
</table>

**Carbon Equivalent:**

\[
C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}
\]
Correct Chemistry allows Welding to AS/NZS 1554.3
Third Party/Independent Certification
ACRS or Equivalent

What does ACRS certify?

- Reinforcing bar and mesh to AS/NZS 4671 & relevant design Codes (AS 3600, AS 5100.5 & AS 2870)
- Prestressing strand to AS 4672
- Structural steel to AS/NZS Standards

Details of current ACRS Certificate Holders can be found at www.steelcertification.com

If in doubt, contact ACRS on (02) 9965 7216 or Email: info@steelcertification.com
Third Party/Independent Certification

ACRS or Equivalent

ACRS certificates cover company and products

Australasian Certification Authority for Reinforcing and Structural Steels Ltd
Certificate of Product Performance

Certificate Number: 811021

AUSREO
WETHERILL PARK, NSW, AUSTRALIA

This document is unauthenticated when printed

VALID TO 31 DEC 2017

Australasian Certification Authority for Reinforcing and Structural Steels Ltd
Products assessed by ACRS to AS/NZS 4671

To be read in conjunction with
Certificate Number: 81102

AUSREO
WETHERILL PARK, NSW, AUSTRALIA

Has satisfied the Authority that it complies with the relevant ACRS Quality and Operations Assessment Procedures. Where appropriate, and as listed below, it manufactures products as indicated by "√" below and is entitled to use the ACRS mark with these products.

Products manufactured:

AS/NZS 4671 Grade 3500 Bars

<table>
<thead>
<tr>
<th>Section Size</th>
<th>3500</th>
<th>4000</th>
<th>4500</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Bar</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectangular Bar</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAS-ANZ Tested</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

In accordance with ACRS, by authority of ACRS Board:

Philip Steiner, Executive Director

Voluntary

31 December 2017

First certified:

November 2008
Concerns about non-conforming building materials in both Australia and New Zealand:

- The AiG report (2013), “The quest for a level playing field - The non-conforming building products dilemma” and the


- Highlights the need for Australian Standards to be updated to address any gaps in the requirements for demonstrating product conformity
Third Party/Independent Certification
ACRS or Equivalent

Need for an ACRS or equivalent certificate?
Every project should have one
Mesh Processing

Mesh welding process – quality of welding critical

Typical mesh-making machine
Mesh Processing

Mesh weld testing & lapping

- Each welded joint develops 50% of the bar’s yield stress
- Overlap a minimum of 2 crosswires

Figure 5.1 from AS 2870
Cutting & Bending – Off Coil

Bar continually drawn from coil and bent around pin of specific diameter
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

Avoids excessive steel strain and crushing of concrete
Bending Reinforcement
Incorrect Site Practices

- Not bending around correct pin diameter

- Over-heating (max. 600°C allowed – Clause 17.2.3.1)
  If temp. exceeds 450°C, yield strength taken as 250 MPa in design

- 'Necking' and fracture of steel at small radius
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 to suit
Recent bending problem – soil anchors

Pre-galvanised N32 bars bent around 47 mm diameter pin then cracking touched up with a zinc rich paint

AS 3600 requires 8 bar diameters for N32 galvanised bars – ie 256 mm dia. pin

Accept or reject?

Engineer prepared to certify? YES

Authority prepared to accept? NO
Recent bending problem – column starter bars

Starter bars can be straightened in compliance with the provisions of Clause 17.2.3.1 of AS 3600.

- Use approved rebending tool
- Pipe of diameter $2d_b$ was able to be used - removed from current AS 3600 public comment draft
- Use single, smooth action
- Bend against flat surface or pin
- Never over-bend (typically 90°)
- Avoid impact from hammers etc.
Re-bending Reinforcement

AS 3600 Provisions – Clause 17.2.3.1

- Reinforcement must be bent around a pin of diameter complying with Clause 17.2.3.2
- Avoid impact loading and damage to surface of bar
- Reinforcement that has been bent and subsequently straightened or bent in the reverse direction shall not be bent again within 20 bar diameters of the previous bend
- Reinforcement partially embedded in concrete may be field-bent provided the bending complies with the above and the bond of the embedded portion is not impaired
Re-bending Reinforcement

**AS 4671:2001 Extract**

Class L are bent around smaller pin diameter
Not rebent as far only 20 degrees as minimal adjustments in site application

**TABLE 4**

<table>
<thead>
<tr>
<th>Nominal diameter (mm)</th>
<th>Mandrel diameter for ductility class</th>
<th>Bend angle</th>
<th>Bend angle after 90° initial bend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>N</td>
<td>E</td>
</tr>
<tr>
<td>d ≤ 16</td>
<td>3d</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4d</td>
<td>4d</td>
<td></td>
</tr>
<tr>
<td>d ≥ 20</td>
<td>4d</td>
<td>4d</td>
<td></td>
</tr>
</tbody>
</table>

**SRIA Seismic Guide Extract**
Severely corroded and pitted steel should not be used unless the material has been checked for strength and cross-sectional area limitations (SRIA TN1).

If in doubt, clean 1 m length and compare to weight in Table 5A of AS/NZS 4671
Fitments (stirrups & ties):
  Plain round bars and wire -10mm +0mm
  Deformed bars & mesh -15mm +0mm
  General (bar and mesh)
    Length ≤ 600mm -25mm +0mm
    Length > 600mm -40mm +0mm
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
Welding of Prefabricated Reinforcement

Reduces congestion on site and speeds up construction

Airport rail link

Chatswood Station columns

Spiral wrap machine
Welding of Prefabricated Reinforcement

Often used for precast elements
Welding of Prefabricated Reinforcement

Often used for difficult sites

Sea Cliff Bridge
(South coast NSW)
Welding of Prefabricated Reinforcement

Non-loadbearing locational welds are permitted on any bend

Must be done by person qualified to AS/NZS 1554.3 Welding of reinforcing steel, welding procedures

Acceptable / Unacceptable images courtesy of Welding Technology Institute of Australia (WTIA)
Welding of Prefabricated Reinforcement

Types of AS/NZS 1554.3 welds used in the preassembly of reinforcing elements are:

- **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

- **Tack Welds** – in accordance with Clause 5.6
  - Used to hold parts of a weldment in alignment until final Welds made
  - If left in place and included in prefabrication they have to meet Table 6.2. A new Note 7 is under consideration by WD-003 Committee which is likely to be “Non-loadbearing welds shall not reduce the full loadbearing capacity of the structural elements (see Note 6)”.
  - Note 6 requirements ensure there is no loss of cross-sectional area or imperfections. If Tack welds are too small they will change the bar metallurgy underneath causing insufficient strength when lifted.
  - If removed properly – minimal (if any) impact.
Welding of Prefabricated Reinforcement

Load bearing welds used for lifting points

- Must be designed by a suitably qualified person
- Must be approved by Design Engineer/Authority prior to lifting
Welding of Prefabricated Reinforcement

EXAMPLE: TMR Qld Release 2011 “Engineering Certified Lifting Points for Transport and Main Roads Projects” for cages >500kgs

- Failures of reinforcing cages do occur from lifting incorrectly or poor non-loadbearing welding practices. Potential serious safety issue.
- TMR guidelines exist for welding cages not fabricated insitu
- Reinforcement design plans/shop drawings are certified by an RPEQ engineer:
  - highlighting location and design requirements for lifting points and welding requirements for the steel located around the lifting points.
  - Linked cage lifting points capacity is based on total mass.
  - Fabricated in accordance with the specification MRTS 71
  - Design to ensure the reinforcing cage remains rigid during the lifting and handling
- Each cage marked with a label identifying the cage type, mass, the design to which the cage was made and how the lifting points are identified.
Welding Technology Institute of Australia (WTIA) – Reinforcing steel welding coordinator course

- WTIA developed a one week welding supervisors course specifically tailored to the reinforcement industry.
- It is not an AS 2214 Certification of welding supervisors ticket, but is 1/3rd of the way there and used ISO 14731 Welding Coordination to identify key tasks and responsibilities which the course addresses.
- Improving weld quality compliance
AS 3600 Concrete structures Update
Draft for Public Comment: Commenced 21 Aug 17 & Closes 23 Oct 17
Section 1 Scope and General

Clause 1.1.2 Application

Higher reinforcing steel grades >500MPa to 800MPa meeting the requirements of Table 3.2.1 added

Table 3.2.1 Yield Strength & Ductility Class of Reinforcement

NOTE added:

For higher reinforcing steel grades permitted in Clause 1.1.2(d) the following characteristic properties shall be met:

1) The following limits for the chemical composition determined by cast analysis shall not be exceeded:
   - Carbon – 0.33%, Phosphorus – 0.050%, Sulphur - 0.050%
   - The Carbon equivalent value shall not exceed 0.49 by cast analysis

2) The maximum yield strength does not exceed the nominal yield strength by more than 150 MPa

3) For steels
   - >500 MPa - 700 MPa
     - uniform elongation $\varepsilon_{su} \geq 0.05$ and the tensile-to-yield stress ratio $R_m/R_y \geq 1.08$
   - >700 MPa - 800 MPa
     - uniform elongation $\varepsilon_{su} \geq 0.04$ and the tensile-to-yield stress ratio $R_m/R_y \geq 1.04$
Section 2 Design Procedures, Actions and Loads

Clause 2.1.2 Design for Earthquake Actions
Where structures are required by AS 1170.4 to be designed for earthquake actions, they shall comply with that Standard, this Standard and the provisions of new Section 14 of this Standard.

➤ AS 3600 Appendix C now becomes Section 14

Clause 2.1.3 Design for Robustness and Structural Integrity
When detailing of reinforcement and connections, members shall be effectively tied together to improve integrity of the overall structure.

➤ Requirements for structural integrity added
➤ Covers both cast-in-place and prefabricated concrete structures
### Capacity Reduction Factors

<table>
<thead>
<tr>
<th>Type of action effect</th>
<th>Capacity reduction factor ($\phi$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Axial force without bending:</td>
<td></td>
</tr>
<tr>
<td>(i) Tension:</td>
<td></td>
</tr>
<tr>
<td>(A) members with Class N reinforcement and/or tendons</td>
<td>0.8</td>
</tr>
<tr>
<td>(B) members with Class L reinforcement</td>
<td>0.64</td>
</tr>
<tr>
<td>(ii) Compression</td>
<td>0.6</td>
</tr>
<tr>
<td>(b) Bending without axial tension or compression—</td>
<td></td>
</tr>
<tr>
<td>(i) for members with Class N reinforcement and/or tendons</td>
<td>$0.6 \leq (1.19 - 13k_{ax}/12) \leq 0.8$</td>
</tr>
<tr>
<td>(ii) for members with Class L reinforcement</td>
<td>$0.6 \leq (1.19 - 13k_{ax}/12) \leq 0.64$</td>
</tr>
<tr>
<td>(c) Bending with axial tension—</td>
<td></td>
</tr>
<tr>
<td>(i) for members with Class N reinforcement and/or tendons</td>
<td></td>
</tr>
<tr>
<td>$\phi + [(0.8 - \phi) (N_u/N_{rub})]$ and $\phi$ is obtained from Item (b)(i)</td>
<td></td>
</tr>
<tr>
<td>(ii) for members with Class L reinforcement</td>
<td></td>
</tr>
<tr>
<td>$\phi + [(0.64 - \phi) (N_u/N_{rub})]$ and $\phi$ is obtained from Item (b)(ii)</td>
<td></td>
</tr>
<tr>
<td>(d) Bending with axial compression, where—</td>
<td></td>
</tr>
<tr>
<td>(i) $N_u \geq N_{ub}$</td>
<td>0.6</td>
</tr>
<tr>
<td>(ii) $N_u &lt; N_{ub}$</td>
<td>$0.6 + [(\phi - 0.6) (1 - N_u/N_{ub})]$ and $\phi$ is obtained from Item (b)</td>
</tr>
<tr>
<td>(e) Shear</td>
<td>0.7</td>
</tr>
<tr>
<td>(f) Torsion</td>
<td>0.7</td>
</tr>
<tr>
<td>(g) Bearing</td>
<td>0.6</td>
</tr>
<tr>
<td>(h) Bending, shear and compression in plain concrete</td>
<td>0.6</td>
</tr>
<tr>
<td>(i) Bending, shear and tension in fixings</td>
<td>0.6</td>
</tr>
<tr>
<td>(j) Singly reinforced walls part of a primary lateral load resisting system</td>
<td>0.7</td>
</tr>
<tr>
<td>(k) Collector in Tension</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**NOTE:** In members where Class L reinforcement together with Class N reinforcement and/or tendons are used as longitudinal tensile reinforcement in the design for strength in bending, with or without axial force, the maximum value of $\phi$ for calculating the member design strength should be taken as 0.64.
Section 6 Methods of Structural Analysis

Clause 6.2.4 Stiffness

- Represent the conditions at the limit state being analysed
- Consistent with all loading conditions
- Generate critical worst-case actions under all failure modes to be considered
- Any assumptions regarding the relative stiffness of members shall be applied consistently throughout the analysis

Clause 6.2.4.1 Stiffness of lateral force resisting elements

- Requirements for the determination of the moment of inertia for flexural members, columns and walls
- Uncracked and cracked sections covered
- Cracked sections expressed as a proportion of $I_g$ (Table 6.2.4)
Section 8 Design of Beams for Strength and Serviceability

Clause 8.1.10 Maximum diameter of longitudinal beam bars in internal beam/column joint zones

- Requirements added where:
  - Earthquake actions need to be considered
  - No earthquake actions, or plastic regions cannot develop, adjacent to the face of the column

Clause 8.1.11.2 Distribution of reinforcement and integrity reinforcement

- Minimum requirements added for insitu construction
Section 9 Design of Slabs for Strength and Serviceability

Clause 9.3.1.2 Deemed-to-comply arrangement for one-way slabs
- Extent of the bottom reinforcement extending into support defined
- Previously not defined

Clause 9.4 Structural Integrity Reinforcement - added
- Minimum bottom reinforcement requirements at walls and columns added to increase the resistance of the structural system to progressive collapse
- Not required if there are beams containing shear reinforcement and with at least two bottom bars continuous through the joint in all spans framing into the column
Section 10 Design of Columns for Strength and Serviceability

Clause 10.2.4 Design for shear
- Minimum requirements for shear reinforcement added

Clause 10.7.4.2 Lateral Restraint
- Arrangement of internal fitments clarified
- Limitations placed on the use of internal fitments having a cog at one end:
  - The design axial force $\leq 0.3 A_g f'_c$
  - The characteristic concrete strength, $f'_c \leq 65$ MPa
- ISSUE: Cogs not anchored when (not if) spalling of cover concrete occurs
Appendix C (IMRF) refers to ‘closed ties’

However, no definition of closed tie within AS 3600:2009

- Closed tie definition now added
- Closed tie referred to in AS 3600-2001, where all ties are closed ties
- Crossties introduced in 2009 edition of Standard
- ISSUE: Was not clear whether these are ‘closed ties’ for use with IMRF’s
- Internal fitments for IMRFs should have a 135° fitment hook at both ends
AS 3600 Update

Column Design

Don’t push your column design too hard unless you have accounted for the drift induced ductility demands and have detailed accordingly.

IDEALLY: Design below balance point to ensure ductile tension failure, or

Determine drift demand and include moment in design.

(ETABS won’t do this)
Section 10 Design of Columns for Strength and Serviceability

Figure 10.7.4.3 Bar diameters for fitments and helices

- Minimum fitment diameter for 28 mm diameter bars now clarified
- Requires 12 mm fitment or helix (ACI 318M-14)
- Previously either 10 or 12 mm dia could be used

Clause 10.7.4.5 Column joint reinforcement

- Requirements clarified – where required and spacing
Section 11 Design of Walls

Clause 11.2 Design Procedures

- Restrictions placed on the use of the simplified method
- For earthquake actions, when determining whether a wall cross section is under compression:
  - Use structural ductility factor, $\mu = 1.00$
  - Use structural performance factor, $S_p = 0.77$

Clause 11.5 Simplified design method for walls

- Clause 11.5.1 added placing limitations on the use of the method:
  - Height $\leq 12$ m
  - When subject to earthquake action, excludes site classes $D_e$ and $E_e$
  - Effective height to thickness ratio of:
    - 20 for singly reinforced walls
    - 30 for doubly reinforced walls
- Otherwise, required to design wall as a column
**Section 11 Design of Walls**

**Clause 11.7.3 Spacing of Reinforcement**

- Reinforcement provided in two grids if:
  - **Wall thicker than 200 mm**
  - **If tension exceeds the tensile capacity of the concrete under design ultimate loads.**
    - For earthquake actions, assessment based on:
      - structural ductility factor, $\mu = 1.00$
      - structural performance factor, $S_p = 0.77$
  - **Height > 12 m**

**Clause 11.7.4 Restraint of vertical reinforcement**

- For walls with a concrete strength $> 50$ MPa
  Restraint to be in accordance with Clause 14.5.4 ie closed ties.
AS 3600 Update

Shear Wall boundary element required for IMRF if:

- Vertical reinforcement is not laterally restrained in accordance with Clause 10.7.4, and
- Extreme fibre compressive stress $> 0.15 f'_c$

If extreme fibre compressive stress $> 0.2 f'_c$, detail wall as a column
AS 3600 Update

Ductile Shear Walls

Clause C5 of AS 3600 - Horizontal and vertical reinforcement ratio $\geq 0.0025$

- Lightly reinforced walls tend to develop single crack
- Reinforcement unable to handle strain and fractures

Actual damage and crack patterns from wall models

(Henry et al., University of Auckland, 2015)
"The building’s overall damage state may be described as being at near collapse. A potentially catastrophic failure might have been observed for a slightly longer duration of severe ground shaking." (Morris et al., 2015)
Section 14 Requirements for Structures Subject to Earthquake Actions

Essentially existing Appendix C (with additions and corrections)

- Structures with IL 4 designed for $\mu > 2$ with appropriate detailing
- Classification of structural walls expanded
  - Non ductile ($S_p/\mu = 0.77$)
  - Limited ductile ($S_p/\mu = 0.38$ no change)
  - Moderately ductile ($S_p/\mu = 0.22$ - previously ductile shear walls)
  - Ductile ($\mu = 4$ and $S_p/\mu = 0.17$, so beyond scope of Standard)

Design required to NZS 1170.5 and NZS 3101 + Ductility Class E

Table 14.3 New classifications added and $S_p/\mu$ factors amended

Note difference between designing for seismic and wind loads.

Clause 14.4.2 Inter-storey drift (added)

- General requirements – horizontal drift, relative movement, ductility & rotational capacity
Section 14 Requirements for Structures Subject to Earthquake Actions

Clause 14.4.3 Ordinary moment-resisting frames
- Requirements for OMRF (beams and columns) now in Section 14

Clause 14.4.4.3 Structural walls
- Limits simplified design method to non-ductile walls
- Limit on axial load $N^*/A_g \leq 0.2f'_c$

Clause 14.4.5 Diaphragms
- Determination of inertia forces

Clause 14.4.6 Ductility of flexural members with $1.25 < \mu \leq 3$
- Requirements for plastic hinge zones

Clause 14.5.4 Columns
- Maximum fitment spacing for IMRFs above and below slabs corrected
- Where $P_u > \phi 0.3A_g f'_c$ or $f'_c \geq 65$ MPa
  
each longitudinal bar shall be restrained by a ‘closed fitment’
Section 14 Requirements for Structures Subject to Earthquake Actions

Clause 14.5.6 Robustness and Structural Integrity (added)

- Stairs and ramps
- Moment resisting frames (strong column/weak beam)
  - Only for IMRFs
  - Only where columns form part of the lateral seismic force-resisting system

Olive View Hospital
San Fernando Earthquake, 1971

Collapsed stairs to the Hotel Grand Chancellor
(Photograph courtesy of Dunning Thornton Consultants Ltd, NZ)
Section 14 Requirements for Structures Subject to Earthquake Actions

Strong column/weak beam requirement

- Column strength $\geq 1.2$ times beam strength
- To promote preferred side sway mechanism

(a) Column sidesway mechanism
- Soft storey (strong beam/weak column)
- Non-preferred arrangement

(b) Beam sidesway mechanism
- Plastic hinges in beams only (weak beam/strong column)
- Preferred arrangement

(c) Mixed sidesway mechanism
- Interior columns form plastic hinges
- Acceptable with adequate design and detailing for ductility

Figure 19 — Column, beam and mixed sidesway mechanisms (after Goldsworthy)
Section 15 Diaphragms

Clause 15.2 Design Actions

- 15.2.1 General design actions
- 15.2.2 Analysis procedure
- Stiffness of diaphragm

Clause 15.3 Cast-in-place toppings

- By itself - Minimum thickness of 75 mm and reinforced for loading
- Compositely with precast elements:
  - Minimum thickness 65 mm
  - Reinforce to act compositely with precast elements

Figure R12.5.2.3 from ACI 318M-14
Section 15 Diaphragms
Clause 15.4 Diaphragm reinforcement

- Minimum – in accordance with Clause 9.4.3
- Spacing – in accordance with Clause 9.4.1
- Development and laps – sufficient to transfer forces
- Collectors – reinforce to transfer loads into shear-resisting elements
- Construction joints – reinforcement must transfer forces across joint

Figure R12.5.3.7 of ACI 318M-14

Figure R12.5.4.1 of ACI 318M-14
Section 17 Material and Construction Requirements and Prefabricated Concrete

Clause 17.7 Prefabricated Concrete Structures

- Minimum provisions for structural integrity
  - Minimum connection capacities
  - Requirements for vertical tension ties
  - Connections that rely on friction from gravity loads not allowed
- Minimum requirements for bearing wall structures ≥ two storeys
- Requirements for:
  - Longitudinal and transverse ties
  - Vertical tension ties
- Requirements for grouted ducts
- Requirements for seating of floor elements
  - Minimum 1.5 times the Ultimate Limit State drifts
AS 3600 Update

Grouted Ducts

Crowne Plaza Hotel, Christchurch
AS 3600 Update

SESOC 2012 Recommendations

Steel pipe or similar to de-bond grouted dowel bar
Thank you

Eric Lume, National Engineer, SRIA
Will now deliver the next presentation
Tensile Development and Lap Splice Lengths

Eric Lume
National Engineer, SRIA
Tensile development length – basic

\[ L_{sy.tb} = \psi_{bc} \psi_{cd} \psi_{sf} \frac{0.5k_1k_3f_{sy}d_b}{k_2\sqrt{f'_c}} \geq 29k_1d_b \]

where:

- \( k_1 \) = factor to allow for bond conditions
  - = 1.3 if \( \geq 300 \text{ mm} \) of concrete is cast below a non-vertical bar
  - = 1.0 otherwise

- \( k_2 \) = factor to allow for bar diameter = \( \frac{132 - d_b}{100} \)

- \( k_3 \) = factor to allow for cover and bar spacing
  - = 1.0 \( - \frac{0.15(c_d - d_b)}{d_b} \) such that \( 0.7 \leq k_3 \leq 1.0 \)

\( c_d = \) minimum \( c \) or \( \frac{a}{2} \)
AS 3600 Section 13

Maximum value of $f_c' \leq 65$ MPa

- Clause 25.4.1.4 of ACI 318M-14: $\sqrt{f_c'} \leq 8.3$ MPa ($f_c' \approx 65$ MPa)
- Development and lap splice tests indicate that force developed in a bar increases at a lesser rate than $\sqrt{f_c'}$ with increasing compressive strength
- Using $\sqrt{f_c'}$ sufficiently accurate for $\sqrt{f_c'}$ values up to 8.3 MPa
- AS 3600 Commentary Clause 13.1.2.2

$L_{sy.tb}$ unreliable for $f_c' > 65$ MPa due to lack of data

$L_{sy.tb}$ multiplied by:

- $\Psi_{bc} = 1.5$ for epoxy-coated bars; and
- $\Psi_{cd} = 1.3$ when lightweight concrete is used; and
- $\Psi_{sf} = 1.3$ for all structural elements built with slip forms

Note that in the current TN7 the symbol $\xi$ (xi) is used
AS 3600 Section 13

Value of $c_d$

A dimension equal to the lesser of:

- The least clear concrete cover to the bars in narrow elements or members: $c$ or $c_1$
- The least bottom cover for wide elements, $c$
- Half the clear distance between parallel bars developing stress, $a/2$

![Diagram of narrow and wide elements/members with dimensions labeled](image)
Tensile development length – refined

\[ L_{sy.t} = k_4 k_5 L_{sy.tb} \]

where:

- \( k_4 \) = factor for effect of transverse reinforcement
  
  \[ k_4 = 1.0 - K \lambda \] with \( 0.7 \leq \lambda \leq 1.0 \)

  \[ k_4 = 1.0 \] with no transverse reinforcement

- \( \lambda = \left( \frac{\sum A_{tr} - \sum A_{tr.min}}{A_s} \right) \) where \( A_{tr.min} = \frac{A_s}{4} \) when \( K > 0 \)

- \( k_5 \) = factor for effect of transverse pressure
  
  \[ k_5 = 1.0 - 0.04 \rho_p \] with \( 0.7 \leq k_5 \leq 1.0 \)

- \( \rho_p = 0 \) to maximum 7.5 MPa

- \( k_3 k_4 k_5 \geq 0.7 \)
**AS 3600 Section 13**

\( K \) factor – allows for effectiveness of transverse reinforcement to control splitting cracks (value depends on bar location)

\[
K = 0 \\
A_{tr} \quad A_s
\]

Splitting crack

\[
K = 0.05 \\
A_s \quad A_{tr}
\]

Splitting cracks

\[
K = 0.10 \\
A_s \quad A_{tr}
\]

Splitting cracks

AS 3600 currently requires use of different \( K \) values depending on bar location

Forces create tension in concrete

(after Figure 13.1.2.3(B) of AS 3600)
AS 3600 Section 13

Splitting failures around developing bars

(Figure C13.1.1 from AS 3600 Commentary)

(a) Forces exerted on concrete by a deformed bar in tension

(b) Tensile stresses in concrete

(c) Horizontal splitting due insufficient bar spacing.

(d) Vertical splitting due to insufficient cover

(e) Splitting (bond) failure at a lapped splice.
AS 3600 Section 13

Tensile development length – refined

Can be less than $29k_4d_b$ if either $k_4$ or $k_5$ is less than 1, as minimum $29k_4d_b$ length not placed on Equation 13.1.2.3

$$L_{sy.t} = k_4k_5L_{sy.tb}$$ (Equation 13.1.2.3)

Note that $L_{sy.tb}$ still has a minimum value of $29k_4d_b$
Tensile Development and Lap Splice Lengths

Technological Note 7

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

December 2016

Note: Basic Tables contained in Detailing Handbook
Multiply factors for $L_{sy.tb}$

- $\Psi_{cd}$ and $\Psi_{bc}$ taken from ACI 318-05 (concrete density, bar coating)
- $\Psi_{s}$ taken from Eurocode 2 Part 1.1 (slip form construction)
- Eurocode 2 includes $\Psi_{s}$ in $k_1$ factor

Therefore:

$$L_{sy.tb} = \Psi_{bc} \Psi_{cd} \frac{0.5 k_1 k_3 f_{sy} d_b}{k_2 \sqrt{f'_c}} \geq 29k_1 d_b$$

Note: Factors $\Psi_{bc}$ and $\Psi_{cd}$ do not apply to minimum value of $29k_1 d_b$

- Minimum $29k_1 d_b$ relates to upper limit of bond strength due to bar pull-out rather than concrete splitting failure
AS 3600 only mentions factor of 1.5 for epoxy coating

ACI 318M-14 has a range of options:

Value of bar coating factor, $\psi_{bc}$ (from Table 25.4.2.4 of ACI 318M-14)

<table>
<thead>
<tr>
<th>Value of factor $k_4$</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>Epoxy-coated or zinc and epoxy dual-coated reinforcement with clear cover less than $3.0d_b$ or clear spacing less than $6.0d_b$</td>
</tr>
<tr>
<td>1.2</td>
<td>Epoxy-coated or zinc and epoxy dual-coated reinforcement for all other conditions</td>
</tr>
<tr>
<td>1.0</td>
<td>Uncoated or zinc-coated (galvanised) reinforcement</td>
</tr>
</tbody>
</table>
### TN 7 - Background Information

**$k_4$ factor**  
$k_4 = 1.0 - K\lambda$ with $(0.7 \leq \lambda \leq 1.0)$

**Use of average $K$ value**  
$K = 0.05 \times \left(1 + \frac{n_f}{n_{bs}}\right) \leq 0.10$

**Figure A.3 from SRIA TN 7**

<table>
<thead>
<tr>
<th>Member type</th>
<th>Examples of potential splitting cracks at a tensile face</th>
<th>$n_f$</th>
<th>$n_{bs}$</th>
<th>$K$ (see Note 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular column</td>
<td><img src="image" alt="Circular column diagram" /></td>
<td>1</td>
<td>1</td>
<td>0.10</td>
</tr>
<tr>
<td>Rectangular column</td>
<td><img src="image" alt="Rectangular column diagram" /></td>
<td>$\geq 1$</td>
<td>$\geq 1$</td>
<td>$0.05 \leq K \leq 0.10$</td>
</tr>
<tr>
<td>Beam</td>
<td><img src="image" alt="Beam diagram" /></td>
<td>$\geq 1$</td>
<td>$\geq 1$</td>
<td>$0.05 \leq K \leq 0.10$</td>
</tr>
<tr>
<td>Slab or wall with fitments</td>
<td><img src="image" alt="Slab or wall diagram" /></td>
<td>$\geq 1$</td>
<td>$\geq 1$</td>
<td>$0.05 \leq K \leq 0.10$</td>
</tr>
<tr>
<td>Slab or wall without fitments</td>
<td><img src="image" alt="Slab or wall diagram" /></td>
<td>0</td>
<td>1 per main bar spacing</td>
<td>0.05 (see Note 2)</td>
</tr>
</tbody>
</table>
Bar areas used in determining refined factor $k_4$

$$k_4 = 1.0 - K \lambda \quad \text{with} \quad (0.7 \leq \lambda \leq 1.0)$$

$$\lambda = \left( \frac{\sum A_{tr} - \sum A_{tr,\text{min}}}{A_s} \right) \quad \text{where} \quad A_{tr,\text{min}} = \frac{A_s}{4} \quad \text{when} \quad K > 0$$

<table>
<thead>
<tr>
<th>Bar diameter</th>
<th>Cross-sectional area</th>
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<tr>
<td>mm</td>
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<td>1020</td>
</tr>
<tr>
<td>N40</td>
<td>1260</td>
</tr>
</tbody>
</table>
**TN 7 - Background Information**

$k_5$ factor  

$k_5 = \text{factor for effect of transverse pressure}$  

\[ = 1.0 - 0.04 \rho_p \quad \text{with} \quad (0.7 \leq k_5 \leq 1.0) \]

\[ \rho_p = 0 \text{ to maximum 7.5 MPa} \]

- Compressive stress perpendicular to the longitudinal axis of the bar improves bond strength
- Strong influence if confinement sufficient to restrain splitting failure mode
- Once this point is reached, the rate of increase reduces
$k_5$ factor

- Influence restricted to support region where the clamping pressure along the face where the stress is applied acts to confine the bars
- Ignore influence for indirect end support conditions
- Ignore influence for cogged and hooked portions of bars that are parallel to direction of compressive stress
When considering loads from upper storeys:

- For indirect end support, ignore stress from floor in question
- For direct end support, consider compressive stress from entire reaction acting at the soffit of the floor member
TN 7 - Background Information

Developing less than the yield strength – Equation 13.1.2.4

\[ L_{st} = L_{sy,t} \frac{\sigma_{st}}{f_{sy}} \]

For \( k_4 \) and \( k_5 = 1.0 \)

\[ L_{st} = \max. \left( \frac{0.5k_1k_3f_{sy}d_b}{k_2\sqrt{f_c}} \text{ and } 29k_1d_b \right) \frac{\sigma_{st}}{f_{sy}} \]

\( L_{st} \) shall not be less than:

\[ \rightarrow 12 \ d_b \text{; or} \]

\[ \rightarrow \text{For slabs, as permitted by Clause 9.1.3.1(a)(ii)} \]
TN 7 – Tensile Lap Splices

Tensile lap length (basic or refined) – Clause 13.2.2 of AS 3600

\[ L_{sy.t.lap} = k_7 L_{sy.t} \geq 29k_1 d_b \]  
(Note: \( L_{sy.t} = L_{sy.tb} \) or \( L_{sy.t} \))

For narrow elements:

\[ L_{sy.t.lap} = \min \left[ k_7 L_{sy.t}, k_7 L_{sy.t} + 1.5s_b, 29k_1 d_b \right] \]

When calculating \( L_{sy.t} \), minimum 29\( k_1 d_b \) does not apply to \( L_{sy.tb} \)

\[ L_{sy.tb} = \Psi_{bc} \Psi_{cd} \frac{0.5k_1k_3f_{sy}d_b}{k_2\sqrt{f_c'}} \geq 29k_1 d_b \]

\( k_7 \) – factor for staggered laps and bar stress levels
TN 7 – Tensile Lap Splices

Tensile lap length (basic or refined)

- $k_7 = 1.0$ if the cross-sectional area of the bars outside the laps equals at least twice the area required for strength, and no more than half the bars are lapped at any section

- $k_7 = 1.25$ otherwise

Note: For the purpose of determining $c_d$,

$$\alpha = 2s_e [or 2(s_{cc} - a_b)]$$

irrespective of the value of $s_b$
Tensile lap length (basic or refined)

- Bars of different sizes – lapped splice length equals:
  - Tensile lapped splice length of smaller bar
  - Development length of larger bar

- Minimum clear distance between bars:
  - 1.5 x nominal maximum aggregate size
  - 1.5 x bar diameter

- Clear distance between lapped bars, \( s_b \):
  - If \( s_b \leq 3d_b \), or for narrow elements, treated as contact splice
  - For non-contact lapped splices, no upper limit specified in AS 3600
  - ACI 318M-14 Clause 25.5.1.3 specifies upper limit:

\[
s_b = \text{less}er \ of \ \left[ 150 - d_b , \ \frac{L_{sy.tb.lap}}{5} \text{or} \frac{L_{sy.t.lap}}{5} - d_b \right]
\]
3 Groups of Design Tables provided:

- General, Cover-controlled and Spacing-controlled
- Cover-Controlled and Spacing-controlled are subsets of the General Design Tables
- Recommend using General Design Tables
- Underlying assumptions need to be met to use either Cover-controlled or Spacing-controlled Design Tables
- All Tables based on plain uncoated bars and normal density concrete
  - Need to apply $\Psi_{bc}$ and $\Psi_{cd}$ factors
All Design Tables provide:

- Basic development and lapped splice lengths
- Minimum possible refined development and lapped splice lengths
  Actual value depends on each individual circumstance
- $c_d$ values up to 100 mm
  Based on Clause 8.6.1(b) of AS 3600 – distance to the centre of the nearest longitudinal bar not to exceed 100 mm
- Bar sizes up to 40 mm
  Based on Clause 13.2.1(e) of AS 3600 – lapped splices shall not be used for bars in tension with diameter > 40 mm
- For minimum cover based on bar size ($c$ not less than $d$)
- Values rounded to the nearest 10 mm
- Maximum $f'_c \leq 65$ MPa
TN 7 - Benefit of refined calculation (Table B.2)

\[(k_4k_5)_{\text{min}} = 1.0 \text{ if } k_3 = 0.7 \text{ (as } 0.7 \leq k_3k_4k_5 \leq 1.0)\]

### Table B.2 – Unique, minimum values of refined factors product, \(k_4k_5\), which apply to the solutions in every General Table with one-to-one correspondence

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<th>(C_d)</th>
<th>N10</th>
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## Technical Note 7 – Example of General Design Tables

### Technical Note 7

**STRESS DEVELOPMENT AND LAP SPLICING OF STRAIGHT D500N TENSILE REINFORCING BARS TO AS 3600-2009**

The Steel Reinforcement Institute of Australia is a national non-profit organization providing information on the many uses of steel reinforcement and reinforced concrete. Since the information provided is intended for guidance only, and in no way replaces the services of professional consultants on particular projects, no legal liability can be accepted for its use.

### TABLE G/20.1.0/1.00 – Tensile Development and Lap Lengths

<table>
<thead>
<tr>
<th>C_d</th>
<th>N10</th>
<th>N12</th>
<th>N16</th>
<th>N20</th>
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**MINIMUM Refined Development Length (mm)**

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</table>

**MINIMUM Refined Lap Length (mm)**

<table>
<thead>
<tr>
<th>C_d</th>
<th>N10</th>
<th>N12</th>
<th>N16</th>
<th>N20</th>
<th>N24</th>
<th>N28</th>
<th>N32</th>
<th>N36</th>
<th>N40</th>
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</thead>
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<tr>
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<td>310</td>
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<td>30</td>
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<tr>
<td>35</td>
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<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
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</tr>
</tbody>
</table>

**Note:** The tabled theoretical values of minimum refined development length, \(L_{d,min}\), and minimum refined lap length, \(L_{lap,min}\), are minimum possible solutions, based on the values of \(\phi(\kappa_d)\) in Table B.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, \(L_{d,b}\), or basic lap length, \(L_{lap,b}\), respectively, then refined design may be beneficial, but a designer must calculate the actual values of \(L_{d,b}\) or \(L_{lap,b}\).
Use of General Design Tables

- Determine the following:
  - Concrete strength grade
  - Bar diameter
  - Value of $k_1$
  - Value of $k_7$
  - Value of $c_d$

Modify value for:
- Bundled bars - increases
- Less than yield strength being developed - reduces
- Bar coating and/or lightweight concrete - increases
Lapping of top reinforcement

The situation

- N24 top reinforcement
- Spacing of bars = 120 mm
- Maximum lap length = 1200
- Slab thickness = 400 mm
- Concrete grade = 32 MPa
- Transverse bars laid on top of lapped bars
- Minimum top cover = 40 mm
- Laps of main bars are all non-contact
TN 7 – Example 1

Solution
Determine if the basic lap length $L_{sy.tb.lap}$ is less than the 1200 mm available, and if not, whether a refined lap length $L_{sy.t.lap}$, will reduce the required lap length sufficiently.

1. Concrete strength grade – 32 MPa
2. Bar diameter – N24
3. Value of $k_1$ – 1.3 (> 300 mm below bar)
4. Value of $k_7$ – 1.25 (as all main bars are lapped at the same location)
5. Value of $c_d$ – 40 mm

No adjustment for bundled bars, bar coating or lightweight concrete necessary.
5. Value of $c_d$ – 40 mm (minimum $c$ or $a/2$)

$c$ taken as 50 mm (40 mm cover + min. N12 transverse bars)

$a = 120 - 2 \times 24 = 72$ mm (refer Figure 13.2.2 of AS 3600)

$c_d = \text{min. } 72/2 \text{ or } 50 \text{ mm } \Rightarrow 36$ mm (round up to 40 mm)

(i) 100% of bars spliced (no staggered splice)

Figure 13.2.2(i) of AS 3600
### Basic Tensile Lap Length, $L_{\text{sy.tb.lap}}$

<table>
<thead>
<tr>
<th>$c_d$</th>
<th>N10</th>
<th>N12</th>
<th>N16</th>
<th>N20</th>
<th>N24</th>
<th>N28</th>
<th>N32</th>
<th>N36</th>
<th>N40</th>
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<tbody>
<tr>
<td>20</td>
<td>500 (410)</td>
<td>650 (500)</td>
<td>950 (690)</td>
<td>1280 (900)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25</td>
<td>460 (410)</td>
<td>600 (500)</td>
<td>910 (690)</td>
<td>1230 (900)</td>
<td>1590 (1120)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>410</td>
<td>560 (500)</td>
<td>860 (690)</td>
<td>1190 (900)</td>
<td>1540 (1120)</td>
<td>1910 (1350)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>35</td>
<td>&quot;</td>
<td>510 (500)</td>
<td>810 (690)</td>
<td>1140 (900)</td>
<td>1490 (1120)</td>
<td>1860 (1350)</td>
<td>2270 (1610)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>40</td>
<td>500</td>
<td>770 (690)</td>
<td>1090 (900)</td>
<td>1440 (1120)</td>
<td>1810 (1350)</td>
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<td>2650 (1890)</td>
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<tr>
<td>45</td>
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<td>720 (690)</td>
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<td>690</td>
<td>990 (900)</td>
<td>1340 (1120)</td>
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<td>2100 (1610)</td>
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<td>3010 (2190)</td>
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<tr>
<td>55</td>
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<td>950 (900)</td>
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<td>1650 (1350)</td>
<td>2050 (1610)</td>
<td>2480 (1890)</td>
<td>2950 (2190)</td>
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<tr>
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<td>2000 (1610)</td>
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<td>65</td>
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<td>1190 (1120)</td>
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<td>1670 (1610)</td>
<td>2090 (1890)</td>
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<td>95</td>
<td>1620 (1610)</td>
<td>2030 (1890)</td>
<td>2480 (2190)</td>
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<tr>
<td>100</td>
<td></td>
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<td>1970 (1890)</td>
<td>2420 (2190)</td>
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</tr>
</tbody>
</table>

[Minimum refined tensile lap length, $L_{\text{sy.tb.lap.min.}}$ in red]

---

**Determine basic lap length from General Design Table G21**
TN 7 – Example 1

Determine refined lap length

- As 1440 mm exceeds the 1200 mm available (basic no good)
- Minimum refined lap length of 1120 mm less than 1200 mm available

Calculate $k_3$ value based on actual $c_d = 36$ mm

$$k_3 = \left[ 1.0 - \frac{0.15(c_d - d_b)}{d_b} \right] = \left[ 1.0 - \frac{0.15(36 - 24)}{24} \right] = 0.925$$

As $k_3k_4k_5 = 0.7$, the value of $k_4$ equals (with $k_5 = 1.0$):

$$k_4 = \frac{0.7}{k_3k_5} = \frac{0.7}{0.925 \times 1.0} = 0.757$$
TN 7 – Example 1

Determine transverse steel required to give $k_4$ factor of 0.757

$$k_4 = 1.0 - K \lambda \quad \text{such that} \quad 0.7 \leq k_4 \leq 1.0 \quad \text{(by definition)}$$

As $k_4 = 0.757$ which is $> 0.7$, condition is satisfied

$$(K \lambda)_{\text{max.}} = 1.0 - k_4 = 1.0 - 0.757 = 0.243$$

From Figure A.3, $K = 0.05$

| Slab or wall without filaments | \[ \begin{array}{c}
\text{Slab or wall without filaments} \\
\end{array} \] | \[ \begin{array}{c}
A_{tr} \\
\end{array} \] | \[ \begin{array}{c}
0 \\
\end{array} \] | \[ \begin{array}{c}
1 \text{ per main bar spacing} \\
\end{array} \] | \[ \begin{array}{c}
0.05 \\
\text{(see Note 2)} \\
\end{array} \] |
|-----------------|-------------------|---|------------------|---|

$$\lambda = \frac{0.243}{0.05} = 4.86$$

$$\lambda = \frac{\sum A_{tr} - \sum A_{tr,\text{min}}}{A_s} = \frac{\sum A_{tr} - 0.25A_s}{A_s} \geq 0 \quad \text{(by definition)}$$

Note: $\sum A_{tr,\text{min}} = 0.25 A_s$ as $K > 0 \quad (K = 0.5)$

If $K = 0$ (ie no transverse steel), $\sum A_{tr,\text{min}} = 0$
TN 7 – Example 1

New SRIA Technical Note TN7

\[ \lambda = \frac{\sum A_{tr} - 0.25 A_s}{A_s} \]

by re-arranging

\[ \sum A_{tr} = \lambda A_s - 0.25 A_s \]

As \( A_s = 452 \text{ mm}^2 \)

\( \sum A_{tr} = 4.86 \times 452 - 0.25 \times 452 \)

\( \sum A_{tr} = 2,310 \text{ mm}^2 \)

Try N20 at 200 top – number of bars over 1200 mm lap = 7

Area = \( 7 \times 452 = 2,200 \text{ mm}^2 \)

Close to 2,310 mm², so check lap length
TN 7 – Example 1

Check refined lap length required

\[ L_{s_y,t.lap} = k_7 \left[ k_4 k_5 \frac{0.5k_1k_3 f_{s_y} d_b}{k_2 \sqrt{f'_c}} \right] \geq 29k_1d_b \]

\[ \lambda = \frac{\sum A_r - 0.25 A_s}{A_s} = \frac{2200 - 0.25 \times 452}{452} = 4.62 \geq 0 \]

\[ k_4 = 1.0 - K \lambda = 1.0 - 0.05 \times 4.62 = 0.77 \]

\[ k_2 = \frac{132 - d_b}{100} = \frac{132 - 24}{100} = 1.08 \]

\[ k_3 = \left[ 1.0 - \frac{0.15(c_d - d_b)}{d_b} \right] = \left[ 1.0 - \frac{0.15(36 - 24)}{24} \right] = 0.925 \]
Check refined lap length required

\[
L_{\text{sy.t.lap}} = k_7 \left[ k_4 k_5 \frac{0.5 k_1 k_3 f_{\text{sy}} d_b}{k_2 \sqrt{f'_c}} \right] \geq 29 k_1 d_b
\]

\[
L_{\text{sy.t.lap}} = 1.25 \left[ 0.77 \times 1.0 \frac{0.5 \times 1.3 \times 0.925 \times 500 \times 24}{1.08 \times \sqrt{32}} \right]
\]

\[
L_{\text{sy.t.lap}} = 1137 \text{ mm} \quad \text{(which is greater than } 29 k_1 d_b = 905 \text{ mm)}
\]

Conclusion:

As 1137 mm is less than the 1200 mm available, lap length is satisfactory with N20 at 200 transverse bars provided.

Note that the lap length required (1137 mm) is only slightly longer than the minimum possible value of 1120 mm given in the General Design Table G21.
AS 3700 Masonry structures Update
### Capacity Reduction Factor (Table 4.1)

Factor for grouted unreinforced masonry increased

<table>
<thead>
<tr>
<th>Type of masonry or accessory and action effect</th>
<th>Capacity reduction factor ((\Theta))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Unreinforced masonry:</td>
<td></td>
</tr>
<tr>
<td>(i) Compression</td>
<td></td>
</tr>
<tr>
<td>(A) Solid or cored</td>
<td>0.75</td>
</tr>
<tr>
<td>(B) Hollow (including grouted)</td>
<td>0.50</td>
</tr>
<tr>
<td>(C) Grouted</td>
<td>0.60</td>
</tr>
<tr>
<td>(ii) Flexure</td>
<td>0.60</td>
</tr>
<tr>
<td>(iii) Shear</td>
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</tr>
<tr>
<td>(iv) Other actions</td>
<td>0.60</td>
</tr>
<tr>
<td>(b) Reinforced and prestressed masonry:</td>
<td></td>
</tr>
<tr>
<td>(i) Compression</td>
<td>0.75</td>
</tr>
<tr>
<td>(ii) All other actions</td>
<td>0.75</td>
</tr>
<tr>
<td>(c) Wall ties, connectors and accessories:</td>
<td></td>
</tr>
<tr>
<td>(i) Wall ties in tension or compression</td>
<td>0.95</td>
</tr>
<tr>
<td>(ii) Connectors across a joint in masonry</td>
<td>0.75</td>
</tr>
<tr>
<td>(iii) Accessories and other actions</td>
<td>0.75</td>
</tr>
</tbody>
</table>
AS 3700 Update

Unreinforced Masonry
Design of grouted members in compression (no testing)

2011

\[ F_o \leq \phi \left[ f'_m A_b + k_c \sqrt{\left( \frac{f'_{cg}}{1.3} \right)} A_g \right] \]

\[ k_c = 1.2 \text{ generally} \]
\[ = 1.4 \text{ for hollow concrete masonry} > 2000 \text{ kg/m}^3 \]

2017

\[ F_o \leq \phi \left[ f'_m A_b + k_c \left( \frac{f'_{cg}}{1.3} \right)^{0.55 + 0.055 f'_{cg}} A_g \right] \]
Reinforced Masonry

Design of members in compression

**2011**

\[ F_d \leq \phi k_s \left[ f_m' A_b + k_c \sqrt{\left( \frac{f_{cg}'}{1.3} \right) A_g + f_{sy} A_s} \right] \]

\[ k_s = 1.18 - 0.03 S_r \text{ but not greater than 1.0} \]

**2017**

\[ F_d \leq \phi k_{es} \left[ f_m' A_b + k_c \left( \frac{f_{cg}'}{1.3} \right)^{(0.55+0.055 f_{cg}')} A_g + \alpha_r f_{sy} A_s \right] \]

\[ k_{es} = \left( 1.0 - 0.025 S_r \right) \left( 1.0 - 2.0 \frac{e}{t} \right) \]

- Requirement to design for interaction of compression and bending has been removed (Clause 8.11.1)
- \( \alpha_r \) - reinforcing contribution factor
Reinforced Masonry
Design of members in compression

2011 Design strength of grout, $f'_{cg} = \text{the lesser of: } f'_c \text{ or } 1.3 \times f'_{uc}$

2017 Design strength of grout, $f'_{cg} = \text{not less than } 12 \text{ MPa}$

Reinforcing contribution factor, $\alpha_r = 1.0 \text{ for piers}$

= 0.4 \text{ for walls}
Contribution of Reinforcement in Walls

Clause 8.5 (e)
Reinforcement in walls shall be surrounded by an annulus of grout of thickness not less than twice the diameter of the reinforcing bar.

Annulus of grout, $5d_b = 100$ mm for N20 bar
AS 3700 Update

Clause 8.4.6 Wide-spaced reinforcement
Clarification that walls can be fully or partially grouted

Stack Bonded Masonry
Clause 4.11.2 – Clarification provided regarding bonding
Where the following cannot be provided:
- At least 90 mm of engagement, or
- One quarter of a unit overlap
the masonry shall be considered to be stack bonded
Stack Bonded Masonry (Clause 4.12 added)

Hollow unit masonry
- Reinforce or prestress to resist actions

Solid and cored unit masonry
- Reinforce with bed joint reinforcement
- Reinforcement continuous between lateral supports
- Max. vertical spacing = 6 x thickness of leaf
- Area ≥ 0.00035 x gross vertical cross-sectional area of the wall
- At specific locations – refer Figure 4.1
- Designed as:
  - unreinforced for compression
  - reinforced for one-way horizontal bending
AS 3700 Update

Stack Bonded Masonry (New Figure 4.1)

Figure 4.1 Reinforcement Placement for Stack Bonded Masonry
AS 3700 Update

**Durability requirements expanded**

Appendix I added (informative)

- Corrosivity Categories and Relationship to Durability Class (ISO 9223)
- Requirements for Durability Class of Components R1 to R5 in Table 5.1 explained

**Stainless Steel Reinforcement**

- Requirements included in Table 3.7
- Clause 5.9.5
  - Durability Class R1 to R3 – galvanised
  - Durability Class R4 – stainless steel reinforcement
# AS 3700 Update

## Table 3.7 Strength and Ductility of Reinforcement

<table>
<thead>
<tr>
<th>Reinforcement</th>
<th>Designation grade</th>
<th>Design yield strength (MPa)</th>
<th>Durability class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar plain to AS/NZS 4671</td>
<td>R250N</td>
<td>250</td>
<td>N</td>
</tr>
<tr>
<td>Bar deformed to AS/NZS 4671</td>
<td>D500L (fitments only)</td>
<td>500</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>D500N</td>
<td>500</td>
<td>N</td>
</tr>
<tr>
<td>Welded mesh, plain, deformed and indented to AS/NZS 4671</td>
<td>D500L</td>
<td>500</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>D500N</td>
<td>500</td>
<td>N</td>
</tr>
<tr>
<td>Stainless steel plain bar to EN 10088-5 (see Notes 2 and 3)</td>
<td>250</td>
<td>250</td>
<td>N</td>
</tr>
<tr>
<td>Stainless steel ribbed bar to BS 6744 (see Notes 2 and 3)</td>
<td>500</td>
<td>650</td>
<td>N</td>
</tr>
</tbody>
</table>

**Note 2** Physical and mechanical properties in accordance with BS 6744 and EN 10088-5 and chemical composition conforming with 1.4311, 1.4162, 1.4362, 1.4462, 1.4404 or 1.4429 to EN 10088-1

**Note 3** Stainless steel bars to BS 6744 and EN 10088-5 are deemed to comply with Ductility Class N in accordance with AS/NZS 4671
AS 3727 Residential pavement Update
**AS 3727 Update**

**Major Changes:**

- 1993 Guide is now a mandatory Standard
- Concrete Pavements

Table 5.2 Concrete Base Parameters (changes highlighted)

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Minimum base thickness mm</th>
<th>Minimum concrete grade</th>
<th>Alternative 1 unreinforced</th>
<th>Alternative 2 reinforced</th>
<th>Alternative 3 reinforced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maximum control joint spacing m</td>
<td>Minimum reinforcing mesh</td>
<td>Maximum control joint spacing m</td>
</tr>
<tr>
<td>Pedestrian only</td>
<td>75</td>
<td>N20</td>
<td>2.0 1.5</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td>Pedestrians and light vehicles</td>
<td>100</td>
<td>N20, N25</td>
<td>2.0 1.5</td>
<td>-</td>
<td>3 2</td>
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<tr>
<td>Pedestrians and commercial vehicles</td>
<td>150</td>
<td>N25, N32</td>
<td>2</td>
<td>-</td>
<td>4</td>
</tr>
</tbody>
</table>
Reinforcement

Required where:

- The panel is of irregular shape
- The length is greater than 1.5 x width (even if regular shape)
- Joint spacing greater than Alternative 1
- Re-entrant corners – 2 N12 x 1000 mm long min.

Cover using bar chairs in accordance with AS/NZS 2425

Lapping of mesh - minimum two transverse bars

Reinforcement NOT continuous through control joints
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Typical Control Joints

Figure 5.4.2 (a) Formed joint (with shear key)

Use of formwork between concrete placements
Typical Control Joints

Figure 5.4.2 (b) Weakened plane joint

Create plane of weakness
- Scoring surface (tooled joint)
- Insert proprietary crack-inducing device
- Sawing the concrete
### Dowel Details

<table>
<thead>
<tr>
<th>Pavement thickness mm</th>
<th>Dowel Type</th>
<th>Dowel dimensions mm</th>
<th>Minimum dowel length mm</th>
<th>Maximum dowel spacing mm</th>
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</thead>
<tbody>
<tr>
<td>75</td>
<td>N/A</td>
<td>N/A</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>100</td>
<td>Round</td>
<td>12 diameter</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Square</td>
<td>12 x 12</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Plate</td>
<td>MR</td>
<td>MR</td>
<td>450</td>
</tr>
<tr>
<td>125</td>
<td>Round</td>
<td>16 diameter</td>
<td>350</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Square</td>
<td>16 x 16</td>
<td>350</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Plate</td>
<td>MR</td>
<td>MR</td>
<td>450</td>
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<tr>
<td>150</td>
<td>Round</td>
<td>20 diameter</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Square</td>
<td>20 x 20</td>
<td>400</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>Plate</td>
<td>MR</td>
<td>MR</td>
<td>450</td>
</tr>
</tbody>
</table>

MR – Refer Manufacturer’s Recommendations
Due to variety of plate dowel types, geometries and installation methods
AS 3727 Update

Typical Dowelled Expansion Joint (Figure 5.4.4)

Spacing
Plain pavements < 100 mm thick – max. 6 m centres
Reinforced pavements ≥ 100 mm thick – max, 12 m centres
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Joint Angles (Figure 5.4.6 added): Where possible $\geq 75^\circ$

[Diagram showing joint angles and minimum 75° angle]

Edge of pavement (or joint)
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Joint Requirements

- Continuous from edge to edge
- Sealing
  - Surfaces clean and dry
  - Concrete fully cured and reached design strength
  - Surface temperature ≥ 5°
  - Correct depth of sealant (0.5W ≤ depth ≤ W)
  - Sealant only adheres to sides of joint
- Saw cutting
  - Correct timing
  - Clean all debris
  - No ravelling greater than 20 mm
- Dowels
  - Ensure adequate alignment and allowance for movement
Appendix B included on Quality Issues

- Random crack width
  - Different to planned cracking
  - Factors causing random cracking
- Reinforcement
  - Brittle surface coverings eg tiles, decorative finishes
- Joint spacing
  - Decreased to reduce the risk of random cracking
- Joint detailing
  - Important issues concerning joint types
- Concrete
  - Importance of uncontrolled addition of water, compaction and curing
AS/NZS 2425 Bar chairs in reinforced concrete
Product requirements and test methods
Keeping Reinforcement in Place

- Bar Chairs
- Concrete
- Plastic
- Plastic tipped wire
- Hurdles
AS/NZS 2425 Bar chairs in reinforced concrete – Product requirements

Load capacity

<table>
<thead>
<tr>
<th>Test</th>
<th>Strength Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum test load capacity</td>
<td>60  120  200   &gt; 300</td>
</tr>
</tbody>
</table>

Chloride permeability of concrete bar chairs

<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>
Bar chairs

Specify

- 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
Thank you

Steel Reinforcement Institute of Australia