Overview of Part 1 - Design

• Low-Ductility Reinforcement Properties

• Design to AS 3600–2009

• SRIA Experimental Research Programs
Low-Ductility Reinforcement Properties

- Hot-rolled R250N bar to AS/NZS 4671:
Low-Ductility Reinforcement Properties

• Cold-worked D500L bar to AS/NZS 4671:
Cold-worked D500L bar to AS/NZS 4671:

- Stress
  - Uniform strain $\varepsilon_u \geq 0.015$ or $6 \varepsilon_{sy,nom}$
  - Elastic yield strain $\varepsilon_{sy} = \frac{f_{sy}}{E_s}$
- Strain
  - Uniform strain $\varepsilon_u$
- Tensile strength $f_u \geq 1.03 f_{sy}$ (onset of necking)
- Bar fracture
Low-Ductility Reinforcement Properties

- Cold-worked D500L mesh to AS/NZS 4671:
Low-Ductility Reinforcement Properties

- Cold-worked D500L mesh average tensile results: *uniform strain or elongation* \( (\varepsilon_u) \)
Design to AS 3600–2009

• Limited ductility of reinforcing steel (Clause 1.1.2 Application):
  Reinforcing steel of Ductility Class L "shall not be used in any situation where the reinforcement is required to undergo large plastic deformation under strength limit state conditions".
Design to AS 3600–2009

- Tensile strength, $f_{tu} = 515$ MPa
- Yield stress, $f_{sy} = 500$ MPa
- Modulus of elasticity, $E_s = 200$ GPa
- Uniform strain, $\varepsilon_{su} = 1.5\%$
- Tensile strength reached at onset of necking: steel fracture assumed in design
- Yield strain, $\varepsilon_{sy} = 0.25\%$
Design to AS 3600–2009

- Mixing Ductility Class N and L bars
  (Clause 2.2 Design for Strength)
Nominal moment capacity, $M_{uo}$

(Clause 8.1 Strength of Beams in Bending)

- rectangular stress block theory can be used to calculate $M_{uo}$ of singly-reinforced sections without having to consider possible steel fracture

- bending without axial tension or compression, for members with Class L main reinforcement:

$$0.6 \leq \{\phi=(1.19 - 13k_{uo}/12)\} \leq 0.64 \text{ (i.e. } =0.8 \times 0.8)$$
• Analysis Methods & Moment Redistribution (Section 6 Methods of Structural Analysis)
  – Methods of analysis for calculating $M^*$, etc. with Class L mesh:
    ▪ Clause 6.2 – Linear Elastic Analysis of any type of concrete structure, **but ignoring moment redistribution**
    ▪ Clause 6.10 – Simplified Methods for beams or one-way slabs; and two-way slabs supported on four sides.
    ▪ **Support settlement does not normally have to be considered**
SRIA Experimental Research Programs

- **SRIA Continuous One-Way Slab Tests under Standard Fire Conditions**
  conducted at BHP Melbourne Research Laboratories in 1997

- **SRIA Ductility Class L Elevated Slab Tests**
  conducted at Curtin University between 2007 and 2012
SRIA Continuous Slab Fire Tests:

- Two unrestrained slabs tested:
  - Ductility Class N mesh; then
  - Ductility Class L mesh
- Min. 2 hour Standard Fire Conditions
- Reinforcement ductility severely tested:
  - -30% moment redistribution in design
  - under-reinforced support regions ($\rho = 0.0033$)
  - longitudinally unrestrained on roller supports
SRIA Continuous Slab Fire Tests
SRSA Continuous Slab Fire Tests

Ductility Class L – 3+ hours

Ductility Class N – 2+ hours
SRIA Ductility Class L Slab Tests:

- Reinforcement ductility
- Moment-curvature relationships
- Moment redistribution
- Mixing Ductility Class L mesh and N bars
- Strength review of AS 3600–2009
- Compressive membrane action
- Doubly-reinforced sections
SRIA Ductility Class L Slab Tests

TW Series

DSOW Series

SSOW Series

Universal Test Rig
SRIA Ductility Class L Slab Tests

Steel tensile capacity controls $M_{uo}$

Concrete compressive strength controls $M_{uo}$

$\varepsilon_c / \varepsilon_{cu}$

$\phi = 0.64$

Critical sections of SRIA test specimens (treated as singly-reinforced)

$k_{uo,min}$

$k_{uo} = 0.36$

Preferred test specimen range

$M_{uo}$

$\varepsilon_c / \varepsilon_{cu}$ predicted steel fracture
SRIA Ductility Class L Slab Tests

- Restrained ends or edges: fully built-in
SRIA Ductility Class L Slab Tests
— reinforcement ductility

![Graph showing uniform strain (ε_u) vs. mesh bar diameter (mm) for different test conditions.](image)
SRIA Ductility Class L Slab Tests — moment-curvature relationships

- $E_c = 27.0$ GPa
- $f_{sy} = 568$ MPa
- $f_{cu} = 620$ MPa
- $e_u = 2.1\%$
- $M_u = 18.27$ kNm
- $\kappa_y = 42.4E-06$ mm$^{-1}$
- $\kappa_{u,\text{min}} = 96.5E-06$ mm$^{-1}$ (under-reinforced AS 3600)
- $\kappa_u = 104.3E-06$ mm$^{-1}$
- $M_{uo} = 17.58$ kNm ($f_{su} = 602$ MPa)
- $\phi M_{uo} = 9.29$ kNm ($f_{sy} = 500$ MPa)
- Mesh bars failed altogether

(Average Curvature over 600 mm long, 16 LVDT bank in mid-span region (mm$^{-1}$))
Degree of moment redistribution approaches about 10%, implying that close to a full plastic hinge mechanism developed.
SRIA Ductility Class L Slab Tests
— strength review of AS 3600 – 2009

Restrained Slab Test Specimens SSO2-ST1, DSOW-ST1, DSO2-ST2 & TW-ST1

AS 3600:2009
1.5Q/φ = 1.56 × (1.5Q)

Mean of 4 tests = 5.19

Normal probability distribution of test results

Ratio of ultimate applied test load to factored design live load,
\[ \frac{P_u}{1.5Q} \]
• Strain-compatibility and force equilibrium assumptions for doubly-reinforced sections:
  - plane sections remain plane
  - concrete has no tensile strength
  - resultant tensile & compressive forces balance
  - maximum concrete comp. strain, $\varepsilon_c=0.003$
  - uniform concrete comp. stress, $\alpha_2 f'_c$
  - max. steel tensile stress, $f_u=1.03f_{sy}$
  - max. steel tensile strain, $\varepsilon_{su}=0.015$
Conclusions: Part 1 - Design

- Low-Ductility Reinforcement Properties
- Design to AS 3600–2009
- SRIA Experimental Research Programs
Recent Developments in the Design and Construction of Concrete Structures incorporating Low-Ductility Steel Reinforcement

Scott Munter & Mark Patrick

Part 2 – Construction
Overview of Part 2 - Construction

- Low-Ductility Reinforcement Types
- Standard Ductility Class L Meshes
- Lapping Mesh & Design Steel Areas
- Doubly-reinforced Slab Sections
- Overcoming 20% Penalty in Bending Strength Design
- Case Study
• 1 point – at least 60% of the steel is made using an energy reduction process
• 1 point – at least 15% of the reinforcing steel is used for off site optimal fabrication techniques
AS 3600–2009 Clause 1.1.2(c):

“Reinforcing steel of Ductility Class L in accordance with AS/NZS 4671 may be used as main or secondary reinforcement in the form of welded wire mesh, or as wire (coil), bar and mesh in fitments”
Low-Ductility Reinforcement Types
Low-Ductility Reinforcement Types
Low-Ductility Reinforcement Types
Low-Ductility Reinforcement Types
Standard Ductility Class L Meshes

Preface

4th EDITION

A.R.C. WELDED WIRE FABRIC, now produced in all States of the Commonwealth by the various A.R.C. manufacturing plants, was introduced to Australia by A.R.C. during 1918. Since that date, it has become universally recognised and accepted as an economical and convenient reinforcing material.

As the pioneers and acknowledged leaders in Welded Mesh and the Steel Reinforcement Industry, we present this up-to-date information for the assistance of Engineers, Architects, and Builders.

A programme of research into the properties of welded mesh and steel reinforcements, together with regular quality control, is now performed in our N.A.T.A. Research Laboratory at Homebush, and certain of the technical information in this booklet is the result of that work. Likewise, as a result of our continuous machine design programme, our equipment incorporates the most modern welding techniques.

A.R.C. FABRIC, used in conjunction with the comprehensive range of A.R.C. reinforcing bars of various types and sizes, give the complete reinforcing for concrete construction.

For full details of the current ACRS certificate holders can be found at www.acrs.net.au

If there’s any doubt, please contact ACRS on (02) 9965 7216 or Email: info@acrs.nct.au

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Standard Ductility Class L Meshes

- R500L (plain) or D500L (ribbed) off coil
- All mesh is factory made and machine welded
- Joints at intersections of longitudinal and transverse bars are electrical resistance welded, with shear strengths not less than 50% of the nominal yield strength of the larger bar
- Bar strength is unaffected by welding
## Cross-sectional areas of standard Australian Ductility Class L meshes (mm²/m)

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Doubly-Reinforced Slab Sections
Overcoming 20% Penalty in Bending Strength Design

• Average cross-sectional areas of Standard meshes are 5 to 10% greater than nominal mesh areas.

• Bending strength of doubly-reinforced sections is typically 10-15% greater than singly-reinforced sections (design assumption)

⇒ Accounting for both these effects in design can nullify the effects of the 20% penalty in construction
Case Study – Medium-Rise Building
Case Study – Medium-Rise Building
Case Study – Medium-Rise Building
Case Study – Medium-Rise Building
Conclusions: Part 2 - Construction

- Low-Ductility Reinforcement Types
- Standard Ductility Class L Meshes
- Lapping Mesh & Design Steel Areas
- Doubly-reinforced Slab Sections
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Questions