



Recent Developments in the Design and Construction of Concrete Structures incorporating Low-Ductility Steel Reinforcement

Scott Munter & Mark Patrick

Part 1 – Design

Part 2 – Construction

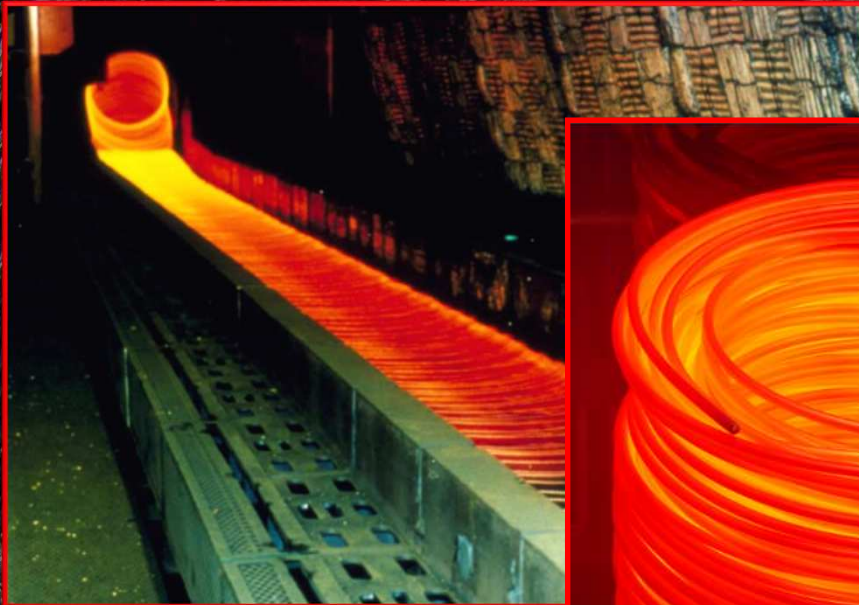


Overview of Part 1 - *Design*

- 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:



Round Rod 8.5mm
M1010
Heat(s): AJS89869 Mass: 2.069 t
Bundle: 15670672 Est. Pcs: 1
Item: 91050 EAN: 9326499910502
(0 1)993264999 10502 (30)000 1 (10)AJS89869

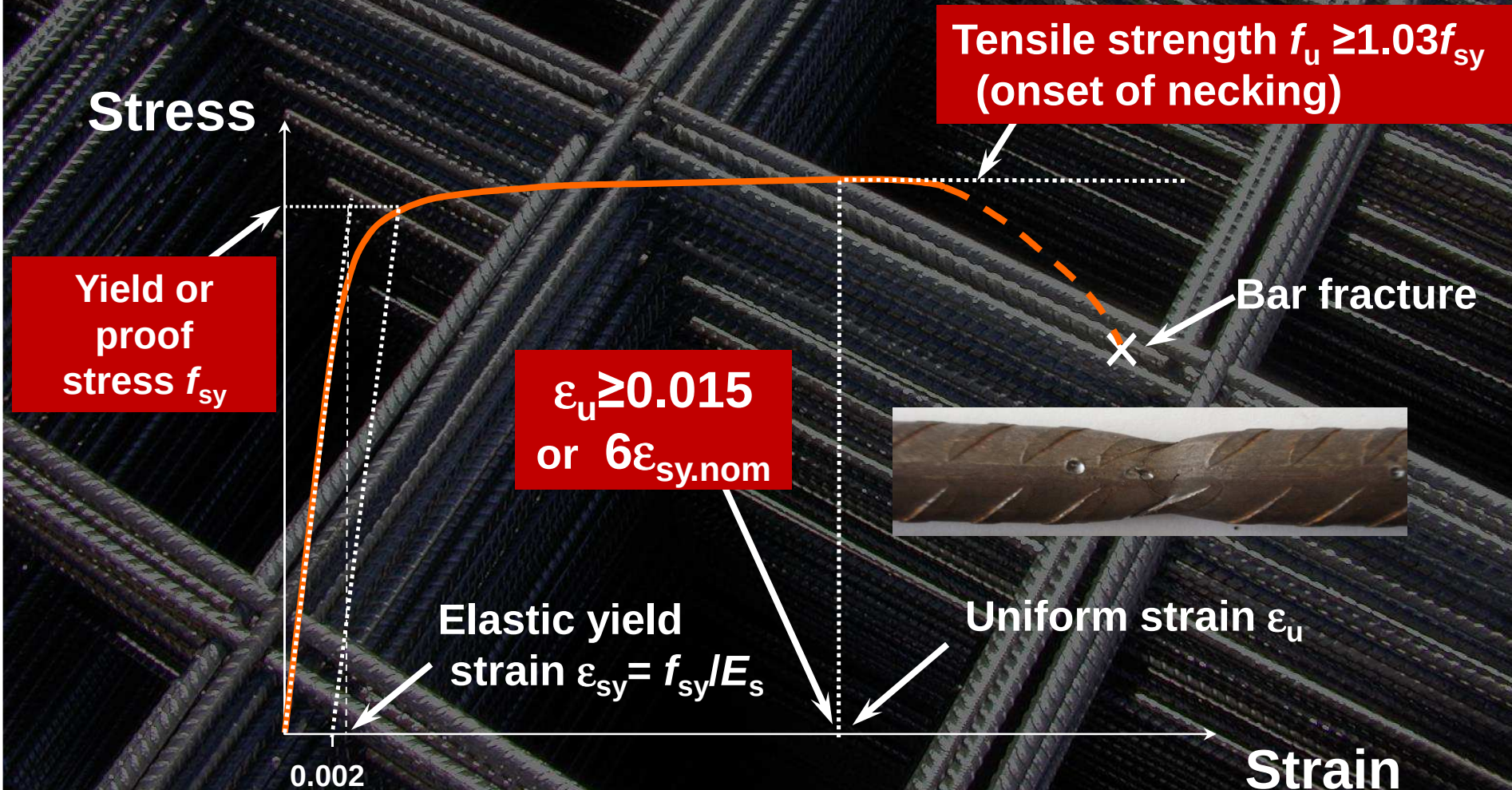
Low-Ductility Reinforcement Properties

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



Low-Ductility Reinforcement Properties

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



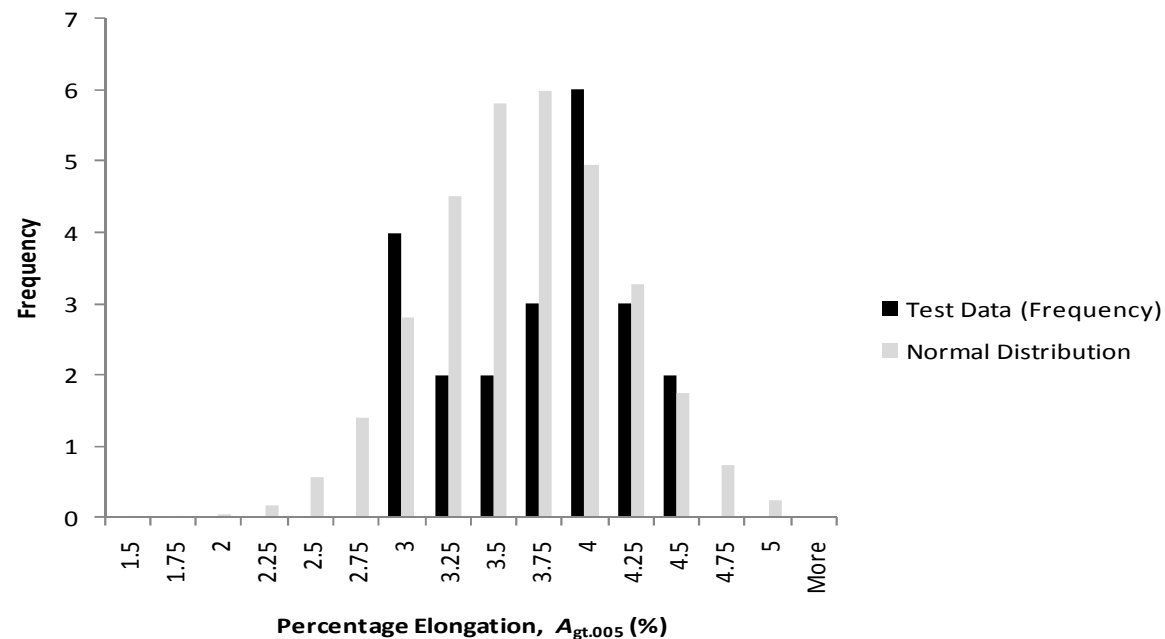
Low-Ductility Reinforcement Properties

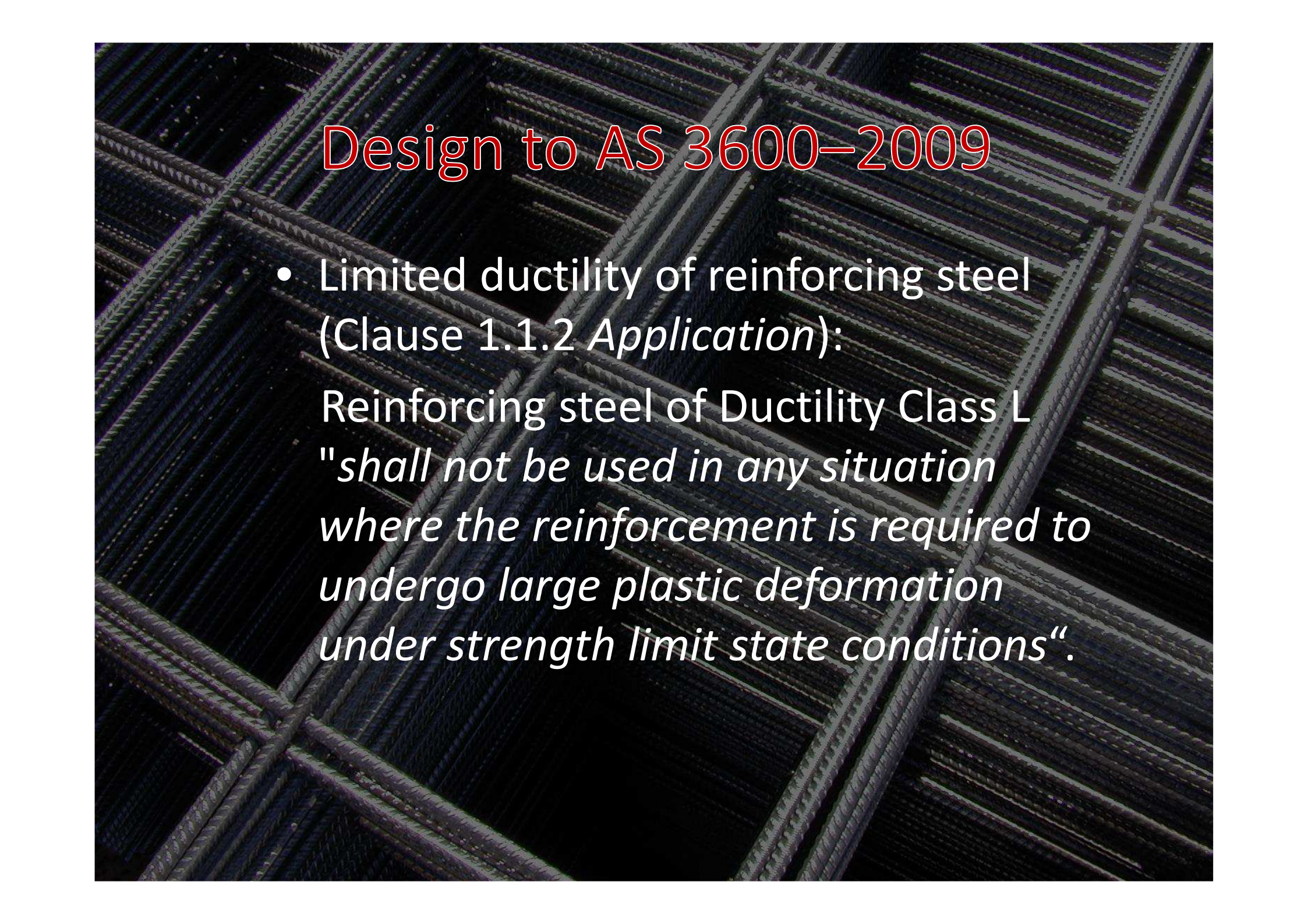
- Cold-worked D500L mesh to AS/NZS 4671:



Low-Ductility Reinforcement Properties

- Cold-worked D500L mesh average tensile results: *uniform strain or elongation* (ϵ_u)

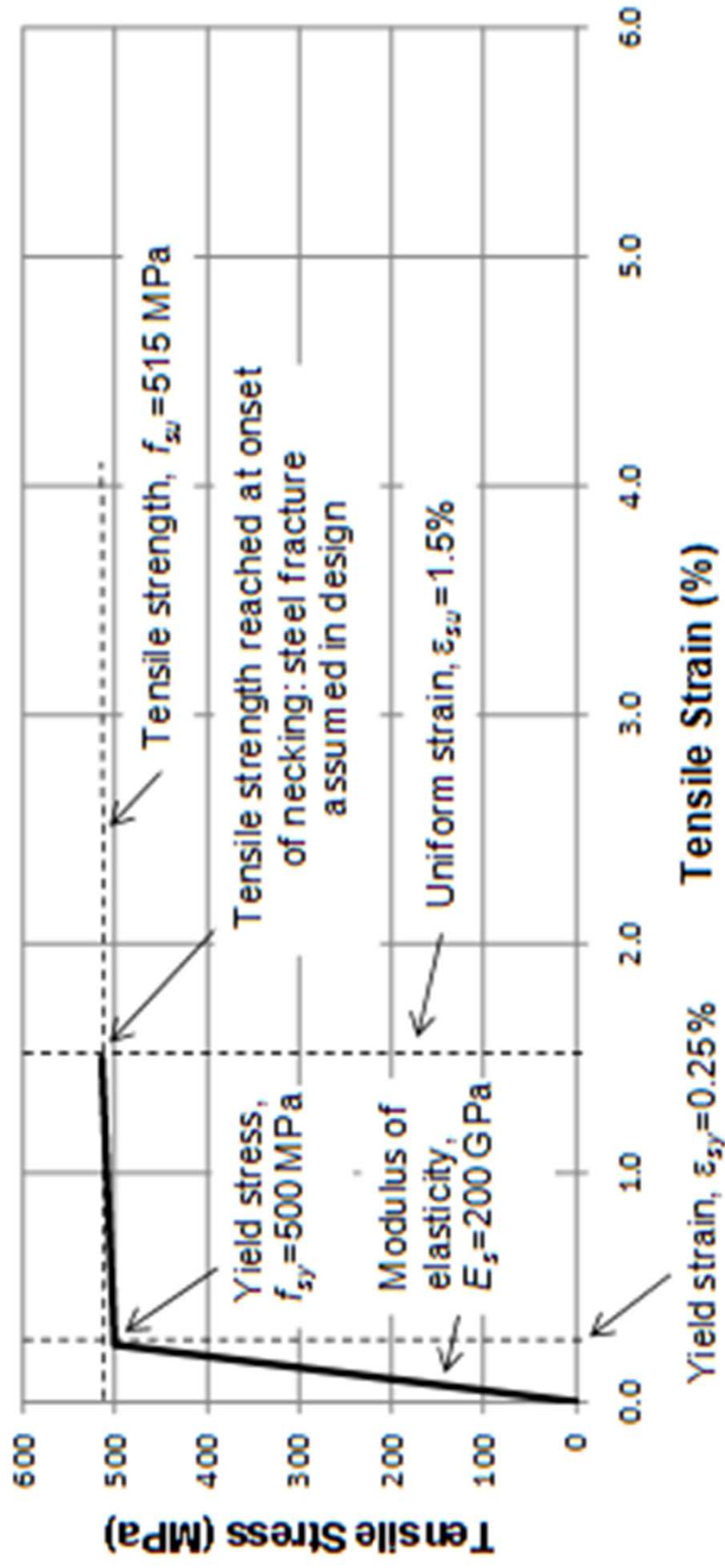




Design to AS 3600–2009

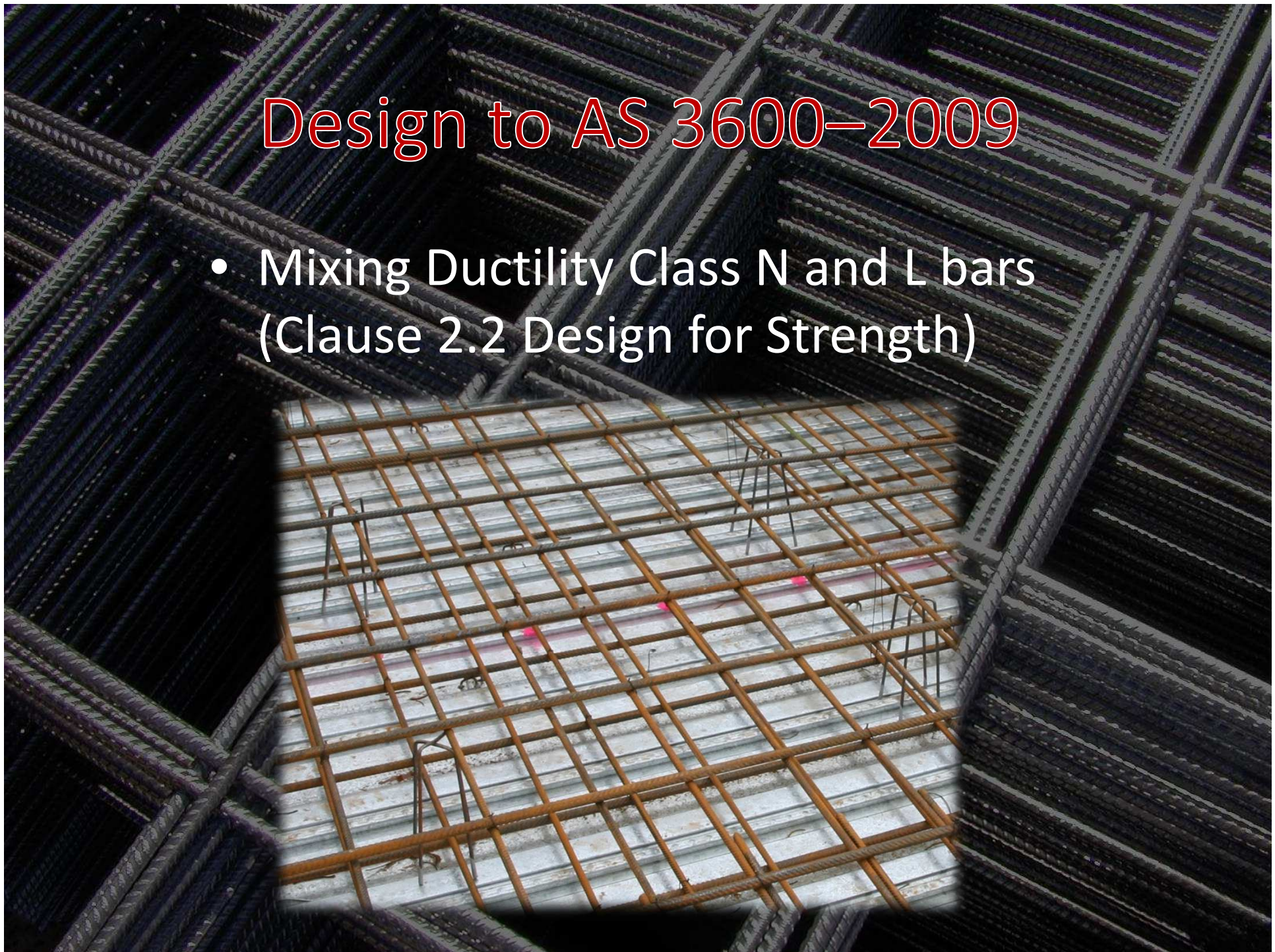
- Limited ductility of reinforcing steel (Clause 1.1.2 *Application*):
Reinforcing steel of Ductility Class L
"shall not be used in any situation where the reinforcement is required to undergo large plastic deformation under strength limit state conditions".

Design to AS 3600-2009



Design to AS 3600–2009

- Mixing Ductility Class N and L bars (Clause 2.2 Design for Strength)



Design to AS 3600–2009

- Nominal moment capacity, M_{u0}
(Clause 8.1 Strength of Beams in Bending)
 - rectangular stress block theory can be used to calculate M_{u0} of singly-reinforced sections without having to consider possible steel fracture
 - bending without axial tension or compression, for members with Class L main reinforcement:
$$0.6 \leq \{\phi = (1.19 - 13k_{u0}/12)\} \leq 0.64 \text{ (i.e. } = 0.8 \times 0.8 \text{)}$$

Design to AS 3600–2009

- 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 Experimental Research Programs

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 ($p=0.0033$)
 - longitudinally unrestrained on roller supports

SRIA Continuous Slab Fire Tests



SRIA Continuous Slab Fire Tests



SRIA Continuous Slab Fire Tests



Ductility Class L – 3+ hours

Ductility Class N – 2+ hours



SRIA Experimental Research Programs

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



Test Report – SRIA Class L Mesh Slab Tests

VOLUME 1 of 3: Report

ISBN: 978-0-9872876-0-1

June 2012

Dr Ian Chandler and Dr Natalie Lloyd

Department of Civil Engineering
School of Civil and Mechanical Engineering



Test Report – SRIA Class L Mesh Slab Tests

VOLUME 2 of 3: Plates



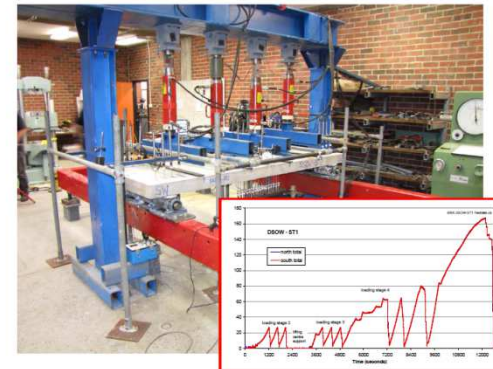
Dr Ian Chandler and Dr Natalie Lloyd
Department of Civil Engineering
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Test Report – SRIA Class L Mesh Slab Tests

VOLUME 3 of 3: Figures



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+ associated Curtin Uni / SRIA documents

SRIA Ductility Class L Slab Tests

DSOW Series

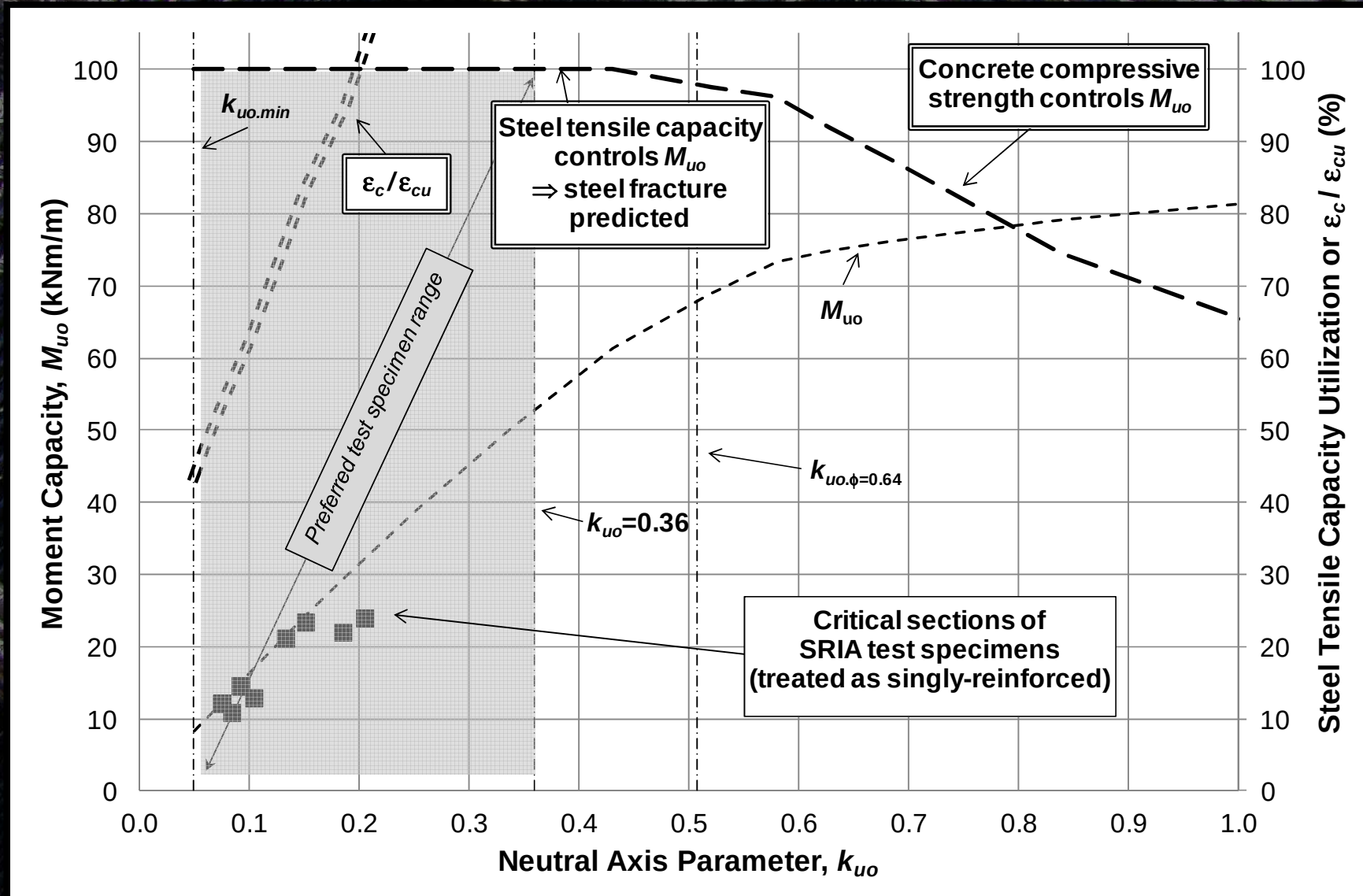
TW Series

SSOW Series

Universal Test Rig

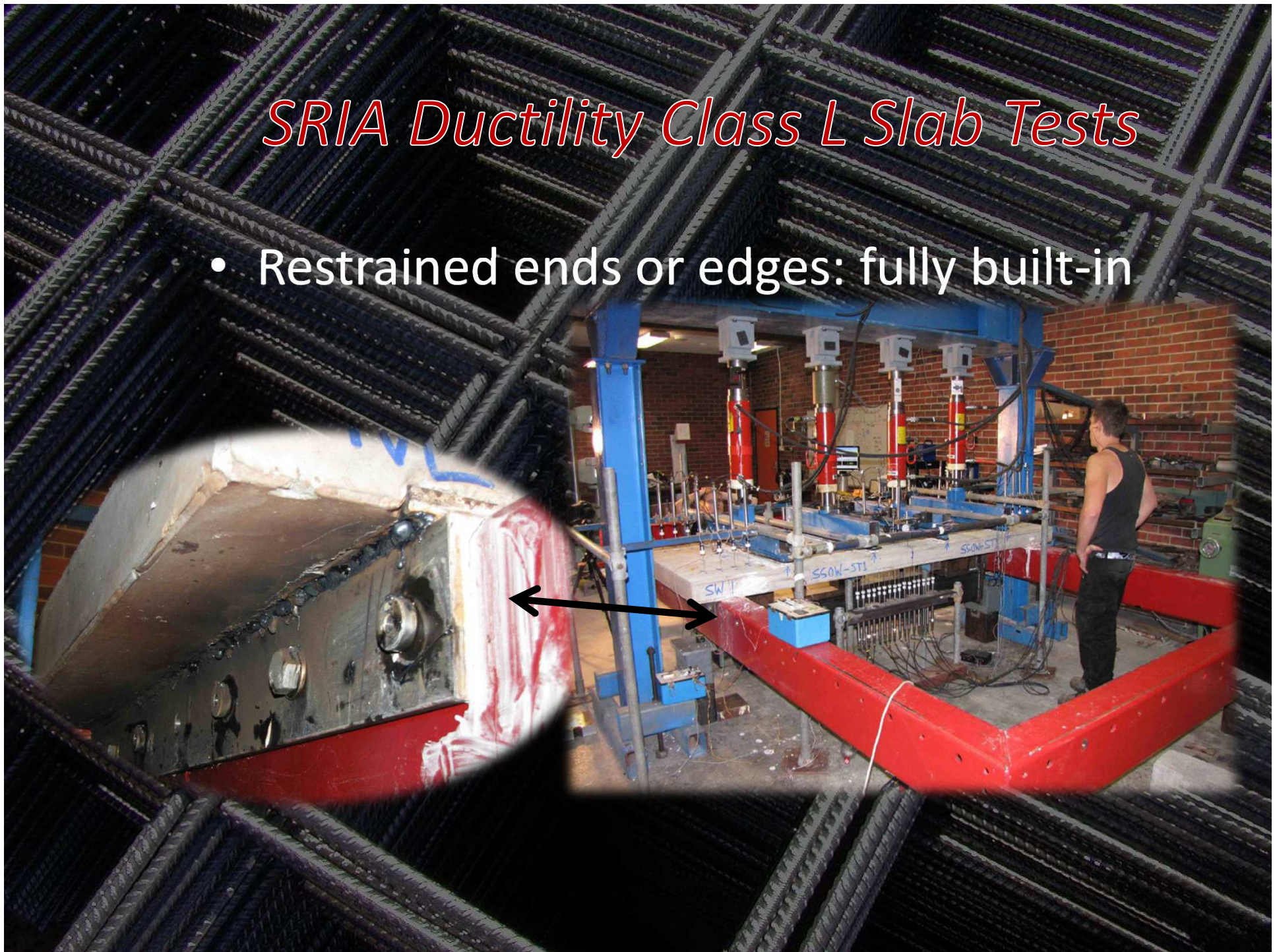


SRIA Ductility Class L Slab Tests



SRIA Ductility Class L Slab Tests

- Restrained ends or edges: fully built-in

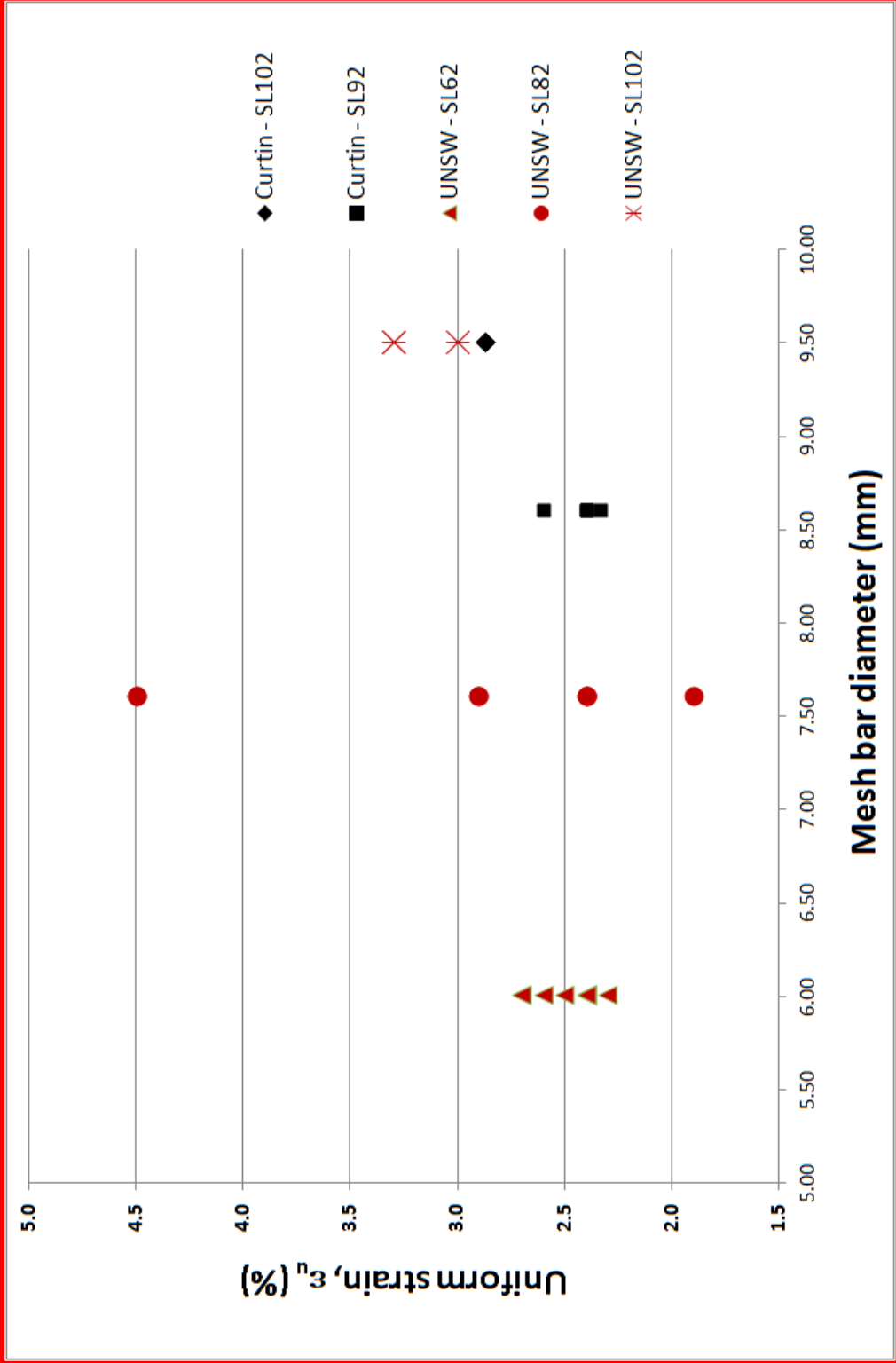


SRIA Ductility Class L Slab Tests

– reinforcement ductility

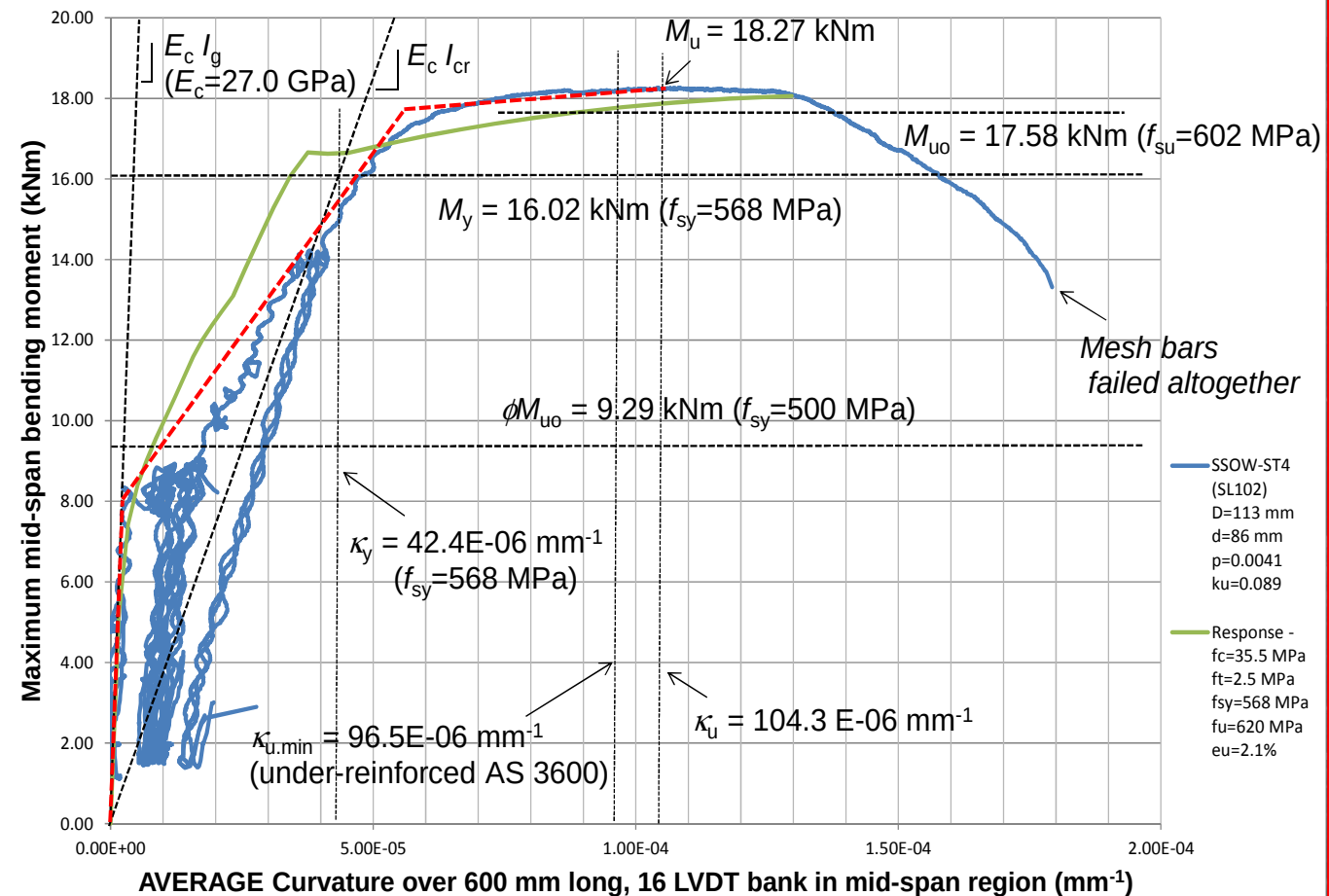
The scatter plot displays the relationship between uniform strain (ϵ_u in %) and mesh bar diameter (mm) for five different slab test series. The y-axis ranges from 1.5 to 5.0, and the x-axis ranges from 5.00 to 10.00 mm. The data points are as follows:

Mesh bar diameter (mm)	Uniform strain, ϵ_u (%)	Series
5.00	2.30	UNSW - SL82
5.50	2.30	UNSW - SL82
5.50	2.30	UNSW - SL102
5.50	2.30	UNSW - SL62
5.50	2.30	UNSW - SL82
5.50	2.30	UNSW - SL102
6.00	2.30	UNSW - SL82
6.00	2.30	UNSW - SL102
6.00	2.30	UNSW - SL62
6.00	2.30	UNSW - SL82
6.00	2.30	UNSW - SL102
7.50	4.50	UNSW - SL82
8.50	2.60	Curtin - SL92
8.50	2.60	UNSW - SL82
8.50	2.60	UNSW - SL102
9.50	3.10	Curtin - SL102
9.50	3.10	UNSW - SL102



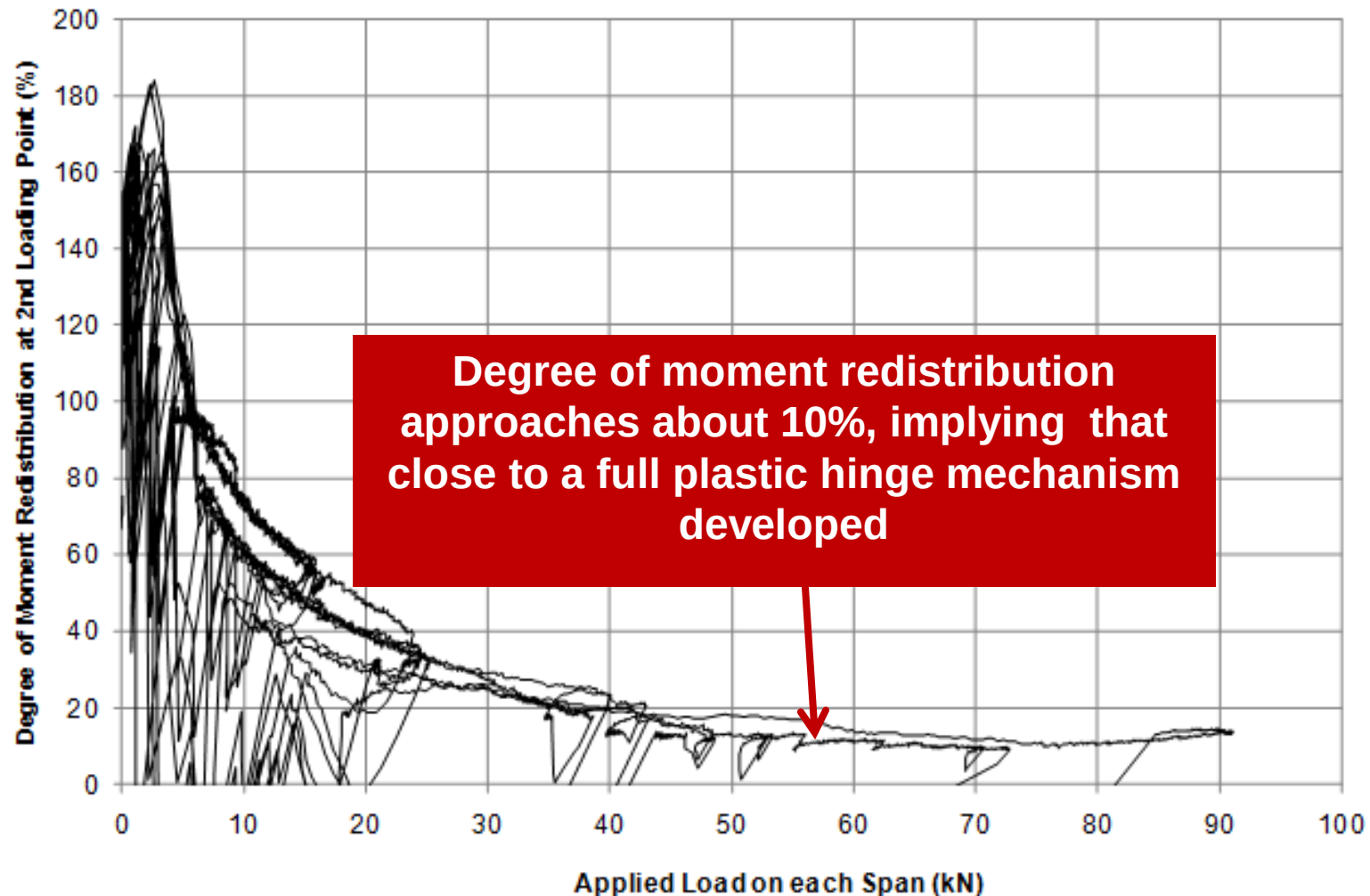
SRIA Ductility Class L Slab Tests

– moment-curvature relationships



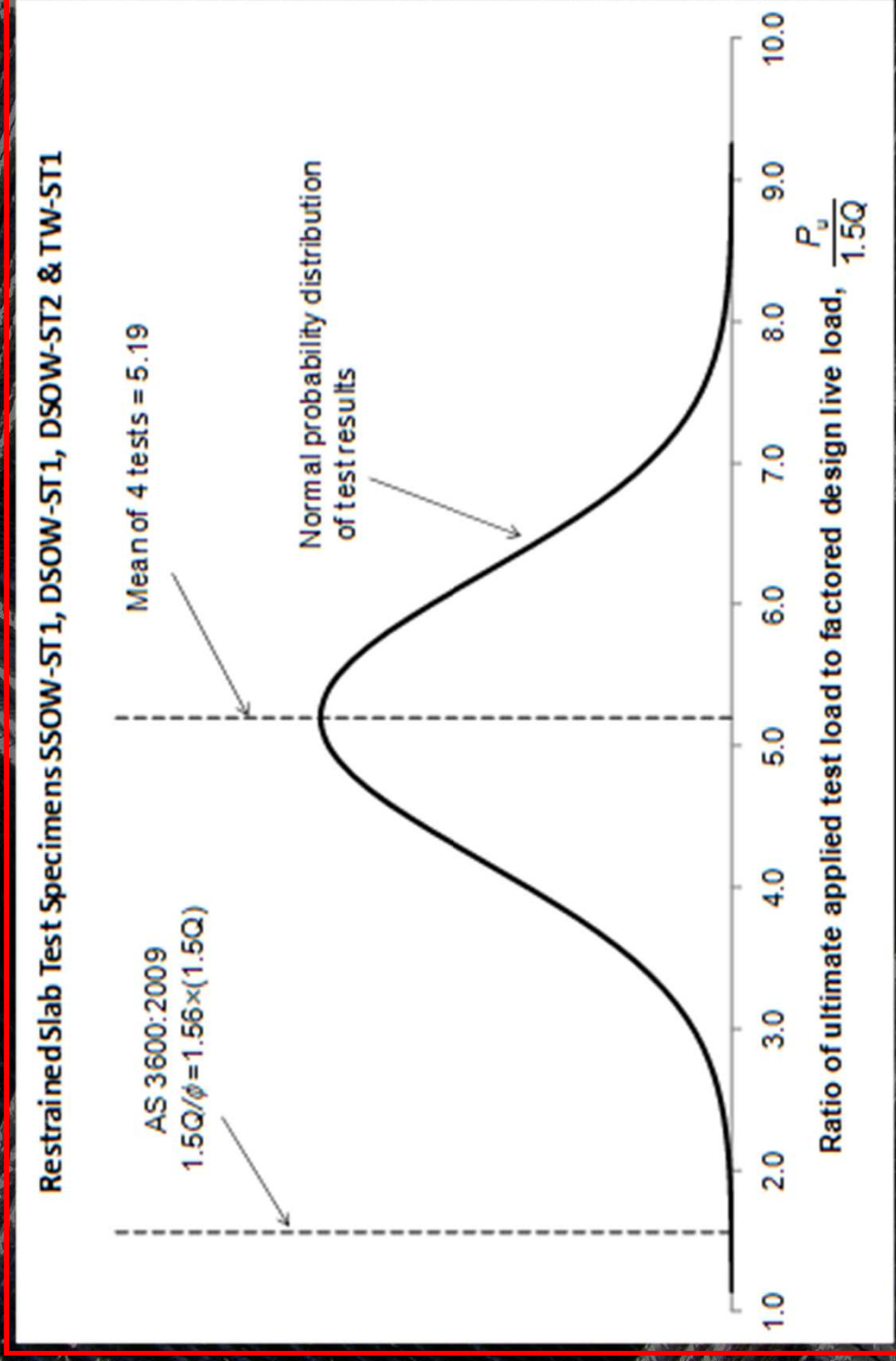
SRIA Ductility Class L Slab Tests

– moment redistribution



SRIA Ductility Class L Slab Tests

– strength review of AS 3600 – 2009





SRIA Ductility Class L Slab Tests

– doubly-reinforced sections

- 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, $\epsilon_c = 0.003$
 - uniform concrete comp. stress, $\alpha_2 f'_c$
 - max. steel tensile stress, $f_u = 1.03 f_{sy}$
 - max. steel tensile strain, $\epsilon_{su} = 0.015$



Conclusions: Part 1 - *Design*

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Part 2 – Construction



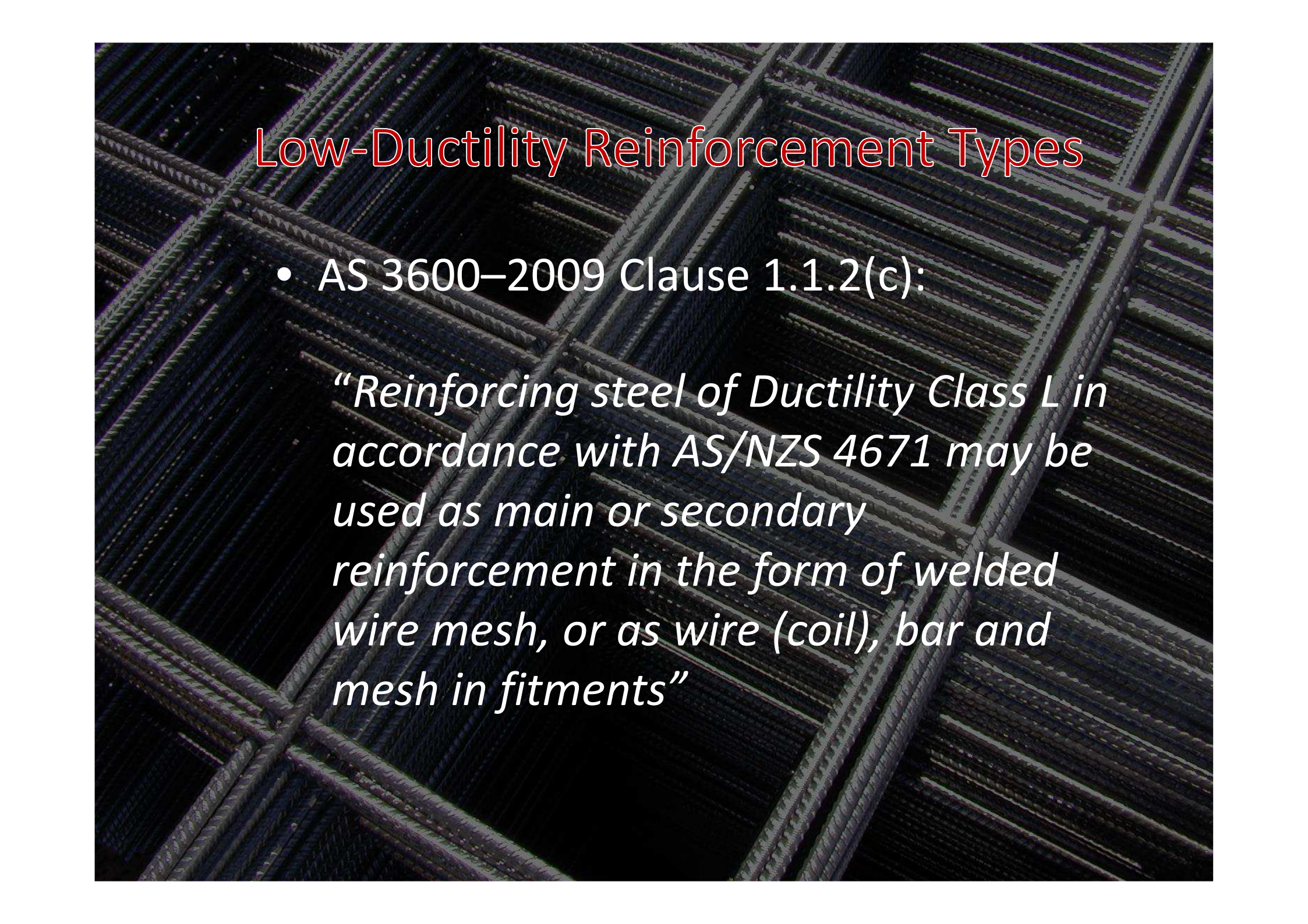
Overview of Part 2 - Construction

- 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

Low-Ductility Reinforcement Types



- 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

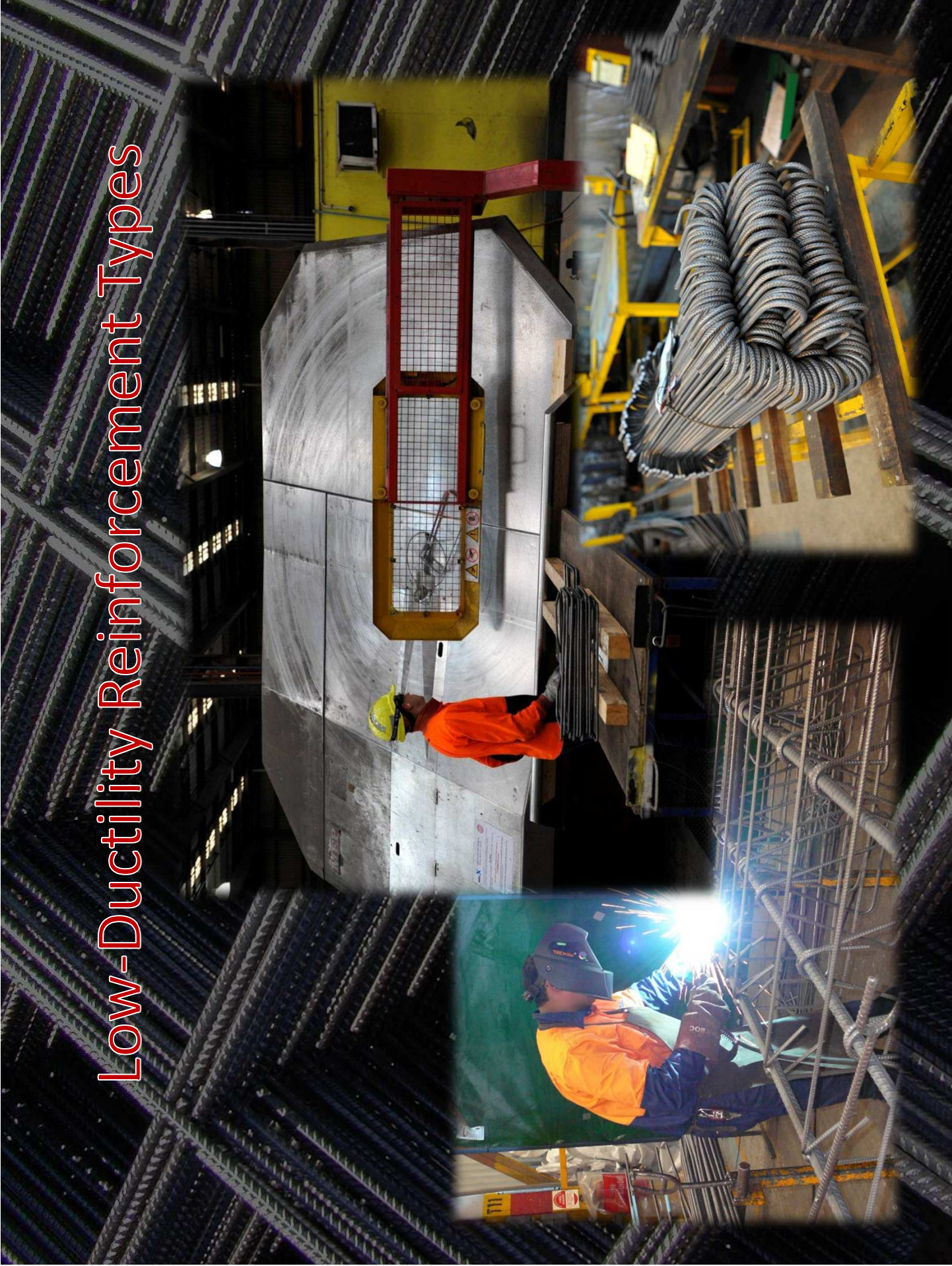


Low-Ductility Reinforcement Types

- 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”

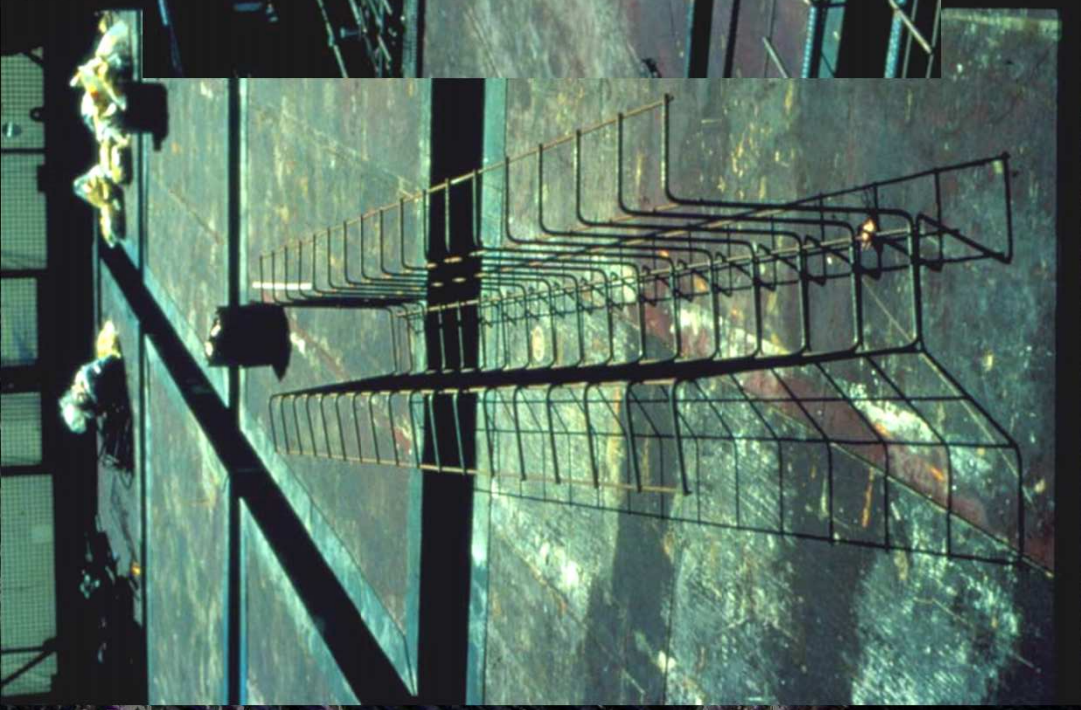
Low-Ductility Reinforcement Types



Low-Ductility Reinforcement Types



Low-Ductility Reinforcement Types



Low-Ductility Reinforcement Types



Standard Ductility Class L Meshes

Preface

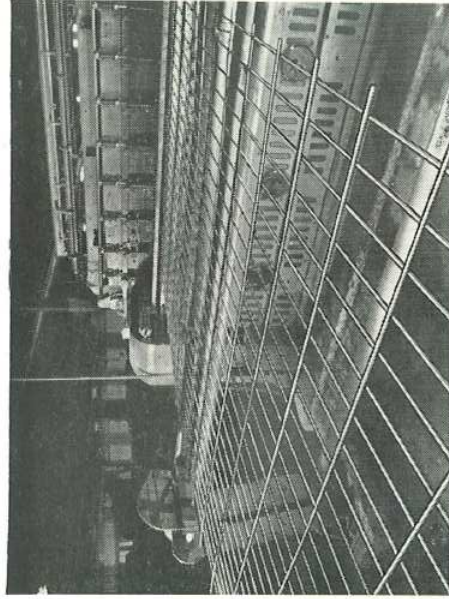
4th EDITION

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.

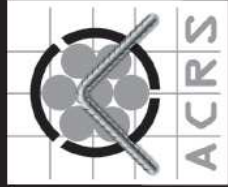
A programme of research into the properties of welded mesh and steel reinforcements, together with regular quality control, is now performed in our N.A.T.A. Research Laboratory at Homebush, and certain of the technical information in this booklet is the result of that work. Likewise, as a result of our 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 the complete reinforcing concrete construction.



A.R.C. Welded Wire Fabric is produced on modern precision equipment that assures exact spacing of wires and perfectly welded joints.

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If there's any doubt, please contact ACRS on (02) 9965 7216 or Email: info@acrs.net.au ABN 40 096 692 545



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



Lapping Mesh & Design Steel Areas

**Cross-sectional areas of standard Australian Ductility Class L meshes
(mm²/m)**

Ref. No.	Longitudinal		Transverse		Ref. No.	Longitudinal		Transverse	
	A_{bl}	$\bar{A}_{bl}$	A_{bt}	$\bar{A}_{bt}$		A_{bl}	$\bar{A}_{bl}$	A_{bt}	$\bar{A}_{bt}$
RL1218	1112	1215	227	243	SL81	454	495	454	470
RL1118	899	982	227	243	SL102	354	372	354	380
RL1018	709	774	227	243	SL92	290	303	290	311
RL918	581	634	227	243	SL82	227	247	227	243
RL818	454	495	227	243	SL72	179	190	179	192
RL718	358	390	227	243	SL62	141	157	141	152

Doubly-Reinforced Slab Sections



Overcoming 20% Penalty in Bending Strength Design

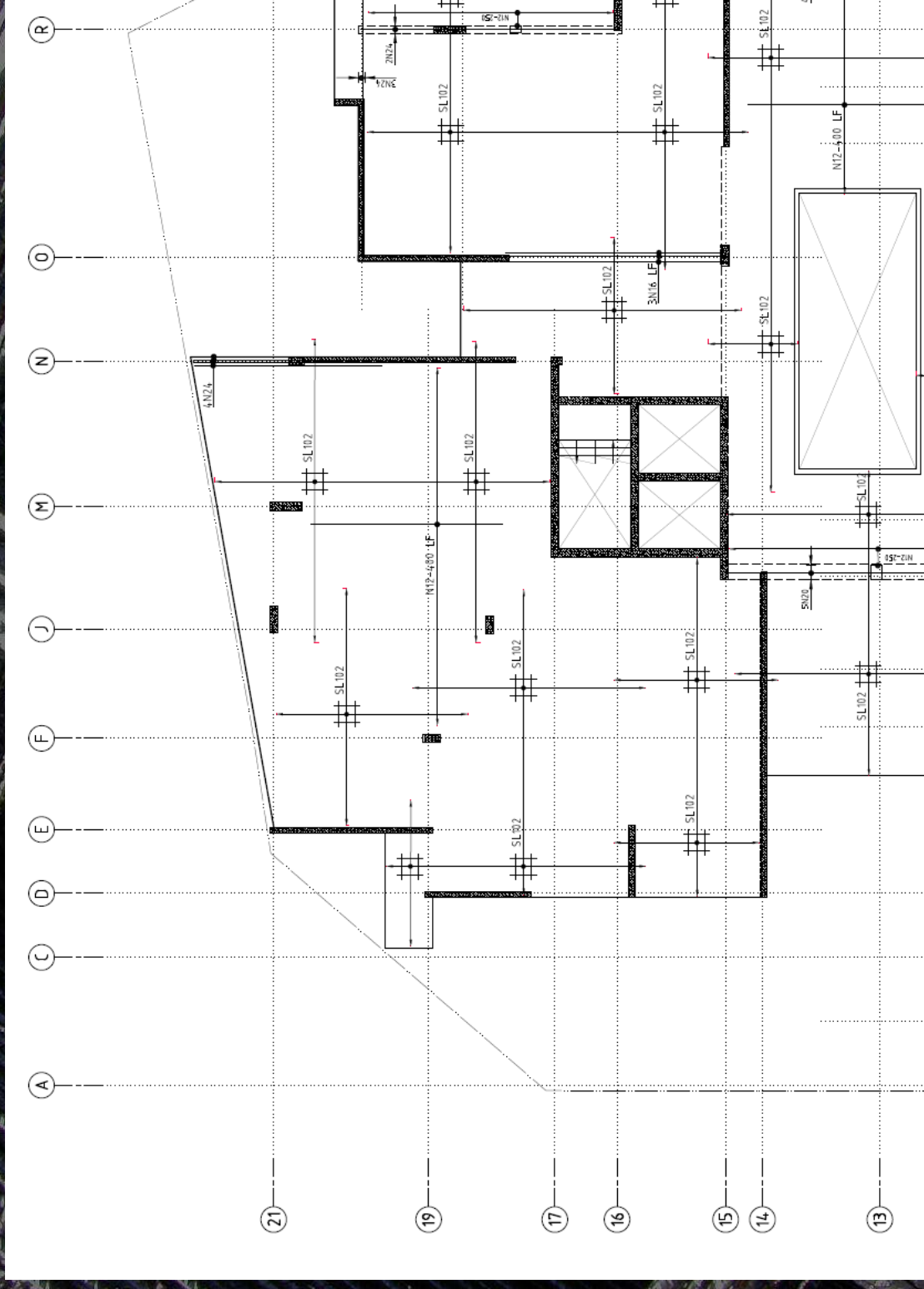
- Average cross-sectional areas of Standard meshes are 5 to 10% greater than nominal mesh areas.
- Bending strength of doubly-reinforced sections is typically 10-15% greater than singly-reinforced sections (design assumption)

⇒ 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



Case Study – Medium-Rise Building



Case Study – Medium-Rise Building





Conclusions: Part 2 - *Construction*

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Questions