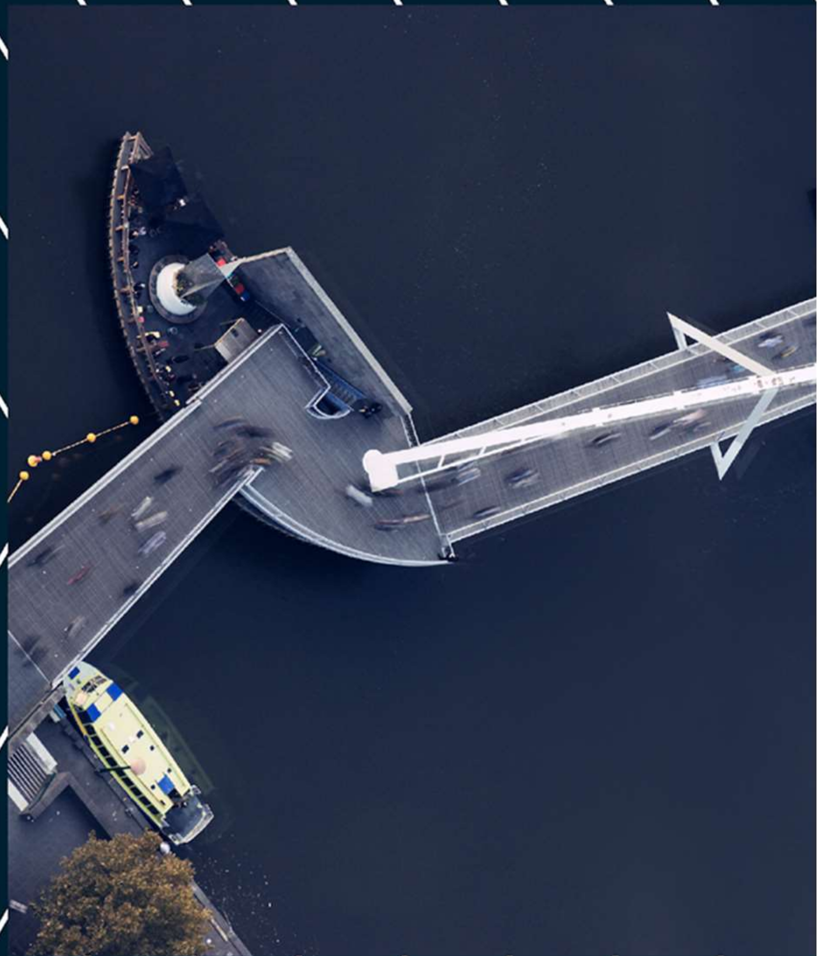
ENGINEERS AUSTRALIA

Australasian Structural Engineering Conference

Engineering Resilience

Australasian Structural Engineering Conference

9–10 November 2022



aseconference.org.au

Critical Reinforcement Design and Detailing for Resilience and Preservation of Concrete Structures

Speaker

Eric Lume
BE MIE Aust CPEng (Ret) National Engineer at the Steel Reinforcement Institute of Australia.

Prior to the last seven and a half years with the SRIA, Eric's extensive industry experience includes a recent engagement with a Consulting Engineering firm in Christchurch, NZ assisting with rebuilding earthquake damaged structures, 5 years as Senior Lecturer at the University of Wollongong, 15 years with Cement Concrete and Aggregates Australia, and some 13 years in the Consulting Engineering Profession. He is also on a number of Australian Standard's Committees.

Web Site: sria.com.au

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SRIA
Steel Reinforcement Institute of Australia

Benefits of Steel Reinforcement
Standards
Research
Downloads
Publications
Conference Papers

Welcome to SRIA

Steel Reinforcement Institute of Australia

The Steel Reinforcement Institute of Australia is Australia's leading non-profit institute for reinforcing steel, providing the hub for knowledge, industry linkage and support.

- Supports Australian capability & quality
- Offers practical solutions to the Australian building industry
- Educates industry
- Disseminates steel reinforcement knowledge via regular publications, lectures, seminars, research programs and tours
- Primarily funded by the vast majority of the processors of steel reinforcement used in Australian construction
- Supported by the founding Australian mill (supplier) members & associate members

THE BENEFITS OF REINFORCED CONCRETE

Resilience

Resilience encapsulates our ability to not only survive disasters and extreme events such as bushfires, floods and earthquakes, but to also recover more quickly from them, with reduced impact on not only peoples' lives, but also in many cases, their livelihoods.

Royal National Park, Sydney

Maribyrnong, Melbourne

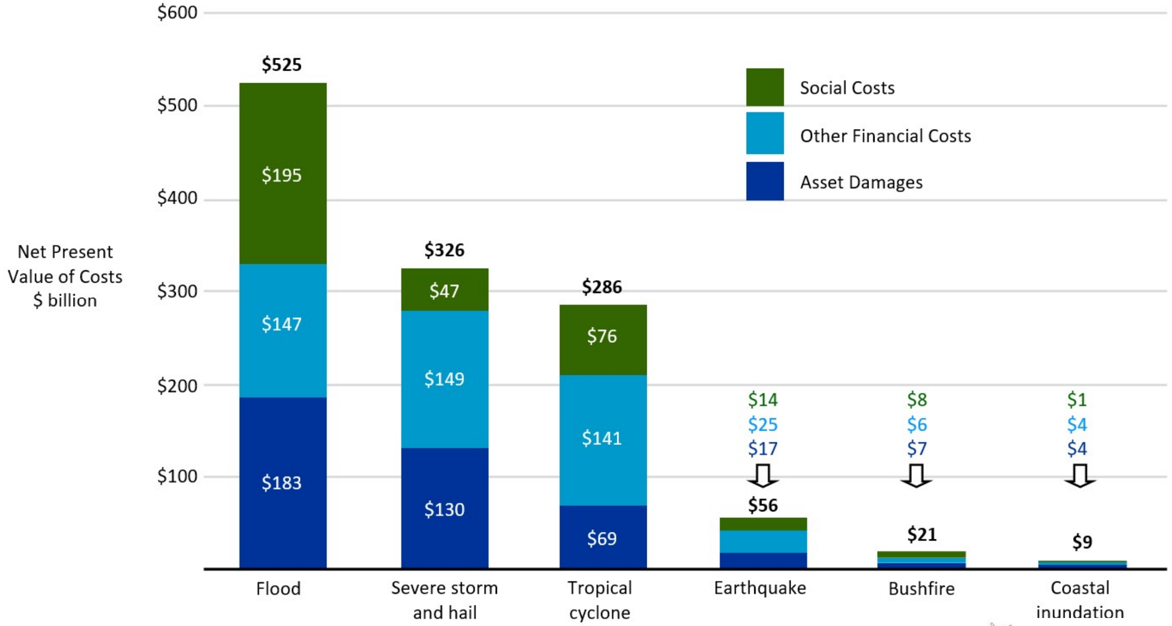
Newcastle Earthquake, 1989

Cost of Natural Disasters

Over the next 40 years, natural disasters will cost Australia $1.2 trillion

Currently $38 billion annually, rising to $73 billion by 2060

Cost of earthquakes relatively low due to low to moderate seismicity in Australia



Predicted Costs over next 40 years

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Earthquake Frequency in Australia

- Low to moderate seismicity.
- Earthquakes are a regular occurrence.
- Often occur in isolated areas, but
- All capital cities are expected to get a Newcastle type earthquake at some point (except Darwin & Hobart).
- Sydney in top 10 financial risks worldwide.
- On average Australia <u>will</u> experience:
  - 1 shallow earthquake Magnitude 6.0 or more once every 10 years (Christchurch was M6.2)
  - 1 shallow earthquake ≥ M5 every 2 years
  - 2 M5 events every year

HAZARD NOTE Bushfire & Natural Hazards CRC Issue 112 February 2022


HAZARD NOTE

ISSUE 112 FEBRUARY 2022

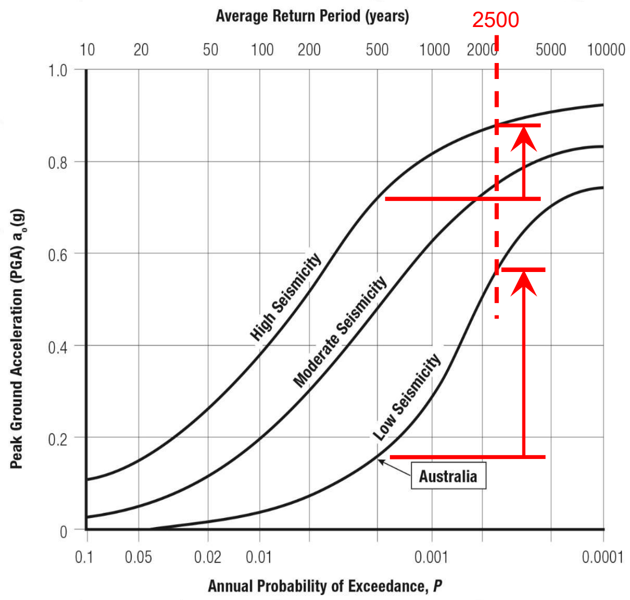
THE BENEFITS OF STRENGTHENING BUILDINGS AGAINST EARTHQUAKES

Summary
Although the international reinsurance industry recognises that a moderate earthquake in Sydney is in their top 10 financial risks, there is a perception in the Australian construction industry that design for earthquakes is a poor use of money due to the low likelihood of a strong earthquake in Australia. As the September 2021 earthquake in Victoria showed, cities like Melbourne are not immune to earthquake damage.

Problem with Low to Moderate Seismicity

Ratio of Rare Event (2500 year) to Design Event (500 year)

- Seismic risk in Australia is considered to be low to moderate (bottom curve in graph)
- Australia is low risk but high consequence country in term of earthquake damage
- 1:500 cf 1:2,500 event – PROBLEM is peak ground acceleration nearly 4 times greater for Australia
- 1:2,500 - Most buildings would not survive
- Proposed 2500 year design requirement for CBD areas?
- Blanket minimum design requirement across Australia?



(from Pauley and Priestley)

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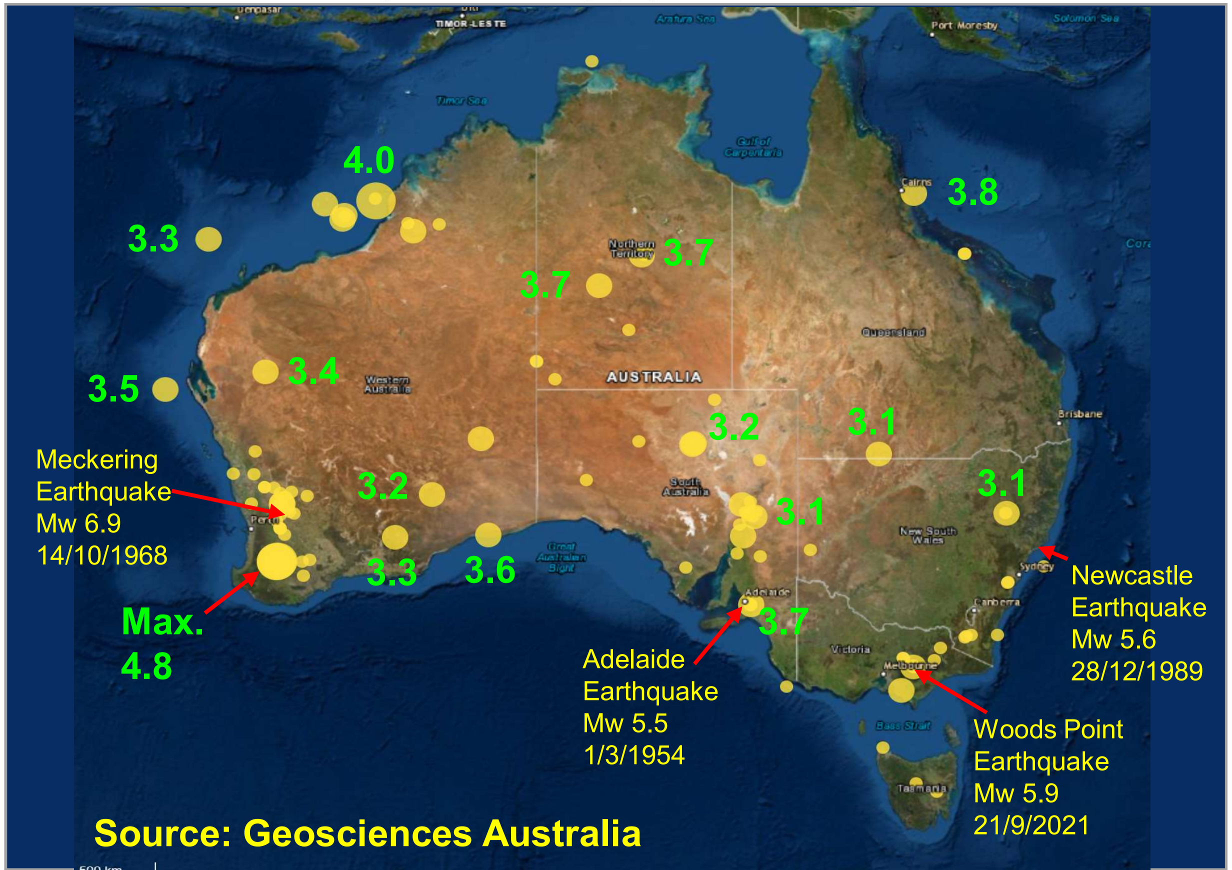
Australia Experiences Earthquakes

1 January to 18 April 2022

- Magnitude: 1.9 to 4.8 (283 events)



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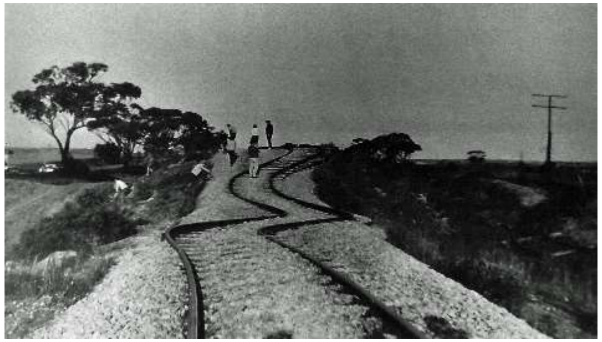
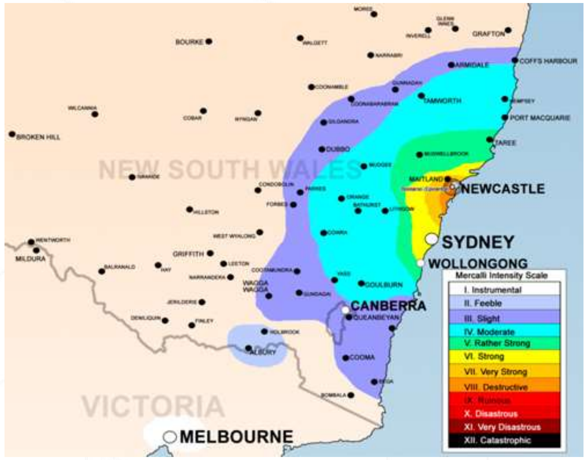
Meckering and Newcastle Earthquakes

Fault line scarp from the Meckering, Western Australia 1968, Magnitude 6.9 earthquake.



Influence of the Newcastle earthquake Magnitude 5.6



Damage to the Newcastle Workers Club, which was subsequently demolished and rebuilt (Photo Courtesy Newcastle Library).

The New Royal Adelaide Hospital

Earthquake Design Hazard

Parra Fault

- Length – 54 km
- Proximity to fault raised concern about vertical ground acceleration
- Distance to site – 2 km
- Max. predicted earthquake Magnitude 7.5

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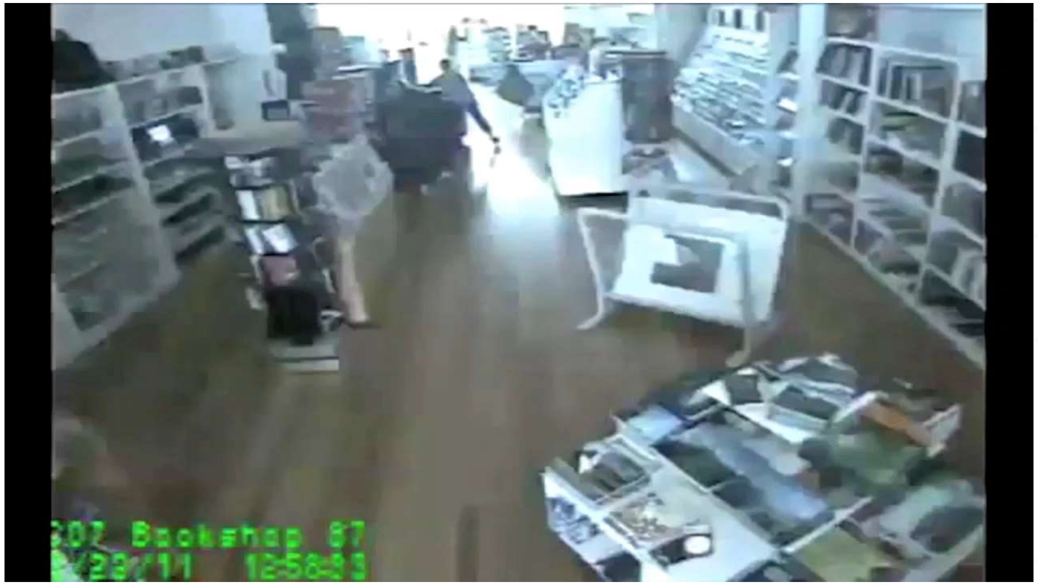
ERIC LUME

Christchurch Earthquake, 2011 – M6.2

- $55 billion loss
- Population 370,000



Christchurch Art Gallery Bookstore during 2011 earthquake

Christchurch CBD: 90% demolished (over 800 buildings)

Resilience of Reinforced Concrete Buildings

FM Global Annual Report 2021

- Resilience is a choice by Clients
- Works with clients to improve resilience, and
- Minimise potential losses from natural disasters
- Produced Worldwide Earthquake Map
- Bldg. Fires considered most significant risk exposure
- Strategies to mitigate fire risk include:
  - Retrofitting of solid (concrete) floors
  - Replace combustible walls with fire-retardant ones
- Strategies also work for flooding
  - Solid walling types unaffected by water

SRIA Steel Reinforcement Institute of Australia

Benefits of Reinforced Concrete are not New

A Paper read before the Queensland Institute of Engineers, Inc. - June 17 1913 by European Engineer L. Messy

- Highlights the rapid acceptance and widespread use of reinforced concrete.
- Highlights the many benefits of reinforced concrete.

"In view of the present enormous developments of reinforced concrete in Europe, as well as in America…… there is no town or country, there is even no large building, without more or less use and utilisation of reinforced concrete…..

The main features of reinforced concrete are: (1) fireproof, (2) antproof, (3) waterproof, (4) easy to build, (5) no skilled labour needed, (6) lowest cost of insurance, (7) substantiality, (8) light construction, (9) good, aesthetic, and attractive appearance, (10) impermeable, (11) unaffected by hot or cold weather, (12) or by sea water, (13) durability, (14) soundproof, (15) decreased maintenance, &c., &c."

Benefits of Reinforced Concrete

A Paper read before the Queensland Institute of Engineers, Inc. - June 17 1913

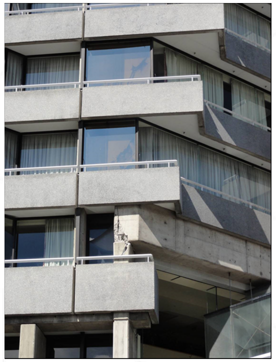
- Concludes that when properly designed and constructed, reinforced concrete is probably the most valuable material for use in buildings (and structures).

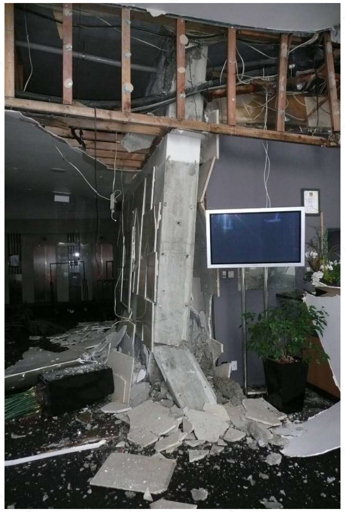
“In conclusion, I may be justified in quoting a resolution of the Congress of Civil Engineers in London which says: "Reinforced concrete combines the structural qualities of steel and timber with the durability of good masonry. It is subject to no form of deterioration which cannot be avoided by reasonable precautions. It is free from many of the limitations surrounding the use of masonry in masses, because of the greater latitude it affords in the design and execution of structures. It often yields the best and most economical solution, and in some cases the only practical solution, of the most difficult problems. When properly designed and executed it is therefore among the most valuable, if not the most valuable material now available for use in connection with building and hydraulic works of all kinds.”

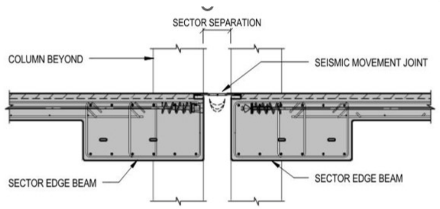
Lessons Learnt from Christchurch Earthquake

Incorporated into AS 3600 in 2018

- Direct load paths
- Design and connection of diaphragms
- Ductility of walls
- Boundary elements to walls
- Non structural parts and components
- Ceilings and services
- Seismic movement joints/gaps
- Structural integrity reinforcement
- Anchorage of fitments





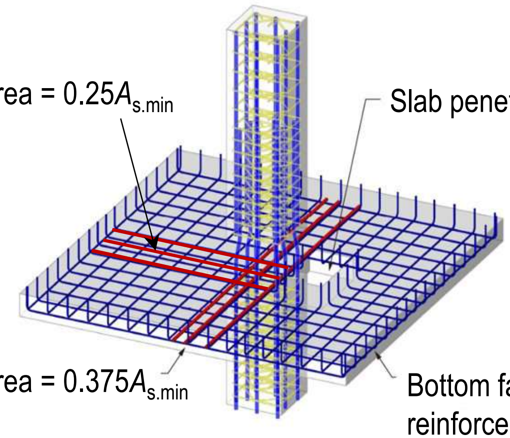


Steel Reinforcement Institute of Australia

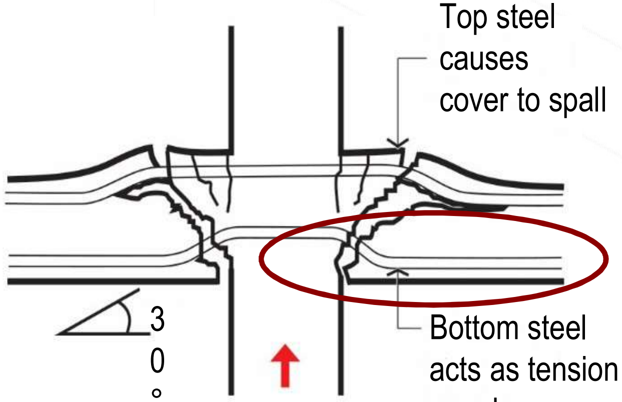
Structural Integrity Reinforcement for Slabs

Increases resistance of structural system to progressive collapse

Simple Reinforcement Detailing ➡ Improves Life Safety



(after Figure C9.2.2(B) of AS 3600 Commentary)



Figures 36 from SRIA Seismic Guide

Common to assess punching shear based on only 3 sides of column

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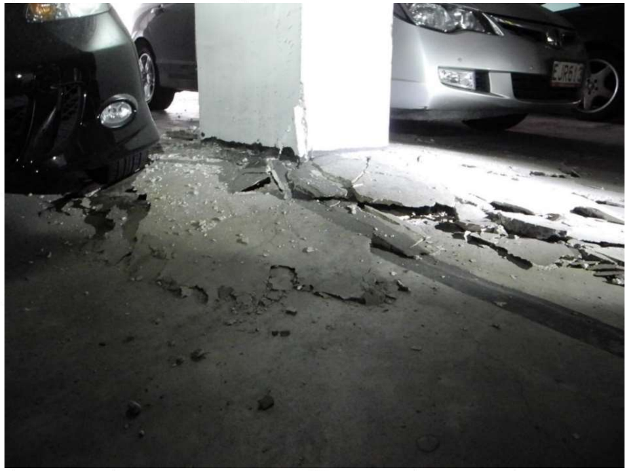
Structural Integrity Reinforcement for Slabs

Providing Structural Integrity Reinforcement – Improves Life Safety



Remains of car park floor – Old Newcastle Workers Club NSW

Brittle failure with no structural integrity reinforcement

➡ caused progressive collapse

(Photo courtesy Cultural Collections, The University of Newcastle, Australia)

Punching shear failure

Collapse prevented by Structural Integrity Reinforcement

Hotel Grand Chancellor, Christchurch, NZ

Minimum Structural Integrity Reinforcement

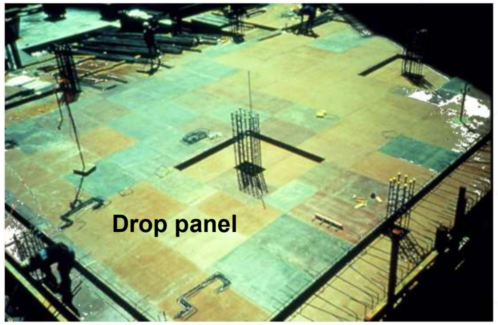
AS 3600 Response

Clause 9.2.2 Minimum structural integrity reinforcement

The summation of the area of bottom reinforcement connecting the slab, drop panel, or slab band to the column or column capital on all faces of the periphery of a column or column capital shall not be less than,

$$A_{\text{s.min}} = \frac{2N^*}{\phi f_{\text{sy}}}$$

Integrity reinforcement shall not be 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.



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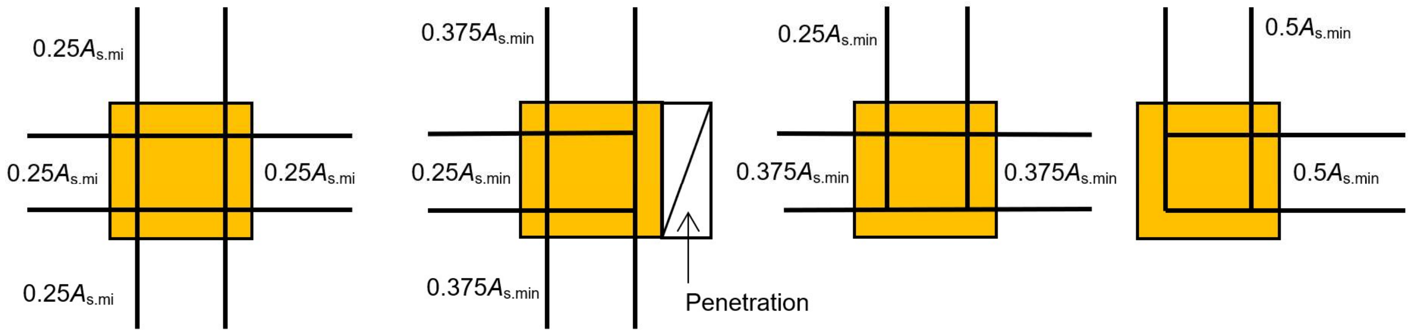
Structural Integrity Reinforcement for Slabs

Distribute evenly on all faces of the column



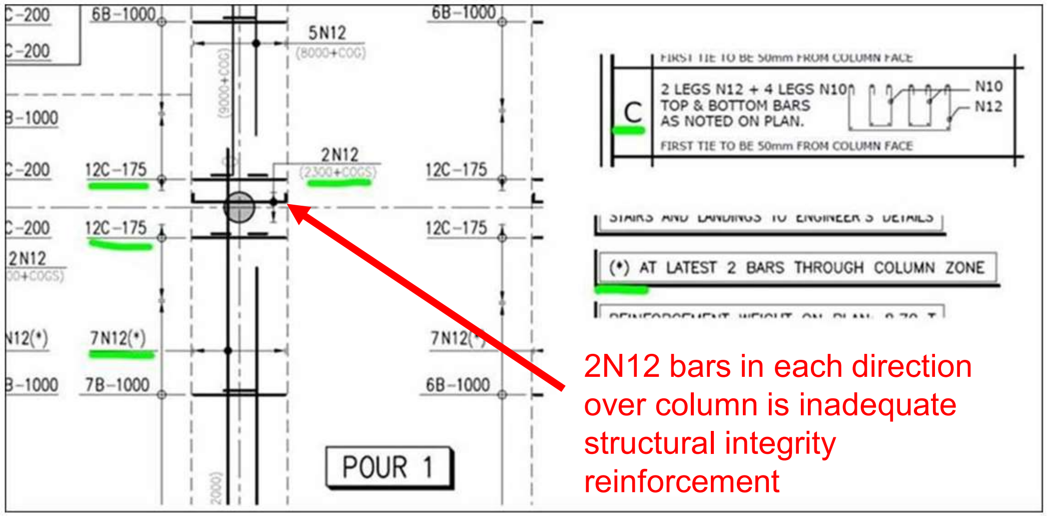
(a) Interior column (b) Penetration or edge column (c) Corner column

Interpretation of Clause 9.2.2

Technical Enquiry – Post-tensioned slab detailing

Clause 9.2.2 of AS 3600 (paragraph 2) states that: "*Integrity reinforcement shall not be 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*" – Intended for beams, not slab bands

- Relates to beam Clause 8.3.1.1 (i) and (ii) – which requires minimum of two bars
- Note that 2N12 bars can be taken to contribute to $A_{s.min}$ required
- $A_{s.min}$ still required



Detailing of post-tensioned slab band (SRIA Technical Enquiry)

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Interpretation of Clause 9.2.2

- **Example – Builder Technical Enquiry**

  Builder had concerns that a PT slab band arrangement did not have the minimum integrity reinforcement over column
- No bottom reinforcement over column
- Therefore, **NO** structural integrity reinforcement provided
- Do not misinterpret requirements of Clause 9.2.2 by taking area of post-tensioning tendons as satisfying the minimum area of structural integrity reinforcement – structural integrity reinforcement must be in the bottom of the slab band.

SRIA Technical Enquiry

Guidance Provided in Commentary Clause C9.2.2

Simple Reinforcement Detailing - Improves Life Safety

States that:

"*Post-tensioning tendons within the column head in the top surface which would normally be considered to contribute to robustness based on a catenary model are not considered to contribute to the post punching shear failure capacity*."

Remains of post-tensioned car park floor – Christchurch

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Detailing of Beams in OMRF's

Prefabricated beam cages can be joined at column locations

- Satisfactory for ordinary moment-resisting frames (OMRF)
- Placement of splice bars at joints avoids interference

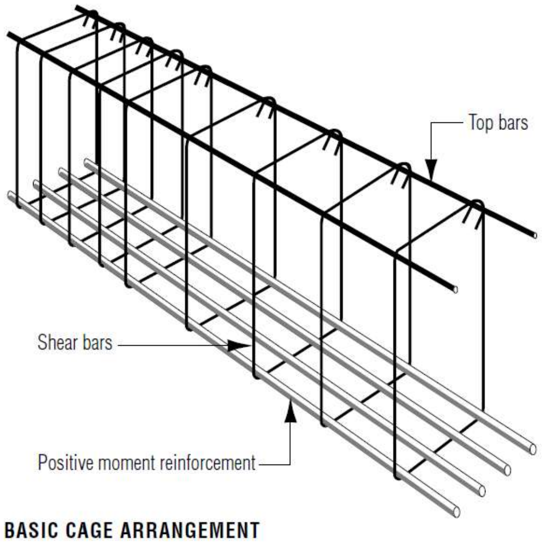


Figure 13.8 Reinforcement Detailing Handbook

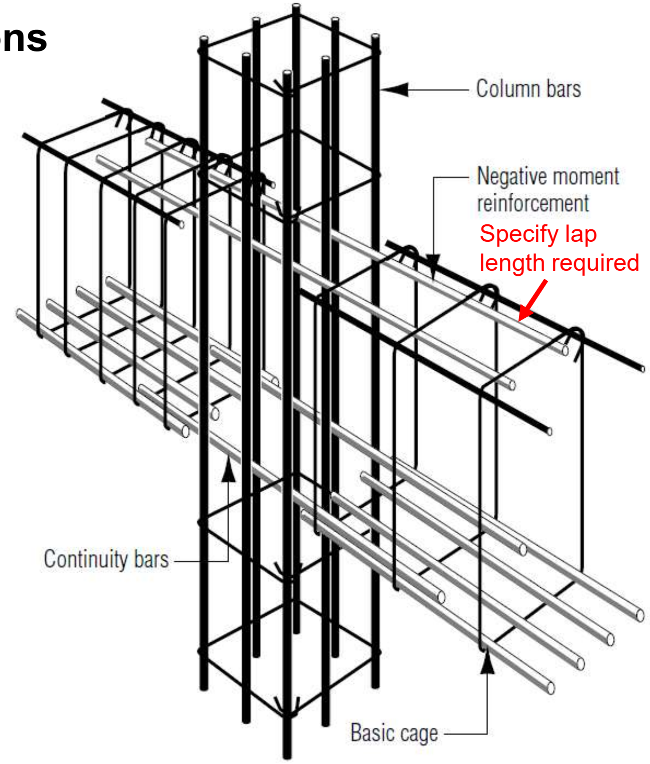


Figure 13.8 Reinforcement Detailing Handbook

Detailing of Beams in IMRF's

Minimum Splice and Fitment requirements for IMRF

S1 Region

Fitment spacing

Clause 14.5.2.2

$\text{Max.} \leq 0.25d_o$

$8d_b$

$24d_f$

300 mm

S2 Region

Fitment spacing

$\text{Max.} \leq 0.5D$

300 mm

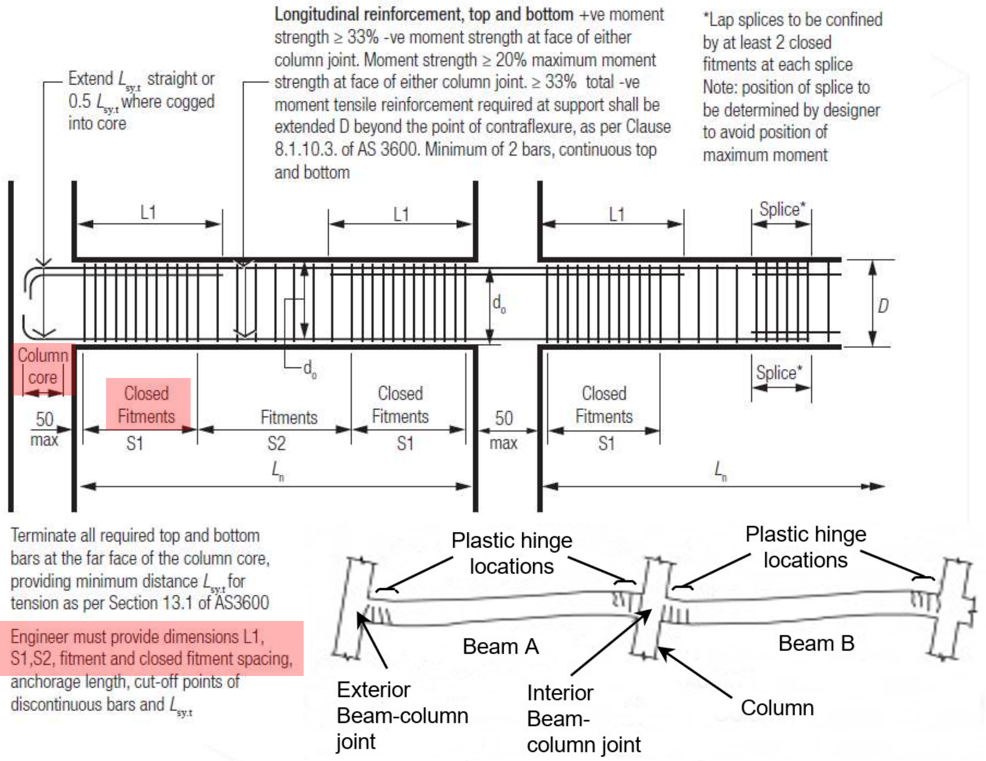


Figure 13.10 Reinforcement Detailing Handbook

Closed Fitments

Clause 1.6.3.11 Closed fitment

External or internal fitment that forms a continuous perimeter around a concrete element with the ends of the fitment anchored into the concrete using a minimum of 135º hooks around a longitudinal bar.

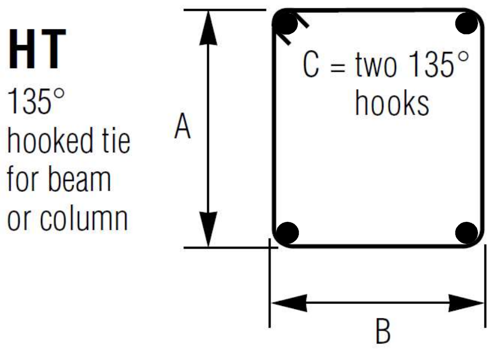


Figure 9.1 from Reinforcement Detailing Handbook
Standardised Bending Shapes for Reinforcement

Anchorage of Fitments

Clause 8.3.2.4 Anchorage of shear reinforcement

The anchorage of shear reinforcement (fitments) transverse to the longitudinal flexural reinforcement shall be achieved by:

- a hook or cog complying with Clause 13.1.2.7, or
- by welding of the fitment to a longitudinal bar, or
- by a welded splice, or
- by lapped splices (some Engineers allowing this!).

NOTE:

- Site welding not recommended (generally poor quality).
- Difficult achieving sufficient weld to a longitudinal bar.
- Lapped splices (in fitments) intended only for deep infrastructure type beams to allow fabrication
- AS 5100.5 requires hook at ends of lapped bars if near concrete surface.

Anchorage of Fitments

AS 3600 Commentary Published 25 March 2022

- **Provides additional background information and clarification of Clauses.**

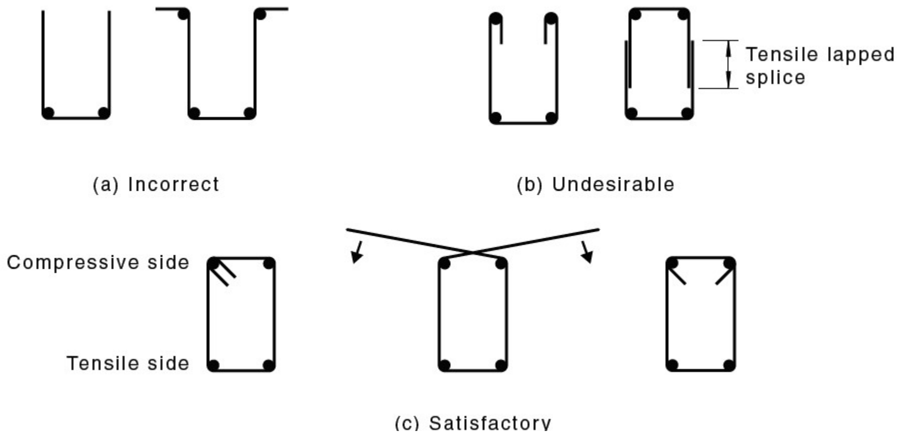


Figure C8.3.2.4(B) — Incorrect, undesirable and satisfactory fitment anchorages (Ref. 37)

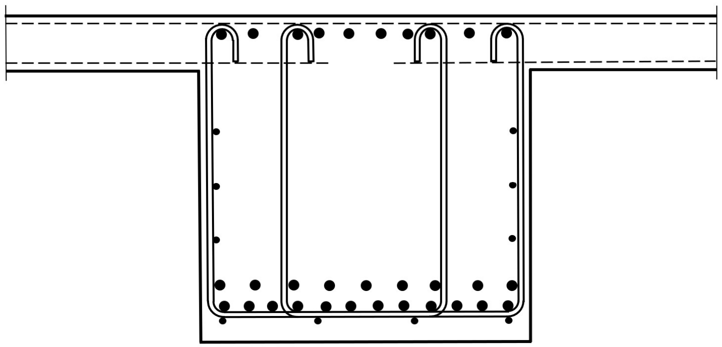
Open fitments shown in Figure C8.3.2.4(B)(b) 'do not provide confinement for the concrete in the compression zone and are undesirable in heavily reinforced beams where confinement of the compressive concrete may be required to improve ductility of the member.'

Interpretation of Standard

Clause 8.3.2.4 Anchorage of shear reinforcement

Hooks to anchor shear fitments

- Do not form a closed fitment – refer Clause 1.6.3.12
- Torsional reinforcement requires closed fitments – Clause 8.3.3(a)
- Clause 8.3.1.6 "Compressive reinforcement required for strength in beams shall be adequately restrained by fitments in accordance with Clause 10.7.4"
- ACI typically requires closing tie at top



Transfer Beam 1200 Deep x 1200 wide

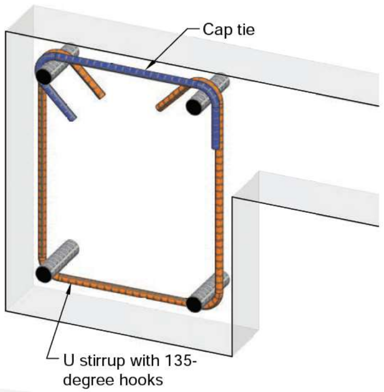


Figure R9.7.7.1 from ACI 318M-19

Fitments and Bars need to be Adequately Anchored

Provide closed fitments anchored in confined core of beam/column

Anchor beam bars in confined column core

Why? ➡ At about 1.5% drift, the cover concrete will typically be lost

Bottom bars not anchored in the confined region of the column

Failure of a beam column joint at Copthorne Hotel, Christchurch 2011

(Images courtesy of Peter McBean Wallbridge and Gilbert)

SRIA Steel Reinforcement Institute of Australia

Spacing of Fitments

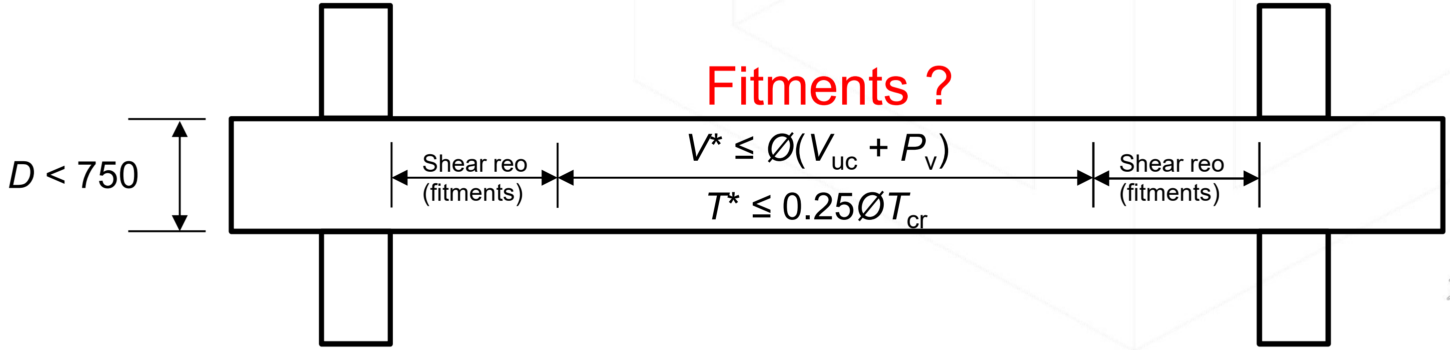
Clause 8.3.2.2 Spacing of Shear and Torsional Reinforcement

"In members not greater than 1.2 metres in depth, the maximum longitudinal spacing shall not exceed the lesser of 300 mm and 0.5*D*; otherwise, the longitudinal spacing shall not exceed 600 mm."

Clause 8.2.1.6 Requirements for transverse shear reinforcement

Transverse shear reinforcement shall be provided in all regions where:

- $V^* > \phi(V_{uc} + P_v)$; or
- $T^* > 0.25\phi T_{cr}$: or
- The overall depth of the member $D \geq 750$ mm



Spacing of Fitments

Where no shear reinforcement is required and D < 750 mm

- Provide stirrups to allow assembly and support of reinforcing bars (and unexpected loads or overloads).

  Recommend maximum 600 mm spacing

  Keep same type as shear reinforcement to simplify fabrication

  Minimise number of different spacings along beam

- Commentary Clause R9.6.3.1 of ACI 318M-19 also states:

  "For repeated loading of beams, the possibility of inclined diagonal tension cracks forming at stresses appreciably smaller than under static loading should be taken into account in design. In these instances, use of at least the minimum shear reinforcement expressed by 9.6.3.4 is recommended even though tests or calculations based on static loads show that shear reinforcement is not required."

New Technical Notes

Download for free at sria.com.au

TECHNICAL NOTE 8

November 2022

SRIA Steel Reinforcement Institute of Australia

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STRUCTURAL INTEGRITY REINFORCEMENT FOR SLABS

In 2018, based on the lessons learnt from the Christchurch, New Zealand earthquake events in 2011, AS 3600[1] was revised to incorporate many new provisions to safeguard future Australian buildings from seismic events and provide important life safety to the occupants if the buildings are subjected to one of these extreme events.

One simple reinforcement detailing requirement that was incorporated into the Standard was structural integrity reinforcement for both beams and slabs. This nominal amount of reinforcement was found to be very effective at preventing the collapse of slabs following punching shear failures in Christchurch, improving the life safety of the building **Figure 1**. The Newcastle Workers Club is an example of punching shear failure where no structural integrity reinforcement was provided **Figure 2**. The benefits provided by structural integrity reinforcement led the SRIA to include this aspect of detailing on the cover of the 2016 *Guide to Seismic Design and Detailing of Reinforced Concrete Buildings in Australia*, which is also available for free as a pdf copy from the SRIA website. While the Guide includes structural integrity reinforcement, it has come to the attention of the SRIA that the provisions for slabs that were included as Clause 9.2.2 of AS 3600 in 2018, are being misinterpreted. This Technical Note is intended to clarify the intent and requirements of AS 3600 for structural integrity reinforcement for slabs.

Figure 1 Punching shear failure with structural integrity reinforcement preventing collapse of slab, Hotel Grand Chancellor, Christchurch

(*photograph courtesy Peter McBean*)

Figure 2 Punching shear failure at Newcastle Workers Club during the 1989 Newcastle earthquake – no structural integrity reinforcement to reduce the risk of collapse

(*photo courtesy Cultural Collections, the University of Newcastle, Australia*)

Page 1

TECHNICAL NOTE 9

November 2022

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FITMENTS

Fitments are defined in Clause 1.6.3.42 of AS 3600 (2018)[1] as a "*Unit of reinforcement commonly used to restrain from buckling the longitudinal reinforcing bars in beams, columns and piles; carry shear, torsion and diagonal tension; act as hangers for longitudinal reinforcement; or provide confinement to the core concrete.*" A typical fitment is shown in **Figure 1**. While AS 3600 has always adopted the terminology 'fitment', they are commonly referred to as either ties, stirrups, ligatures or helix. Note that the term 'tie' was redefined in AS 3600 (2009)[2] as a "*tension member in a strut-and-tie model*", and the term helix refers to helical reinforcement, which was introduced in AS 3600 (2009), with the same definition now included in Clause 1.6.3.50 of AS 3600 (2018), "*reinforcement that is wound in a helical fashion around the main longitudinal reinforcing bars in a column or pile restraining them from buckling and to carry shear, torsion and diagonal tension or around tendons at an anchorage to resist bursting action effects.*"

Figure 1
Typical closed fitment

Typically, fitments will be closed fitments as defined in Clause 1.6.3.12 of AS 3600 (2018), "*A unit or multiple units of reinforcement used as an external or internal fitment that form a continuous perimeter around a concrete element with the ends of the fitment anchored into the concrete using a minimum of 135º hooks around a longitudinal bar.*" While a closed fitment would typically resemble the single unit or shape shown in **Figure 1**, the reference to multiple units is to allow for the various options covered in Clause 8.3.2.4 of AS 3600 for the anchorage of shear reinforcement. These include anchorage by a "*hook or cog complying with Clause 13.1.2.7 or by welding of the fitment to a longitudinal bar or by a welded splice, or by lapped splices.*"

Page 1

SRIA Steel Reinforcement Institute of Australia

Resilience Starts with Quality Materials

Third Party/Independent Certification - ACRS or Equivalent

Should be specified on every project and obtained to guarantee quality

ACRS Mill Certificate Example


2022 VALID TO 31 DEC

ACRS PRODUCT CERTIFICATION

Australasian Certification Authority
for Reinforcing and Structural Steels Ltd

CERTIFICATE OF PRODUCT PERFORMANCE

Certificate Number: 31102

InfraBuild

INFRABUILD STEEL
LAVERTON, VIC, AUSTRALIA

SCOPE OF CERTIFICATION

Reinforcing Bar Manufactured in straight lengths to AS/NZS 4671:2019

Andrew Wheeler, Acting Executive Director

Valid until: 31 December 2022

First certified: November 2003

JAS-ANZ

Required by Processors as proof that quality reinforcement used

ACRS Processor Certificate Example


2022 VALID TO 31 DEC

ACRS PRODUCT CERTIFICATION

Australasian Certification Authority
for Reinforcing and Structural Steels Ltd

CERTIFICATE OF PRODUCT PERFORMANCE

Certificate Number: 811021

AUSREO

AUSREO
WETHERILL PARK, NSW, AUSTRALIA

Scope of Certification

Processing and distribution of carbon steel bars, welded mesh, including couplers

Andrew Wheeler, Acting Executive Director

Valid until: 31 December 2022

First certified: November 2008

JAS-ANZ

- Required by Purchasers to prove quality reinforcement delivered to site
- **SRIA members must have ACRS Certification**

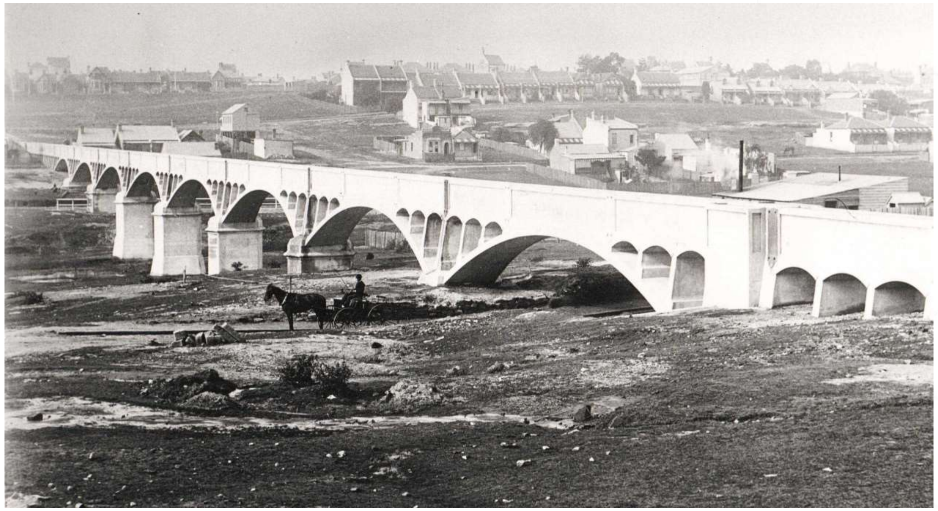
Processed steel reinforcing materials may only be relied upon as having the benefit of ACRS Product Scheme certification when manufactured by ACRS certified mills.

SRIA Steel Reinforcement Institute of Australia

Reinforced Concrete has a Long History

First reinforced concrete structure in Australia

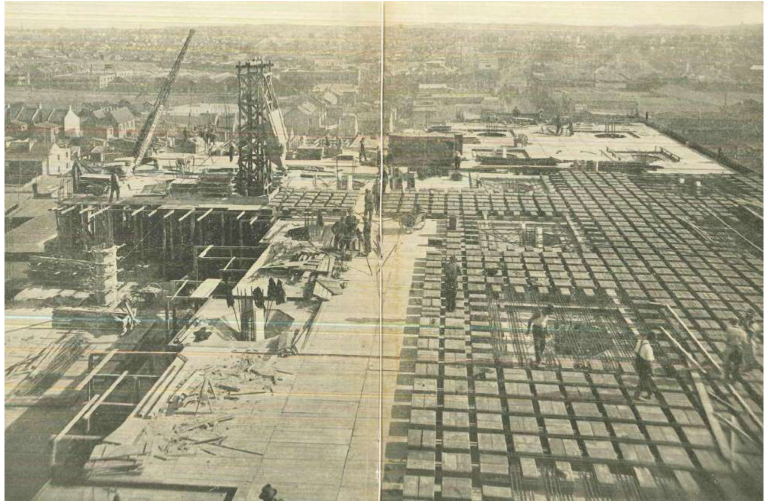
Johnstons Creek Sewer Aqueduct
Annandale, Sydney (started 1895)



Still in us today

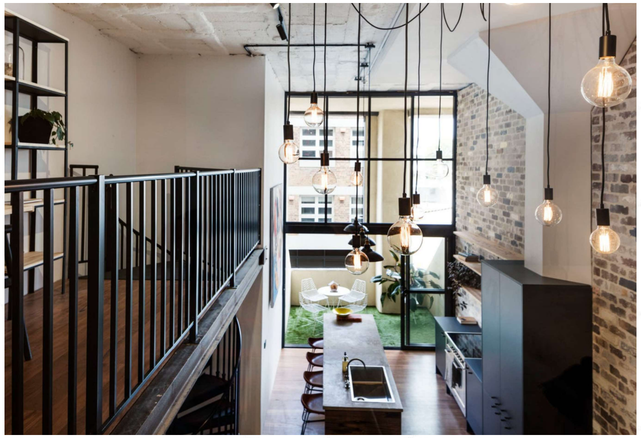
Preserving Historic Structures

Smith and Waddington's Limited Factory, Sydney, circa 1927



Construction circa 1927
(Innes-Bell Concrete Construction Booklet)

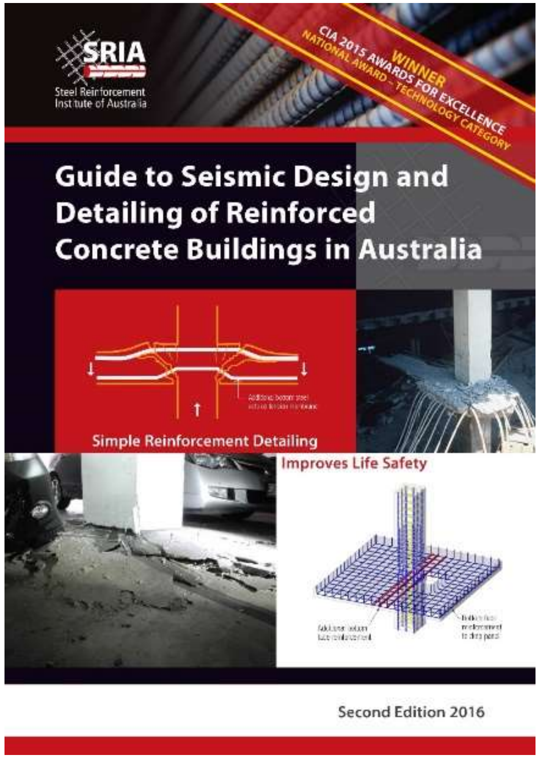
Re-purposed into
Luxury Apartments
Rhodes House, 1993



SRIA Steel Reinforcement Institute of Australia

SRIA Guides to Assist Designers, Certifiers and Builders

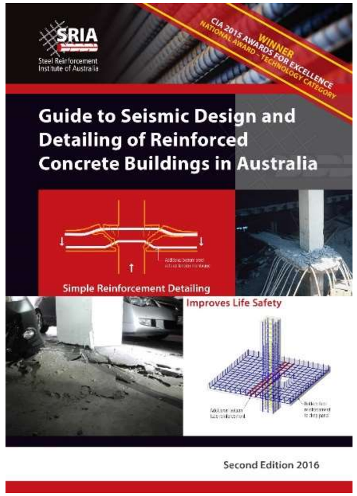
- Covers design and detailing requirements for Australia
- Good detailing practices covered
- Checklists included
- Free Pdf download at SRIA.COM.AU



SRIA Steel Reinforcement Institute of Australia

Conclusions

- SRIA is here to help
- Cost of natural disasters set to increase
- Resilience is a choice
- Benefits of reinforced concrete improve resilience
- Proper design and construction is essential
- AS 3600 (2018) has addressed many of the lessons learnt regarding earthquake performance
- Changes will ensure future buildings are more resilient
- Preservation of buildings/structures improves sustainability
- Resources available to assist Engineers (SRIA.COM.AU)



SRIA Steel Reinforcement Institute of Australia

SRIA Mill and Processor Members

SRIA website provides links to industry - sria.com.au

InfraBuild
Building futures through sustainable steel

ARC
THE AUSTRALIAN REINFORCING COMPANY

AUSREO
Build with confidence

NEUMANN STEEL
REINFORCING

activesteel

WIRE INDUSTRIES

BIANCO
REINFORCING

Mesh & Bar Pty Ltd

BESTBAR

SRIA Associate Members

SRIA website provides links to suppliers - sria.com.au

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A CRH COMPANY

reid™

nVent
LENTON

aSa®

RBSC
REINFORCING BAR SPACER COMPANY
Established 1958

ACTION PRODUCTS

ARMA+
GRAITEC GROUP

MB direct
supporting the construction industry

DYWIDAG

SPACERS
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Q & A