CONCRETE 2023

10–13 September 2023 • Perth Convention & Exhibition Centre, Australia

Resilient and Sustainable Concrete: Breaking Down Barriers

#Concrete2023 ciaconference@arinex.com.au www.ciaconference.com.au

Design and Detailing for Resilience and Sustainability of Concrete Structures

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Steel Reinforcement Institute of Australia

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Resilient and Sustainable Concrete: Breaking Down Barriers

Web Site: sria.com.au

SRIA
Steel Reinforcement Institute of Australia

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Benefits of Steel Reinforcement
Standards
Research
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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

SRIA
Steel Reinforcement Institute of Australia

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.

Fires: Royal National Park, Sydney, 2018

FLOODS: Maribyrnong Melbourne, 2022

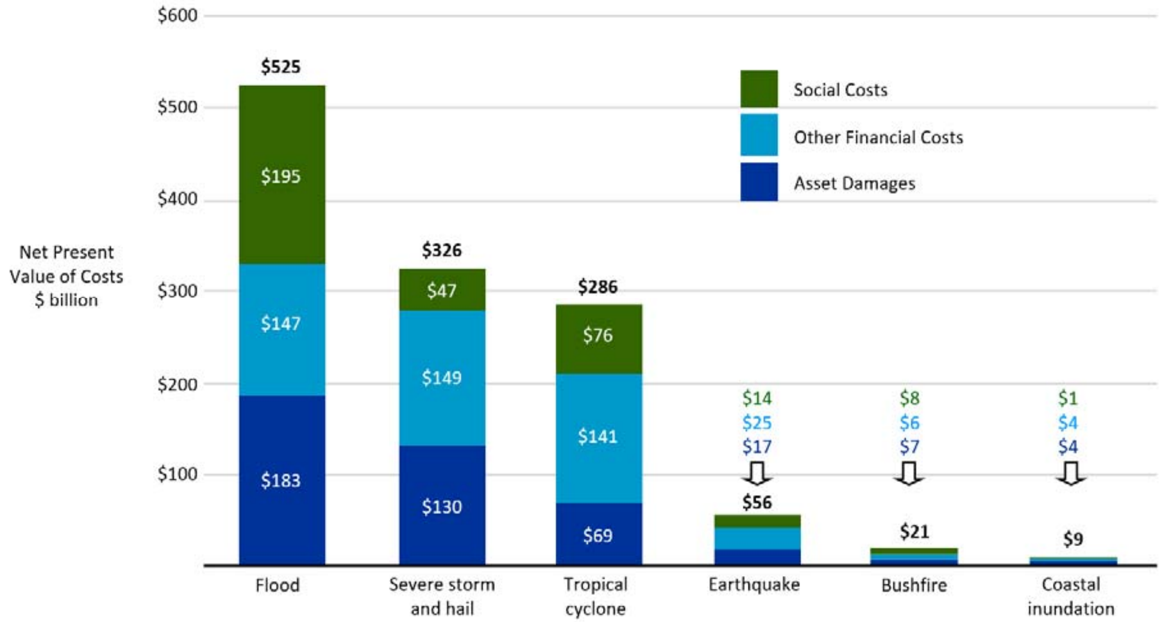
EARTHQUAKES: Newcastle, 1989

Properly designed and detailed RC construction provides resilience in Fires, Floods, Cyclones and Earthquakes

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 will 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

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.

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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?

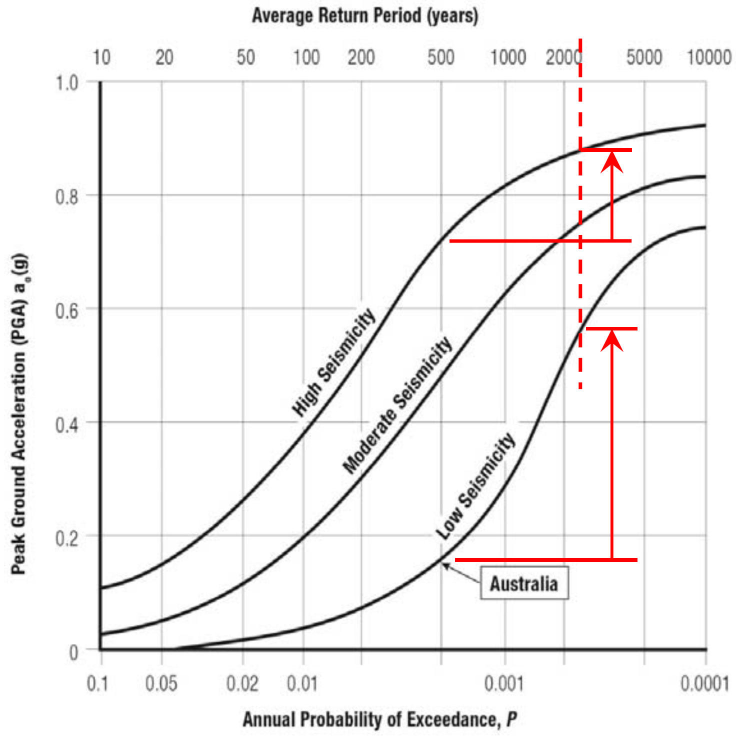

Figure 10 SRIA Seismic Guide

(from Pauley and Priestley)

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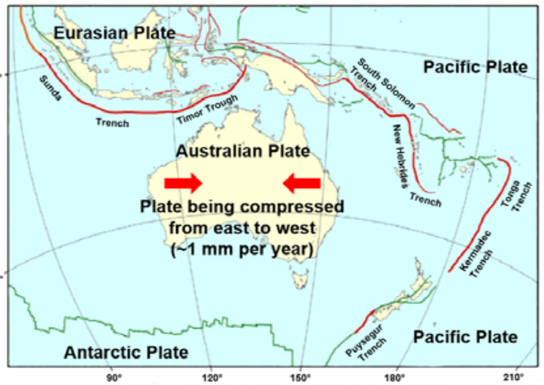
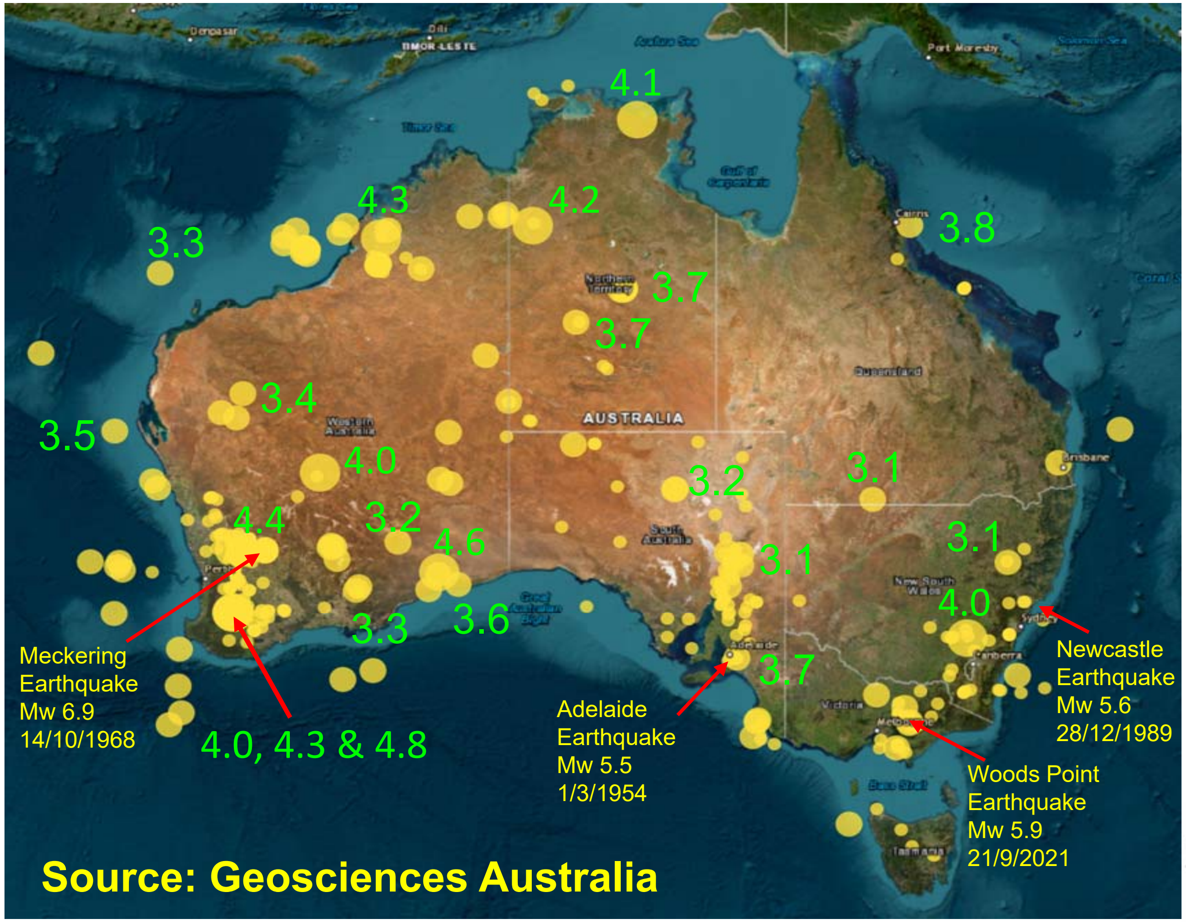
Australia Experiences Earthquakes

1 Jan to 31 Dec 2022

- Magnitude: 2.0 to 4.8
- 715 events

Australia is a *'low-risk'* but *'high-consequence'* country in terms of earthquake damage ie CBD's





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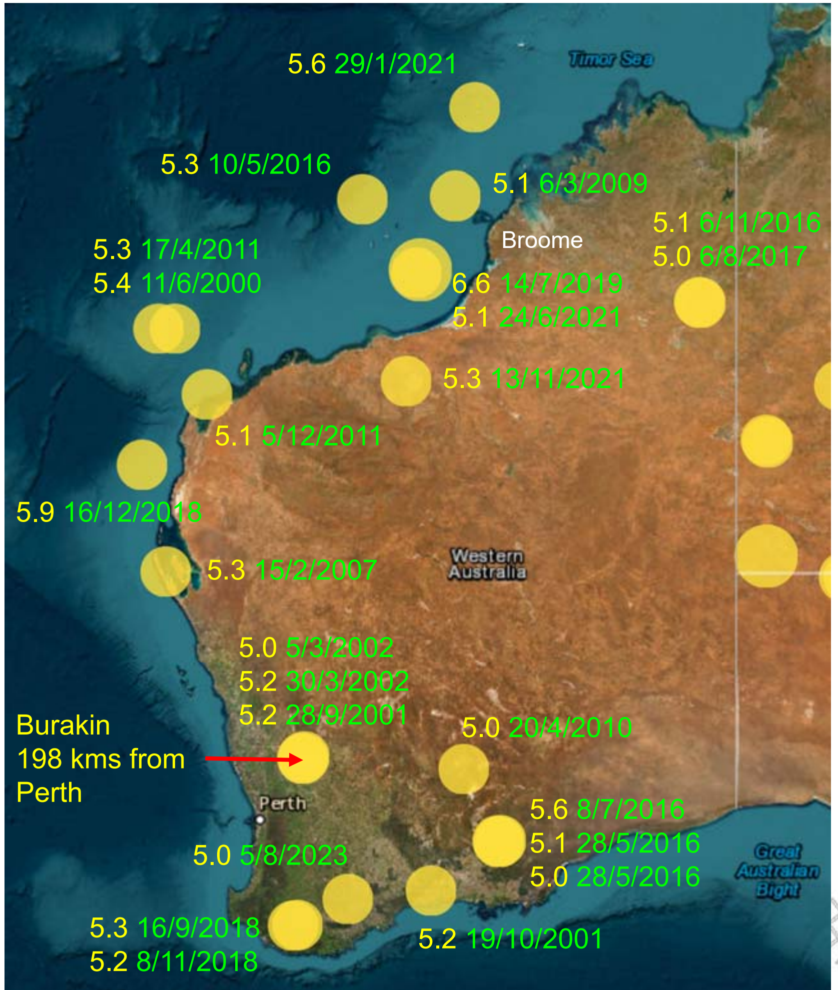
Western Australian Earthquakes

1 Jan 2000 to Present

Total Events - 7420

- Magnitude 0.2 to 6.6 (Offshore Broome)

Magnitude	
0 – 0.9	469
1.0 – 1.9	1888
2.0 – 2.9	3899
3.0 – 3.9	1029
4.0 – 4.9	111
5.0 – 6.6	24

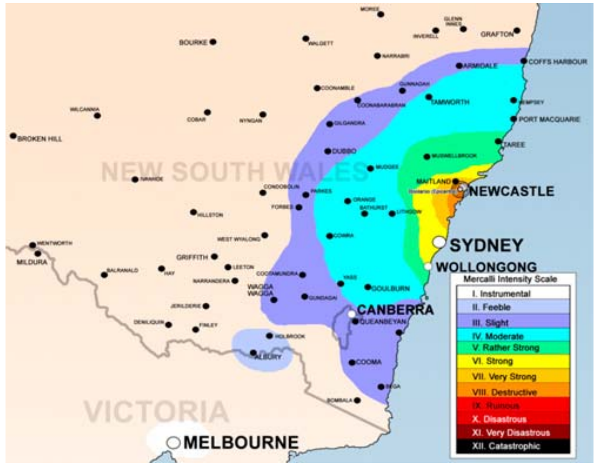


Source: Geosciences Australia

Meckering and Newcastle Earthquakes

Fault line scarp (37 km long) 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**
- **For post-disaster buildings**
  Site specific assessment
  Serviceability + Strength

Christchurch Earthquake, 2011 – M6.2

- $55 billion loss with population of 370,000

Christchurch CBD:
90% demolished
(over 800 buildings)

Christchurch CBD
closed off

Christchurch Art Gallery Bookstore
during 2011 earthquake

Resilience and Sustainability 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
- Resilience and longer service life = sustainable solution

The Benefits are just as Important Today

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

- Highlighted the rapid acceptance and widespread use of reinforced concrete.
- Highlighted the many benefits of reinforced concrete, which include: *fireproof, termite resistant, waterproof, easy to build, no skilled labour needed, lowest cost of insurance, substantiality, light construction, good, aesthetic, and attractive appearance, impermeable, unaffected by hot or cold weather, or by sea water, durability, soundproof, decreased maintenance, etc.”*

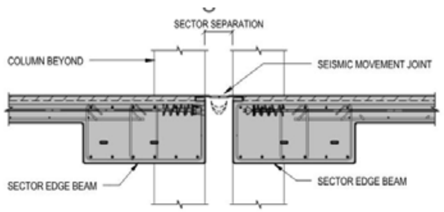
Concluded that Reinforced Concrete:

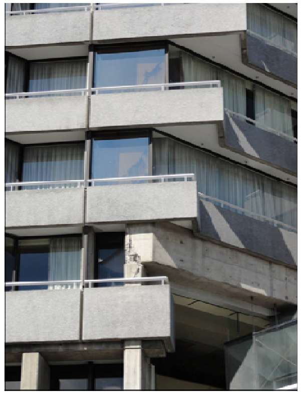
- When properly designed and constructed, is probably the most valuable material for use in buildings (and structures).
- Provides the best and most economical solution to the most difficult problems.
- Combines the structural qualities of steel and timber with the durability of good masonry.
- Can provide long service life (evident by the number of historic buildings).

AS 3600 Response - 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





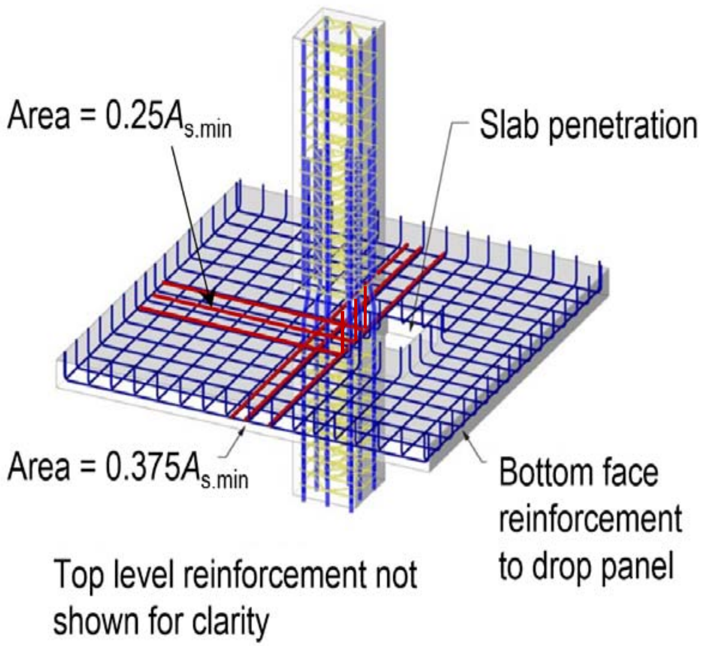




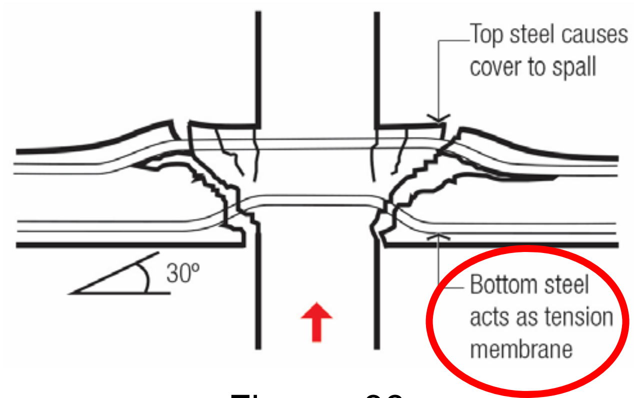
Structural Integrity Reinforcement for Slabs

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
SRIA Seismic Guide

Unrestrained cover concrete to column lost during Christchurch Earthquake
(photo courtesy of Peter McBean)

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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

(photo courtesy Peter McBean)

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Minimum Structural Integrity Reinforcement

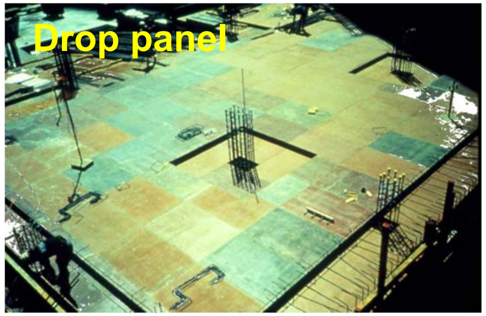
AS 3600 Response

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,

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

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.



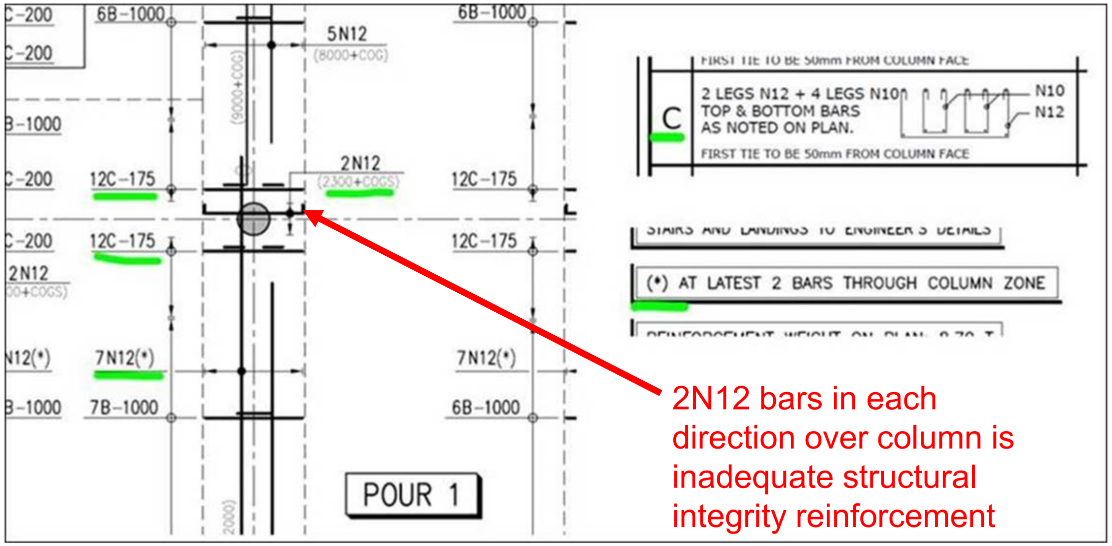
Interpretation of Clause 9.2.2 of AS 3600

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

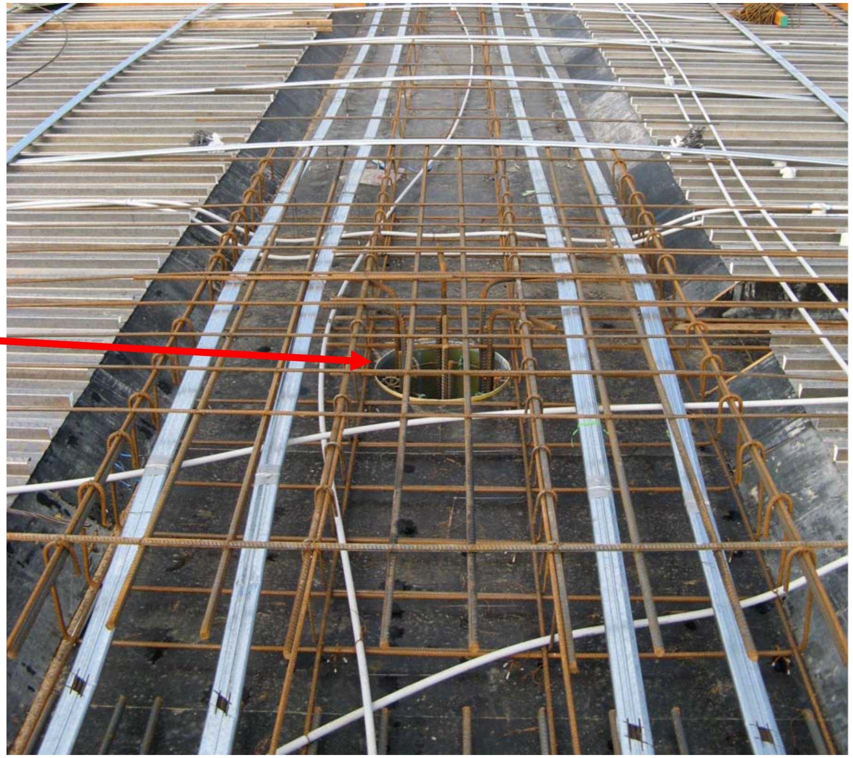
Detailing of post-tensioned slab band (SRIA Technical Enquiry)



Interpretation of Clause 9.2.2 of AS 3600

- **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

Fitments in Beams

Clause 1.6.3.12 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.

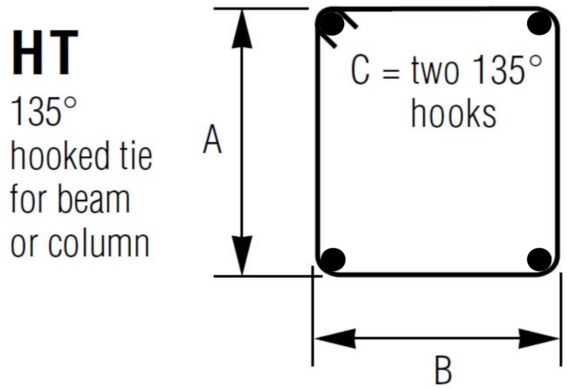


Figure 9.1 from Reinforcement Detailing Handbook
Standardised Bending Shapes for Reinforcement

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.

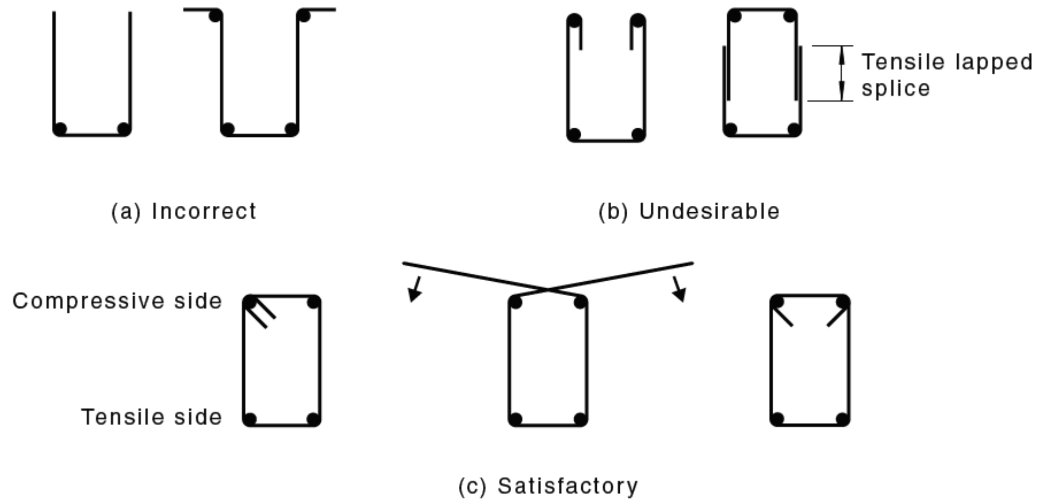
Figure C8.3.2.4(B) — Incorrect, undesirable and satisfactory fitment anchorages (Ref. 37)

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)



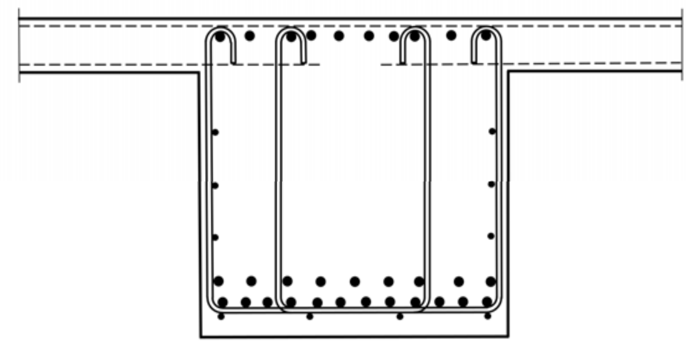
Open fitments shown in Figure C8.3.2.4(B)(b) 'do not provide confinement for the concrete in the compression zone and are **undesirable** in heavily reinforced beams where confinement of the compressive concrete may be required to improve ductility of the member.'

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

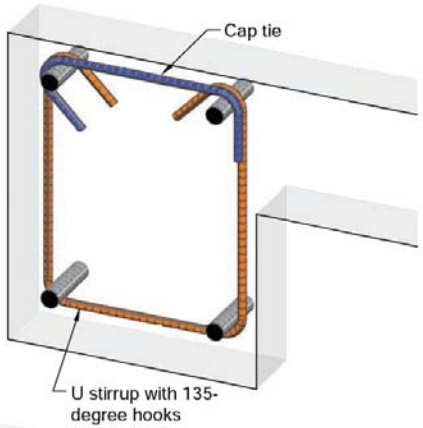


Figure R9.7.7.1 from ACI 318M-19

Spacing of Fitments

Clause 8.3.2.2 Spacing of Shear and Torsional Reinforcement

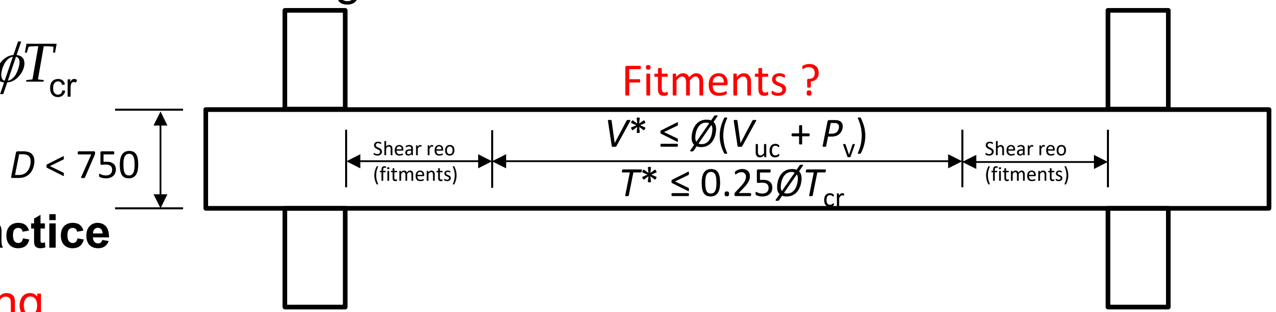
Where shear reinforcement is required (AS 3600, Amdt 2: May 2021):
"Shear reinforcement shall be spaced longitudinally not further apart than 0.5*D* or 300 mm, whichever is less. Where $V^* \leq ØV_{u.min}$, the spacing may be increased to 0.75*D* or 500 mm, whichever is less."

Note: Current AS 3600 has no definition of $ØV_{u.min}$ (but $ØV_{uc}$ includes $A_{sv.min}$ in k_v factor)

Clause 8.2.1.6 Requirements for transverse shear reinforcement

Transverse shear reinforcement shall be provided in all regions where:

- $V^* > k_s \phi V_{uc} + \gamma_p P_v$ or $T^* > 0.25 \phi T_{cr}$
- The overall depth $D \geq 750$ mm



Where not required, good detailing practice

- Recommend maximum 500 mm spacing
- Keep same type as shear reinforcement to simplify fabrication
- Minimise number of different spacings along beam

New Technical Notes

Download for free at sria.com.au

TECHNICAL NOTE 8

November 2022

SRIA Steel Reinforcement Institute of Australia

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)

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TECHNICAL NOTE 9

June 2023

SRIA Steel Reinforcement Institute of Australia

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 135° 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.*"

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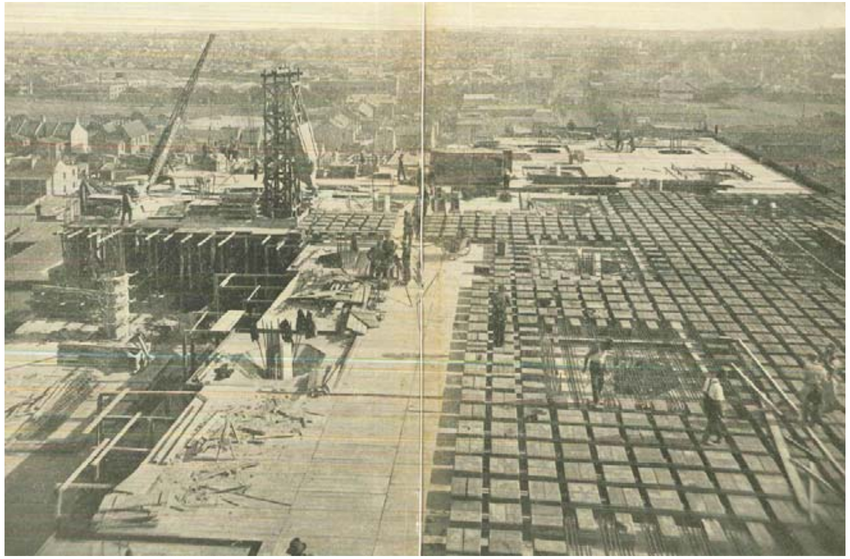
Preservation of Historic Structures is a Sustainable Solution

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

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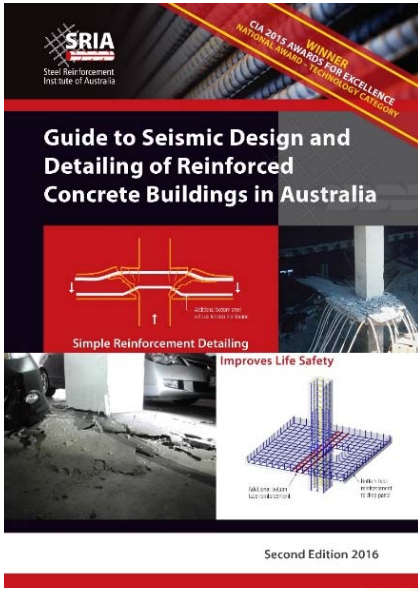
Conclusions

- SRIA offers free technical support
- Cost of natural disasters set to increase
- Resilience is a choice
- Benefits of reinforced concrete improve resilience
- Improved resilience and service life, improve sustainability
- AS 3600 (2018) has addressed many of the lessons learnt regarding earthquake performance
- Ensure minimum reinforcement detailing is provided
- Changes will ensure future buildings are more resilient
- Preservation of buildings/structures improves sustainability
- Resources available to assist Engineers (SRIA.COM.AU)



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ARC
THE AUSTRALIAN REINFORCING COMPANY

AUSREO
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NEUMANN STEEL
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activesteel

WIRE INDUSTRIES

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