Role of Engineers in Seismic Design and Detailing of Reinforced Concrete Buildings in Australia

by

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Introduction

- Australia has a long history of damaging earthquakes
- Despite this, many people believe that our cities and towns are immune from earthquakes
- Many Engineers do not appreciate the differences between designing for wind and earthquake actions
- The structure must be designed for both wind and earthquake loads
- Design and detailing of reinforcement are inseparable when it comes to seismic actions
- The SRIA's new *Guide to Seismic Design and Detailing of Reinforced Concrete Buildings in Australia* addresses this important issue

Earthquakes occur in Australia

Top 10 worst Australian onshore earthquakes in modern times (ranked by cost, magnitude and damage)

(source Australian Geographic July 10, 2012)

1.	Newcastle NSW	28 Dec 1989	(Magnitude 5.6) Public Holiday
2.	Beachport SA	10 May 1897	(Magnitude 6.5)
3.	Meckering WA	14 Oct 1968	(Magnitude 6.9) Public Holiday
4.	Ellalong NSW	6 Aug 1994	(Magnitude 5.4)
5.	Adelaide SA	1 Mar 1954	(Magnitude 5.5)
6.	Warooka SA	19 Sept 1902	(Magnitude 6.0)
7.	Meeberrie WA	29 Apr 1941	(Magnitude 7.2)
8.	Tennant Creek NT	22 Jan 1988	(Magnitude 6.3-6.7)
9.	Kalgoorlie-Boulder WA	20 Apr 2010	(Magnitude 5.0)
10.	Cadoux WA	2 June 1979	(Magnitude 6.1)

Past Earthquakes

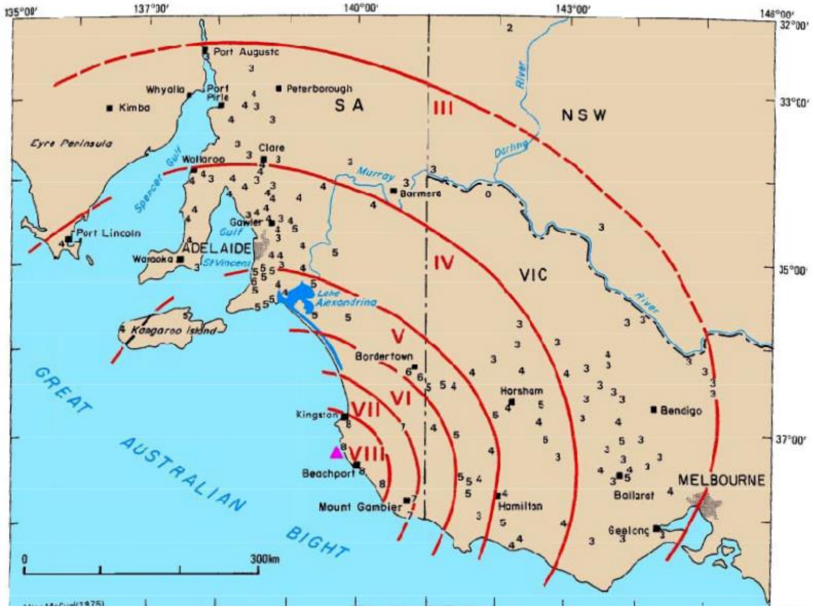
Newcastle, NSW (1989)

- Magnitude 5.6
- One of Australia's worst natural disasters
- Killed 13 people, hospitalised 160
- A small intraplate event with soft soils intensifying shaking
- Boxing Day Public Holiday so few people in CBD
- Several events had occurred previously
- Estimated $4 billion of damage to 35,000 homes, 147 schools & 3000 buildings
- Damage over 9,000 square kms with movement up to 800km away

The Newcastle Worker Club
Subsequently demolished & rebuilt
(Photo Courtesy Newcastle Library)

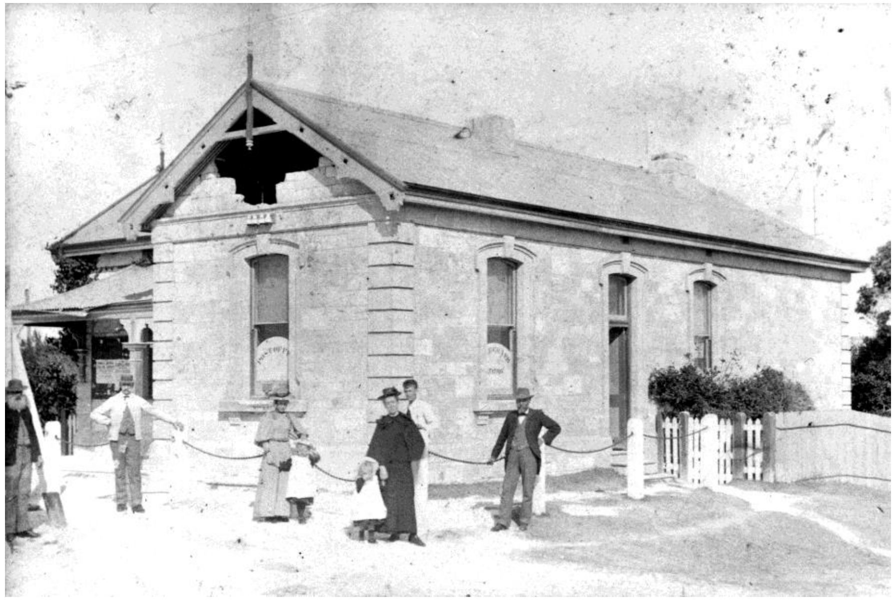
Past Earthquakes

Beachport, SA (1897) – Magnitude 6.5



Isoseismal map

Created by McCue & BMR/AGSO/GA



Damage to Beachport Post Office

(image courtesy of AEES)

Slumping near Robe due to liquefaction

(image courtesy of AEES)

Past Earthquakes

Meckering, WA (1968) – Magnitude 6.9

- Duration 40 seconds at 10.59 am on Public Holiday
- 20 people injured and 50 buildings damaged
- Epicentre 9km SW of town and felt over 700km radius (2nd strongest onshore in Australia)

37 km fault line scarp

Height of step 1.5 m

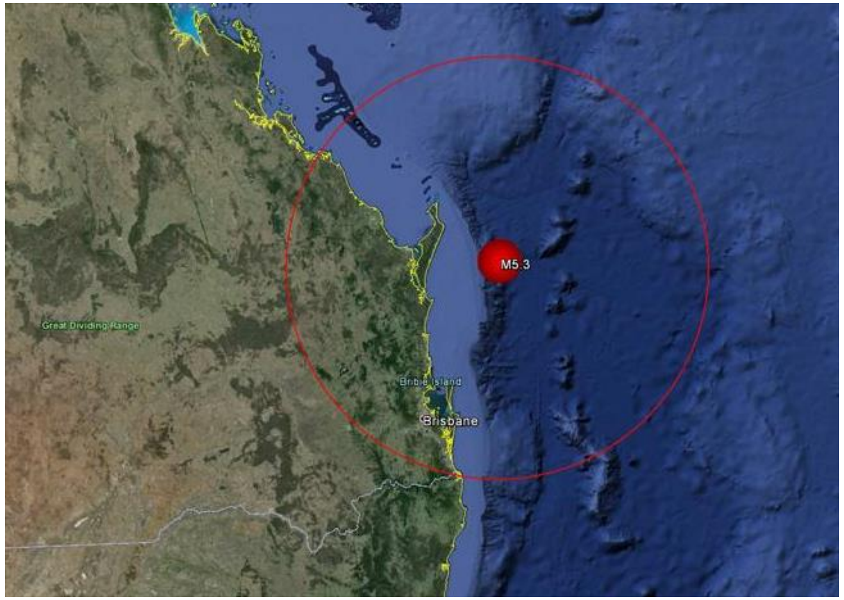
Most structures damages or completely destroyed

Most Recent Earthquakes

Fraser Coast, QLD (2015) – Magnitude 5.1 to 5.7

Date	Time	Depth (kms)	Lat.	Long.	Magnitude
30/7/2015	9.41	53	25.54S	154.00E	5.3
1/8/2015	13.38	10	25.38S	154.29E	5.7
1/8/2015	14.46	0	25.39S	154.23E	5.1

- Largest earthquake in region since 1918
- Felt in Brisbane, Gold Coast and Toowoomba

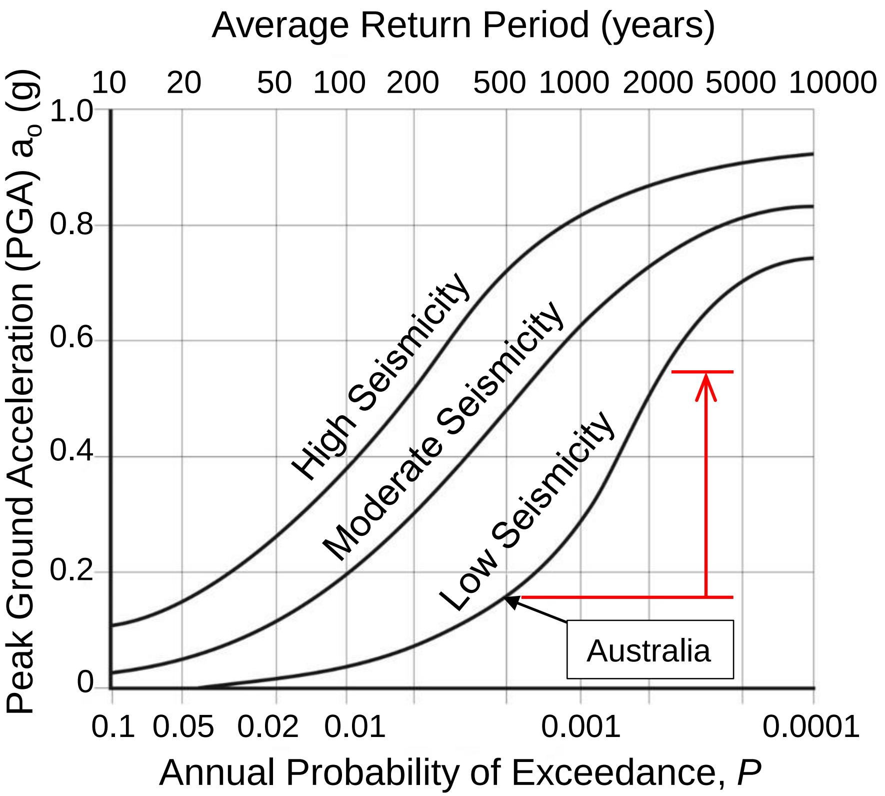


(Image courtesy Geoscience Australia)

Note: Christchurch earthquake on 22 February 2011 - Magnitude M6.3

Earthquake Risk

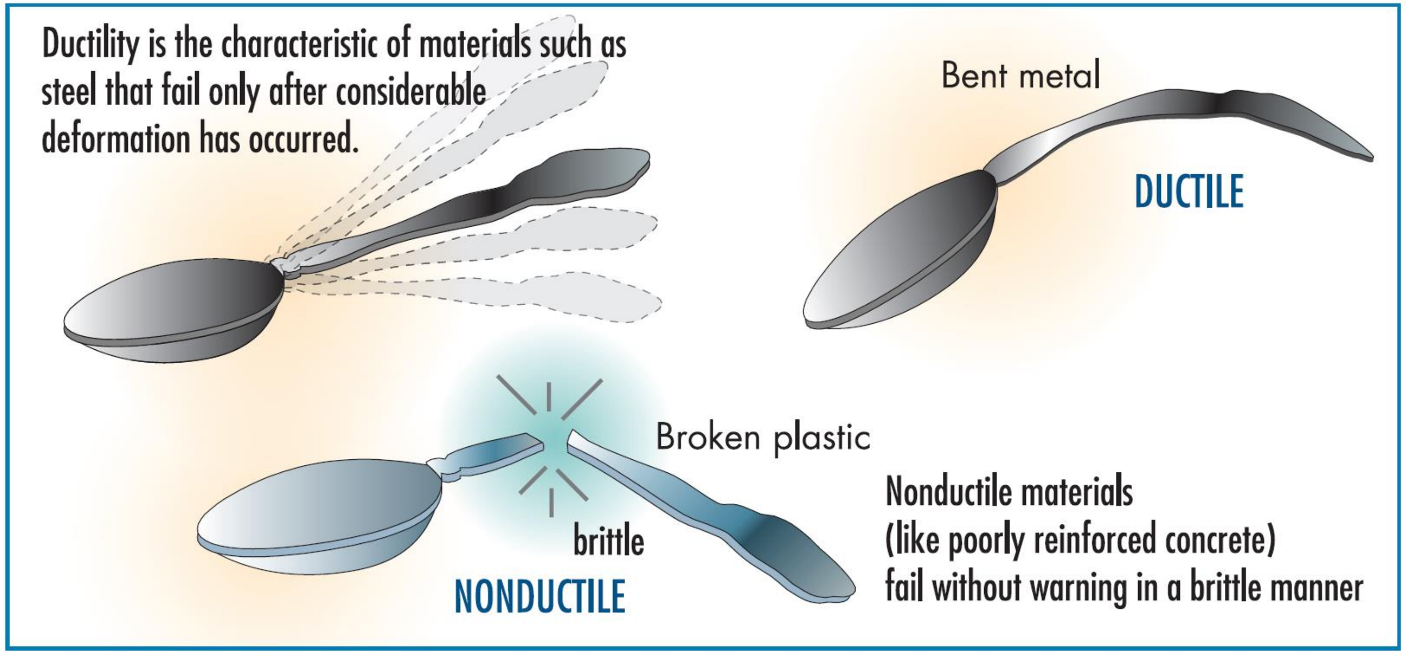
- Australia is not immune from earthquakes. It is estimated that:
  - On average 1 shallow M5 earthquake every 2 years (equivalent to Newcastle, NSW)
  - On average 1 shallow M6 earthquake every 10 years (equivalent to Christchurch, NZ)
- A major earthquake will generate the most severe structural ductility demand experienced by a building
- For a rare event, in a low seismicity region, peak ground acceleration may be nearly 4 times greater



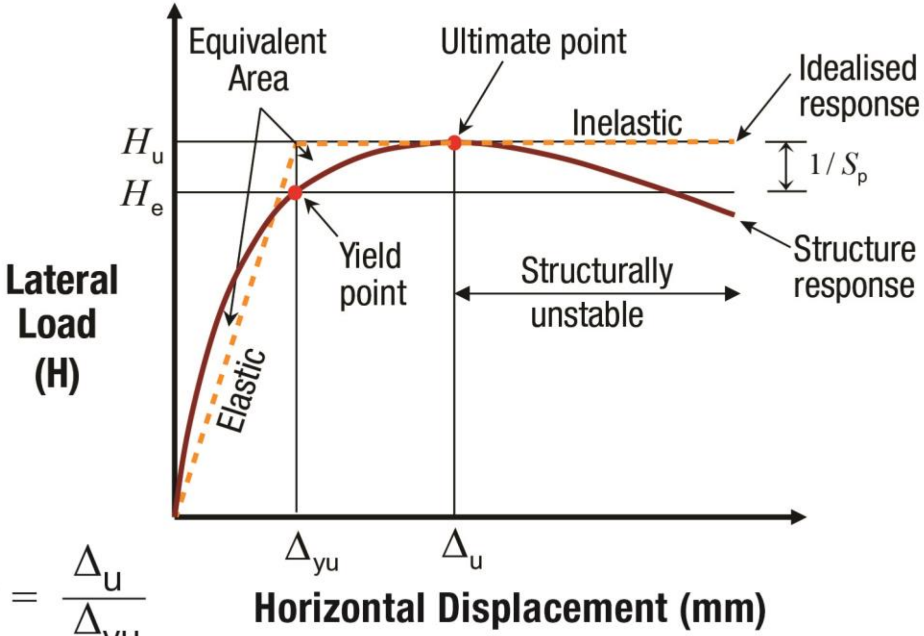
Wind and Earthquake Loads

- There are fundamental differences between designing for wind and earthquake loads
- Designers often undertake a quick earthquake base shear check, compare it to the wind design actions, find that wind "governs", and stop. This practice ignores the detailing requirements necessary to achieve structural behaviour consistent with the earthquake design base shear.
- BCA requires designers to consider both wind & earthquake as separate design events
- For wind, elastic methods of analysis, design and detailing based on static forces may be safely used.
- Given the rare and extreme nature of earthquakes, for economic reasons, designers are largely concerned about preserving life and preventing structural collapse
- For most structures, this will require the structural system to resist the imposed deformation inelastically over a number of load cycles.
- The difference is the poorly understood concept of structural ductility

Ductility



Source: FEMA



$$\mu = \frac{\Delta_u}{\Delta_{yu}}$$

Importance of Ductility

Allows structure to withstand seismic induced drift

Source: Christchurch Art Gallery Bookshop CCTV

Structural Ductility in AS 3600

AS 3600 provides designers with the minimum design rules for Australia's lower seismicity region

Structural system description	μ	S_p
Intermediate moment-resisting frames (moderately ductile) designed in accordance with this Standard and Paragraph C4 of this Appendix	3	0.67
Combined systems of intermediate moment-resisting frames and ductile shear walls designed in accordance with this Standard and Paragraphs C4 and C5 of this Appendix	3	0.67
Ordinary moment-resisting frames designed in accordance with the main body of this Standard	2	0.77
Limited ductile shear-walls designed in accordance with the main body of this Standard	2	0.77
Other concrete structures not listed above	1.5	0.77

Table C3 of AS 3600

Special Moment-Resisting Frames (referred to in AS 1170.4) are not covered by Australian Standards. In this case, overseas Standards must be used.

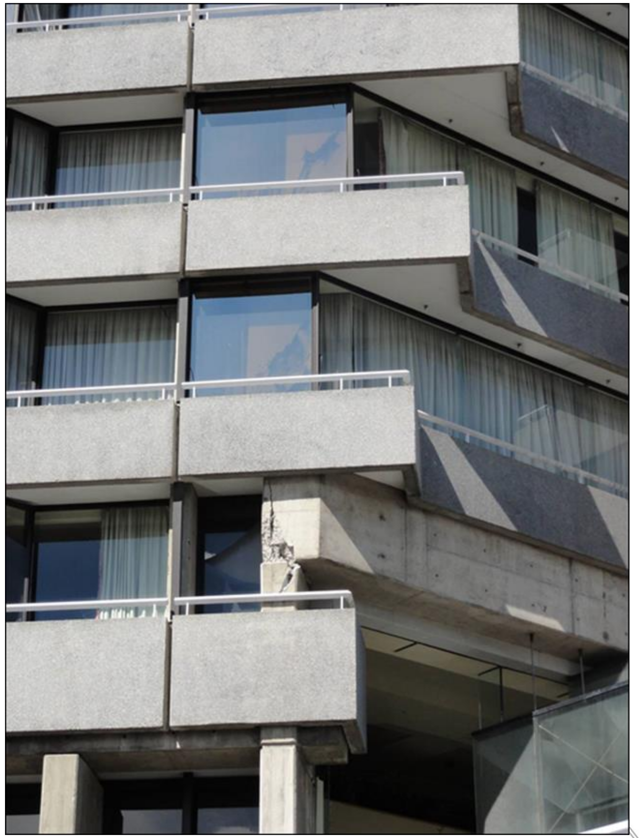
Risk Mitigation and Low Damage Design

- Relying on structural ductility when designing for life safety results in significant damage from inelastic deformation - typically results in demolition of the structure as it will be unrepairable
- Should consider whether building requires protection of irreplaceable contents, has a post disaster function, or whether it should be repairable
- Highest level of protection is by base isolation but seldom used in Australia due to low seismicity
- Typical method is to use a more robust, regular structure with defined load paths
- Cost can be as little as 1% to 3% of the total construction cost
- Lowest level of protection is the minimum requirements in the body of AS 3600

Christchurch CBD

Analysis and Design

- Strive for simplicity and clarity in designing load paths
- Maintain strong focus on detailing of reinforcement
- Earthquakes exploit the weakest link
- Static loads calculated may not resemble actual earthquake
  - Earthquake actions are dynamic
  - Stiffness of structure changes
- Understand the behavior of each member

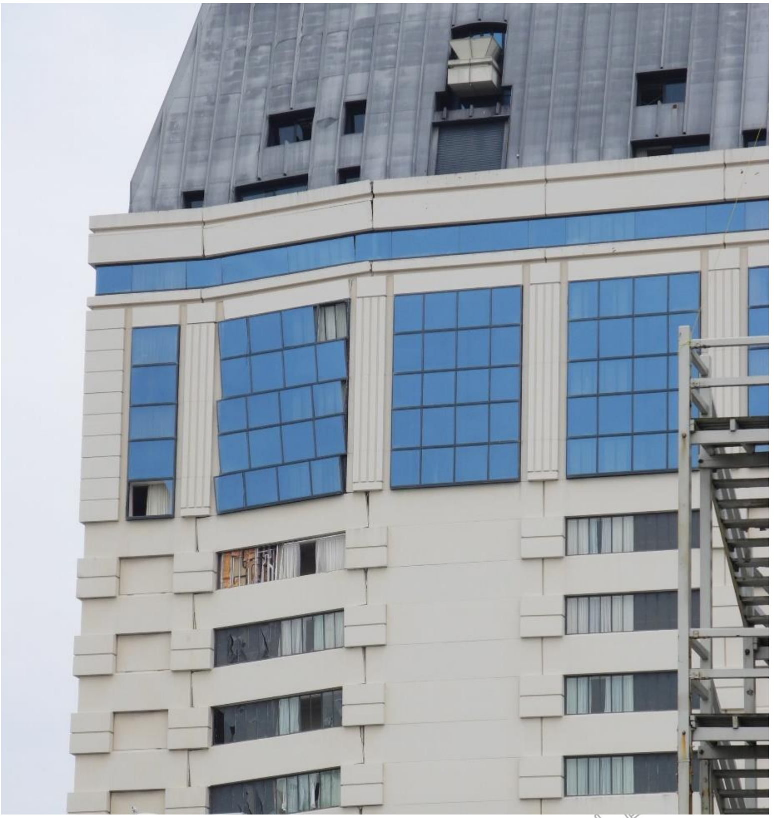


Provide simple load paths

Transfer beam - stiffness of structure changes with cracking

Robustness

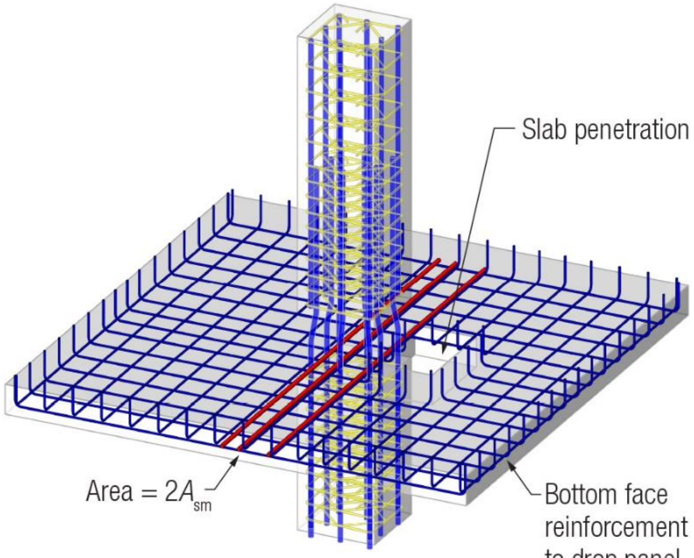
- Structural robustness is not well defined
- No specific requirements in AS 3600
- BCA deem to satisfy ignores (BCA separate performance section covers but is optional)
- Progressive and disproportionate collapse must be avoided
- Redundancy is an important issue
- Failure of one part should not lead to the collapse of the entire structure

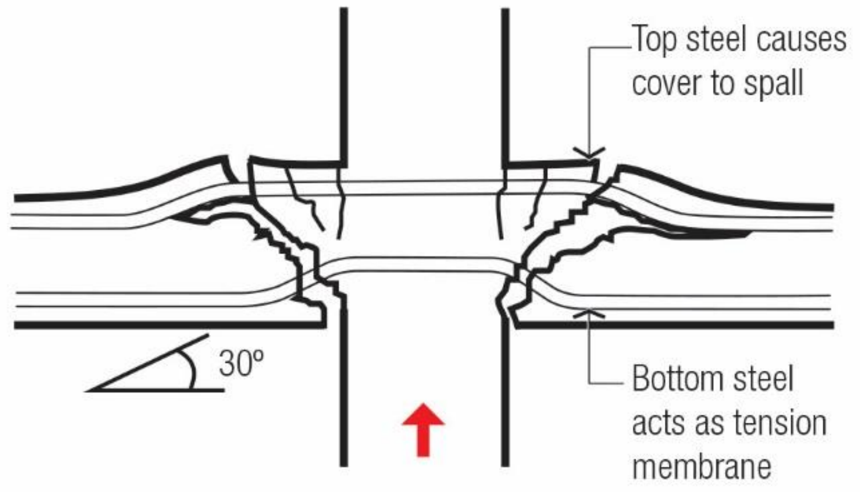


Failure of loadbearing shear wall did not result in collapse of entire building
Hotel Grand Chancelor, Christchurch

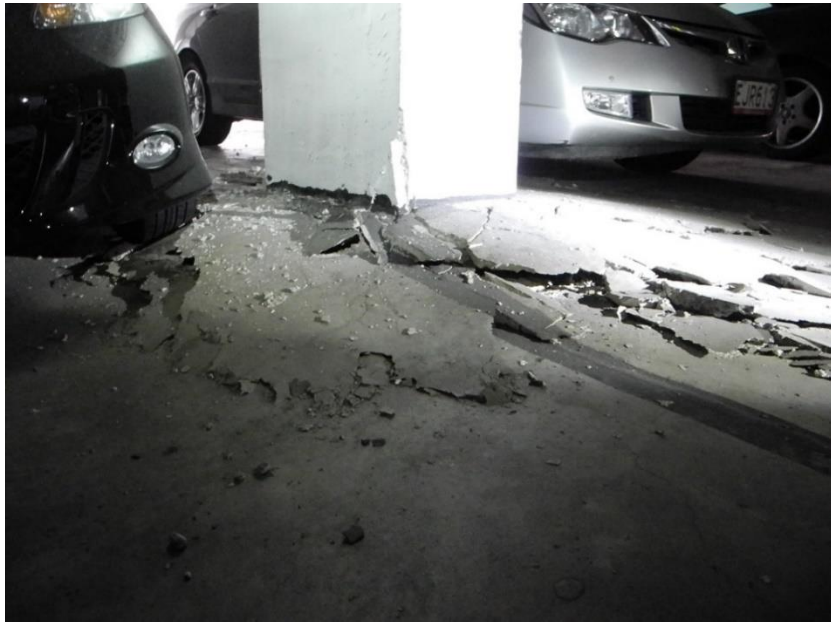
Structural Integrity Reinforcement for Robustness

Increases resistance of structural system to progressive collapse





Figures 36 and 37 from Seismic Guide



Hotel Grand Chancellor, Christchurch, NZ

Structural Integrity Reinforcement for Robustness

Simple Reinforcement Detailing ➡ Improves Life Safety

Punching shear failure at column

Resultant progressive collapse

Remains of car park floor – Old Newcastle Workers Club, NSW

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

Acceptable Drift Limits

- All parts of a structure (framing & components) must be able to accommodate the required drift
- AS 1170.4 requires a drift capacity of 1.5%
- At about 1.5% drift (AS 1170.4 requirement), the cover concrete will typically be lost and confined core will be adequate

Bottom bars not adequately anchored in the confined region of the column

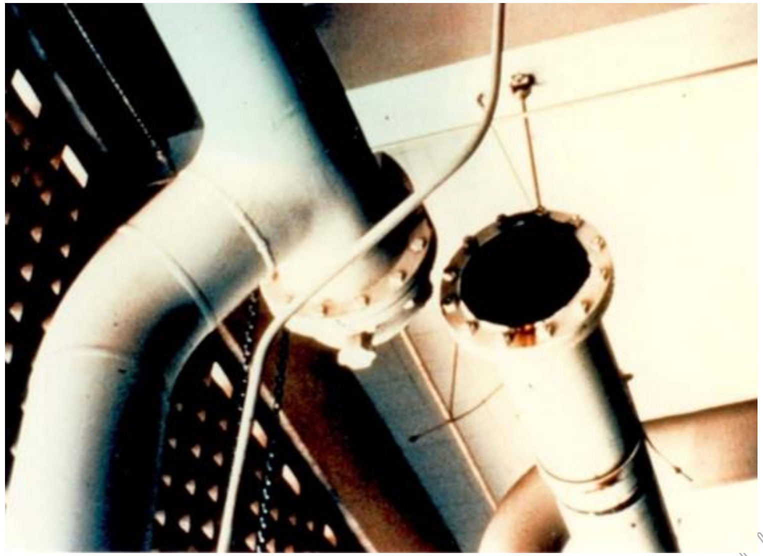
Failure of a beam column joint
Copthorne Hotel, Christchurch 2011

Responsibility for the Design

- Overall responsibility should be taken by the Principal Designer
- Coordinate design work of subcontractors for parts and components
- Failure of CTV Building, NZ attributed to senior engineer not supervising work of others

Failure of precast connection
Bedford Row Carpark
Christchurch, NZ

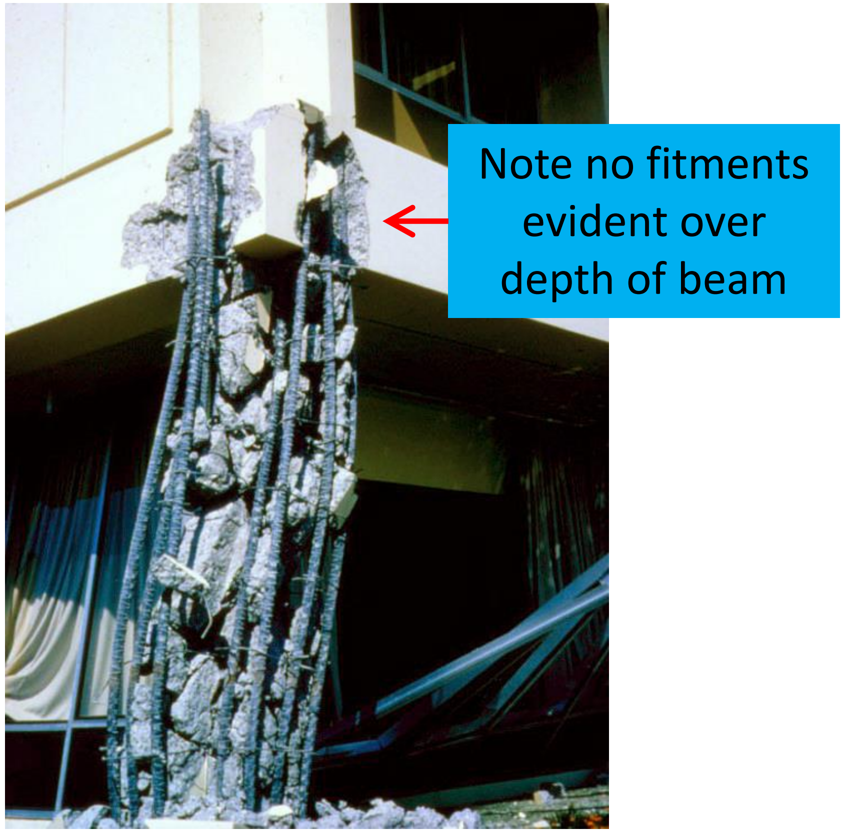
Failure of precast connection
Crown Plaza Hotel
Christchurch, NZ



Pipe joint failure
San Fernando Earthquake, 1971
(FEMA 74, 1994)

Reinforcement Detailing

Column fitments provide restraint of longitudinal reinforcement and allow drift of columns



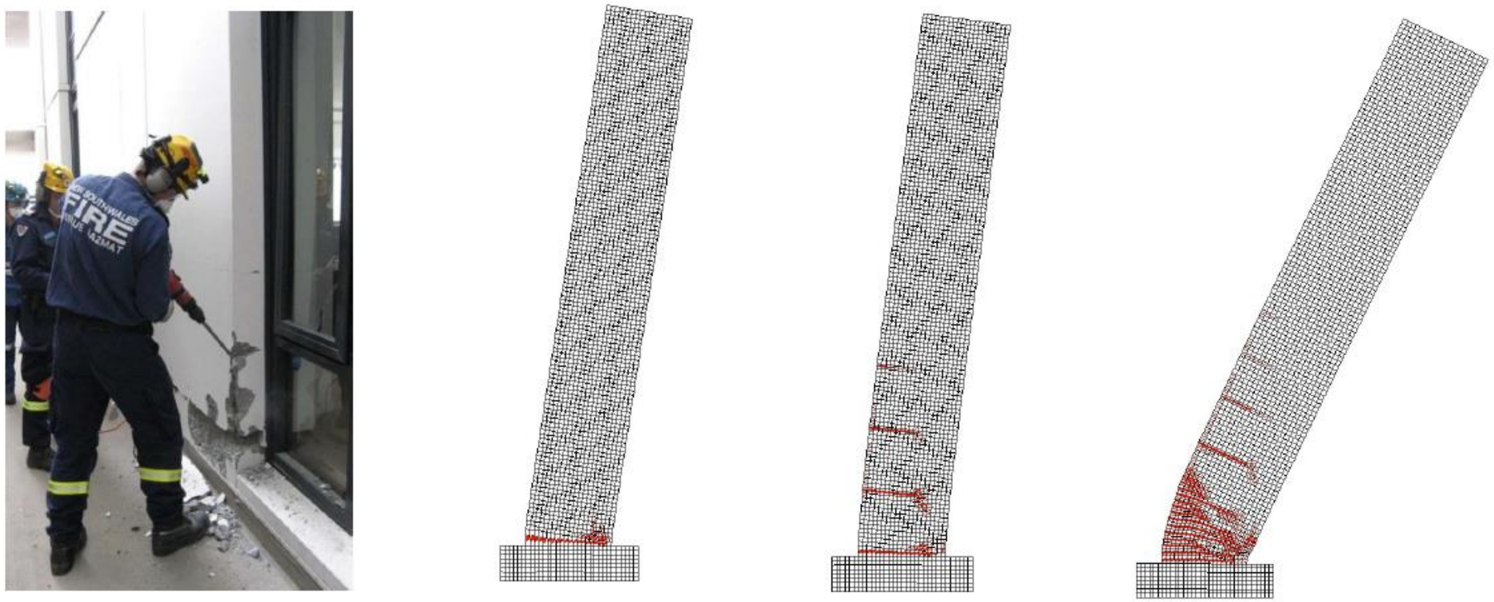
Loss of confined core due to fitment failure
Kobe earthquake, Japan 1995

Restraint of longitudinal bars lost due to fitment failure
Hotel Grand Chancellor, Christchurch, NZ 2011

(Photograph courtesy Peter McBean)

Reinforcement Detailing

Walls must be adequately reinforced to provide ductile behaviour and allow for drift



(a) Crack in grid-F wall (b) As-built grid-F (c) NZS 3101 (A2) (d) Additional reo at ends

Actual damage and crack patterns from wall models

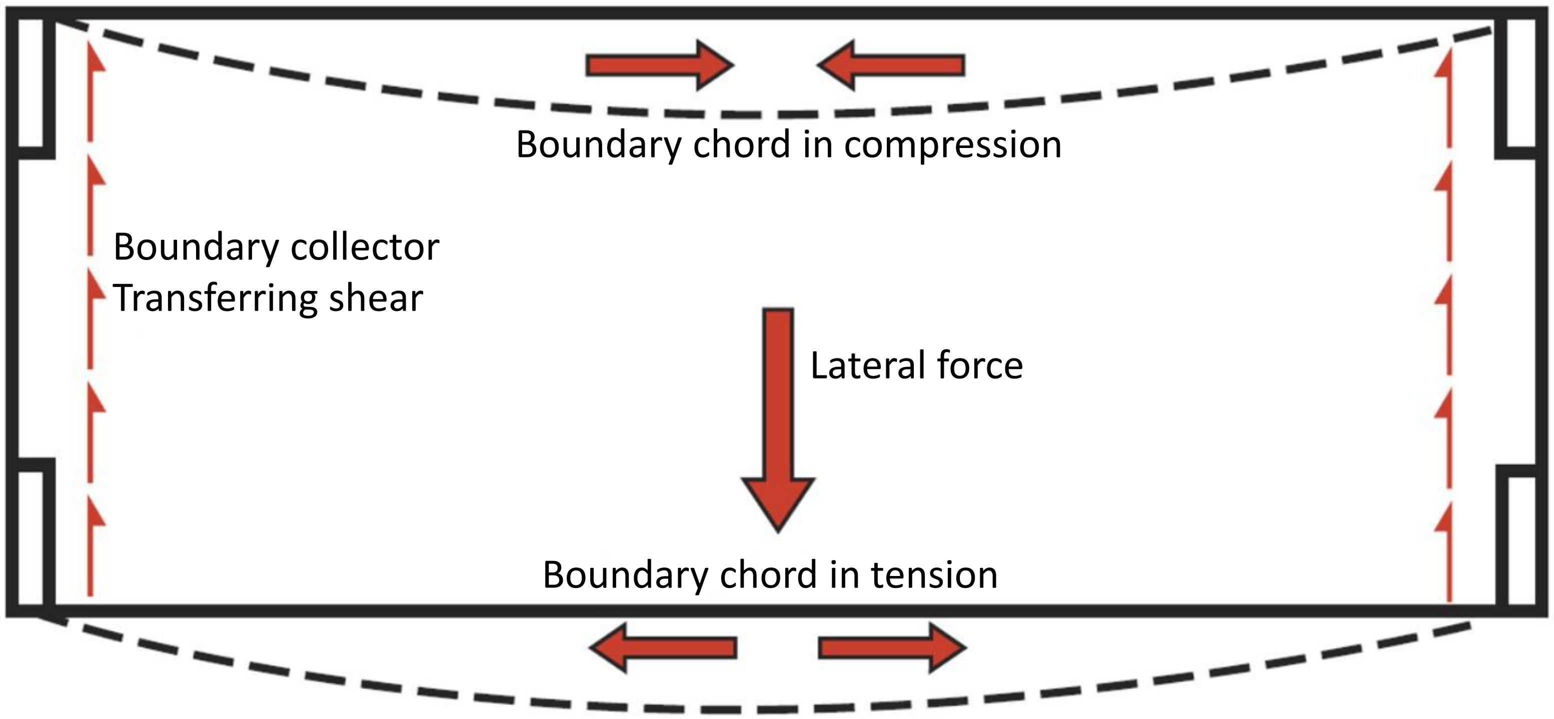
(Henry et al., University of Auckland, 2015)

Fractured reinforcement at base of wall – Grid F

Gallery Apartments, Christchurch NZ

Diaphragms

- Transfer lateral forces to shear resisting elements
- Not covered by AS 3600
- Refer to ACI 318M-14 for guidance

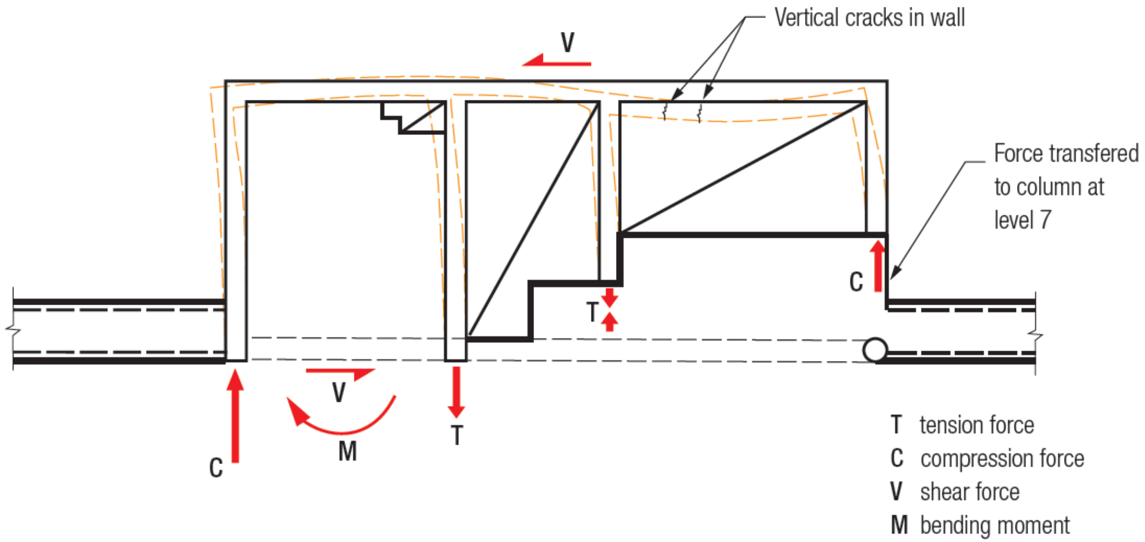


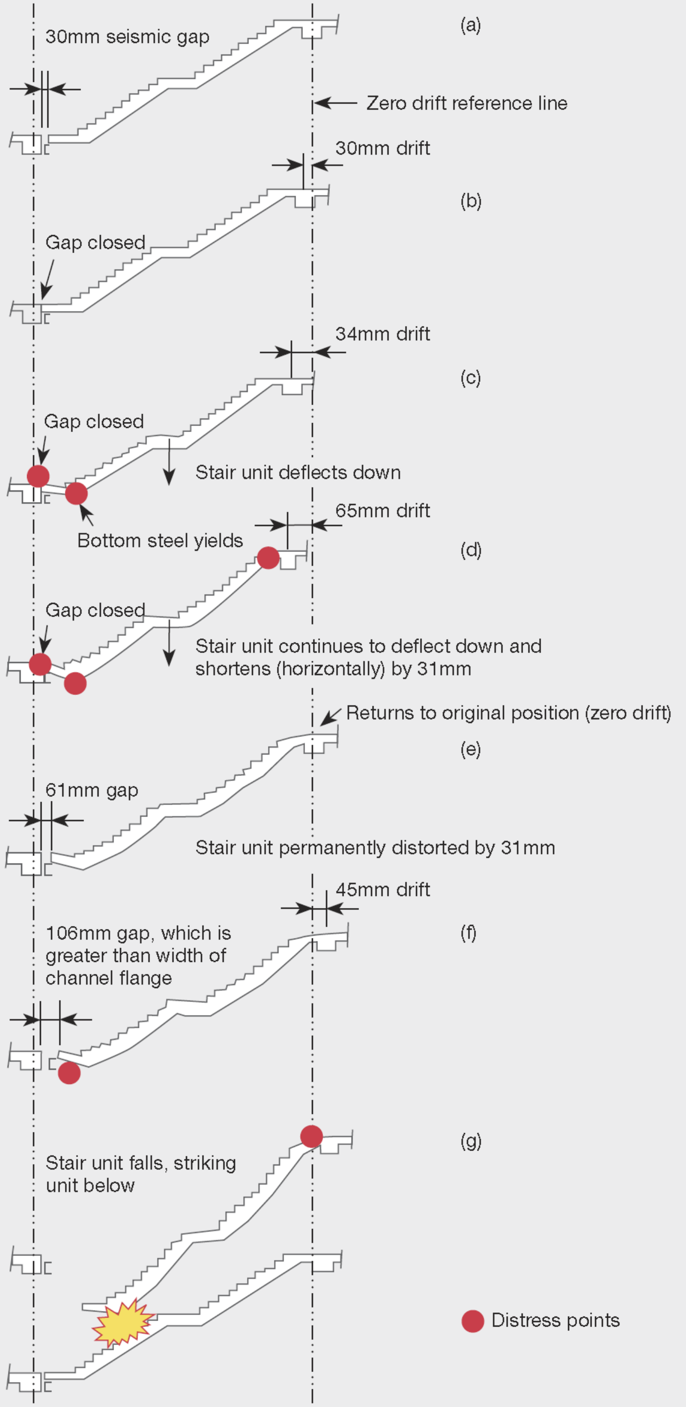
Floor as diaphragm
(after ATC/SEAOC briefing paper)

Diaphragms

Ensure connection to shear resisting elements is adequate

CTV Building, Christchurch, NZ



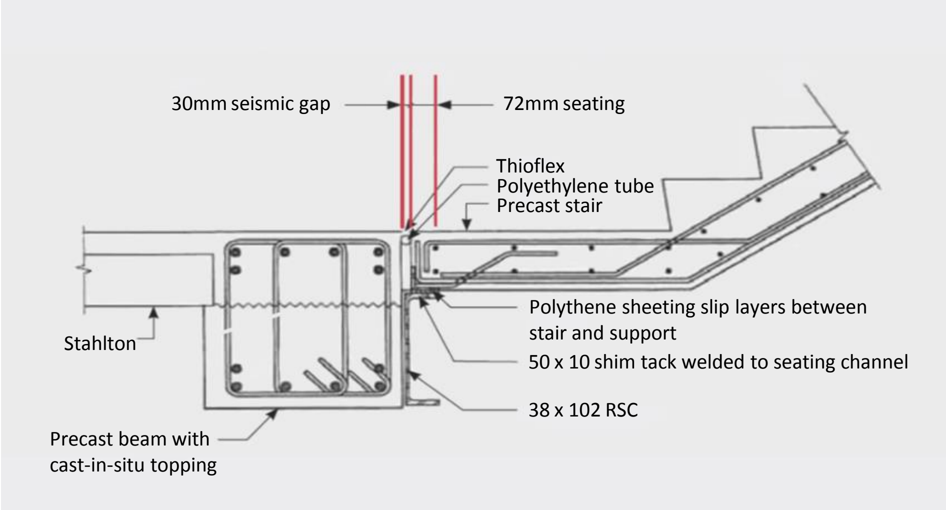


Stairs

Must allow for an interstorey drift of 1.5d_{st}

(where d_{st} =1.5% of storey height)

Approx. 75mm total



Collapsed stairs to the Hotel Grand Chancellor

(Photograph courtesy of Dunning Thornton Consultants Ltd, NZ)

Conclusions

- Australia is not immune from earthquakes
  - On average 1 shallow M5 earthquake every 2 years
  - On average 1 shallow M6 earthquake every 10 years
- Australia may be categorised in an area of low to moderate seismicity, but the consequences of an event in a city area would be very high eg the Christchurch scenario
- Wind and earthquake loads are different and each needs to be considered
- Designers need to adopt basic seismic design principles and to understand that seismic actions and detailing are **very different** in order to develop compliant structures
- Reinforcement detailing is just as important as the seismic design itself and trying to **understand how the building might fail under earthquake actions**

Conclusions

- Do not ignore non-structural elements as they are just as critical as the primary structure - **a lack of compliance may void your PI**
- The Guide has checklists included to provide a summary of issues that should be considered by all parties
- The Guide has many references which can generally be downloaded for free eg Canterbury Earthquakes Royal Commission Reports Volumes 1-3 inclusive

Thank you

SRIA
Steel Reinforcement Institute of Australia