A Guide to Seismic Design & Detailing of Reinforced Concrete Buildings in Australia

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ABSTRACT:

A Guide on the Seismic Detailing of Reinforced Concrete Buildings in Australia was published in 1995 by the SIRA. There have been two revisions of AS 3600 and a new version of AS 1170.4 since then. A new updated Guide is to be published in 2015.

Since the mid 1990s there have also been significant advances in the analysis of buildings and earthquake design methods which have improved through advances in research, combined with the evaluation of actual performance during seismic events. AS 3600 provides Australian designers with earthquake design rules to meet the typically lower seismicity of Australia.

The fundamental principle of concrete design is that the design and the detailing of steel reinforcement for concrete are inseparable. This ensures that the structure will respond under seismic actions in the manner for which it has been designed. The overall aim of the new Guide is to provide cost effective, simple design solutions with practical detailing information under seismic loadings.

Keywords: Seismic design concrete, design and detailing for seismic loads, reinforcement

Introduction

The original Guide on the seismic detailing for reinforced concrete buildings in Australia was published in 1995 following the publication of the second Australian earthquake code [1] AS 1170.4 (Ref *1*) titled *Minimum design loads on structures, Part 4: Earthquake loads*. There have been two revised versions of the concrete standard AS 3600 *Concrete Structures* (Ref *2*) and a new version of the earthquake standard AS 1170.4 (Ref *3*) titled *Structural design actions, Part 4: Earthquake actions in Australia* published in 2007 since the original Guide.

While there are many texts on the design of buildings for seismic actions, there is no document in Australia setting out the seismic design and detailing of concrete buildings in accordance with Australian Standards. The Guide has been written to assist graduate engineers, practicing engineers with limited seismic experience and senior engineers seeking to refresh themselves of the current developments and practical aspects of reinforcement design and detailing of concrete in Australia.

The Guide is a collection of simple seismic principles, design advice and fundamentals to advise and help designers and to suggest further study of the principles and practice of seismic design and detailing.

Since the original Guide was published in 1995, there have been significant advances in analysis software for buildings and earthquake design has improved through advances in research, combined with the close evaluation of actual building performance during seismic events overseas. AS 3600, provides Australian designers with the earthquake design rules to meet the typically lower seismicity of Australia. Most commercial buildings in Australia are cast in situ reinforced concrete, designed and detailed in accordance with AS 3600. Complying with the Standard for regions of lower seismicity deems the structure to have adequate ductility as a life safety measure.

For lower values of the ductility factor μ, detailing of reinforcement is only required to comply with the body of the Concrete Standard whereas for higher values of ductility factor μ, detailing in accordance with Appendix C is required. For levels of ductility beyond the Standard, reference to NZS 1170.5 and NZS 3101 for design and detailing, is suggested. The fundamental principle of concrete design is that the design and the detailing are inseparable. Appropriate detailing of reinforcement is required to ensure that the structure will respond under seismic loading in the manner for which it has been designed.

The information in the new Guide is to be presented, focusing on the key, functional and practical aspects of seismic design and detailing of reinforcement with references to specialist information. Technology and reduced design times can shift the focus away from the vital reinforcement detailing phase of the project. The overall aim of the Guide is to facilitate cost effective, simple design solutions by providing designers with practical detailing information for them to efficiently determine the requirements for the overall structural performance under seismic actions.

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1 The BCA was introduced in 1996 as the Building Code and to avoid confusion *the* words **Standard** r*eplaced the word* ***Code*** for any Standards Australia publications.

Unfortunately, there is no shortage of opportunities for designers to continue to learn from earthquake damage and the results of poor design and poor construction practices such as occurred during the recent Canterbury earthquakes in Christchurch.

The late Professor Tom Paulay in 1997 said:

- ***"In many countries the design process is synonymous with sophisticated dynamic analysis,"***
- ***"The high degree of precision achieved with the use of computers is often held in inordinate reverence, 'at the expense of basic conceptual choice'"***
- ***"By choosing an unambiguous load path, establishing a strength hierarchy, and providing well-thought details one can tell the building how to behave. The weak links selected in the hierarchy must be detailed to provide a rationally conceived plastic mechanism. The regions between these plastic hinges must be sized to remain elastic. Engineering choices can be based on simple static, elastic models rather than sophisticated dynamic analyses."***
- ***Detailing is "very often considered a subordinate, depreciated drafting activity with apparent lack of intellectual appeal. The exact opposite should be true in our practices. The detailing of potential plastic regions of the structural system is partly an art," Paulay said. "It relies on the feel for, and understanding of, the natural disposition of internal forces. It often invites innovations. Rational detailing of high quality will compensate for the crudeness inherent in our ability to predict the magnitude of earthquake-induced displacements."***

The new Guide will provide an overview of the history and seismicity in Australia, the role of the Building Code of Australia (BCA) and Australian Standards in designing buildings for seismic actions. It will also discuss the need for sound engineering practice, the expectation of clients, relevant Standard requirements and responsibility for design.

The Guide also examines the lessons learnt from previous seismic events in Australia as well as high seismic events such as the Canterbury earthquakes in New Zealand. It focuses on the analysis, the design methodology and most importantly the reinforcement detailing aspects for concrete building structures in regions of lower seismicity.

It will show how the requirements of the current Standards can be met through the use of predominantly simple *'seismic'* details and general good detailing practice. Further, it will be shown how an appreciation of structural performance under seismic loads will enable the structure to withstand the anticipated earthquake actions.

While there are a number of excellent overseas texts on the design of buildings for seismic actions none of them covers the detailed design issue in accordance with requirements of Australian Standards. Some of these include:

- *Booth - Earthquake Design Practices for Buildings. (Ref* 4*)*
- *Paulay and Priestley - Seismic Design of Reinforced Concrete and Masonry Buildings. (Ref* 5*)*
- *Priestley, Calvi and Kowalsky - Displacement-based seismic design of structures. (Ref* 6*)*

- *Booth - Concrete Structures in Earthquake Regions: Design and Analysis. (Ref* 7)

This paper sets out what the new Guide is endeavouring to do to help designers in designing and detailing concrete structures correctly for seismic loads in Australia.

Reinforced Concrete Structures and Earthquakes

The Canterbury earthquakes in New Zealand of 2010 and 2011, the Kobe (Great Hanshin) earthquake in Japan of 17 January 1995 and the Northridge earthquake in Los Angeles of 17 January 1994 were significant and large earthquakes. Studies of building performance during these events have highlighted the strengths and weaknesses of reinforced concrete in terms of design and as a structural material.

The Kobe earthquake
(Photograph courtesy John Woodside)

Reinforced concrete possesses a number of attributes that allow it to be successfully employed in structures resisting seismic loads:

- Properly conceived and detailed concrete structures possess excellent ductility in flexure, which can equal that of structural steel.
- Well-confined concrete can possess good ductility under flexure and axial compression,
- Correctly detailed concrete construction provides a monolithic structure, with load path redundancy and good overall structural continuity, in itself a good earthquake-resistant feature.
- Shear (Structural) walls are an economical means of providing high lateral strength and stiffness while still retaining significant ductility. Most multi storey buildings will have lift shafts and stair shafts constructed from reinforced concrete.

- Internal damping before yielding is greater than in steel structures (approximately 6% compared with 3%). Damping is important for serviceability considerations during moderate earthquakes.
- In many countries including Australia, concrete is the building material of choice; the technology is familiar, the materials are locally available and cost-effective, while the finished structure will have good sound and thermal insulation properties.
- SRIA steel reinforcement processors purchase their raw materials from quality Australian and overseas mills. A list of third party accredited mills can be found at www.steelcertification.com

The commonly held view that modern steel structures are immune from collapse or significant damage during seismic events is not correct and in Christchurch some steel structures suffered significant damage or collapse.

Many well-designed concrete structures have survived major earthquakes undamaged as seen in Canterbury, Kobe and Northridge. Readily available literature has a wealth of experimental and theoretical evidence to support the potential for good seismic performance from structural concrete. **Good detailing of a reinforced concrete structure can enhance the structural system strength and behaviour whilst minimising the potential weaknesses identified.**

Risk mitigation and low damage design for buildings

The traditional focus for earthquake design worldwide, and that adopted by AS 1170.4,concentrates on life safety and considers minimising damage to the building and contents as a secondary issue. By considering the inelastic response of structural systems, design values in earthquake codes allow the designer to use loads the order of 30% to 60% lower than might be expected elastically during a large earthquake. A properly designed and detailed building will allow people to get out of the building, but can result in significant damage to the building requiring either repair or in extreme events demolition of the building after the earthquake.

Alternative methods are now being proposed as a way of reducing the risk of damage sustained in earthquakes. These methods include some new technologies to minimise damage. (Ref *8*)

The highest level of protection for a building is base isolation to protect the building structure and its contents and provide a fully operational building. The order of increased cost is thought to be of the order of 8% to 10% the construction cost of a building.

The next level of protection is to try to minimise the damage by using a more robust and regular structure with a higher ductility. This will protect the primary structure even in the most severe earthquake with many alternative load paths and backup systems capable of accommodating higher forces than the minimum required by the Standard. The great advantage of this approach is that the structure should be operational and repairable; insurance claims will probably be less, and the risk to structural damage and business continuity is mitigated, but at an increased cost to the original construction. It is expected that the increased cost for providing this level of structural performance would be order of an additional 2% above the construction cost of the building designed to provide the lowest level of protection as required by the BCA.

The lowest level of protection is compliance with BCA requirements where the building is expected not to collapse and to allow people to exit in the event of a significant earthquake. This level of protection however does little to prevent serious damage and demolition is likely following an extreme event.

Sound engineering practice

"Good design is risk led, rather than code dependent", John Carpenter, former secretary SCOSS *2*.

We seem to be too driven, and limited, by Standards & Codes (and I am not denying their usefulness) so that deep understanding of structural behaviour is not seen as vital – provided we satisfy the rules in the Standards we believe we have done all that is necessary. Bill Boyce, former Associate Professor Civil Engineering, the University of Queensland.

Standards represent the current technical information, but can be out of date after their issue. They are however critical in establishing a minimum benchmark and consistent level of confidence and building reliability. A better understanding of the design issues, the performance of structures in recent earthquakes and new research and testing has increased the designer's knowledge of the performance of buildings under earthquake actions. Often these new developments are codified following market implementation.

AS 3600 sets out minimum requirements for the design and construction of concrete structures. These requirements have been developed over many years and draw on the experience embodied in international standards and local expertise. In general, the rules have been developed to protect the public (safety) and provide a general level of amenity. However, the Standard represents a minimum requirement and will not prevent damage to the structure of a building in a major earthquake event.

Sound engineering practice involves the designer applying principles of engineering that are broadly accepted by engineers at the time of design and which may be additional to minimum legal requirements.

Currently sound engineering practice would for example involve identifying the loads and load the paths through beam-column and beam-wall joint zones and junctions between other structural elements under cyclic loading conditions and detailing the reinforcement appropriately for them.

Client/building owner's expectations

The needs of a particular owner for a given structure may require more stringent requirements than that provided by AS 1170.4 and AS 3600. These matters should be

2 CROSS (Confidential reporting on structural safety) and SCOSS (Standing committee on structural safety) and sponsored by the Institution of Structural Engineers, the Institution of Civil Engineers and the Health and Safety Executive *UK*.

discussed early in the preliminary design phase with the owner to determine their expectations of their building in the event of a severe earthquake and whether they should be considering a life safety or low damage design strategy.

Commonly client/building owners have a different view on what earthquake design means for their building. They mistakenly assume that their building will survive a major earthquake without damage, which is not the concept of design for earthquake actions in the Standards.

For example in the recent high magnitude Christchurch earthquakes, buildings designed using *capacity design* reportedly behaved as expected by engineers but the expectations of the client and owners were less favourable.

Client/building owners should also be made aware that while the probability of earthquakes is low, the damage can be extreme when compared to wind where the probability is higher, and the damage is usually moderate. Many businesses failed after the Newcastle earthquake because they were unable to continue to operate from their premises; they were underinsured or had no loss of business insurance; they were unable to access their data or computer systems. There were also many examples of this problem following the 2011 Japanese tsunami.

The greatest reinsurance risk in Australia is for earthquake damage, albeit an unlikely event, but the damage and loss of life when it occurs could be very extensive and expensive.

Buildings may have minor, moderate, or major damage depending on the size of an earthquake, but these terms are not concisely defined and are subjective. The possibility that a building may survive a major earthquake allowing people to escape, yet may have suffered irreparable damage to the point where demolition is required, should always be discussed early in the design phase. To assist the client/building owner, designer and builder/contractor checklists have been developed in this new guide to stimulate communication to facilitate the process of design and construction of suitable seismic systems that ideally align individual expectations with actual outcomes. The design of non-structural elements such as building services, partition walls and ceilings are also briefly discussed the Guide as failure of non-structural elements can lead to people being unable to safely exit the building.

Raising seismic design performance levels from the significant damage design criteria adopted in AS 1170.4 by using higher design actions together with additional detailing may significantly increase the ability of the building to resist seismic actions at relatively small additional cost to the design and construction.

The responsibility for earthquake design

Whilst there may be a number of designers working on the project, to ensure the sound design and detailing of a concrete structure for seismic actions, it is vital that one structural engineer (called the ***Principal Designer*** in the Guide) takes overall responsibility for the structural aspects of the project. This will ensure that the building integrity is achieved by providing continuity of the overall structural system and individual elements act as together as intended.

The *principal designer* responsible for the structure must be a practising civil or structural engineer eligible for Chartered Status of Engineers Australia or equivalent and experienced in the design and detailing of concrete structures of comparable importance for earthquake actions.

The design approach for earthquake design and detailing should be independently peer-reviewed by somebody with experience in structural and earthquake design to ensure that the correct design philosophy is adopted and the appropriate detailing to be used.

In the failure of the CTV building in Christchurch, where 115 people lost their lives, is largely attributed to the designer of the building who was not experienced in earthquake design and did not fully understand what was required [3].

From the study of selected buildings in Christchurch, some of which failed in the 2011 Canterbury earthquake in New Zealand (Ref *9*), design mistakes were made and poor detailing was used which in some cases lead to the failures of building. Therefore correct design and detailing is fundamental to earthquake design.

The *principal designer* and the design team should preferably carry out all the structural design of the building. Where the *principal designer* of the structure assigns or subcontracts the detailed design of parts of the project to a manufacturer or supplier, they should ensure that this work is fully specified and controlled by way of detailed performance requirements and also that the manufacturer's components are coordinated with the structure as a whole. Examples of where design by others commonly occurs include the detailed design of precast concrete elements and post tensioned slabs. If such design is assigned or subcontracted to others, there are important matters that need to be fully understood by the *principal designer* who must retain overall responsibility for not only their design, but those working under *principal designer* including any subcontractors. The same applies to the builder/contractor and their subcontractors in the procurement of the building components and in particular the supply of conforming building materials that meet the engineers design specifications and nominated Australian Standards.

Conclusions

The new Guide to Seismic Design & Detailing of Reinforced Concrete Buildings in Australia to be published in 2015 will provide valuable information for building owners, designers and constructors in Australia and assist them in designing and detailing of resilient concrete structures for seismic actions in accordance with Australian Standards. The new Guide seeks to assist in establishing a consistent approach to high quality rational detailing via compilation of simple seismic design principles which attempt in part to compensate for our inability to accurately predict either the magnitude of earthquake actions or the seismic response of structures.

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[3] In the failure of the CTV building in Christchurch in New Zealand where 115 people lost their lives, the Royal Commission concluded that there were a number of non-compliant aspects of the CTV building design. They considered that a primary reason for this was that the design engineer was working beyond his competence in designing this building. He should have recognised this himself, given that the requirements of the design took him well beyond his previous experience. They also considered that his superior was aware of the engineers lack of relevant experience and therefore should have realised that this design was pushing him beyond the limits of his competence.

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