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Cyclone Tracy:

Relevance for Earthquake Engineering Today

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Abstract

This year marks the 50th anniversary of Cyclone Tracy. Although it was the consequence of severe winds, its impact on Darwin was not unlike the potential impact that a severe earthquake would have on a major Australian urban area. The author led the investigation of damage but has an earthquake engineering background. Looking back, he has realised that a major lesson that should have been learnt by both the wind and earthquake engineering communities from this event is that community disaster resilience was the driving force for the resulting changes to construction, not life safety per se, but it was assumed that designing individual new buildings for human safety would achieve this. However, although this approach has led to a significant improvement in community resilience to tropical cyclones, the impacts of the most severe cyclones since then have continued to test community disaster resilience. This paper outlines some of the reasons for this, many of which equally apply to the earthquake design of buildings. Correcting this requires meeting an acceptable level of community disaster resilience as a prescribed performance objective of building regulations in addition to the human safety of occupants of individual buildings. Such an approach will require a major extension of the current scope of building regulations, including introducing the concept of a design earthquake for the community within which the building is located, in addition to a design ground acceleration for the building, and inclusion of all buildings within the scope of building regulations, not just new ones. Some of the implications for earthquake engineering have already been recognised by earthquake engineering researchers, but there is still much to be done if designing for community earthquake disaster resilience as an additional limit state to human safety is to become a reality.

Keywords: community disaster resilience, earthquake design, building regulations.

1 Introduction

This year marks the 50th anniversary of Cyclone Tracy. The author was privileged to lead the investigation of the damage and to be the principal author of the resulting report (Walker, 1975).

The primary characteristics of the impact of Tracy were the huge level of destruction of houses with only about 10% of the estimated 8000 houses remaining permanently habitable, and the huge socio-economic impact on Darwin, with most of the population having to be evacuated and the economic cost estimated to have been of the order of $400-$500 million at the time (Mason & Haynes, 2010) which in today's values would be of the order of $4-$5 billion. Together this led to an almost complete loss of community functionality, the restoration of which took 2-3 years. In modern terminology we would describe the latter as the measure of Darwin's community disaster resilience to the event, which, although considered unacceptable, was quite remarkable by comparison with other major disasters of similar impact – Christchurch took much longer. (The relatively short recovery time was probably primarily due to Darwin at the time being under Commonwealth Government jurisdiction and most of the houses government owned.)

The primary objective of the investigation was to ascertain what lessons should be learned from the event if Australian communities at risk from tropical cyclones were to be spared from such an experience. Consequently, it was largely focussed on the shortcomings regarding wind engineering design, with the major recommendation being that houses should be subject to the same level of structural design as larger commercial buildings. However, a recommendation for adopting a Limit State Design approach sped up the introduction of this approach to structural design nationally for all loading conditions. The resulting Ultimate Limit State design loads were based on a specified estimated return period of the load being exceeded at the location of the building which was deemed to satisfy public expectations of occupant human safety, it being assumed that this would result in much greater community resilience to such an event.

However, it was not the death toll of about 45 due to building damage that made it one of Australia's worst disasters – by comparison over 3500 were killed by road accidents in the same year and nearly 20,000 have died from the Covid pandemic. It was the loss of functionality of the Darwin community and the consequent socio-economic impact on its inhabitants and the nation that made it one of Australia's worst natural disasters. Subsequent major cyclone events have shown that although the measures have significantly reduced the level of building damage and loss of life, community disaster resilience is still an issue. Similar issues with community disaster resilience have been experienced in response to major flood and bushfire disasters. The issue in all cases has not been loss of life but loss of community functionality and recovery from it. In retrospect this should have been a lesson learned from Cyclone Tracy.

2 Community Disaster Resilience

The word resilience is derived from the Latin word 'resilio' which means rebound and in most cases its use retains this concept either literally as a mechanical property of materials like rubber, or figuratively in terms of the quickness of recovery of functionality of systems whose functionality has been disrupted by the impact of a sudden event. It has also been adapted in the climate change field to describe the ability of systems prone to impact from climate change to retain their functionality by adapting to gradual changes in the environment arising from this.

As Mitchell (2013) pointed out, it is important to differentiate between two fundamentally different ways in which the word resilience is currently used. In common public use it is widely used in a somewhat fuzzy sense as a political agenda, but if this agenda is to be implemented it needs to be used in a technical sense which requires specific definition. Community disaster resilience is a good example with the topic being currently high on the priority of politicians and public officials concerned with emergency risk management. A communique following a recent meeting of State and Commonwealth Building Ministers (2024) provides a good example of its use as a political agenda. This reports a decision to instruct the Australian Building Codes Board to include community disaster resilience to the widely anticipated impact of climate change on the built environment as a result of more frequent and larger magnitude weather events as an additional objective of building regulations. However, it is very unlikely that these Ministers and their advisors had any real understanding of what this will mean in a technical sense. Determining how this political agenda may be applied in a technical way is the focus of this paper.

Walker and Musulin (2015) proposed that for use in a technical sense resilience requires a more precise definition in terms of the **system** to which the word is being applied, the **impact** for which the resilience of the system is being described, and the **loss of functionality** due to this impact on this system and its **recovery** following the impact. Unless each of these terms is specifically defined for the situation to which the word resilience is being used, it cannot be technically analysed and controlled. For use regarding community disaster resilience, it is therefore necessary to express these terms technically along the following lines.

1. The **system** is the community of interest, which will need to be described by its various defining characteristics such as its geography, the size and nature of its population, the characteristics of its built environment, and how these contribute to the functioning of the community. This community of interest may be a subset of the total community impacted by an event, or it may be the wider community beyond the community directly impacted by the event.

2. The **impact** will need to be defined in terms of the type of event - eg earthquake, tropical cyclone, flood, bushfire, etc. – along with its characteristics such as frequency, magnitude and other characteristics which have the potential to affect the functionality of the community of interest.

3. A way of describing the **loss of functionality** of the community of interest following a specified impact, and its subsequent **recovery** as a function of time, will need to be devised. This will be function of not only the damage but also the availability of the resources required for the recovery such as funding, human and material resources, and organisational capability, which will in turn be a function of the event characteristics and vulnerability of the overall community to the event.

Note that if there is no loss of functionality the system is fully resilient as the recovery time is zero, but most discussion about resilience concerns situations where there is an impact on functionality, and the issues of concern are at what level of impact will there be a loss of functionality, and at what level of impact greater than this will the time taken to recover functionality be unacceptable.

3 Limitations of Current Building Regulations Regarding Community Disaster Resilience

Some major limitations of current building regulations regarding community disaster resilience can be summarised as follows.

1. Current building regulations are focussed on individual buildings which are planned for construction -i.e. individual new buildings - whereas the major contribution to community functionality following a major event is usually the cumulative effect of all damage to buildings in a community, including older buildings which are not compliant with these regulations.

2. Current Ultimate Limit State design criteria is based on the return period of hazards to which the planned building is potentially at risk exceeding what is considered acceptable for occupant life safety, typically 500 years for earthquake and wind loads, with no consideration of what might happen if this load is exceeded. In the case of earthquakes this raises two issues regarding community disaster resilience.

    a. A characteristic feature of earthquakes in the Australian region is that the return periods of earthquakes arising from major fault displacement are probably of the order of several thousand years, not a few hundred years. Consequently, building regulations do not consider the community disaster resilience to such an earthquake impacting a major community in Australia. Yet most major earthquake disasters around the world are in this category including the 2011 Christchurch earthquake which was estimated to have had a return period of the order of several thousand years (Canterbury Earthquakes Royal Commission, 2012).
    b. Earthquake design for life safety does not necessarily mean without damage as modern earthquake design is based on the principle of ductility whereby deformation of the structure beyond the elastic limit is permissible providing it does not lead to structural collapse. This form of structural failure meets the life safety requirement as was demonstrated in the 2011 Christchurch earthquake when a large proportion of modern buildings in the CBD were deemed unsuitable for occupancy following the earthquake because of the unacceptable structural deformation, despite no fatalities to the occupants of most of them.
3. Ultimate Limit State design criteria is based on structural reliability theory which implies that if subjected to the specified Ultimate Limit State design loads, structures designed to these can have up to a 5% probability of their strength being exceeded. Consequently, in a large community a significant number of buildings designed to the Ultimate Limit State load may be damaged by loads approaching the design load.
4. The resilience of individual buildings in a major event can make a very significant contribution to a community's disaster resilience, but it is often very dependent on the performance of the community infrastructure with which it is integrated. However, building regulations generally ignore this interaction assuming the performance of the building is independent of this supporting infrastructure.
5. The actual lifetimes of buildings are usually at least 50 years and often 100 years or more. In designing for rare events, the likely community expansion over this period needs to be considered in ascertaining the possible contribution of the resilience of current new buildings to the disaster resilience of the communities in which they are built during their lifetime.

4 Regulating the Design of Buildings for Community Disaster Resilience

Designing buildings with community resilience in mind, in addition to the life safety of the occupants of individual buildings, will require a big change in the paradigm underlying the development of building regulations. Addressing community disaster resilience to extreme events will require recognition of both the need for individual building resilience as well as the contribution this may make to community resilience to major events. The performance objectives ideally will need to be incorporate these terms.

A framework for such objectives in building regulations might be along the following lines.

1. For each type of event a Community Resilience Serviceability Limit State could be specified in terms of the magnitude of the event which should result in no impact on individual building functionality and thus make no contribution to the loss of community functionality. This will be a function of the impact of the event on the individual building only and may not be much different to current serviceability design, although minor

damage would be permissible providing it does not result in loss of the building's functionality.

2. Similarly, a Community Resilience Ultimate Limit State could be specified in terms of the maximum magnitude of an event for which individual buildings must be designed to ensure adequate community disaster resilience in terms of recovery from such an event. This will vary from community to community depending on community size, its nature and its resources for recovery, and will be a decision made by emergency management authorities. However, once this Limit State has been specified it will be up to building regulators to determine what this will mean for the Resilience Limit State criteria of individual buildings in each community. In contrast with current building regulations, these criteria will need to be event based not hazard based, and future community based not point location based.
3. There will need to be performance criteria for all buildings, not just new ones.
4. Associated deemed to satisfy solutions will need to be developed.

Fully incorporating this framework into building regulations, will require integration with all other community sectors affecting community disaster resilience. This will only be achievable through the development of computer-based models capable of simulating community resilience for which a starting point will probably be the catastrophe insurance loss models used in the reinsurance industry for designing reinsurance programs. These already incorporate the damage risk from all causes, not just structural failure, and the costs of repair and reconstruction arising from this damage. However, they do not consider the impact of these on community functionality and recovery times for any loss of functionality. Nor do they consider all the other factors which affect these which a community resilience model will need to do if the relative contribution of individual buildings to overall community resilience is to be assessed. The primary function of such models should be to determine the relative importance of different contributions so that attention can be focussed on those factors making the most significant contribution. In the author's opinion the task is no more formidable than was the development of the insurance-based catastrophe loss risk models when they were first mooted over 40 years ago. Indeed, there are probably researchers already developing such models but more likely at present as research tools rather than for public use as a basis for community planning including building regulation and design.

However, there are some things that could be done without waiting for such modelling to be implemented in everyday planning and design. Some of these are:

1. The scope of building regulations could be extended to cover all existing buildings with regulations formulated for handling the large number of buildings which are not compliant with current building regulations. New Zealand has already gone down this track in respect of the earthquake resistance of buildings.
2. For large communities for which community disaster resilience following a major event could be an issue, the Ultimate Limit State Design earthquake criteria could be extended to include consideration of the potential community disaster resilience to the estimated local maximum credible earthquake event irrespective of return period.
3. In individual building design special attention could be given to features which may affect building functionality such as solar roof panel systems with batteries, which can provide limited electricity supply offline from the electricity network if the latter is disabled; connections to underground supplied infrastructure services such as power, energy and communications, and minor damage allowing rainwater entry which could

affect smart house and building control hubs and components to ensure they are protected from exposure to rainwater in the event of damage to the building envelope.

5 What it Means for Earthquake Engineering Research

This paper has been largely centred on the short falls of current regulations in respect of improving community disaster resilience from extreme events such as severe earthquakes, and the ways these could be addressed. Underpinning current regulations is a large amount of structural engineering research conducted over the past 50 years or so. To date this has been largely focussed on building performance if exposed to these severe conditions with human safety and comfort the primary focus. Increasing the focus to include community disaster resilience increases the scope of this research.

In relation to earthquake performance, unlike in Australia following Cyclone Tracy, the 2011 Christchurch earthquake served as a wake-up call for the need to consider community disaster resilience in the design of the built environment, particularly in relation to earthquakes. The earthquake engineering community in New Zealand has responded to this and awareness of this underpins much of their research. Legislation requiring the earthquake resistance of many older buildings to be investigated and if found wanting to be upgraded or demolished has been a catalyst for some of this research, while research focussed on controlling damage to components that can be readily repaired or replaced has become a major area of research. Professionally there also seems to be an increased awareness within the structural engineering profession of the need to consider disaster resilience in addition to human safety in the design of buildings. Because earthquakes are a much greater threat in New Zealand than in Australia this response has strong public support.

In Australia the same level of public support does not exist, but history shows that in relation to natural hazards it is the unexpected ones that cause the greatest disasters and consequent test of community resilience. The strong response to the 2011 Christchurch Earthquake was in part due to it being an unexpected event in terms of public perception. The greatest threat to the resilience of Australian communities from earthquakes is unlikely to be life safety from a 500-year return period ground acceleration at a point location, but a large-scale disruption of community functionality, and maybe significant loss of life, from a much rarer but much larger event affecting one of Australia's major population areas. Some implications for earthquake engineering research in Australia are:

1. Research needs to be undertaken to determine which communities in Australia pose the greatest risk to their resilience from earthquakes. A starting point to this could be using an open earthquake model like OpenQuake (GEM, 2024) to estimate the damage costs to Australia's major cities in terms of risk of exceedance from credible maximum earthquakes occurring in their vicinity, and the contribution to them from various sectors of the built environment in terms of building type and compliance to earthquake regulations based on current knowledge of seismicity.
2. Research should then focus on those population centres posing the greatest risk, with the objectives such as:
   a. Reducing the uncertainty regarding the estimation of maximum credible earthquake risks.
   b. Determining ways of reducing the losses from the impact of the maximum credible earthquake on these communities.
3. Collaboration with New Zealand researchers in this area is already occurring and should be regarded as essential.

4. The focus to date of damage investigations following major natural disasters including earthquakes has been on the structural damage and the reason for it, primarily in relation to buildings. To be useful in relation to community disaster resilience the scope of these investigations needs to be expanded to include the impact of the damage on the functionality of both the buildings themselves and the overall community. This needs to be done within a framework of community disaster resilience linking the attributes of the communities with the attributes of the events with the potential to cause the disasters, the object being to quantify these linkages.
5. There is a need for education of the structural engineering profession in Australia of the need to consider community disaster resilience in designing the built environment, including both buildings and infrastructure, even if not strictly required by the current building regulations which are only intended to prescribe minimum requirements and do not override the professional responsibility of structural engineers to the community. Because New Zealand regulations in general are more advanced regarding earthquake design for community disaster resilience, there should be encouragement of Australian structural engineers to consider these when designing for earthquake actions.

6 In Conclusion

The current move towards including community disaster resilience as an objective of building regulations covered by the National Building Code is driven by the perceived threat of larger more frequent major weather events such as tropical cyclones, floods and bushfires. However, it is unlikely that any of these perceived threats will pose a greater threat at national level than that posed by a maximum credible earthquake with a return period in the thousands of years impacting one of Australia's major centres of population. Once a framework for including community disaster resilience as an objective of regulations is established it will only be a matter of time before earthquakes are included in its scope as well as other sectors of the built environment not covered by the National Construction Code. The earthquake engineering community in Australia should not be waiting for this to happen, but should be actively promoting it and. preparing for it through its research activities

This paper is not an exhaustive description of the issues involved in community disaster resilience becoming an additional Limit State for building design in respect of earthquake risks. Nor is it an exhaustive list of suggested future actions. Hopefully, however, it is enough to excite the minds of some of the current and up and coming generation of earthquake engineering researchers to address these issues and in so doing ensure that should a major earthquake strike a major Australian community it will prove to be resilient to any disruption to its functionality from it.

7 Acknowledgements

This paper has been over 60 years in the making, beginning with the commencement of a PhD in earthquake engineering at the Auckland University in 1961 which was focussed on the post-elastic behaviour of structures in earthquakes, an understanding of which has underpinned much of my approach to earthquake engineering since then, with the major question being how much distortion beyond the elastic limit is acceptable. The most influential earthquake engineers on my early development in this field were George Housner, Joe Penzien, and particularly Nathan Newmark. Later, towards the end of the 1970's I came under the influence of Don Friedman, the founder of GIS modelling of catastrophe insurance company losses, and subsequently I played a significant role in the adoption of this approach by insurance companies in determining how much reinsurance to purchase, and, through my involvement

with the New Zealand Earthquake Commission, in the design and operation of national catastrophe insurance schemes, particularly in regard to earthquake losses. This work, which dominated my latter working life taught me that the impact of major damaging events like earthquakes is a function of community size because of a non-linear relationship between cumulative damage loss and the impact on a pro rata basis, in the insurance case for the same pure risk of loss, the premium rates increasing with the increasing magnitude of the probable maximum event loss. The immediate genesis of the ideas presented in this paper was my interaction with Paul Grundy who in his retirement devoted his time to what we now call community disaster resilience to major disasters. During our meetings we developed the idea that an additional limit state was required which would require considering the consequences of a maximum credible event. After his death I continued to develop this idea with an Aon colleague Rade Musulin the results of which were presented in Walker & Musulin (2015a and 2015b). This paper is a follow up on these papers.

8 References

State & Commonwealth Building Ministers. (2024). Building Ministers Meeting: Communique June 2024. https://www.industry.gov.au/news/building-ministers-meeting-communique-june-2024

Canterbury Earthquakes Royal Commission. (2012). Final Report, Part 1. https://canterbury.royalcommission.govt.nz/Final-Report---Volumes-1-2-and-3

GEM (2024). OpenQuake, https://www.globalquakemodel.org /

Mason, M. & Haynes, K. (2010). *Adaptation lessons from Cyclone Tracy*, National Climate Change Adaptation Research Facility, Gold Coast, 82 pp.

Mitchell, A. (2013). *Risk and Resilience: From Good Idea to Good Practice*. OECD Working Paper 13/2013, December 2013 *OECD, France*

Walker, G.R. (1975). *Report on Cyclone Tracy – Effect on Buildings – December 1974*. Vol.1, Commonwealth Department of Housing & Construction, March 1975. (Available at https://www.jcu.edu.au/__data/assets/pdf_file/0018/1171341/Cyclone_Tracy_GRW_Report_1975_vol1.pdf)

Walker, G. & Musulin, R. (2015a). Disaster risk reduction and the earthquake code: A disconnect. Aust J of Structural Engineering, Vol.16, No.1, pp 1-6

Walker, G.R. & Musulin, R. (2015b). The development of a formal framework for discussing earthquake resilience of the built environment. Paper presented to NZSEE 2015 Annual Conf, Rotorua. https://db.nzsee.org.nz/2015/Orals.htm