A Risk Framework for Earthquake Prone Building Policy

a report produced for the New Zealand Ministry of Business, Innovation and Employment

by Tony Taig, TTAC Limited and GNS Science

November 2012

Executive Summary

This is the report of a study into a risk framework in support of earthquake prone building (EPB) policy review, carried out for the NZ Department of Building and Housing (now the Ministry of Business, Innovation and Employment, or MBIE) by Tony Taig of TTAC Ltd in collaboration with GNS Science between April and November 2012.

The report provides an overview of risk concepts and principles (Section 2) and a substantial description of earthquake risk in several different forms, both in absolute terms and in comparison with other hazards (Section 3). The report aims in particular to draw out some important and distinctive features of earthquakes for risk management. It then addresses the factors central government needs to consider in developing risk and evidence based policy for EPBs (Section 4), and provide my observations on current arrangements for EPB risk control (Section 5).

My conclusions are as follows:

1. Earthquakes stand out from other hazards in New Zealand in terms of the frequency of very large impact events and the individual risk they present to people in high risk locations. But averaged over the whole population and long periods of time they have a lower impact than some other hazards such as road accidents.
2. Building risk from shaking has been the largest contributor to damage and lives lost in NZ earthquakes to date, but is not the whole picture. Had the 22/2/11 earthquake happened at night fatalities due to slope collapse in the Port Hills may have exceeded those in the CBD.
3. Earthquakes are unusual relative to most other hazards in that most of the overall time-averaged risk from earthquakes is associated with very severe, rare events. This is because, as shaking increases, its likelihood gets lower but its consequences get worse. For a given increase in shaking the effect of increasing consequence outweighs the effect of decreasing likelihood, so that overall risk (in terms of likelihood x consequences) gets bigger as shaking increases.
4. Important implications of earthquake risk being greatest for rare, severe events include
   a) NZ earthquakes since the 1850's may under-represent long-term average risks, and
   b) Care is needed to ensure that measures designed to protect against medium levels of shaking do not make things worse in the more severe events that dominate the risk.
5. Earthquake risk is distributed amongst different people in a complex fashion, for example:
   a) In smaller earthquakes economic risk is well aligned with building owners and users. But the wider social and economic impacts of major earthquakes are unlikely to be attributable to specific owners/users; governments typically play a major part in addressing these issues (and bear a significant share of associated costs).
   b) Life risk is greater for neighbours and passers-by than for occupants of some older buildings, and
   c) Heritage conservation may be completely disconnected from building ownership and use.
6. The definition of limit states in ground shaking terms in the NBS provides a practical and consistent way of controlling risk due to building damage from shaking, but the relationship

between shaking and risk is complex. This relationship has not been well characterised to date in New Zealand but much work has been carried out in the USA and elsewhere to develop methods enabling life and other risks to be assessed present.

7. The Building Code and NBS do not control earthquake risk to any specific level because
   a) they do not specify performance requirements of buildings below, at and above the ULS, (the risk for two compliant buildings could be very different) and
   b) they do not address other hazards than building damage due to ground shaking.
8. The primary objective of public policy in relation to EPBs should be to control life risk to the lowest reasonably practicable level – balancing reduction in risk with the cost of doing so, subject to the constraint that tolerable life risk thresholds are not exceeded.
9. Additional constraints to safeguard other highly valued assets (e.g. heritage buildings or buildings of strategic importance) may readily be added in to such an approach, but should be subject to safeguards that they do not unduly over-ride life safety.
10. In comparing the benefits of strengthening to 33%NBS vs 67% NBS or some other level, there is a "window" of shaking within which benefits would be significant. At lower levels, there is no difference as either level would ensure minimal damage; at higher levels there is no difference as neither would prevent very severe damage. In terms of safety benefits, the experience of the Christchurch 22/2/11 event suggests that the shaking threshold above which there would be significant benefits of moving from 33% to 67% NBS is quite high (there were no fatalities involving buildings that had been strengthened to 33% NBS or better). In terms of economic benefits, the Christchurch 22/2/11 experience suggests that this threshold would be lower (the proportion of buildings which suffered severe damage short of total collapse was significantly lower for buildings strengthened to 67% or better compared with those strengthened to 33% NBS).
11. There can be high confidence that other measures would have a greater impact in reducing safety risk associated with buildings in earthquakes, in particular
    a) reducing delay in getting identified high risk buildings upgraded
    b) bringing high risk buildings not readily identifiable as EPB within the EPB framework, and
    c) extending the scope of building-related measures to provide equivalent risk control over other life hazards from earthquakes.
12. The state of the art of building risk assessment in earthquakes is insufficiently mature to contemplate setting building standards in risk-based terms. An improved risk assessment framework for buildings in earthquakes could, though, provide a more direct link between building controls and risk than is available at present.
13. The benefits of such a framework would be considerable, in particular in providing
    a) assurance of risk control across the whole range of ground shaking severity
    b) a more consistent, outcomes-focused basis for aspects of NBS such as building importance definitions
    c) a firm foundation for policy settings in relation to EPB and other matters, and
    d) a clear line of sight between safety policy goals and the measures intended to deliver them.
14. Local Authorities play an important part in determining, implementing and enforcing EPB policy, but this leads to considerable local variation in policy and significant practical difficulties for the majority of Authorities who do not have relevant in-house expertise.

My recommendations are:

1. **Policy Goals and Building Requirements:** MBIE in conjunction with other departments and agencies as appropriate should progress work to develop a risk-based framework which connects building requirements laid down in the Building Code, NBS and related documents directly to the safety and other outcomes they are intended to deliver. This will involve

   a) developing proposals for national criteria and values for life risk in relation to earthquakes and other natural hazards, as part of a broader framework of objectives and decision making on building performance in earthquakes to underpin national and local policy decisions,

   b) collecting and applying available risk assessment methods and information to establish the life and other risks associated with different building types, and the sensitivity of those risks to building characteristics,

   c) bringing together (a) and (b) to establish national outcome criteria and decision processes related to building risk from earthquakes in the knowledge of their implications for existing and new buildings,

   d) reviewing Building Code, NBS and EPB policy settings in light of those criteria and of the implications of building design for performance,

   e) adoption of any new policy settings for both new and existing buildings, and

   f) ongoing evaluation of assessed and actual building performance in comparison with the outcome goals established, along with continued development (maximising learning from the Canterbury earthquakes of 2010 and 2011 and taking advantage of ongoing research and development overseas) of the methods and evidence needed to assess the risk implications of building features.

   The approach is illustrated in Figure ES1.

2. **Interim Priorities**: In the short term (ideally until the linkages shown in Figure ES1 can be established) MBIE should give priority to addressing the issues identified in Conclusion 11 rather than to changing the definition of an EPB from 33% to 67% NBS or some other value.

3. **Local Authority Involvement**: The role of Local Authorities in EPB policy development, implementation and enforcement should continue but with an enhanced level of oversight and support from MBIE to provide
   a) for consistency of policies with high-level national safety policy objectives, and
   b) greater guidance, support and if necessary capability to assist Authorities with this work.

   Tony Taig
   TTAC Ltd
   12 November 2012

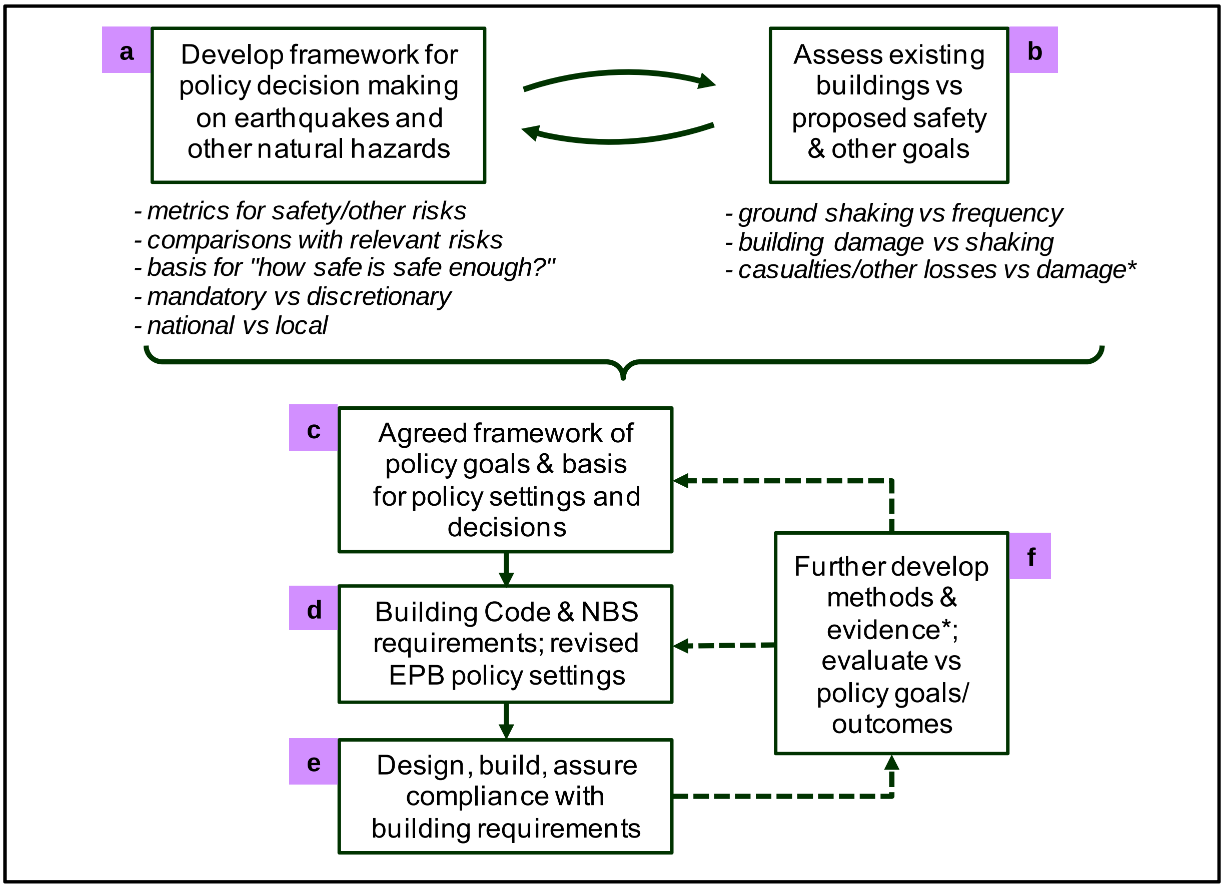

Figure ES1: Towards a Risk-Based Framework for Earthquake Policy Settings

* More knowledge of risk to life in the event of building collapse should be obtainable via the 22/2/11 tragedy. Casualties have been well researched, but parallel information is needed on where people were at the time in order to understand the risk from collapse – this is not to my knowledge being pursued at present.

Contents

1. Introduction

The New Zealand Department of Building and Housing (DBH – now the Ministry of Business, Innovation and Employment, or MBIE) is carrying out a review of earthquake prone building (EPB) policy settings and their implementation. As an input to that review, DBH commissioned this "Risk Framework" document from Tony Taig of TTAC Ltd (a UK based risk expert who has worked extensively in the UK and New Zealand in various natural hazard and other government policy contexts), with support from GNS Science.

Current approaches to managing earthquake risk to buildings and the people in and around them are largely deterministic. New buildings must be built to the National Building Standard (NBS), which requires a specified degree of integrity in a specified earthquake, as laid out in the standard NZS 1170.5:2004. For existing buildings not built to NBS, the law gives powers to local authorities to require owners of EPBs (defined as those not demonstrably capable of withstanding shaking at 33% of the levels specified under NBS) to demolish or strengthen those buildings. Local authorities must develop an EPB policy in consultation with their local communities; they have considerable discretion as to how they will give effect to their EPB policy.

The intent of such a deterministic approach, which is used in many other walks of life besides building risk in earthquakes, is to ensure that levels of risk associated with earthquakes within the design limits of the building are very low. No limits are set or implied on the levels of risk associated with either a) events beyond the design limits, or b) unexpected failures (always a serious possibility in the real world) within the design limits of the building.

This paper considers an alternative approach based on setting policy for building performance in earthquakes in terms of risk. Such an approach starts from consideration of what overall risk (from all possible earthquakes) New Zealand is prepared to tolerate, and how risk might be traded off against other economic or cultural costs and values. Quantifying and valuing risk provides an objective basis for making policy choices – the scale we use to measure risk can also be used to measure the ultimate benefits of policies aimed at reducing it. So we shall address in turn:

- The concept of "risk" and how it can be measured and used in decision making (Section 2)
- The nature and extent of risk associated with buildings in earthquakes, in absolute terms and relative to some other hazards (Section 3)
- EPB policy and risk management factors relevant to it (Section 4), and
- Existing EPB risk management arrangements (Section 5), before discussing
- How best to apply risk concepts to EPB policy and its administration (Section 6).

I would like to acknowledge the considerable help and assistance provided by staff and consultants to DBH, by members of the Sector Reference Group established by DBH for the EPB review, by GNS Science, particularly Terry Webb, Jim Cousins and Graham McVerry, and by DBH' peer reviewer Brian Meacham. The opinions expressed in this paper are my own and do not necessarily represent the views of GNS Science or any other party.

2. Risk Concepts and Principles

The concept of risk and how to measure it is discussed first, followed by the principles of risk management as applied to public regulatory policy, and implications for EPB policy.

2.1 Risk Concepts and Measurement

One of the biggest problems in dealing with risk is that the term is used to mean many different things by different people in different contexts. The most recent international and Australia/New Zealand standard defines risk as “the effect of uncertainty on objectives”. This is extremely broad; when dealing with hazards, “risk” generally relates to the uncertain likelihood and/or severity of adverse events occurring.

In the insurance industry “risk” is often used to refer to a situation or asset subject to the possibility of loss. In the safety sphere a situation with a potential for harm or loss is generally referred to as a “hazard”, while “risk” is used to characterise the severity/likelihood of such loss occurring. This hazard/risk terminology is adopted here.

Three types of metric are widely used to quantify the level of risk associated with a given hazard:

1. The aggregate rate (over some area/population) at which specified harms or losses occur;

   EXAMPLE 1 – on average 393 people died per year on NZ roads in the decade to 2011.

   EXAMPLE 2 – insurance claims for weather and natural hazards averaged just over $70M per year from 2002 to 2011, excluding the 2010/11 Canterbury earthquakes.

2. The expected loss or harm to an individual, usually expressed per year, or per event, or per some other unit of activity relevant to the context;

   EXAMPLE 3 – the average New Zealander’s chance of dying on the roads from 2002 to 2011

was about	1	per 10,000 years,
or	8	per billion km travelled,
or	0.6	per billion trips,
or	1	per 4 million hours spent on the roads.

   EXAMPLE 4 – insurance claims from the 2010/11 Canterbury earthquakes are estimated to total around $4,000 for every person in New Zealand.

3. The likelihood of specific losses or harms which might trigger particular societal concern being realised

   EXAMPLE 5 – there was a fatal accident on New Zealand roads about once per day on average from 2002 to 2011.

   EXAMPLE 6 – earthquakes killing over 100 people have occurred twice in New Zealand’s post-European settlement history, or about once in 80 years.

Other types of metric can be and are used in various contexts, but these three types of metric are the most widely used and it is on these that this paper focuses.

There are clearly lots of different ways of measuring risk. Choosing the right one for a particular context is a major issue. This is not just a question of what risk is involved, but also of why it is that it particularly concerns us (see text box for an everyday example).

> ***What's the right risk measure for "Losing your shirt"?***
>
> It all depends on why this matters to you. If the problem is the cost of replacement, then (value of the shirt x chance of losing it) might make a good metric. But if the problem is that it is an irreplaceable family heirloom, or that you dread being left bare-chested, the monetary value of the shirt may be almost irrelevant. The chance of losing the shirt you are prepared to tolerate might be much lower than the figure you would have arrived at based on the cost of replacement.

This may seem a rather trivial example, but when lives or buildings which people value highly are at stake as they are in earthquakes, such factors can be extremely important.

It is possible to devise metrics of risk which incorporate value judgments about people's preferences for risk of one sort relative to another. This approach is not followed here as in my experience it tends to blur the boundaries between the proper role of technical specialists (estimating risk and how it will change under various different possible course of action), and the wider social or political role of making decisions about what risks we are prepared to accept and "how far is far enough?" to reduce risk.

Thus "risk" is treated throughout this discussion paper largely as a metric defined in clear physical or technical terms. Making decisions about risk is quite another matter – it involves a wide range of value judgments and should involve all those interested in or affected by risk (whether affected directly by the risk itself or by the measures adopted for its reduction), or their appropriate representatives.

2.2 Risk Management and Public Policy

Establishing a quantitative scale by which to measure risk facilitates adoption of a management process very similar to that which might be applied to anything else – that is, a "Focus, Plan, Do, Review" type of approach. The general risk management process is illustrated in Figure 1, taken from the Australia/NZ Standard for Risk Management[1].

[1] Australian/New Zealand Standard on Risk management – Principles and guidelines (AS/NZS ISO 31000:2009)

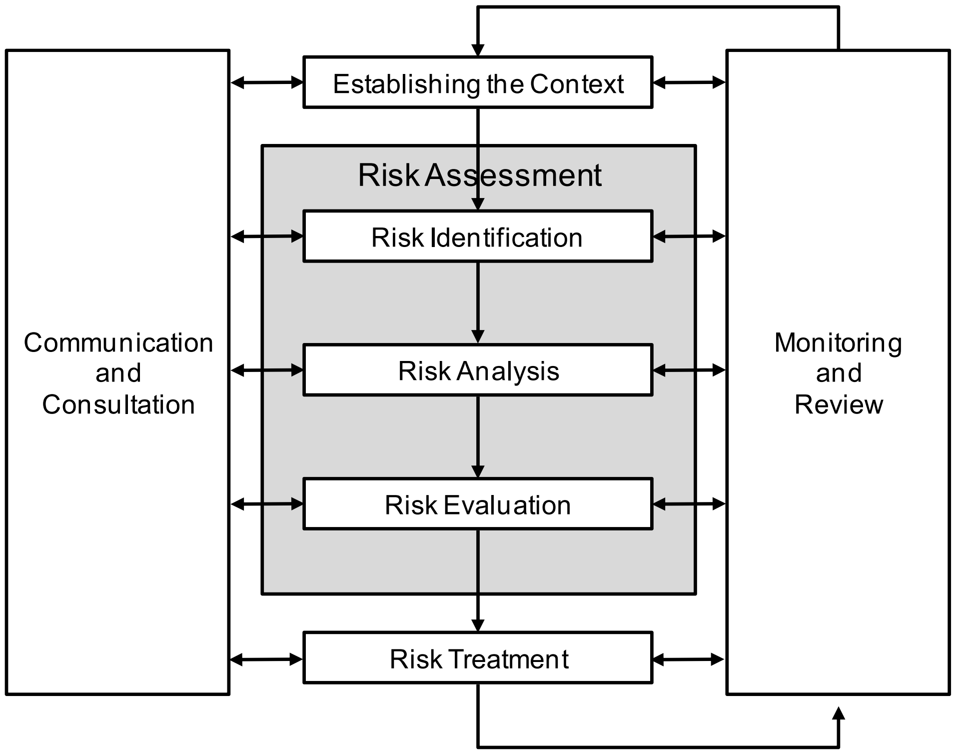

Figure 1: The Risk Management Process (from AS/NZS ISO 31000:2009)

Establishing the context – which includes determining who is going to make decisions about the risks, what metrics of risk we will use, and establishing values in relation to them – is fundamental to any risk management process. The first question for any regulator is whether the risk is one where decisions can be left to the individuals involved, or whether it is something that requires government regulation. There can be many different facets to this question, but the most fundamental issue is typically whether one person's action or inaction imposes significant risk on someone else. If so, then regulation is likely to be important. If not, Government may choose to advise people on how best to control their own risks and let them get on with it, as illustrated in the text box below.

Climbing Mt Cook or rowing across the Tasman is very dangerous –should ill-prepared people be stopped from trying?

The risk involved in either case is very high. But we are reluctant to stop people doing things that put themselves at risk, so long as they do not impose risks on others. So we inform people how to look after themselves, and urge them to behave responsibly, but leave the decision on whether to take the risk to them. This is not a zero-risk option for everyone else – mountain rescue or lifeboat crews may be put at risk saving the ill-prepared – but we and they accept that risk as part of the price of living in a free society.

If the hazards and losses involved could all be valued in monetary terms (a popular approach among economists but very difficult to use to reach consensus on risk decisions because the issues are so complex and people disagree fundamentally on their importance), the basic principle of risk management would be straightforward: to minimise the overall cost of risk, taking into account both

a) the costs of losses as and when they happen, and

b) what we spend to control the risks, over and above what we would otherwise have spent.

To continue the economic analogy, there is often a relationship between how much is spent on managing risk, and the cost of risk when realised, roughly of the shape shown in Figure 2.

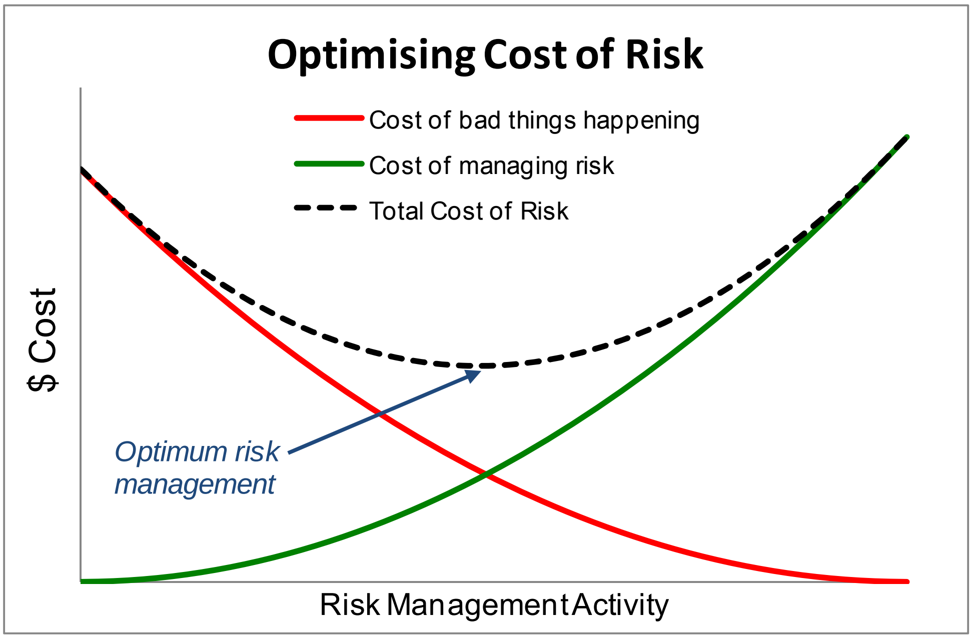

Figure 2: Optimising the Cost of Risk

What Figure 2 illustrates is that doing nothing at all to manage risk will cost dearly, because bad things will happen frequently. As risk management activity starts to increase the easiest and most effective things are tackled first, and the cost of risks being realised drops quickly. At some point, though, making incremental reductions in an already low level of risk starts to get harder, and the cost of further risk reduction starts to rise more steeply. The best position is somewhere in the middle, where the costs of risks being realised and of activity to control risk are in balance.

A classic economics-led approach to safety risk might use exactly this approach. If monetary values are attached to preventing fatalities and injuries, then cost-benefit assessment can be used to find the optimum as in Figure 2 above.

However, when dealing with people's safety and (in the context of earthquakes) with a wide range of very severe social as well as economic impacts, this approach may be inadequate for reasons such as

a) society may place particular value on preventing unfair distribution of safety risk, or on preventing disasters in which many people are killed

b) very large events may exceed local or national capacity to recover (part of the original rationale for establishing the EQC)

c) heritage and other special buildings may be valued over and above their monetary value.

Perhaps the easiest of these constraints to deal with, because precedents have been established in other walks of life, are those relating to people's safety. As a society we are not comfortable trading off safety risks against costs in situations where individuals are at very high levels of personal risk. The UK Health and Safety Executive[2] first proposed the risk tolerability framework shown in Figure 3, which is now very widely used in many different countries and contexts. At the top of the figure, individual risk above a certain threshold is considered intolerable. At the bottom, the risk is so small as to be broadly acceptable. In-between it is considered fair to balance further reduction of aggregate risk against cost and other factors.

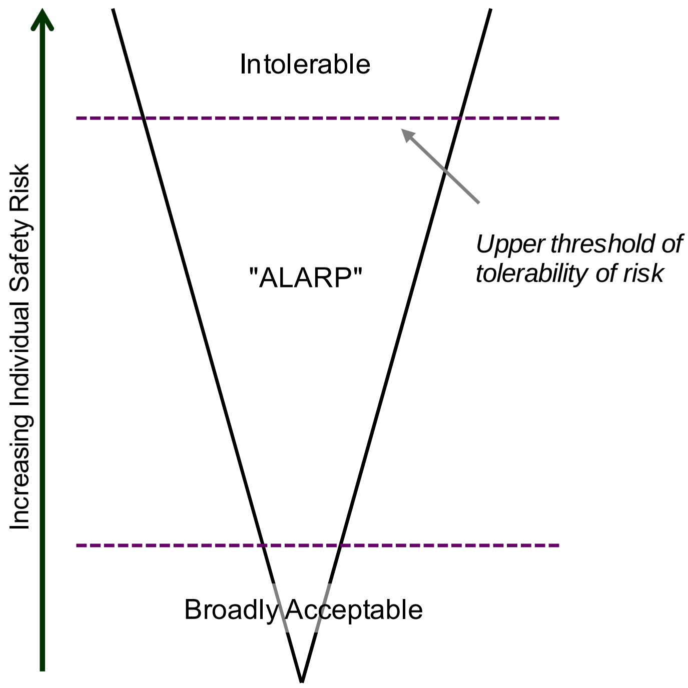

Figure 3: HSE Tolerability of Risk Framework

As regards numerical levels, UKHSE's general policy in regulating workplace risks is that levels of annual individual fatality risk greater than 1 in 1,000 (workforce) or 1 in 10,000 (members of the public) should be regarded as intolerable. The distinction between workforce and members of the public recognises that employees generally

a) benefit directly from the activity in question (via their employment and pay)

b) have greater choice over their participation than do visitors, neighbours or passers-by, and

c) have a greater degree of personal control over their own risk exposure.

A risk management approach using this UKHSE framework will thus reduce risk to the lowest reasonably practicable level in two stages:

1. A check on individual risk is made, and measures are taken if necessary to ensure no employees, customers or members of the public are being exposed to intolerable levels of individual risk.

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[2] HSE 2001. Reducing risks, protecting people: HSE's decision making process, Sudbury, HSE Books.

2. Once it is clear that risks are not intolerable, the lowest practicable level of risk can then be determined by exploring different risk management options and selecting that which best balances reduction in aggregate risk, cost and other practical advantages and disadvantages.

The approach thus uses individual risk as the test for particular unfair burdens being placed on individuals, and aggregate risk as the quantum to be balanced against cost and other pros and cons of different risk control solutions. Note that the aggregate risk is simply the sum over all exposed individuals of the individual risk to each. For example if 1 million people each face an individual risk of 1 in 10,000 per year of dying in road accidents, their aggregate risk is 1,000,000 x (1 in 10,000) = 100 average expected fatalities per year from this cause.

The term "Societal Risk" has been coined to address another major safety concern – the possibility of accidents killing larger numbers of people. The most widely used measure of societal risk is a relationship between the frequency with which accidents occur and the number of people killed – a so-called "F/N Curve". An example which has been widely used in Australia and New Zealand is the ANCOLD criteria for large dams[3]. These propose (in addition to individual risk criteria) that risks should be regarded as intolerable for existing dams if they involve fatal accidents:

- killing 1 or more people more than once in 1000 years
- killing 10 or more people more than once in 10,000 years, and
- killing 100 or more people more than once in 100,000 years.

Criteria for new dams are 10x more restrictive, recognising the greater feasibility of building in risk reduction whilst a dam is still at the design stage.

Such criteria were the subject of much debate and development in the 1970's and 1980's when the UK and some European countries first developed risk-based approaches to regulation of major hazards such as nuclear installations, hazardous chemical plants and transport of dangerous goods. In the Netherlands they were enacted into law for hazardous installations. But today they are much less widely agreed and applied in public policy in countries with well-developed risk-based regulatory regimes than are individual risk criteria and aggregate risk-based approaches[4]. This is partly because of concerns over whether people genuinely believe that 100 deaths at once matter more than 100 deaths occurring one at a time (opinion research findings show mixed results, depending how the questions are framed[5]). But it is also because it is much harder to

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[3] ANCOLD 2003. Australian National Committee on Large Dams. 2003. Guidelines on risk assessment.

[4] For example in the 1990's the railways in Great Britain introduced a higher monetary value to be attached to saving lives for accidents involving multiple fatalities than for individual accidents, in response to regulatory pressure. Subsequent research showed that there was considerable public disquiet about a public policy that would prioritise "Saving lives in multi-fatality accidents" over "Saving the most possible lives". The policy of attaching higher monetary values to multiple fatality accidents was widely consulted on, and was then dropped. (see e.g. rssb.co.uk/SiteCollectionDocuments/pdf/achieving_clarity_in_safety_decisions.pdf)

[5] See for example M Jones-Lee, G Loomes et al, "Definition of the Value of Preventing a Fatality & the Impact of Societal Concerns", RSSB Research Report T430, http://www.rssb.co.uk/RESEARCH/Lists/DispForm_Custom.aspx?ID=752

generalise such criteria across different populations and activities than is the case for individual risk.

While much work has been carried out in other contexts to establish an appropriate basis for safeguarding heritage, protecting against the social dislocation of major disruptive events and other adverse impacts of earthquakes, there are no such clear and widely-applied metrics established to help bring such issues into direct comparability with economic and safety risks. But the general result of considering any such impacts and concerns is likely to be similar in kind to that of safety, as summarised in the text box below.

> ***The effect of safety, social, heritage and other concerns on risk policy:***
>
> The general effect of all such concerns is to place limits and constraints on the degree to which policy settings represent a straightforward trade-off between the benefits (in terms of risk reduction) and costs (or other downsides) of possible action to reduce risk. Consideration of such factors always acts to REDUCE, never to increase, how often we are prepared to tolerate harmful accident outcomes.

2.3 Implications for Earthquake Prone Buildings Policy

In order to apply good practice in risk management to the definition and management of earthquake prone buildings it is necessary to establish

a) what is meant by "Risk" in the context of buildings in earthquakes and how it is to be measured

b) what criteria and values are to be used in making decisions about "how far is far enough" in reducing risk, and

c) means of estimating risk in the relevant terms, both as it is now and as it would be under different policy settings.

The first of these is non-trivial. Buildings in earthquakes represent an assortment of risks to different people, including risks:

- of direct financial loss to their owner,
- to the business and lives of their tenants,
- of wider social and economic impacts on large communities
- to the lives of visitors, building users, neighbours and passers-by
- to the viability of whole communities, and
- to heritage and other intangible values of which people have widely differing views.

The difficulty in defining simple risk measures to represent all of these will become clearer in Section 3 where earthquake and other risks are compared.

A major advantage of taking a directly risk-based approach is that it makes a clean separation between the criteria and values used in making decisions about risk, and the specialist business of estimating risk. The former is clearly the province of public policy (with appropriate specialist advice), while the latter is clearly the province of specialists who understand buildings, earthquakes and risk assessment good practice. Establishing criteria and values is a non-trivial exercise; this process has been ongoing in relation to rockfall risk in the Port Hills area of Christchurch for the past year and is only now approaching policy resolution at the time of writing. An important first step here is to identify which areas can be left to individuals to make their own decisions about risk, and which require regulatory intervention.

Finally, estimating risk associated with earthquakes is by no means a mature science. There are major uncertainties associated with how often earthquakes of different severities occur, their impacts on buildings and lives, and with the whole process of assembling an aggregate picture of risk across the whole spectrum of possible earthquakes that could be faced in future. The result is that it is difficult to estimate earthquake risks for new or existing buildings with a high degree of confidence. Ability to forecast the impacts of different policy choices on risk is similarly limited.

This is not a reason for giving up – risk management is all about making decisions under uncertainty, and it is often possible to make better decisions when starting with the right information (albeit uncertain) about the right things than when starting with a mass of precise information on things that are less important. In the case of buildings exposed to earthquakes it is the outcomes and how often they occur that really matter, and a risk framework provides the obvious best starting point for outcomes-focused policy. But the limitations of the information available to support decisions need to be recognised from the outset. Dealing with uncertain risk information is discussed further in discussing the way forward in applying risk concepts to earthquake prone buildings (Section 6).

3. Earthquake Risk to Buildings

Earthquake risk is considered first in overall context against other risks in New Zealand (3.1). Particular features of earthquake risk of significance for risk management and earthquake prone buildings are then considered (3.2) before summarising (3.3). Unless otherwise stated, earthquake incident information is based on data collected and published by GNS authors, particularly D. Dowrick *et al* for earthquakes prior to 2011, and on published papers of the Royal Commission for the 2011 Christchurch earthquake, while comparator statistics are derived from Statistics New Zealand, Ministry of Health, Department for Transport and the Belgian/WHO Centre for Research on the epidemiology of disasters on-line sources.

3.1 Earthquake and other Risks in New Zealand

Risk is considered in turn in terms of the three types of metric introduced in Section 2.2, i.e.

- Annualised losses/harms (3.1.1)
- Annualised individual risk (3.1.2) and
- Frequency of specified adverse events (3.1.3)

3.1.1 Overall Losses/Harms

In economic terms, earthquakes stand out from other natural hazard events in New Zealand in terms of both total cost over time and extreme individual event costs, as illustrated in Figure 4.

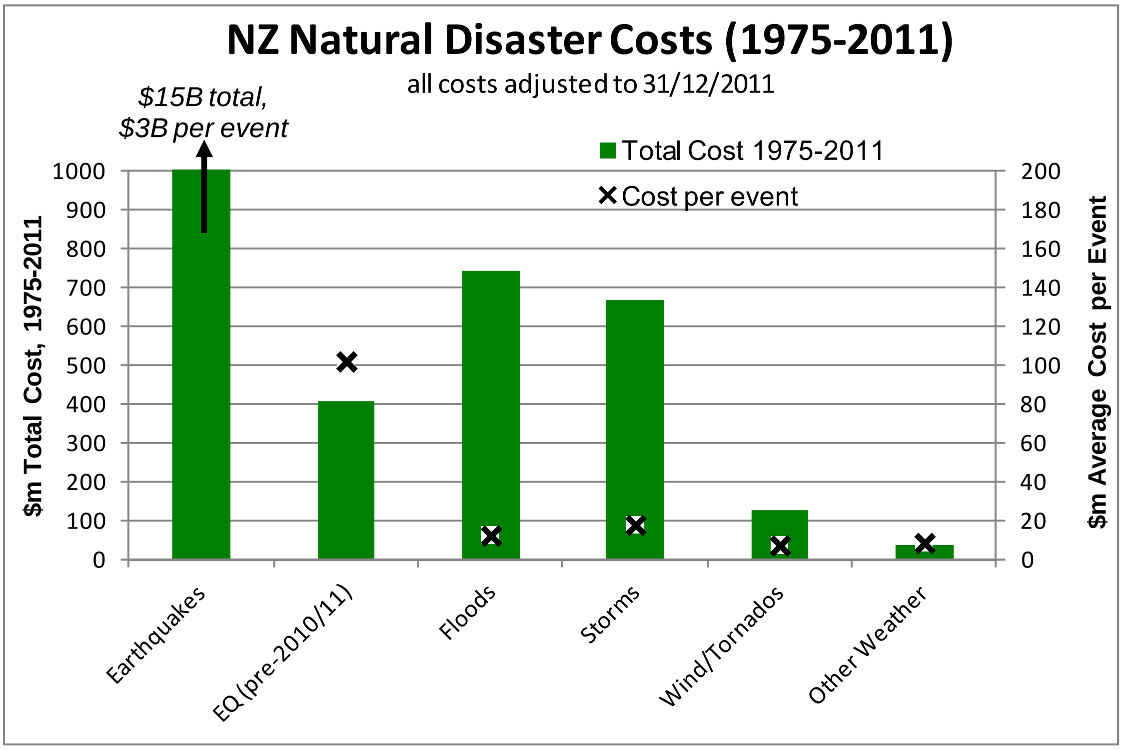

Figure 4: Earthquake & Other Natural Hazard Costs in New Zealand (see note below)
Source: Insurance Council of New Zealand, http://www.icnz.org.nz/current/weather/

Note on Figure 4: The Canterbury earthquake costs shown in the figure may be out of date. Latest advice from the NZ Treasury is that the damage costs of the 2010 and 2011 Canterbury earthquakes total about $20 billion, plus a further $10-15 billion for inflation, higher building standards, administration costs and business disruption.

Most of the $15B total costs of earthquakes is from the 2010/11 Canterbury events – but the other 4 significant earthquakes since 1975, though far smaller, averaged many times the cost per event of the other natural hazards shown. It is notable that without the 2010/11 Canterbury events the average annual cost of earthquakes over several decades would have been less than that of storms and floods. Earthquakes dominate the annualised costs over long time periods, but there may be long periods of several decades when earthquakes account for lower annualised costs than do other natural hazards.

DBH is keen to set earthquakes in context against other, more everyday risks. Though such comparisons are difficult to make overall because the context of different hazards differ so greatly, it is possible to compare individual risk metrics and make some useful observations. None of these single metric comparisons should be taken as implying that earthquakes overall are a larger or smaller issue or matter of public concern.

In comparison with road accidents (Figure 5), the Christchurch 2011 earthquake stands out in cost terms in relation to an individual year's road accidents (note that the road accident cost includes a value attached to lives lost which the earthquake point for Christchurch does not – this would add about 5% to the Christchurch point). But on this basis, averaged over a decade, road accidents cost more per year than do earthquakes.

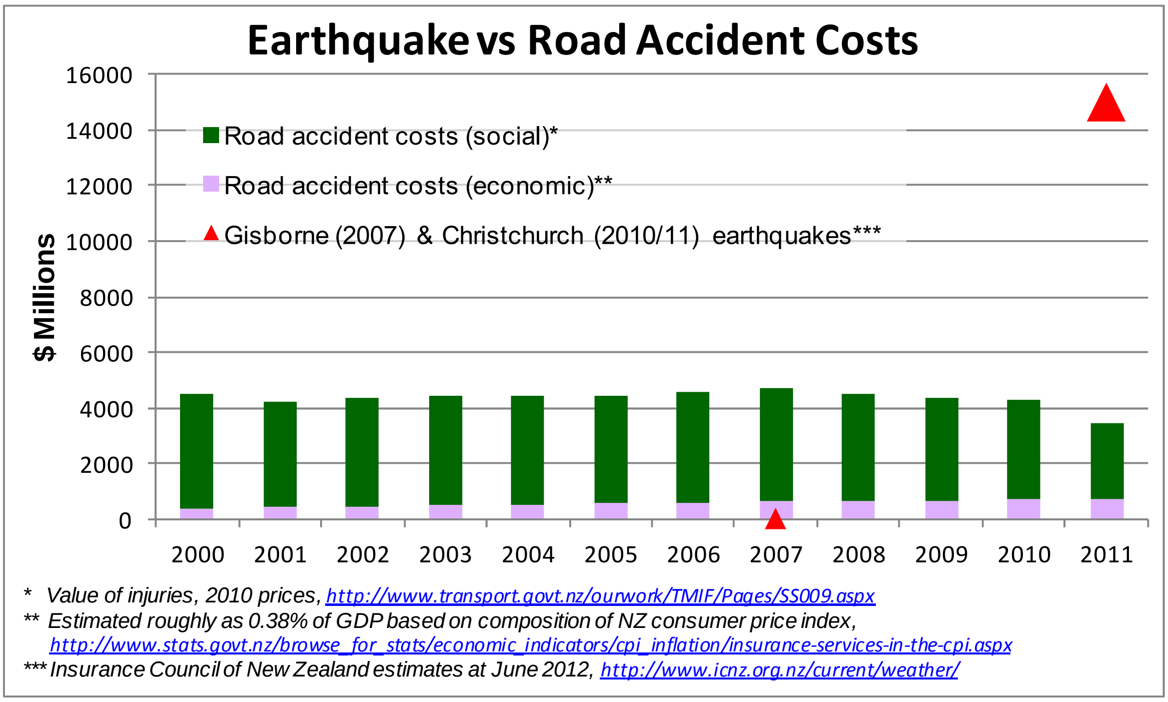

Figure 5: Earthquake v Road Accident Costs 2000-2011

In safety terms earthquakes are a relatively small contributor to average annual accident casualties in New Zealand. Figure 6 illustrates this in relation to road accidents, which on average have killed about 80x more people in New Zealand each year than have earthquakes going back to 1921. Figure 7 illustrates a similar point in relation to other natural hazard events.

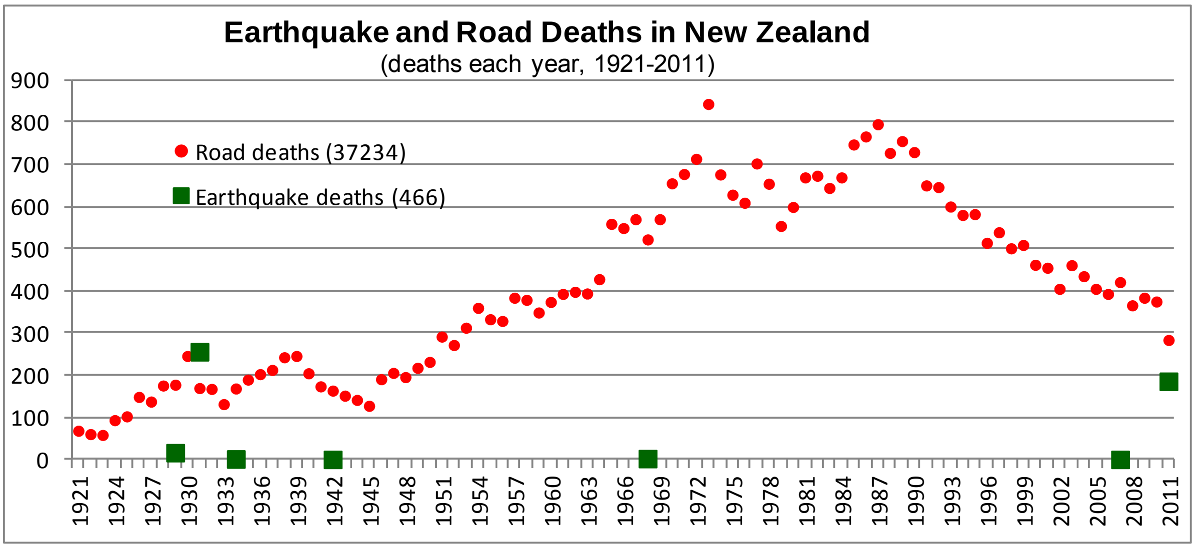

Figure 6: Earthquake v Road Accident Fatalities 1921-2011

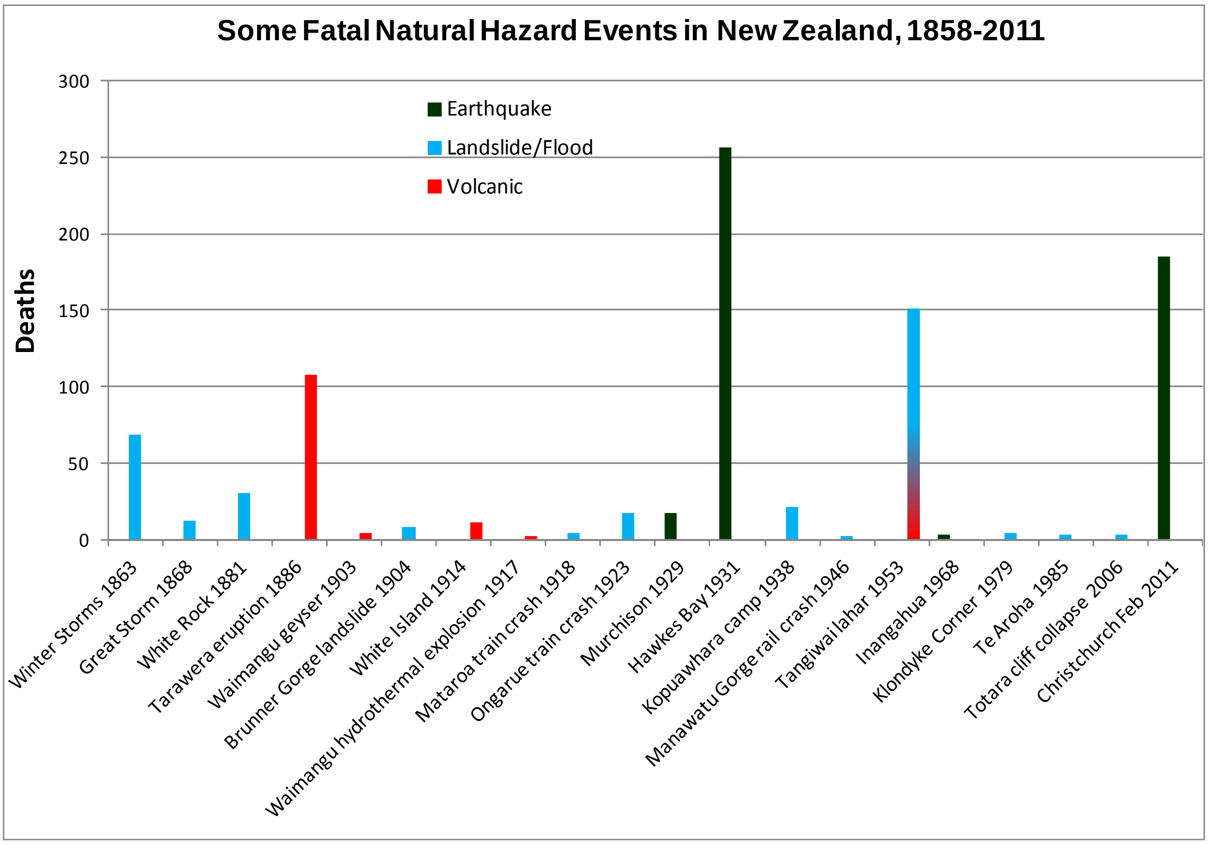

Figure 7: Fatalities in Major NZ Natural Hazard Accidents

In summary, the annualised impacts of earthquakes in NZ to date have been modest in relation to those of road accidents in economic and particularly in safety terms, but are large in relation to those of other natural hazard events, particularly in economic terms.

3.1.2 Individual Risk Comparisons

Taking historic fatality statistics and averaging them over the whole NZ population produces results which reflect the aggregate impacts of earthquakes on the country. Figure 8 shows the annual individual fatality risk faced by New Zealanders of different ages from different causes.

Averaged over all age groups for the whole population, cancer and heart disease represent the largest annual individual risks. But these are associated particularly with ageing; for younger people, accidents (road accidents in particular) are the largest single contributor to overall fatality risk. Earthquakes are shown as averages over the whole population, both evenly distributed by age (the age distribution of fatalities in earlier earthquakes is not known) and redistributed by age pro rata to the fatalities in the Christchurch 22/2/2011 earthquake. This age distribution shows a pattern which is unusual in comparison with other sources of risk, in that it is greatest for people in their prime. This can be expected to be a general feature of earthquake risk associated with commercial buildings, which tend to be populated and surrounded predominantly by adults of working age.

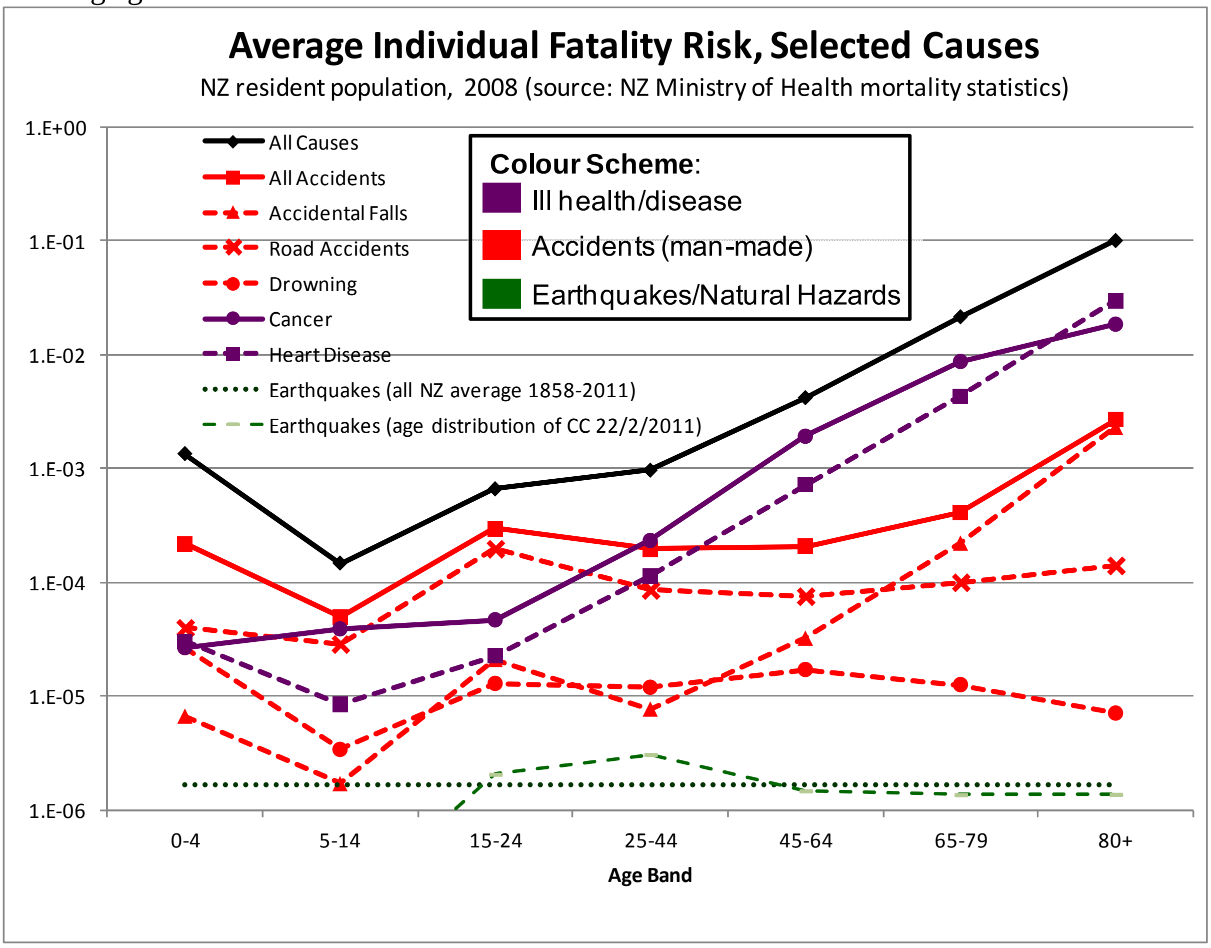

Figure 8: Average Individual Fatality Risk for New Zealanders

The earthquake risk in Figure 8 appears very low, because it has been averaged across the whole NZ population, many of whom are at very low levels of earthquake risk. Most calculations to date of earthquake impacts have been for selected specific earthquakes at particular locations[6], rather than attempting to estimate individual or aggregate risk across all possible earthquakes. Figure 9 shows some tentative ranges of individual fatality risk associated with earthquakes and natural hazards at particular locations in New Zealand in comparison with various other hazards. Note that:

a) The ranges of risk for whole-population hazards on the right hand side of Figure 9 show the variability of risk with age.

b) With the exception of the “All NZ population (seismic, volcanic ..)” item at the bottom left of Figure 9, all of the natural hazard risks referred to apply to local populations either in major towns/cities (Wellington earthquake, tsunami risk) or in much smaller areas; the overall numbers of people at the levels of risk shown (and thus the contribution of these hazards to aggregate risk for the whole NZ population) is relatively small.

c) The local natural hazard risks shown in Figure 9 are the subject of risk reduction actions which are likely to reduce them considerably.

Perhaps unsurprisingly, there are smaller groups of New Zealanders who are potentially exposed to levels of risk from earthquake and tsunami which are considerable in relation to other accidental causes of death.

In summary then, individual risk from earthquakes is small when averaged over the whole population, but can be significant relative to other hazards at higher risk locations. People of working age are particularly exposed to earthquake risk from commercial buildings, which is not the case for most other hazards.

[6] See for example Cousins, J. 2010. Wellington area earthquake casualty estimate – 2010 update. GNS Science Client Report 2010/60.

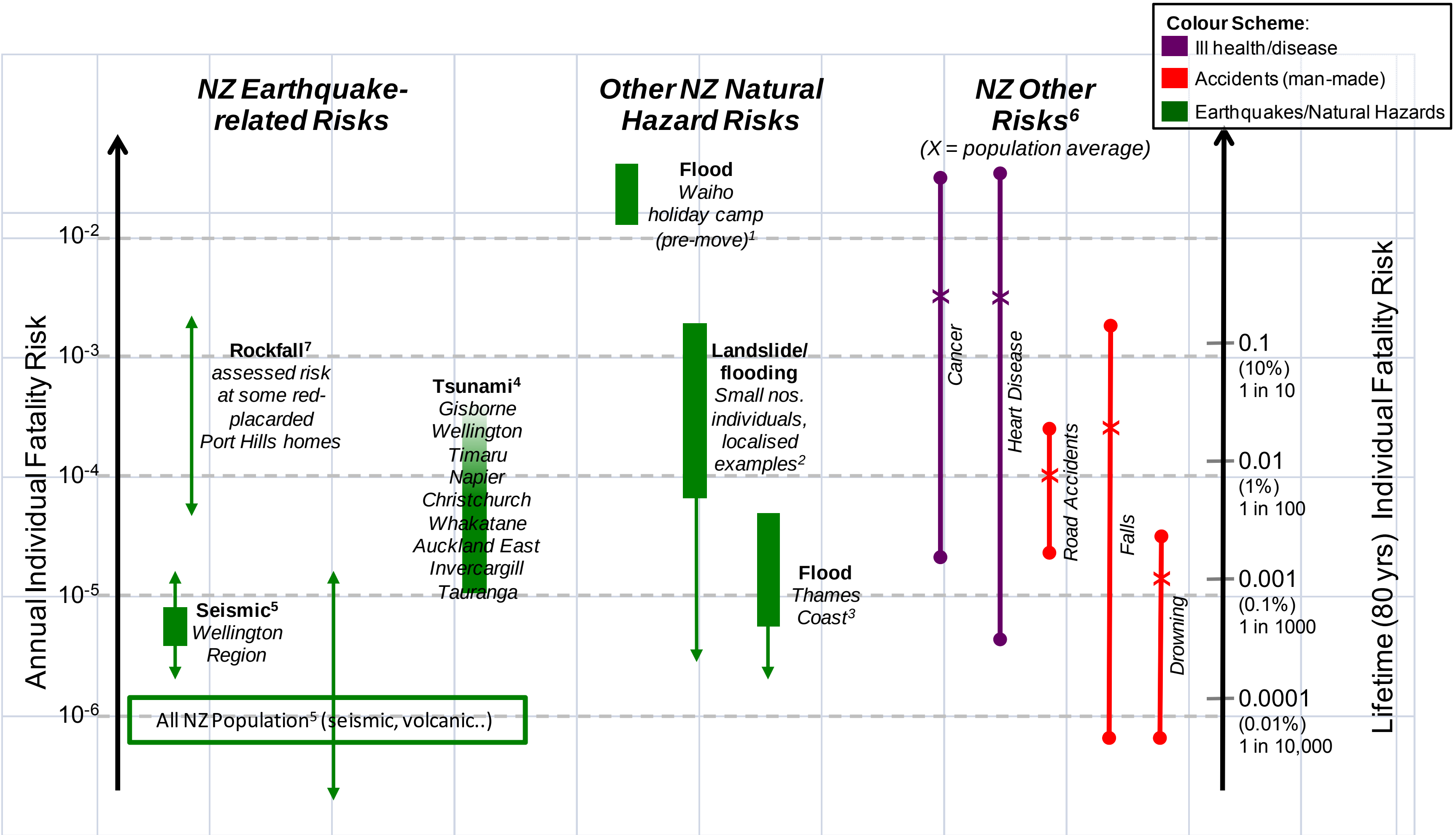

Figure 9: Selected Individual Risk Comparisons

Notes on Figure 9:

1. *Derived by the author from results of 2002 Optimx risk assessment for MCDEM*
2. *Estimated by the author for Waihi & Aoraki Villages and Matata – see GNS Consultancy Report 2011/319*
3. *Upper estimate (URS, 2003) for High Risk zones; arrow denotes wide range of risks downward*
4. *AIFR at 2-4m above sea level, no effectiveness assumed for warning (Webb, 2005)*
5. *Averages over large populations; arrows denote likelihood of substantial groups of people at higher/lower risk*
6. *Bars show range of values across age bands for men and women (NZ Ministry of Health, 2008)*
7. *Based on recent GNS risk assessments for rockfall and cliff collapse – see GNS CR 2011/311 and CR 2012/57*

3.1.3 Frequency of Severe Events

In economic terms, earthquakes stand out against other natural disasters on a "per event" basis, as discussed earlier. However, in terms of how frequently large events happen, the place of earthquakes depends very much on what we define as "large", as can be seen in Figure 10a.

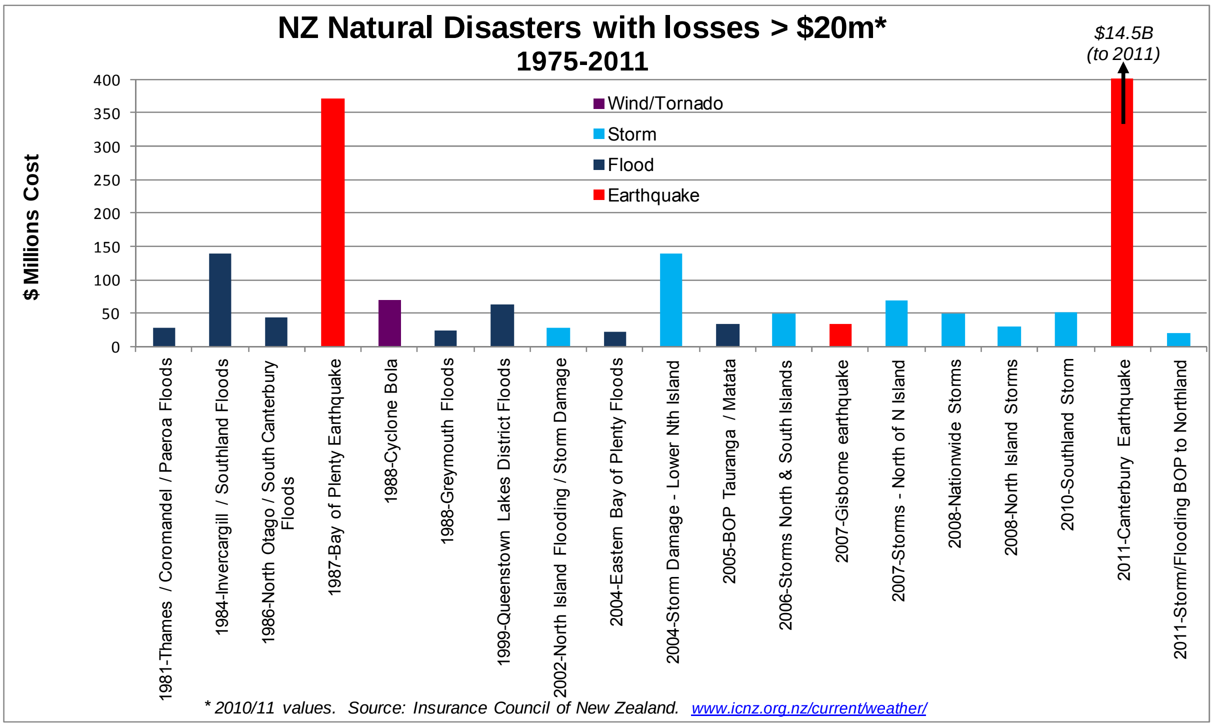

Figure 10a: Major NZ Natural Disaster Losses 1975-2011

There are considerably more flood and storm events than earthquakes in Figure 10a. But if "large" is redefined as "greater than $100m loss" then earthquakes equal floods and storms combined in terms of annual frequency over this period. If "large" is redefined as "greater than $200m" then there are no flood or storm events but 2 earthquakes qualifying as "large" during this period.

Although the period considered is relatively short, this illustrates a very important feature of earthquake risk in relation to many other man-made and natural hazard risks: the bulk of the time-averaged risk from earthquakes is associated with very rare events, whereas the bulk of the time-averaged risk from floods, storms and many other natural and man-made hazards is associated with more frequent, less extreme events.

This becomes clearer when the chart is re-plotted to show the frequency of events greater than or equal to a given loss as in Figure 10b.

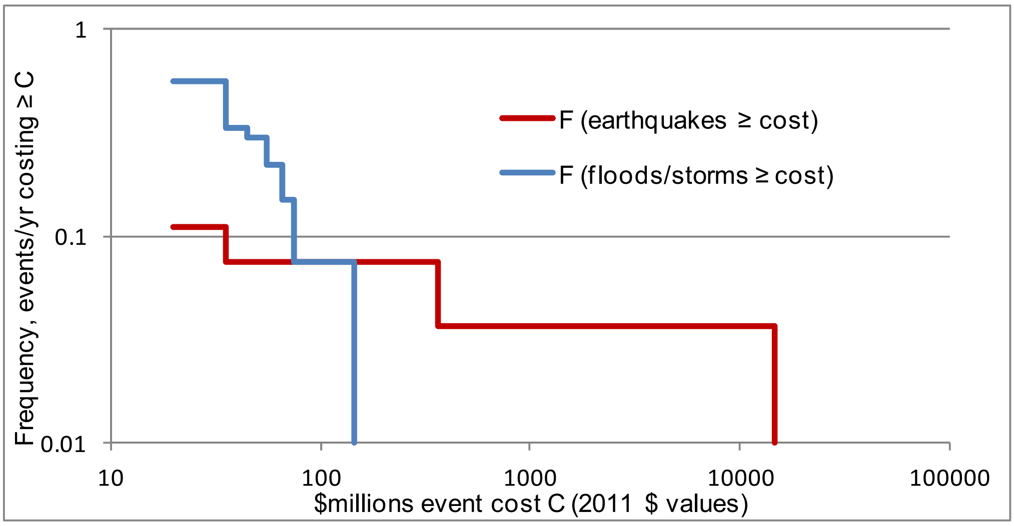

Figure 10b: Frequency of NZ Natural Disaster Losses
(Figure 10a data re-plotted)

Figure 10b shows the frequency/consequence curves crossing over in the area around $100m per event loss. Floods and storms account for more frequent events below this level of loss, whereas earthquakes account for more frequent events above it.

Figure 10c plots the same data again, this time showing the composition of the average annualised loss for earthquakes in comparison with storms and floods, broken down by bands of events of different scale.

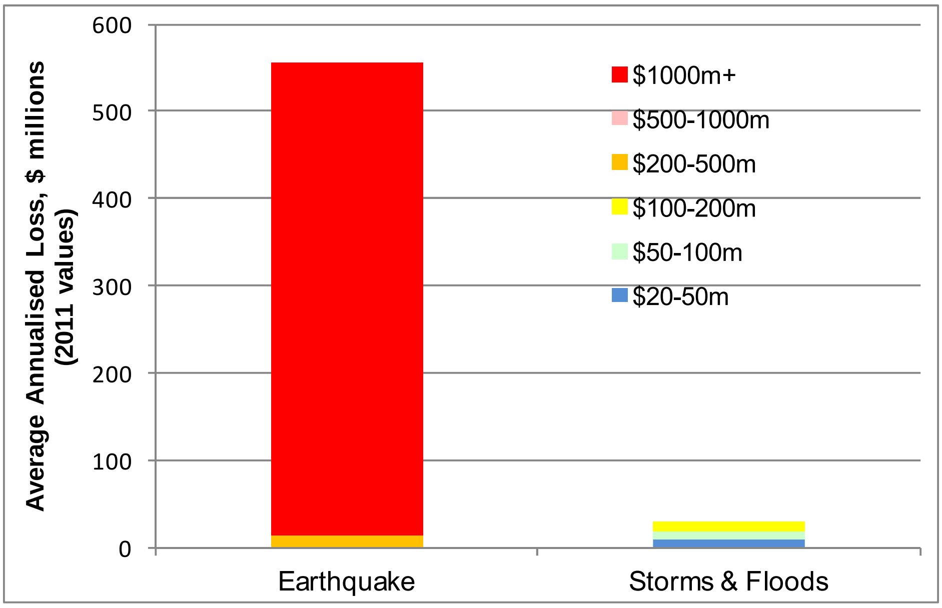

Figure 10c illustrates vividly another distinctive feature of earthquake risk which is observed worldwide, not just in New Zealand: the average annualised impact of earthquake events is dominated by the contribution from very large, very rare events. For many other natural and man-made hazards the reverse is true.

The large scale of consequences associated with earthquakes is also of great importance when it comes to safety and lives lost. Figure 11 is a “F/N curve” – a graph showing how often events leading to N or more fatalities happen – for road traffic accidents, storms/floods and earthquakes in New Zealand[7]. The worst ever road traffic accident in NZ was the Northland bus accident killing 15 people in 1963; a large majority of the massive burden of road fatalities involve a single fatality per event. The very different shape of the curves shows that while fatal road accidents are, sadly, virtually a daily occurrence, earthquakes have much greater likelihood of causing incidents involving many 10’s or 100’s of fatalities. Storms and floods fall in-between.

Also shown in the F/N chart are the results of GNS/CARL predictive risk assessments of earthquake risk for the whole of New Zealand[8]. This work involves carrying out a computer simulation of the effects of a large catalogue of realistic NZ earthquakes on buildings and people. For each earthquake, casualties are predicted using correlations between earthquake magnitude and ground shaking, and between ground shaking, building damage and casualties. These estimates were produced prior to the 2010/11 Christchurch earthquakes and there is much research in progress which is expected significantly to update the results of such studies in due course. The state of the art in assessment of risk due to earthquakes is developing rapidly; this is not yet a mature science.

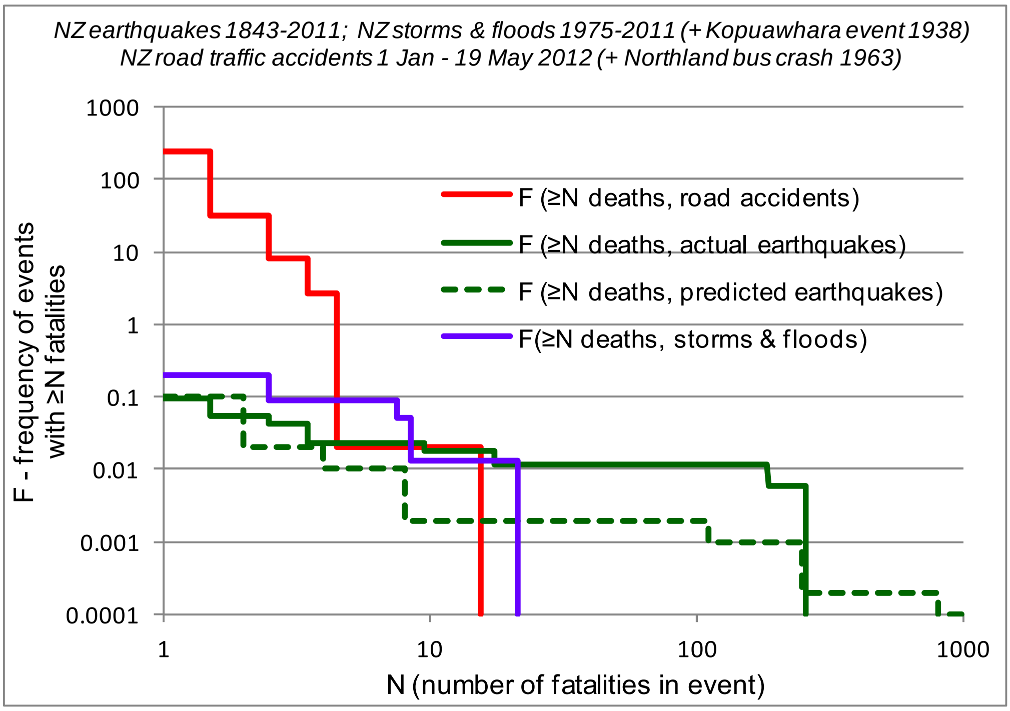

Figure 11: New Zealand Earthquake, Storm/Flood and Road Accident F/N Curves

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[7] For purposes of illustration of the potential for larger numbers of fatalities other than in earthquakes, the flood event which killed 21 people at Kopuawhara in 1938 and the 1993 Northland bus crash killing 15 people in 1993, have been added into the data sets charted in Figures 10a and 10b.

[8] Jim Cousins (GNS Science), Robin Spence & Emily So (Cambridge Architectural Research Ltd), Estimated casualties in New Zealand earthquakes, AEES 2008

The insights into the nature of earthquake risk available from predictive models are discussed further in Section 3.4

The simple summary point from this section is that earthquakes appear to stand out from other hazards in New Zealand in terms of the scale of the economic and safety impacts of rare events occurring perhaps once every 50-100 years or less often. This is an important point which is explored further in Section 3.2.1 in a wider context than NZ alone.

3.2 Other Characteristics of Earthquake Risk

In addressing risk characteristics relevant to EPB policy some general features of earthquake risk (3.2.1) and the sensitivity of risk to building construction (3.2.2) are considered in turn.

3.2.1 Other General Characteristics of Earthquake Risk

Three key points are raised here:

- earthquake risk is not all associated with buildings,
- the risk associated with earthquakes is, in contrast with many other hazards, heavily weighted towards more rare and severe events, and
- the picture of who is at risk of what from earthquakes is a complex one.

3.2.1.1 Buildings and Other Earthquake Hazards

Figure 12 shows the contribution from building damage and other causes to deaths in earthquakes in New Zealand since the time of European settlement[9]. The red and pink bars in the chart are all associated with building damage, which accounts for a large majority of the fatalities in the two major events (Hawkes Bay in 1931 and Christchurch in 2011). A large proportion of the casualties of the Hawkes Bay earthquake involved unreinforced masonry buildings, but unfortunately information on who was where and how they were hurt was not collected in any way comparable to the Royal Commission into the Canterbury earthquakes of 2011, so it is not possible to show a similar distribution of risk between building occupants and passers by for that event.

Figure 12 shows that ground movement, in particular slope collapse, is also potentially very significant. Over 50 homes in the Port Hills were struck by boulders 1m or more across in the 22/2/2011 Christchurch earthquake, and several more at the tops and bottoms of cliffs were destroyed by cliff collapse. It is worth remembering that had this event occurred at night-time the fatalities due to slope collapse might well have exceeded those due to building collapse in the

[9] From Dowrick D & Rhoades D, Risk of Casualties in New Zealand Earthquakes, Bulletin of the NZ Society for Earthquake Engineering, Vol 38 No. 2, June 2005 (updated by the author using casualty information for the Christchurch 22 Feb 2011 earthquake derived from Royal Commission papers and the police casualty list). It is not possible to break down fatalities for earlier earthquakes in the detail available for Christchurch 2011 as the information is not available, but 240 of the Hawkes Bay deaths in 1931 were attributable to URM buildings, and it was conjectured in 1933 that “Over 60% lost their lives on footpaths ... or while attempting to escape from collapsing buildings.”

CBD. So there is a potentially quite significant portion of earthquake life risk associated with hazards other than those within the scope of the Building Act provisions relating to EPB.

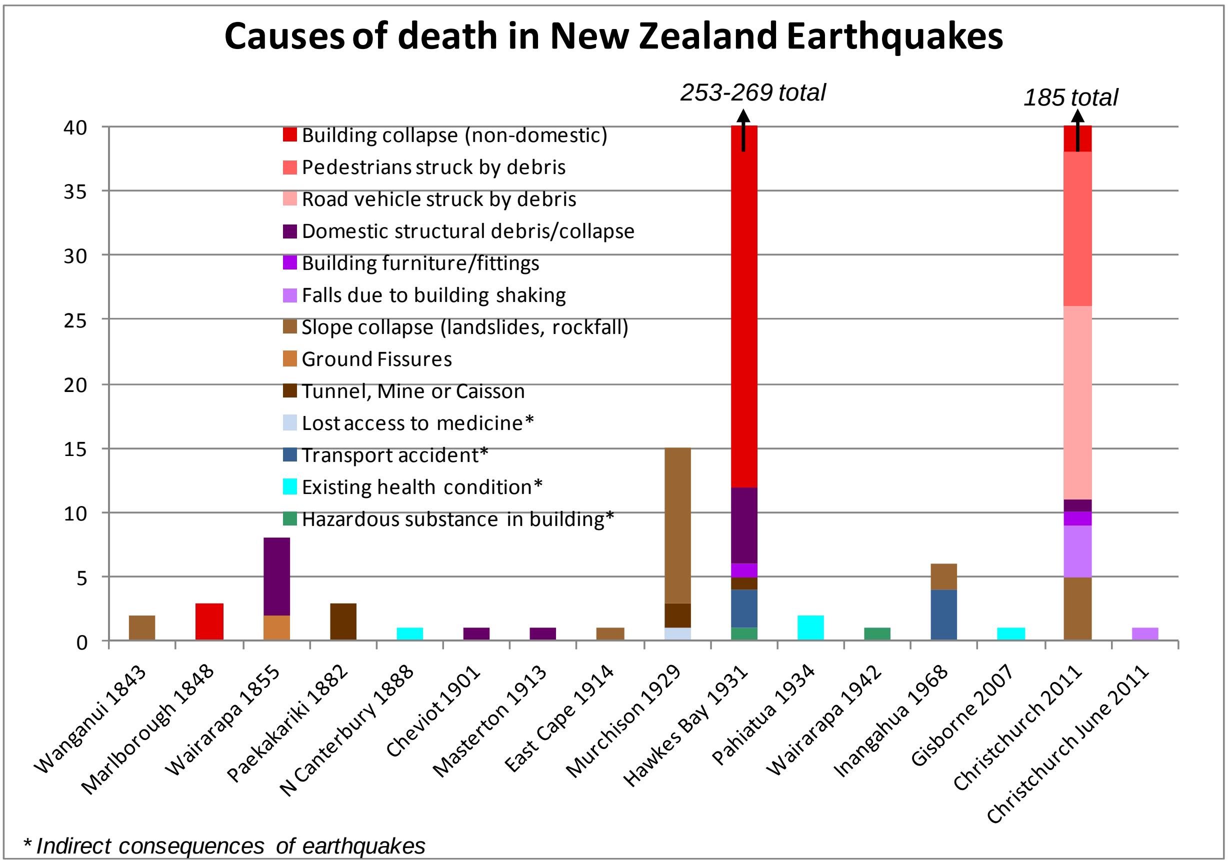

Figure 12: Causes of Fatality in NZ Earthquakes

3.2.1.2 The Dominance of Severe, Rare Earthquakes for Risk

An obvious feature of historic New Zealand earthquakes is that the time-averaged losses and deaths from earthquakes are dominated by the contribution made by occasional very severe earthquakes. This then begs the question as to whether rarer earthquakes than have been seen in New Zealand to date might add a further substantial contribution to the annual average losses. Is it possible that the annual average losses and deaths seen in the past 150 years significantly underestimate the longer-term averages?

The answer to this question is very possibly "yes". Earthquakes are well-known to be unusual among most major hazards globally in terms of the relatively very shallow slope of the F/N curve relating frequency of events to number of people killed. Figure 13a provides an illustration of this point, showing F/N curves globally for major earthquakes (including tsunamis but excluding secondary effects such as fires) and other disasters while Figure 13b provides equivalent data for developed countries (OECD members) only. The source[10] covers events meeting one or more of the criteria:

- 10 or more people killed,
- 100 or more people affected,
- State of emergency declared, or
- International call for assistance raised.

The data is thus incomplete for events involving less than 10 fatalities, so the charts show curves only from N=10 upward. It should be noted that, with the exception of the geological hazards (earthquakes, volcanic events), a large proportion of all deaths are associated with such (<10 fatalities) events.

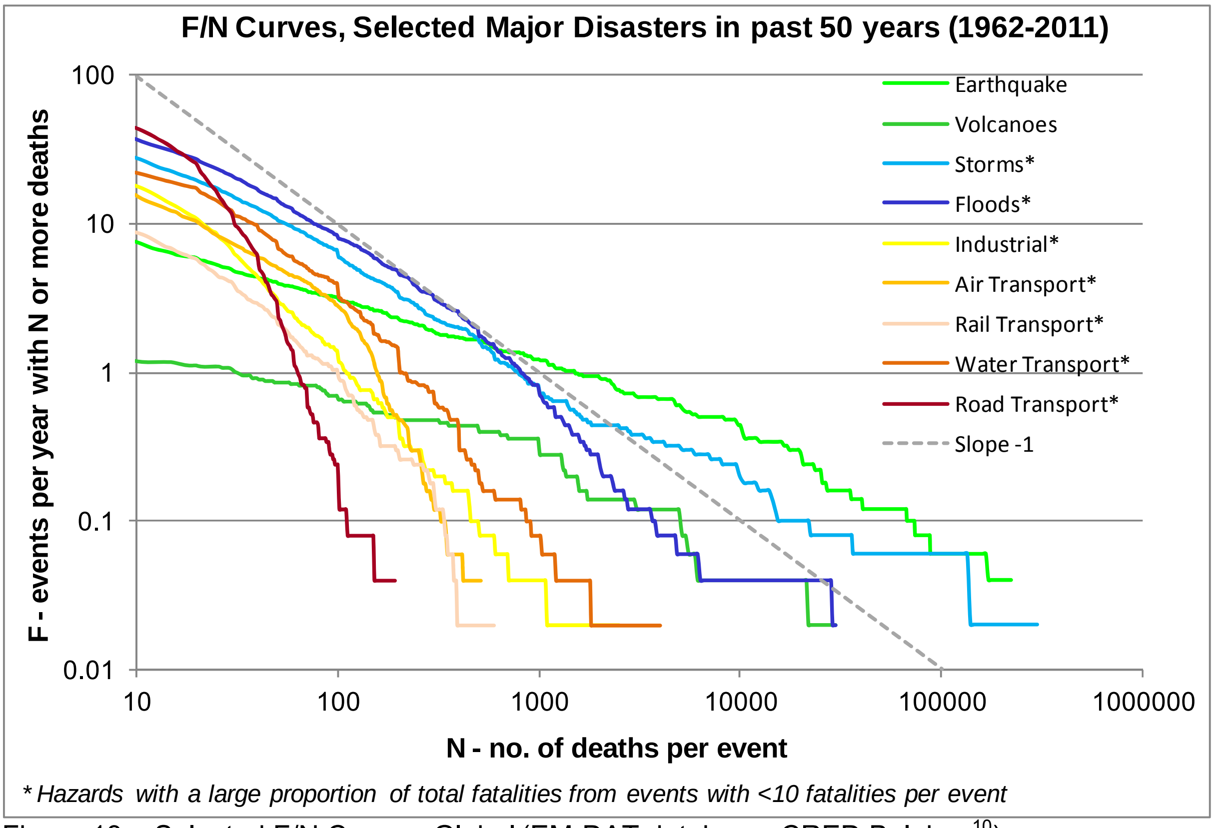

Figure 13a: Selected F/N Curves, Global (EM-DAT database, CRED Belgium[10])

The dotted line "Slope -1" is significant in interpreting these curves. Any curve dropping more steeply than that line represents a hazard where more of the overall fatalities arise from incidents to the left (i.e. from incidents involving smaller numbers of fatalities at a time). Any curve falling less steeply than that line denotes a hazard where more of the overall fatalities arise from incidents to the right (i.e. from incidents involving larger numbers of fatalities at a time).

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[10] OFDA/CRED International Disaster Database – www.emdat.be – Université catholique de Louvain – Brussels – Belgium.

Based on Figure 13a natural hazards globally have shallower F/N curves than do the man-made hazards shown; most deaths from natural hazard events globally are associated with large events rather than smaller ones. As Figure 13b shows, though, the effects of climatological hazards (floods, storms) tend to be less pronounced in developed countries; in the developed world weather warnings and well-developed emergency plans tend to limit the scale of life risk for even the worst weather-related disasters, whereas a significant proportion of earthquake occur without warning.

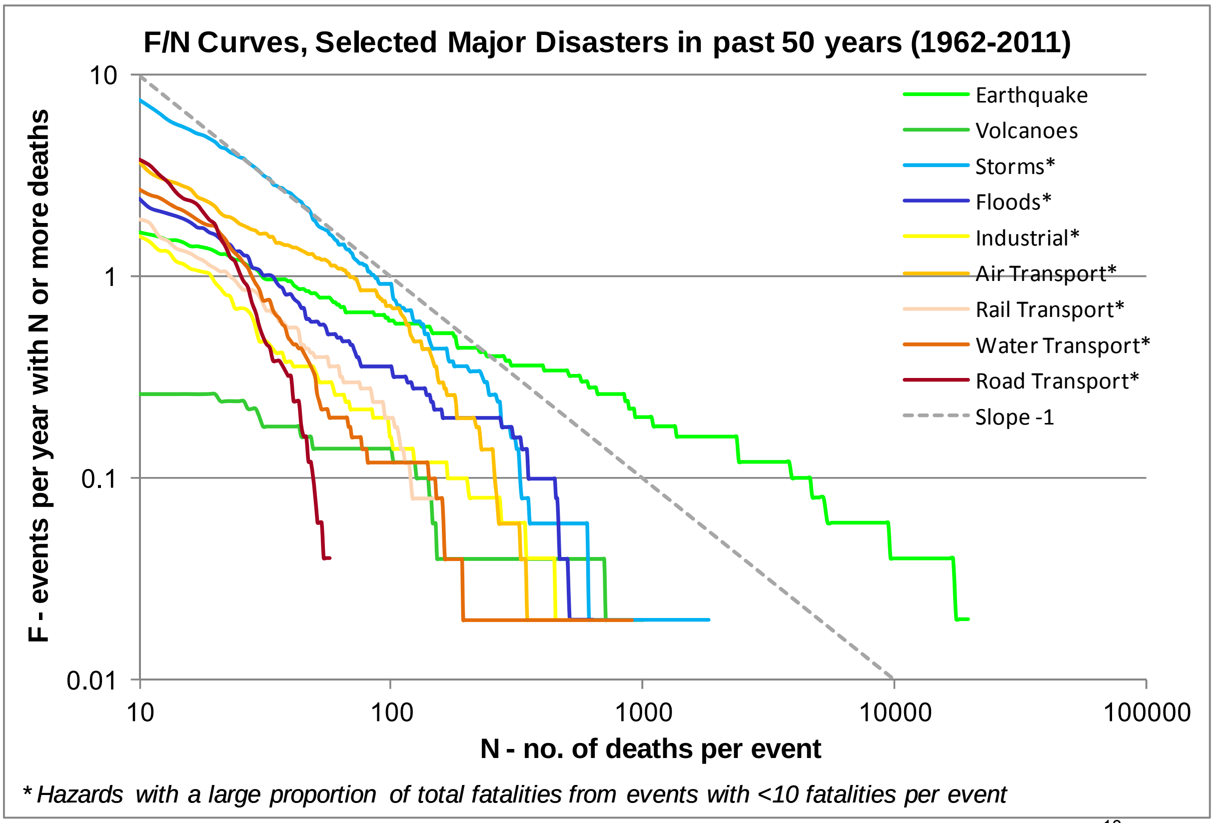

Figure 13b: Selected F/N Curves, OECD Countries (EM-DAT database, CRED Belgium[10])

Another notable distinction between the global and developed country pictures in Figures 13a and 13b is that volcanic hazards, which have similarly shallow F/N curves to earthquakes in both developed and developing countries, are significantly less risky relative to earthquakes in developed countries. This may involve a mix of fewer volcanic centres, smaller populations located in areas at risk from volcanic events, and better volcanic activity monitoring and emergency preparedness. The overall effect is that for developed countries in particular, earthquakes stand out as having a particularly shallow F/N curve and involving substantial time-averaged risk in relation to other major hazard events.

An alternative way of expressing this is shown in Figure 14, which shows the data from Figure 13b for developed countries re-plotted in terms of the % of overall fatalities in major disasters (those killing 10 or more people) broken down by different bands of N, the number of fatalities per event.

Figure 14 illustrates starkly the high proportion of earthquake and volcanic (as opposed to other major disaster) deaths in developed countries that are associated with very large events. NZ earthquakes are shown for comparison, showing both a) the high proportion of earthquake casualties associated with very large events, but also b) that casualties in NZ earthquakes to date have been at a lower scale than those globally. While most of this is probably due to the smaller population and better housing in NZ than in many countries that have suffered very heavy earthquake casualties, it is also possible in principle that some of this may be because NZ has too few years of recorded history to have recorded larger events which might make a substantial contribution to annualised average aggregate fatality risk.

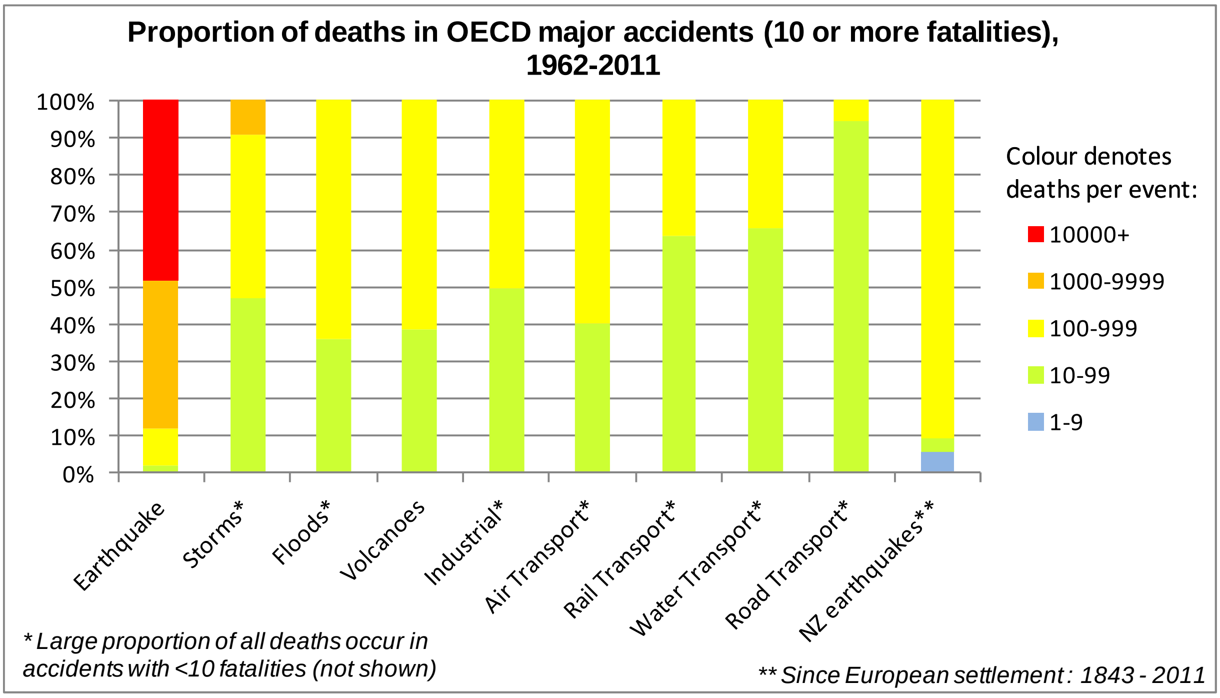

Figure 14: Contribution of different N fatality bands to overall casualties in major disasters in developed countries

The possibility of more serious events contributing significantly to NZ earthquake risk is explored below using the seismicity data and models of building damage and fatality used by GNS in their more comprehensive analyses of earthquake casualties. The annual individual fatality risk (AIFR) for people in and around various building types in Wellington, and the contribution to that overall AIFR from different bands of earthquake shaking, are shown for "Sound URM buildings[11]" in Figure 15.

[11] Throughout this and subsequent sections of this report the GNS distinction between "Sound" and "Defective" buildings is that "Sound" for most building types means the building is well constructed in accordance with the code of the era. "Defective" means that the building has some well-known form of deficiency. For URM buildings, which were all pre-Code, "Defective" means as-constructed, while "Sound" implies buildings that have been strengthened in some way (most strengthening has been carried out in relatively recent decades).

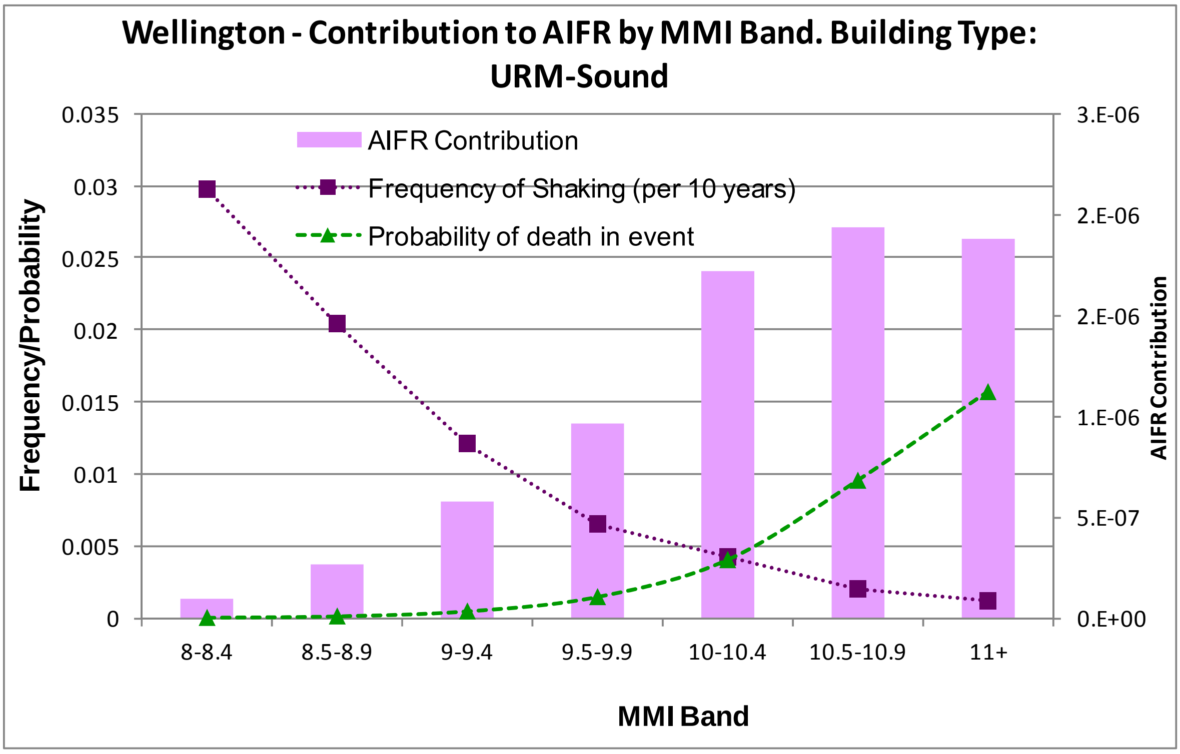

Figure 15: Contributions to Earthquake Risk from Different Levels of Shaking (illustrative)

Figure 15 shows the underlying reason why the contribution to overall earthquake risk rises with the scale of the event. The purple dotted line (with square markers) shows the annual frequency of events in a given MMI band, as derived from the NZ National Seismic Hazard Model – as expected, the more severe the shaking, the less likely the earthquake. The green dashed line (with triangular markers) shows the probability of death for a person in a sound URM building for events in the same MMI band - for a given degree of shaking rising as shaking increases, as would be expected.

The lilac bars show the resulting risk when event frequency and likelihood of death are multiplied together[12] – showing that the contribution to overall risk increases as shaking increases. That is, in moving from left to right (from lower to higher shaking), the effect of rising likelihood of dying outweighs the falling event frequency. The contribution to risk is thus greatest from the heaviest shaking (right hand side) part of the chart. This pattern is repeated in the GNS Science/CARL risk estimates for every class of building modelled.

Figure 15 should be treated as illustrative rather than definitive; there may be substantial re-calibration of the correlations when knowledge from the Christchurch earthquakes is fully

[12] Individual risk contribution from events in a particular MMI band = frequency (events/year in band, derived from NZ national seismic hazard model) x probability of death (per event in band, derived by CARL from analysis of casualties by building type in NZ and other earthquakes). Based on data and correlations supplied by J Cousins, GNS Science, as used in *Jim Cousins (GNS Science), Robin Spence & Emily So (Cambridge Architectural Research Ltd), Estimated casualties in New Zealand earthquakes, AEES 2008*

digested, but there can be high confidence that the point it illustrates is real and not an artefact of the model:

Figure 16 shows an alternative illustration of this point, based on the same AIFR calculations for Wellington as Figure 15 above. The lilac bars show the % of overall risk contributed by events involving shaking above a given MMI band. The conclusion, for all types of building construction for which GNS and CARL have developed correlations between shaking, building damage and fatality, is that a substantial majority of time-averaged risk is contributed by events involving shaking as strong as or stronger than that experienced in Christchurch in the 22 February 2011 earthquake.

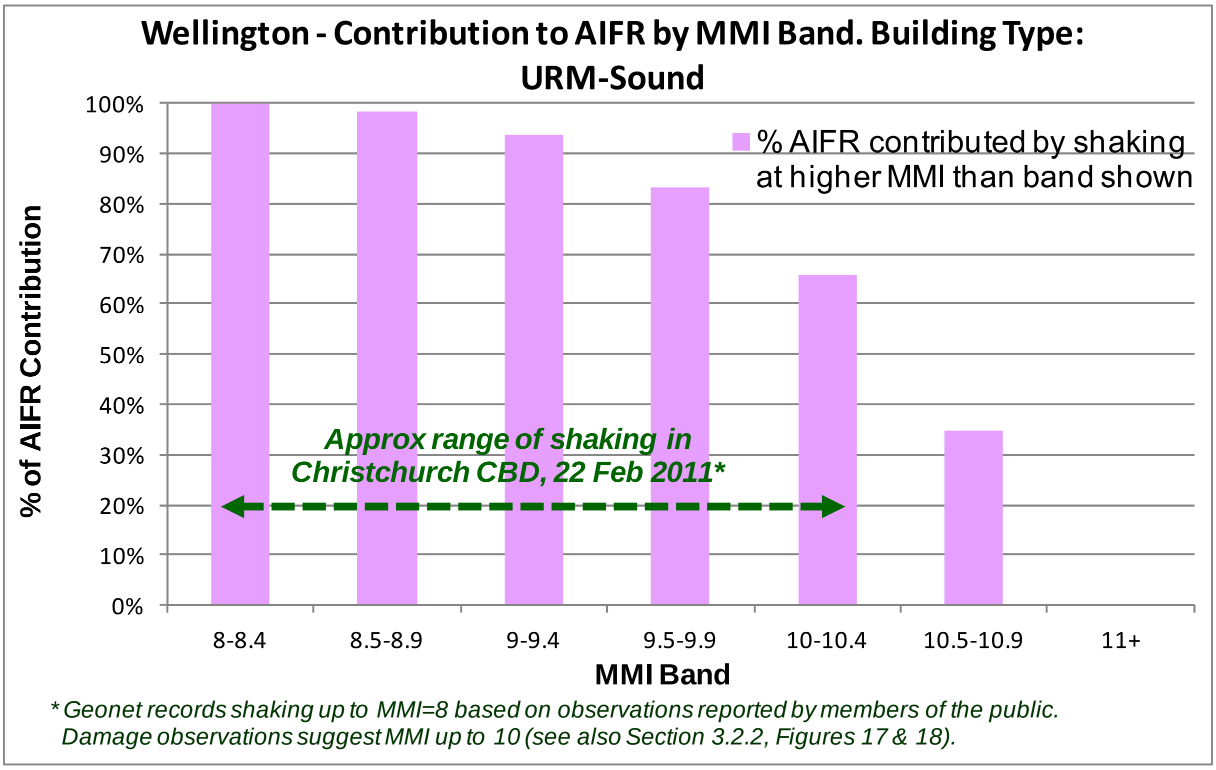

Figure 16: Most Risk is Contributed by the Highest MMI Bands

In a typical real earthquake, only a relatively small proportion of the area affected may be subjected to the highest shaking, while a relatively larger area may be subjected to shaking at lower levels. Thus the individual risk relationship above may not apply to aggregate casualties in a particular event – if many more people experience lower levels of shaking, the casualties may be dominated by areas away from the peak shaking area.

However, in considering the risk for NZ from ALL earthquakes, the individual risk calculations above reinforce the observation from both global and NZ earthquakes that both individual risk and the aggregate (average annual) risk of fatalities are dominated by severe, rare events. It may be possible to argue that there is a ceiling on earthquake shaking – a physical limit on how bad shaking can get in even the very worst case – which limits how much risk can be contributed by earthquakes worse than those experienced in NZ to date. Exploring this issue is beyond the scope of this report, but it is unlikely that any such physical limits will alter the broad conclusion that time-averaged earthquake risk is dominated by rare and severe events. Until it can be demonstrated otherwise, policy should recognise the strong possibility that earthquake risk in New Zealand (in terms of time-averaged aggregate impacts or individual risk to specific at-risk populations) is dominated by events more severe than any experienced in the country to date.

This is an important conclusion for risk management as it means that when choosing solutions to reduce building risk in earthquakes, care needs to be taken to avoid doing things that would work well for earthquakes involving lower or medium levels of shaking, but which might make matters worse for higher shaking. Some of the more popular treatments for older buildings have this characteristic – for example it was noted during the Royal Commission hearings into the Canterbury earthquakes that a common way of dealing with parapets of URM buildings during the 1990s was to tie the masonry together with concrete and/or other forms of reinforcement[13]. This reduces the likelihood of masonry falling in smaller and moderate earthquakes, but means that once shaking is high enough for dislodging of the parapet to be inevitable, material is likely to fall in larger and more dangerous pieces.

> ***Policy needs to address HOW strengthening is achieved, not just "% NBS".***
> Building strengthening measures need to be evaluated against the full spectrum of earthquakes important for risk – not just the last earthquake that happened or the earthquakes experienced to date – to avoid increasing overall risk by exacerbating rare/severe events whilst mitigating more frequent, minor earthquake consequences.

3.2.1.3 Who is at Risk from What in Earthquakes

Risk management is always simpler in situations where the same people create the risk, are exposed to it, and can choose what to do about it. In this respect earthquakes are particularly complex and difficult.

In economic terms there is perhaps greatest alignment between risk exposure and risk control, in that the building owner (and their insurer) is the person with most to lose from building damage in an earthquake. But building tenants may also suffer greatly if their stock and business interruption are not covered by insurance. And the social and economic impacts can be so widespread and so great that a) it is very difficult to attribute them fairly back to individual buildings, and b) they exceed any reasonable capacity of building owners, tenants and their insurers to cover. In such circumstances there will almost always be an important role for local and national governments

In safety terms it is the exception rather than the rule that the owner of a commercial building is also its user. Tenants and their staff, other building users (e.g. shoppers and visitors), passers-by and people in neighbouring buildings may also be at risk. In the event of collapse of a high-rise modern concrete building, it is primarily the occupants who are at risk (as illustrated by the CTV and PGC collapses in Christchurch). In contrast, older, lower-rise, URM buildings may primarily put neighbours and passers-by at risk, as is illustrated by the pattern of fatalities associated with

[13] See for example the transcript of hearings into the building at 265-271 Manchester Street.

buildings (other than the PGC and CTV buildings) which has been exposed during the Royal Commission hearings[14] and is illustrated in Figure 17.

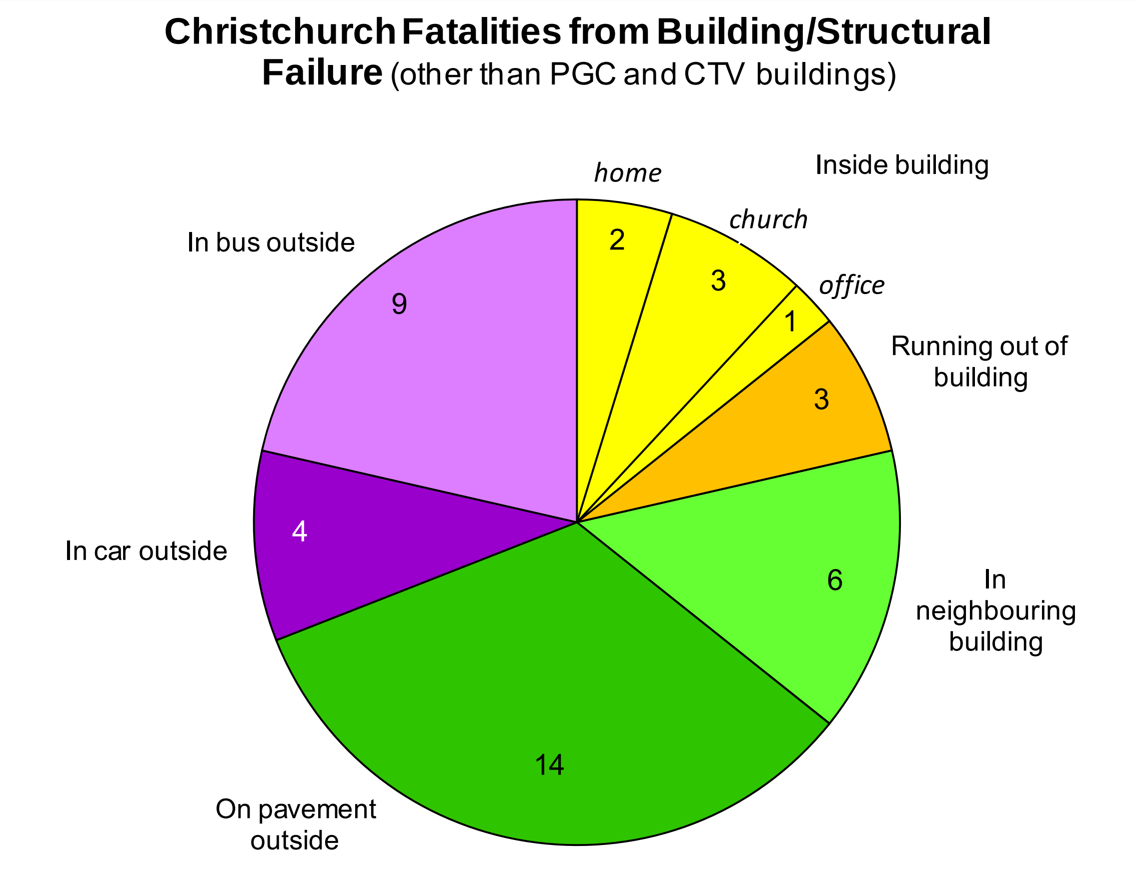

Figure 17: Deaths due to Building/Structure Failure, Christchurch, 22 February 2011

With the exception of one of the deaths in a car (which was caused by a concrete facade/spandrel panel detaching from a car park building), all of these fatalities were caused by the collapse of URM buildings or other structures[15]. Of the 40 fatalities caused by failure of commercial buildings, 10 were killed inside (4 in the buildings that collapsed, 6 in neighbouring buildings) and 30 by facade collapse (27 on the street or footpath and 3 whilst exiting a building).

Other socially important aspects of risk such as the impact on heritage buildings can be more complicated again. Different people value "heritage" differently, and have very different views about what constitutes a high value heritage building. Some owners value their heritage buildings very highly, but more generally it is the wider community which benefits from conserving heritage. Given estimates that it might cost $2.1B to strengthen the national stock of URM buildings, in relation to a total value of those buildings of $1.5B[16], it is clear that there is much scope for discussion as to who benefits from such strengthening and who should pay for it.

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[14] As summarised by Counsel for the Commission in introducing the hearing on 593 Colombo Street.
[15] The other structures involved were a free-standing outside wall and a chimney breast inside a home.
[16] J Ingham & M Griffiths, The Performance of Unreinforced Masonry Buildings in the 2010/2011 Canterbury Earthquake Swarm, Report to the Royal Commission of Inquiry, August 2011

3.2.2 Earthquake Risk and Building Characteristics

In terms of risk to people there are two key issues:

a) how likely is a given building to sustain specified damage in a given earthquake? (probability of given damage for a given building in a given earthquake, P_{dam}), and

b) what harm will be caused as a result? (probability of specified harm to a person present in or around a given building when that building reaches a given damage state, P_{harm}).

The overall risk to a building occupant (in terms of the probability of dying in a specific earthquake) is given by the product of P_{dam} x P_{harm}, integrated over all possible damage states.

The NZ Society for Earthquake Engineering produced a major report in 2006 on the assessment and improvement of the structural performance of buildings in earthquakes[17], which included an assessment of the relative risk of buildings strengthened to different degrees. The NZSEE recommendations include the following:

"*The NZSEE recommends upgrading to as nearly as is reasonably practicable to that of a new building. However NZSEE considers it is more important and realistic to identify the high risk buildings, and reduce the risk they pose to a more acceptable level, than to attempt to ensure that all existing buildings comply with the latest standards. The elimination of non-ductile failure mechanisms and critical structural weaknesses is in itself of greater importance than the actual assessment and strengthening level. Building failures during earthquakes rarely occur solely because the design forces have been underestimated. More often than not, poor performance results from some obvious configurational or detailing deficiency.*"

I agree strongly with this statement/recommendation. The big question is then what constitutes "as nearly as reasonably practicable to that of a new building". The NZSEE report recommends a minimum of 67% NBS rather than the 33% NBS required under the current EPB definition, on the basis that buildings strengthened to just over 67% NBS would bear approximately 2-5x the risk of a 100% NBS building, while buildings strengthened to just over 33% would bear about 10-25x that risk. However, what the NZSEE means by "risk" is defined in terms of the likelihood of exceeding ultimate strength as follows:

"Relative risk (RR) is the ratio of probabilities that the ultimate strength will be exceeded in any given period of time, i.e. RR = (probability for existing building with %NBS value shown) ÷ (probability for building with 100%NBS)."

Using this definition, there is clearly a substantial difference in risk between 33% and 67% NBS. There is a major question, though, as to whether the same applies to the difference in life risk. Models and predictions used in recent risk assessments, and analysis of casualties in the 22/2/11 Christchurch earthquake, can help shed some light on this question.

[17] "Assessment and Improvement of the Structural Performance of Buildings in Earthquakes", Recommendations of a NZSEE Study Group on Earthquake Risk Buildings, June 2006

GNS, CARL and others have researched earthquakes in New Zealand and other developed countries to come up with predictions of building damage and of risk to life in the event of such damage in earthquakes. For building damage, the results take the form of correlations between shaking (MMI) and the probability of a building of a given construction type reaching one of five building damage states, where State 1 represents minimal damage, and States 4 and 5 (those with a significant possibility of death) represent 60-90% and 90-100% damage respectively. Figure 18 shows the current correlations used by GNS between shaking and likelihood of different buildings reaching the worst damage states (4 or 5).

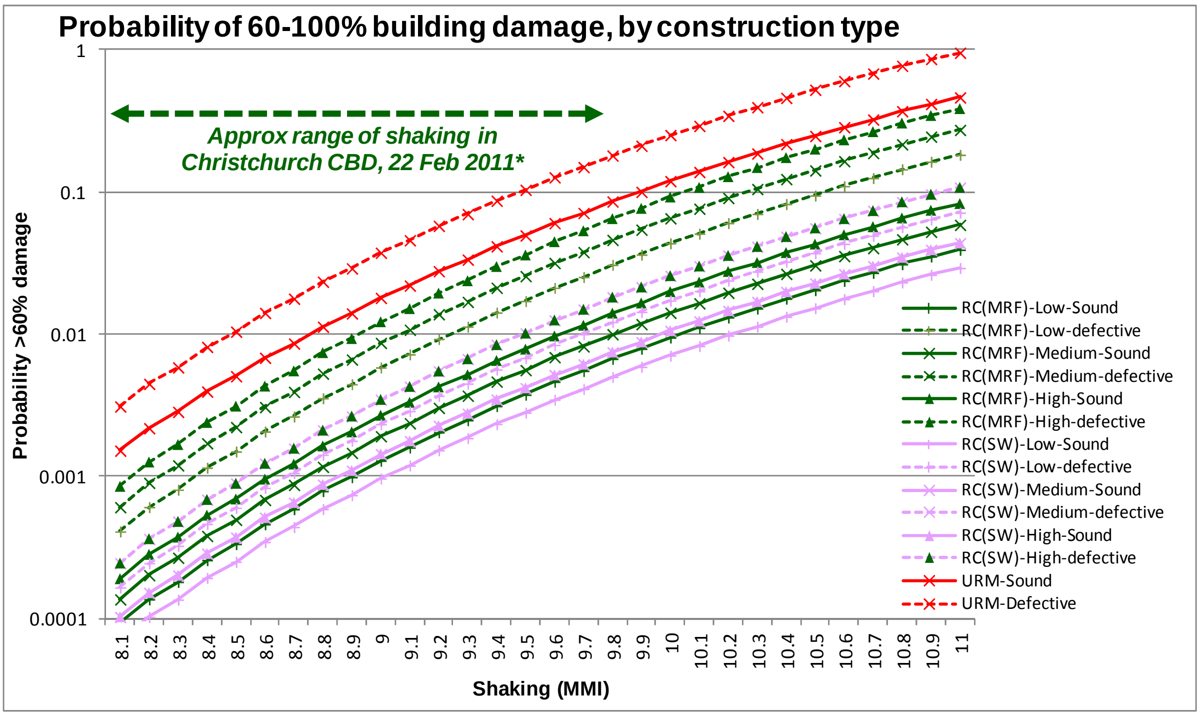

Figure 18: GNS Correlations between Building Damage and Ground Shaking

The abbreviations RC, MRF and SW in Figure 18 refer to reinforced concrete, moment-resisting frame and shear wall respectively, while High, Medium and Low refer to 8 or more, 4-7 and 1-3 storey buildings respectively.

As would be expected, unreinforced masonry (URM) buildings are at the top of the chart, but the worst case concrete buildings are not very far behind. In every case there is

- more than 10x increase in probability from MMI 8 to MMI 9, and
- roughly a 10x increase in probability from MMI 9 to 10, and then again from MMI 10 to 11.

Figure 19 shows the results of a very rough and ready analysis of a spreadsheet of buildings in the Christchurch CBD which was provided to GNS by Christchurch City Council. The scope, date and provenance of this spreadsheet is not known at the time of writing (for example it does not include some of the buildings whose collapse caused fatalities in the 22/2/11 earthquake). The numbers of buildings shown in Figure 19 include only those buildings for which a reasonable assumption as to % damage could be made (there are substantial numbers for which either damage or construction type or both was not entered into the spreadsheet). So this figure should be regarded as illustrative and not definitive – thanks to the efforts of the Royal Commission, Christchurch City Council and others one legacy of the tragedy will be a large body of evidence as to the effects of earthquakes on buildings and people, but the full fruits of this are not yet available.

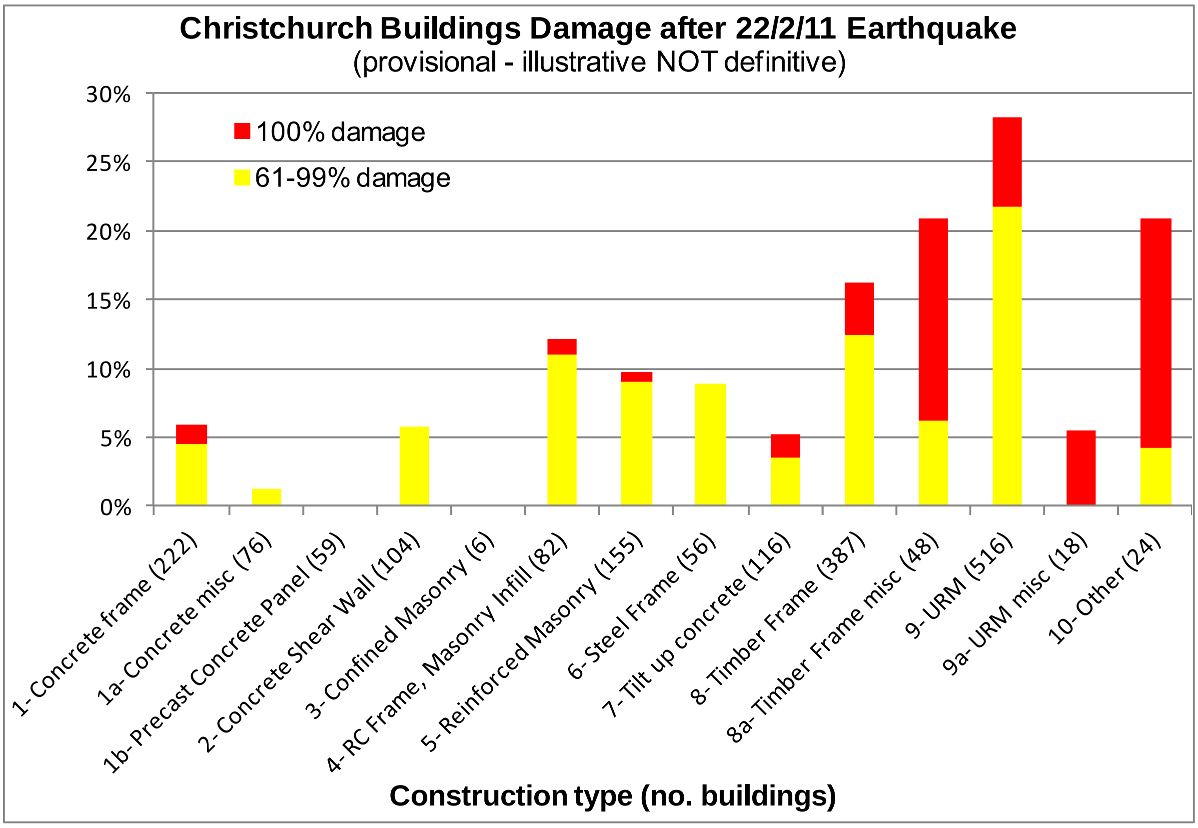

Figure 19: % Buildings with severe damage following 22/2/11 Christchurch Earthquake

Comparing Figures 18 and 19 suggests an effective MMI in parts of the CBD for the earthquake sequence culminating on 22 February 2012 of about 10, and (although the construction types could not be analysed against identical headings) broadly supports the relativities between concrete and URM buildings that are built into the GNS correlations in Figure 18, with

- Around 25% of URM buildings sustaining >60% damage, and
- A few % on average of concrete buildings sustaining >60% damage.

For the second question, as to the effects of building damage on people, GNS and CARL estimate that the proportion of New Zealand building occupants killed when buildings reach damage states 4 (60-90% damage) and 5 (90-100% damage) are as shown in Figure 20[18].

[18] Based on data and correlations supplied by J Cousins, GNS Science, as used in *Jim Cousins (GNS Science), Robin Spence & Emily So (Cambridge Architectural Research Ltd), Estimated casualties in New Zealand earthquakes, AEES 2008*

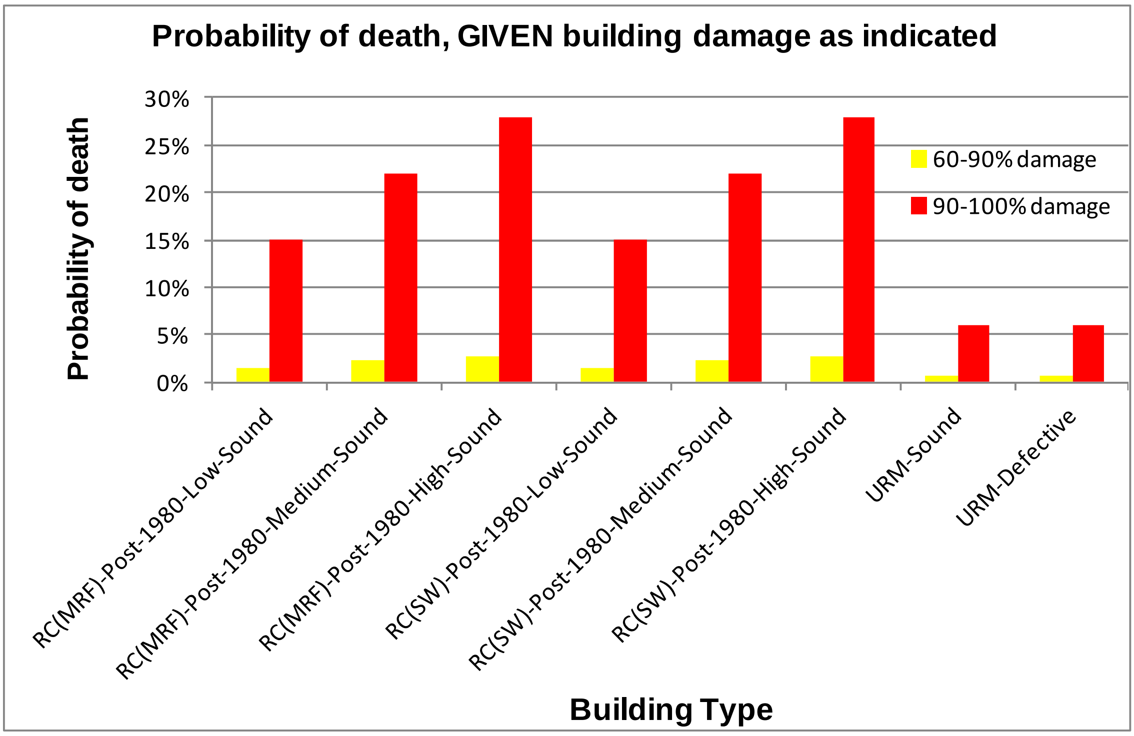

Figure 20: Mortality Rate given Severe Building Damage in New Zealand

A key point of note in Figure 20 is that URM buildings are less likely than concrete buildings to kill their occupants in the event of a major collapse. The reason is that concrete buildings usually have heavy concrete floors, meaning that when they collapse there is a lot of weight of material to fall onto people, and to be removed before they can be rescued. URM buildings in contrast typically have wooden floors, reducing the weight of material available to crush people or requiring to be removed before rescue can occur.

A higher percentage mortality in concrete than in URM buildings **for a given building damage state** is a general finding of research based on large numbers of earthquakes in many countries and is independent of the number of people occupying a given building. It is reflected in the tragic failures of the CTV and PGC buildings in the 22 Feb 2011 earthquake in Christchurch, which killed a high proportion of the people present at the time, whereas URM building collapses killed a relatively small proportion of their occupants (most of the people killed by URM building collapse were outside the collapsed building – see Figure 17 above).

We can now combine the correlations behind Figure 18 with those in Figure 20 to estimate the proportion of building occupants killed for given building construction types, as a function of ground shaking, by adding up the contributions from each damage state, where the probability of death for a building occupant associated with damage state I is given by

P(death,I) = P(dam,I) x P(person killed,I)

The results of this calculation are shown in Figure 21, which uses identical terminology to that in Figure 18 for building types. Note that URM, though very high on the chart, is not now at the top

– the effect of higher mortality in the event of collapse has taken the worst concrete buildings up above the worst URM ones.

To complete this series of calculations, Figure 22 shows the results of combining the probabilities of death shown in Figure 20 with the expected frequency of ground shaking in the Wellington CBD to estimate the annual individual fatality risk (AIFR) for occupants of each building type, across the whole spectrum of possible earthquakes. The results fall within a range from about 1 to 20-30 per million per year. These results are all significantly uncertain and may change significantly once the lessons from Christchurch are fully digested (it is considered likely they may be increased significantly across the board). But the broad relativities between building types are considered reasonably robust to the uncertainties involved. Figure 22 thus illustrates again the important point that while URM buildings may be the most likely to collapse in earthquakes, they are not necessarily always the riskiest.

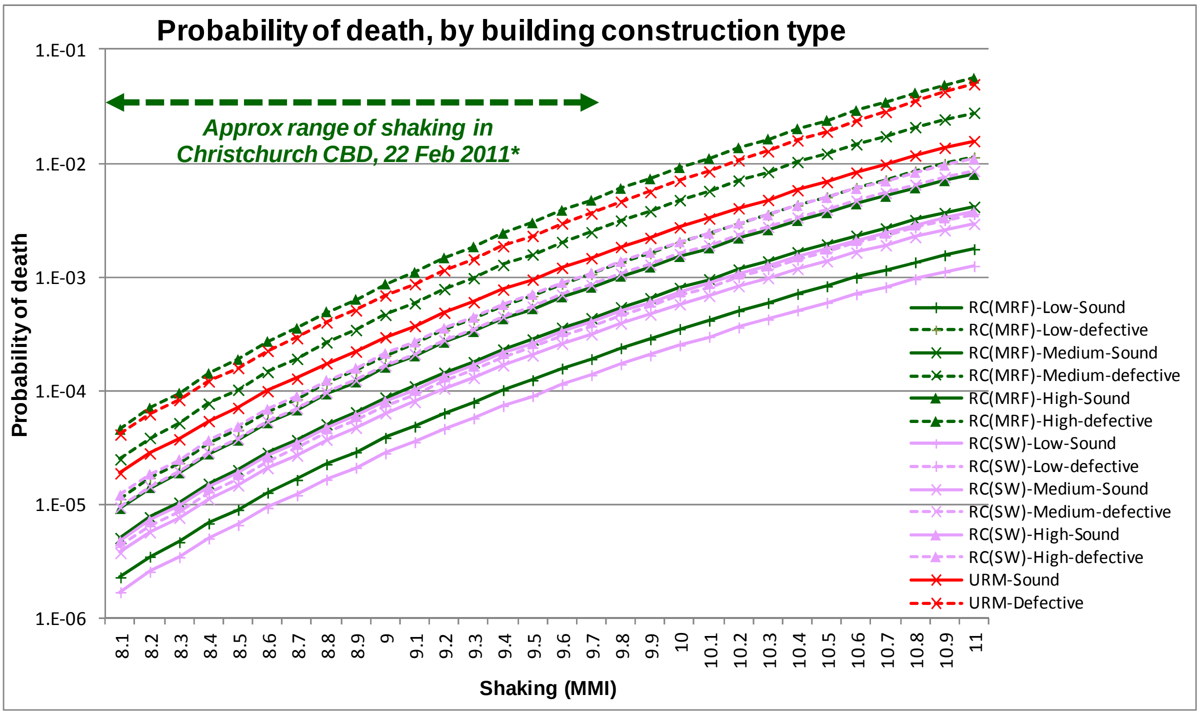

Figure 21: GNS Correlations – Building Occupant Mortality vs Ground Shaking

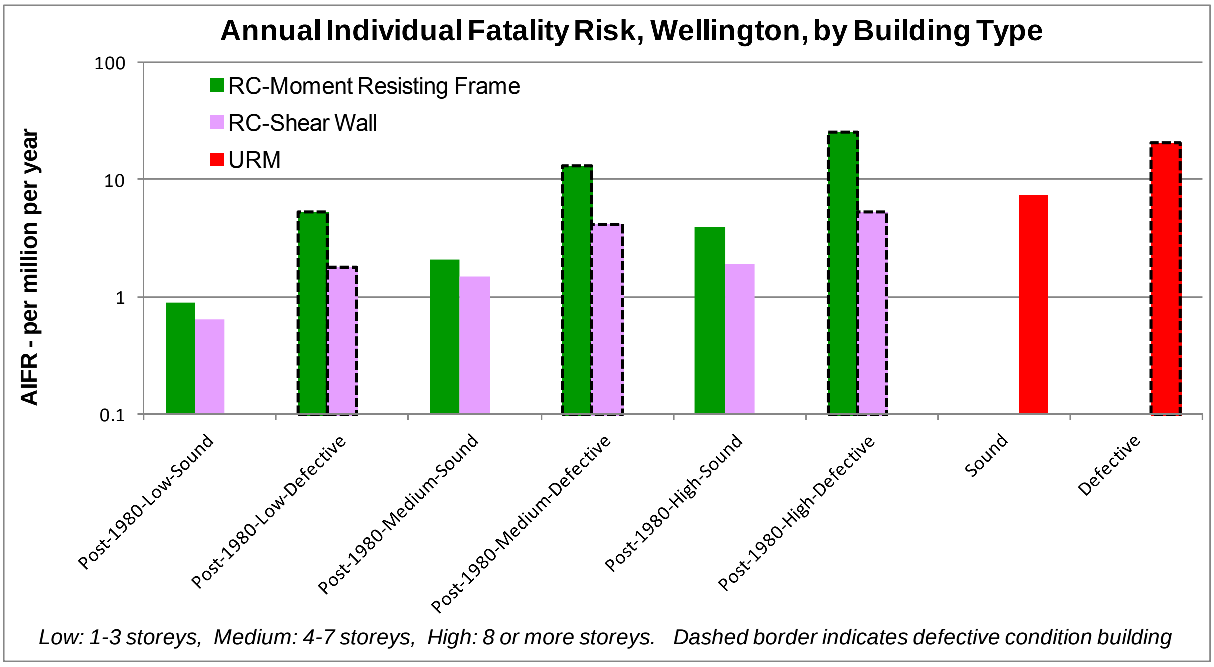

Figure 22: Individual Risk for Building Occupants (GNS correlations + shaking frequencies)

All of the above discussion has related to differences between buildings of different construction types, and in different condition (broadly categorised as "sound" or "defective"). What policy makers in DBH really want to know in the context of earthquake prone buildings is what effect CHANGES to a particular building will have.

This is very difficult to assess based on available information; the NZSEE view in 2006 based on relative risk of encountering earthquakes exceeding the ultimate limit state, as explained above, was that 67% NBS was strongly preferable to 33% NBS.

Evidence collected from the Christchurch earthquake sequence may shed a good deal of light on the relative risk of 67% NBS and 33% NBS strengthened buildings in terms of risk to life. Substantial research has already been published to help identify which measures are more or less effective[19] in preventing building damage, with results such as that shown as Figure 23 (reproduced from Figure 6.1 of the reference below) for URM buildings. Note that "major" in this figure corresponds to 60-99% and "destroyed" to 100% damage, so there is reasonable correspondence with the GNS damage states 4 & 5 used in Figures 18-22.

[19] J Ingham & M Griffiths, The Performance of Unreinforced Masonry Buildings in the 2010/2011 Canterbury Earthquake Swarm, Addendum Report to the Royal Commission of Inquiry, October 2011

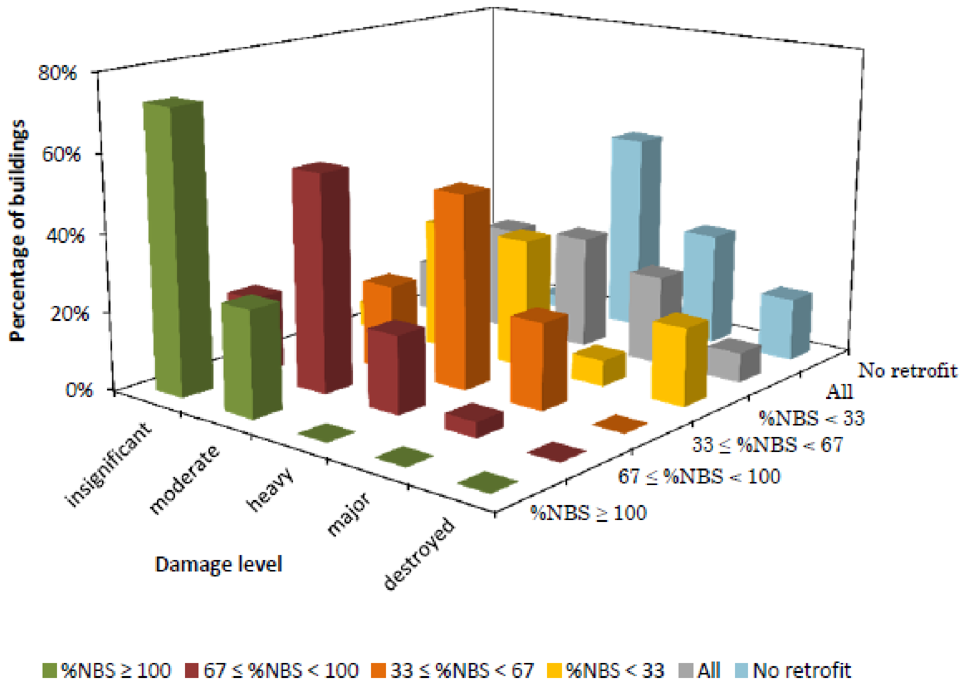

Figure 23: Damage Levels for Different Levels of URM Building Strengthening[11, Figure 6.1]

Alternative interpretations of this chart are possible. From a safety point of view, the risk to life in a building at the "destroyed" damage level is much greater than that at the "major" damage level (about 10x greater according to the GNS/CARL correlations shown in Figure 20 above). As shown in Figure 23, it was buildings of <33% NBS which suffered significant rates of total destruction, and indeed there were no deaths in URM buildings strengthened to 33%NBS or better in the 22 February 2011 earthquake. From an economic and social point of view, though, many buildings in the "major" and "heavy" damage categories became total losses and, as Figure 23 also shows, strengthening to 67% NBS or better still 100% NBS significantly reduces the likelihood of URM buildings reaching these damage levels.

The authors of the Royal Commission study carried out a qualitative hazard classification exercise for people inside and outside each of the buildings studied, and concluded that there were potentially significant safety benefits of moving from 33% to 67% NBS (i.e. comparing the pale and dark brown bars in Figure 23).

Using the GNS/CARL correlations it is possible to translate the effects of different levels of strengthening on collapse probability (as shown in Figure 23) into effects on the probability of persons present being killed. Combining the data in Figure 23 with the GNS/CARL correlations for probability of death for building occupants (Figure 20 above) produces estimates of the probability of death in the 22/2/11 earthquake as shown in Figure 24.

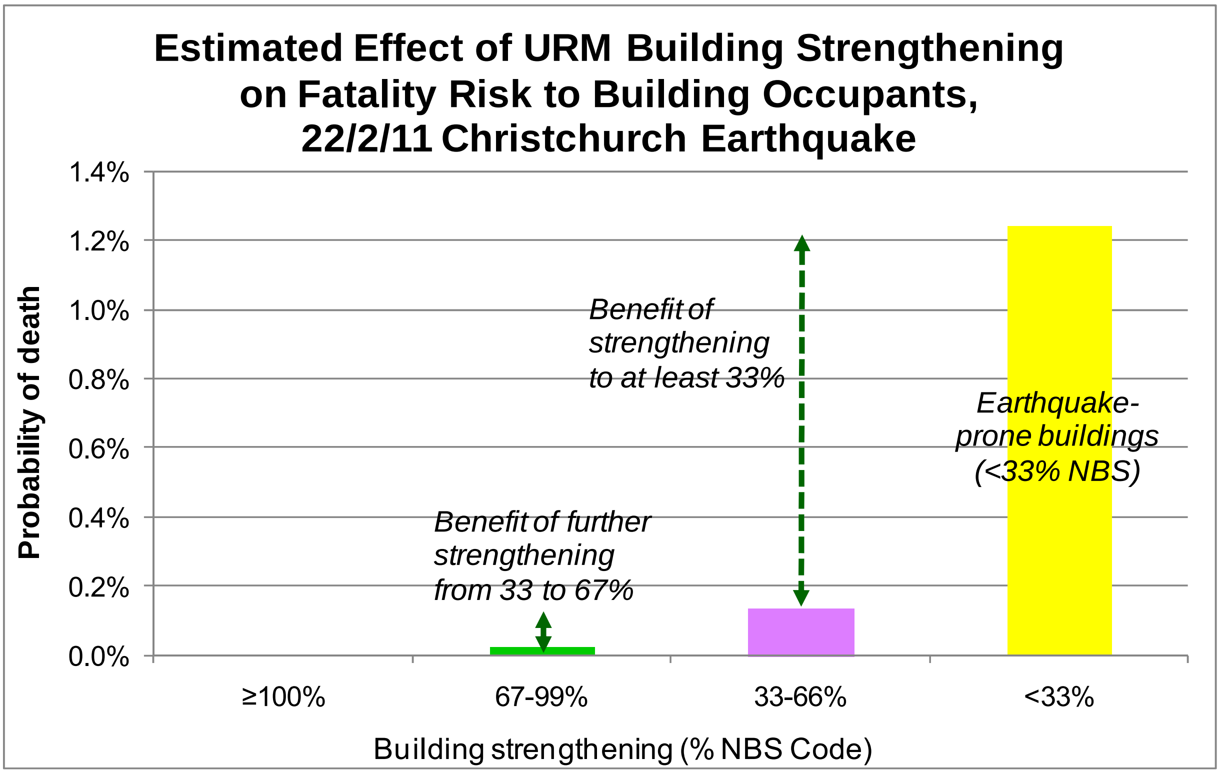

Figure 24: Estimated Effect of Strengthening on URM Lethality in 22/2/11 Earthquake

This quantified assessment using the combination of

- Available results of research following the 2010/11 Canterbury earthquake "swarm" into the impact of building strengthening on damage probabilities, and
- GNS/CARL correlations between damage and life risk,

suggests that the bulk of the safety benefit is associated with moving from "worse than" to "at or better than" 33% NBS, and that while there would be further safety benefit in moving to 67% NBS or better, this would be marginal, as shown by the relative scale of the dark green arrows in Figure 23.

This result is an inevitable consequence of the GNS/CARL correlations between building damage and probability of death – shifting from Damage State 5 (100% damage) to Damage State 4 (60-99% damage) reduces the probability of death by about a factor of 10 for all building types. Thus strengthening sufficient to turn 100% damaged buildings into 60-99% damaged buildings (which is what Figure 23 implies would be achieved for an earthquake such as that in Christchurch on 22/2/11 by strengthening to 33% NBS) removes 90% of the life risk. Only 10% then remains to be reduced by further strengthening, however good it is.

Both the quantitative analysis of life risk implications of the effects of building strengthening on damage, and the anecdotal observation from the 22/2/11 earthquake that no-one was killed by collapse of URM structures that had been strengthened to 33% NBS or better, suggest that the safety benefit in moving from a "33% NBS" to a "67% NBS" definition of earthquake-prone buildings would make only a modest difference to the lives saved in earthquakes of severities up to those experienced in Canterbury in 2010/11.

It is worth noting here that uncertainty as to the lethality of buildings when damaged is considerable because, even for earthquakes where detailed information is available on who was killed, where and how, parallel information on who else was present is seldom if ever available. Thus good information is obtained about casualties, but poor information about the proportion of people at risk who were hurt (or unhurt). This uncertainty could be substantially reduced if it were possible to establish where people in Christchurch were at the time of the 22 February 2011 earthquake. While it would almost certainly be hugely costly to do this in a 100% rigorous way, it should be possible to do in an approximate way which could significantly reduce this uncertainty. For example, the community could be invited to contribute information on their whereabouts in some user-friendly and low-cost way (e.g. by visiting a public web site and providing brief text and "click a pin onto the map" type data entry).

In moving from the Christchurch earthquake sequence to earthquakes in general it should be noted that there will be a certain "window" of shaking within which the difference between 33 and 67% NBS strengthening will be significant. For shaking below this window (anything much below MMI) it will make no difference because neither would be severely damaged. For shaking above this window (much beyond MMI 10) both would be likely to sustain severe damage. As mentioned above, care is needed in devising measures to reduce risk from lower MMI earthquakes to ensure that the consequences of the higher MMI earthquakes (which would be expected to dominate overall average risk) are not unintentionally exacerbated.

In summary, while research is still in progress using the insights gained from building performance in Christchurch during the 2010 and 2011 earthquake sequence, there appear to be good grounds for concluding that getting buildings that are weaker than 33% NBS up to 33% or better should be a higher priority **on life risk grounds** than strengthening to 67% NBS or some other higher number, for earthquakes up to and including the severity of the February 2011 event. This observation should be re-examined as research into the Canterbury earthquakes of 2010-11 matures.

As noted above, strengthening beyond 33% may have significantly greater benefits for earthquakes up to the severity of the 22 February 2011 Christchurch event in terms of preventing or mitigating severe damage to buildings at levels somewhat less than total collapse. While the safety benefits of such mitigation are arguable, the social and economic benefits could be considerable. As earthquake severity increases, a point will be reached (as for safety) above which it makes no difference whether buildings were strengthened to 33% or 67% NBS, as effectively total loss would be suffered in either case. Likewise, there will be some lower severity below which strengthening to 33% or 67% would be irrelevant, as neither would suffer significant damage.

It is not possible to provide finer resolution than "less than 33% NBS", "33-66% NBS" and "67% NBS or better" at present, as the uncertainties are large and these are the bands around which the research currently available has focused.

Figure 25 summarises in qualitative terms the benefits of strengthening to 67% rather than 33% NBS, once such strengthening has been completed.

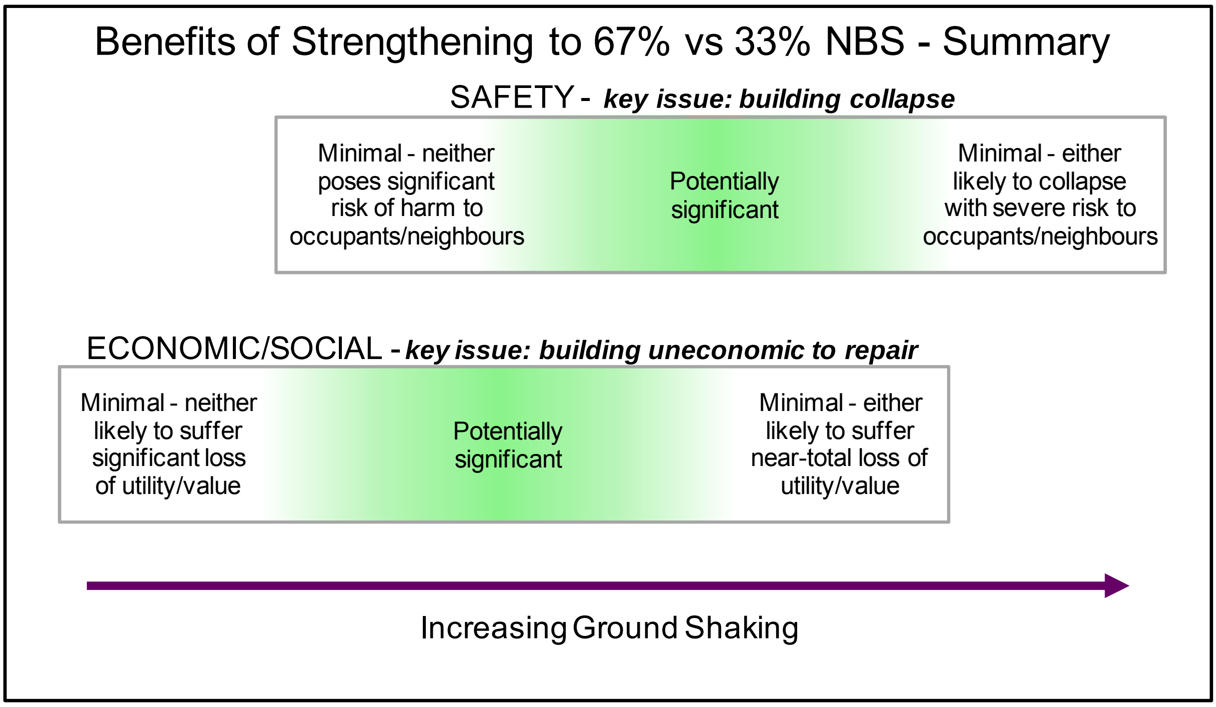

Figure 25: Qualitative Representation of Benefits of Alternative Strengthening Thresholds

The key issues in deciding which (33% or 67% NBS) would be a better threshold for definition of an earthquake-prone building thus boil down to

a) where the boundaries of the shaded zones lie in Figure 25 for different buildings

b) how large the benefits are in terms of risk or loss reduction, and

c) what costs are involved in achieving, and values attached to gaining, such reductions.

What seems clear from the experience of the Christchurch 2011 earthquakes and from current models used in New Zealand for estimating casualties in earthquakes is that there is quite a high level of shaking required for there to be a significant **safety** benefit of 67% over 33% NBS. On the other hand significant **economic/social** benefits might be achievable at lower levels of shaking. This is because safety benefits are associated largely with avoiding near-total collapse of buildings (which for all but very severe shaking appear to be achievable via strengthening to 33% NBS for many buildings), whereas economic benefits are associated largely with avoiding damage at levels making it uneconomic to repair buildings (which occurs at significantly lower levels of shaking than those required to cause collapse).

3.3 Earthquake Risk to Buildings - Summary

Major points of significance for risk management emerging from this section are:

1. Earthquakes stand out from other natural and man-made hazards in New Zealand in terms of the scale of the economic and safety impacts of rare events occurring every few decades or more rarely.
2. However, when the effects of earthquakes are averaged over long periods of time and the whole NZ population their numerical levels are smaller in relation to other hazards. This applies to both life and economic outcomes, but to the former in particular.
3. Building risk from shaking has been the largest contributor to damage and lives lost in NZ earthquakes to date, but is not the whole picture. Had the 22/2/11 earthquake happened at night fatalities due to slope collapse in the Port Hills may have exceeded those in the CBD.
4. Earthquakes are unusual relative to most other hazards in that, as the degree of shaking increases, the severity of outcomes increases faster than the likelihood of shaking decreases. Thus most of the time-averaged risk from earthquakes is associated with very severe, rare events. Important implications include
a) NZ earthquakes since the 1850's may under-represent long-term average risks, and
b) Care is needed to ensure that measures designed to protect against medium levels of shaking do not make things worse in higher shaking events that dominate average risk.
The implication of the latter point is that solutions to building strengthening are not just about what % NBS is defined as an acceptable minimum, but also about what sort of strengthening solutions are adopted so as not to make matters worse in very severe earthquakes.
5. Earthquake risk is distributed amongst different groups of people in a complex fashion. For small-moderate earthquakes, economic risk is well-aligned with building owners and users but for larger events the scale of social and economic disruption can be so large that governments and taxpayers will also carry a major burden. Life risk is greater for neighbours and passers-by than for occupants of many older buildings, while risks to heritage or other broader social values (e.g. the vital importance of lifelines and recovery focal points post-earthquake) may be largely disconnected from building ownership and use.
6. Combining results of early research into the effects of building strengthening on damage sustained in the Canterbury earthquakes of 2010-11 with GNS/CARL correlations between building damage and loss of life suggests (as does the observation that no-one was killed on 22 February 2011 in a building that could confidently be said to be at or above 33% NBS) that the safety benefits of strengthening from <33% up to 33% NBS are substantially greater than the benefits of upgrading to 67% or 100% NBS, whereas the economic and social benefits of upgrading may be more significant, for shaking up to the levels experienced in Christchurch. These observations should be tested as research into the 2010-11 Canterbury earthquakes matures.
7. While URM buildings are the most likely to collapse in earthquakes, they are not necessarily the highest risk. Some concrete buildings can be more dangerous to life because, though they are less likely than URM buildings to collapse, they are more likely to be lethal to their occupants when they do so. This is because of their greater weight of floors and other internal structures which can fall onto people, and which make rescue more difficult.

4. Risk Management Issues for EPB Policy

DBH wants to know what factors, from a risk management perspective, need to be taken account of by central government in reviewing the adequacy or otherwise of current EPB policy settings, including the definition of an earthquake-prone building. The key factors are

1. What "Risk" means in this context and how to measure it;
2. Which aspects of risk should be regulated by government, and which can be left to individuals to make their own decisions;
3. The criteria and values that should be used in making decisions about what risk is or is not tolerable (where government is to regulate);
4. Translating between levels of risk and the actual features of specific buildings;
5. Identification of buildings that are earthquake prone;
6. Evaluation of what best to do about buildings that are earthquake prone, and
7. The real risk reduction that policy will achieve, taking into account the time it will take to implement and its effectiveness once implemented and in the meantime.

A brief discussion of each follows.

4.1 What "Risk" means

As discussed in Section 3.2, there are several different aspects of risk associated with buildings in earthquakes. Economic risk is notionally borne largely by building owners and tenants but in practice is likely for large events to spill over into society more widely (through wider social and economic knock-on effects and through government/taxpayer involvement in responding to and paying for earthquake damage). Safety risk is borne largely by building occupants for large modern buildings but largely by people outside the at-risk buildings for older URM buildings – and has a significant component associated with other hazards such as slope collapse. Heritage conservation may be of great concern to communities but not necessarily to building owners and vice versa.

So, once policy is established on what government is to regulate, careful thought will be needed about the best way to measure risk and whether/how to use risk as the primary vehicle for expressing policy objectives.

4.2 What needs to be regulated

Where one person's action or inaction may impose an undue risk on others, then regulation is likely to be required. Where that person's action or inaction affects only themselves regulation is less likely to be needed.

In the case of earthquake risk and buildings the immediate economic loss is largely borne by building owners and tenants. The Building Code for new buildings should take economic loss into account in setting standards, but there is no reason in principle why government should tell building owners how far they should strengthen their existing buildings for the sole purpose of preserving the value of their asset. Assuming that leases and insurance properly protect tenants against failings of their landlords, this is perhaps a risk that the market can be left to sort out.

For larger earthquakes, though, this correspondence between building ownership/use and loss breaks down. Government is almost certain to be involved in dealing with and paying for wider social and economic impacts which are not directly attributable to specific buildings and which exceed local communities' capacity for recovery. It may thus be in the national interest for Government to regulate so as to optimise the overall cost of risk to Government, and in particular to safeguard against Government being left with unmanaged liabilities as a "funder of last resort".

In the case of safety risk there appears to be an equally clear need for government regulation, as inaction by building owners can have clear major consequences for tenants of, visitors to, neighbours of and passers-by outside their buildings.

Heritage and other broader social values attached to particular buildings do not lend themselves easily to any sort of quantitative risk framework. These could be dealt with by imposing constraints on what can be done with particular buildings linked to the value placed on them by the local community. Reasonable expectations of central government might be that

a) there would be a relatively small, select set of buildings identified as being of national importance, where decisions could not be left to local communities, while

b) some "ground rules" should be established to safeguard people from undue safety and economic consequences of (largely local community) decisions about heritage and other special buildings.

Such ground rules might cover issues such as how far safety policy may be varied in order to accommodate specially valued buildings (it seems inequitable that there should be unlimited freedom for buildings to be kept open to the public or indeed to be kept standing regardless of the risk they impose on their users and others). Some sort of framework would be helpful for dealing with situations where the community (or part of it) particularly values a building, but where the cost of bringing it up to meet safety standards exceeds the value attached to it by its owner. There is clear potential for safety obligations to create costs for heritage or other special building upgrades which exceed the value of those buildings; it is hard to see how a free society could force a building owner to spend more than their building is worth in order to provide some broader community benefit. If buildings that cannot reasonably economically be brought up to an acceptable level of safety are to be saved, there will have to be a debate about who will pay for them. Governments should clearly be involved in setting the rules of that debate:

- Central government in stipulating where bounds are to be set (e.g. ensuring that passionate local concerns for heritage do not allow adoption of policies leaving large numbers of people at extreme levels of risk), and

- Local governments in brokering policy that balances social, economic, heritage and other community interests and concerns.

4.3 Risk Criteria and Values

The core of the approach recommended here is to reduce risk to the lowest reasonably practicable level – i.e. striking an appropriate balance between safety, economic, heritage and other concerns. To do this, government would need to establish clear criteria and guidance relating to

1. Any constraints that should apply in terms of, for example, maximum tolerable risk levels (note that communities might add in their own constraints at this stage, relating to heritage buildings or other particular local wishes) and then
2. Requirements for duty holders (presumably building owners in this case) to provide for the lowest reasonably practicable level of risk.

These two types of criteria (intolerable risk, and judging reasonable practicability) and their application are discussed in turn, followed by a brief discussion of what would be involved in developing such criteria.

4.3.1 Applying Intolerable Risk Criteria

A possible framework for applying intolerable risk criteria is illustrated in Figure 26

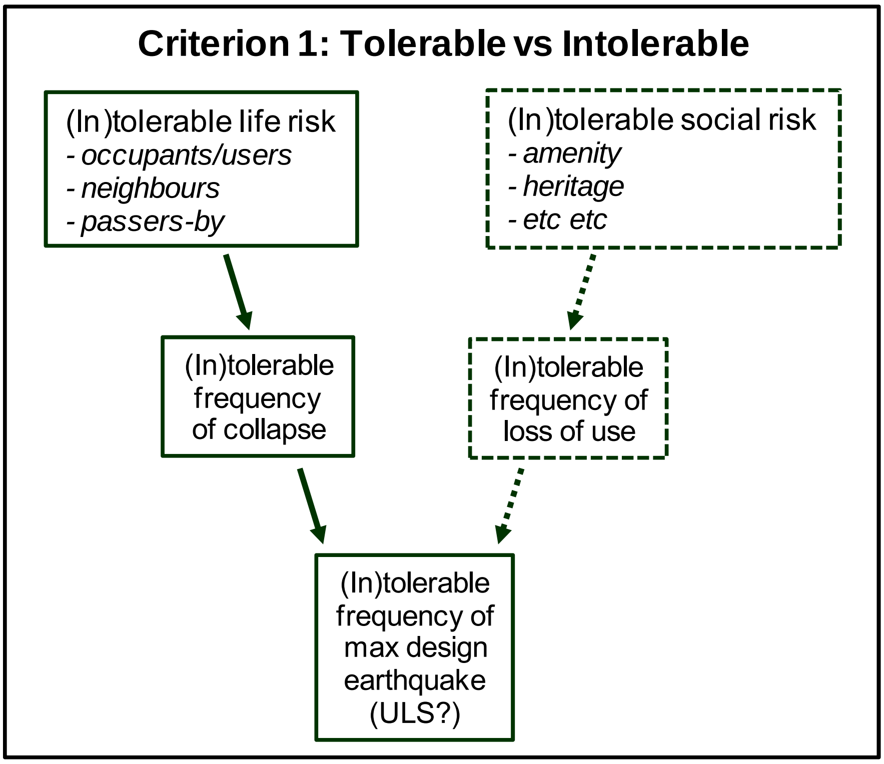

Figure 26: Application of Risk (In)tolerability Criteria

Figure 26 uses solid and dotted lines to reflect that decisions about what is or is not an intolerable level of risk may best be taken by different parties depending on the outcome being discussed. A starting point, as illustrated in Figure 26, might be:

- Safety risk – central criteria set by national government, reflecting widespread desire for reasonable consistency and assurance of safety decisions

- Heritage/social risk – largely local criteria set by the community, who are the primary beneficiaries and may need to be involved in financing risk mitigation (with the possible exception of a small number of buildings of major national importance)
- Economic risk – left to building owners, users and their insurers, as the parties who between them both suffer the adverse impacts and pay for mitigation, to decide.

Individual risk is in my view generally the best starting point for setting safety risk tolerability criteria; it focuses on the outcome people actually experience, and on avoiding undue inequity in the way risk is distributed. Individual risk also has the attractive feature that it takes into account how much time people spend at risk – someone spending 24 hours a day at risk is exposed to 24x the risk of someone spending 1 hour a day. So if a threshold is set in terms of tolerable annual individual fatality risk, this will automatically be more permissive of building failures where people spend small amounts of time, and less permissive where people spend more time.

For large modern buildings risk can probably be adequately controlled by focusing on building occupants and users, as it is largely they who are at risk (from rare but severe building failures) in such buildings. For older buildings (URM in particular) consideration is also needed of what is or is not tolerable in terms of the risks buildings impose on passers-by and people in neighbouring buildings. Neighbouring buildings could be dealt with using individual risk criteria applied to their heaviest users. Passers-by are more difficult as particular individuals may be at very low risk from individual buildings, but from significant risk from buildings collectively (imagine a postie making a round among older buildings in Wellington for example). One approach might be to assume that a most-exposed person spending X hours per day outside/around buildings collectively spent all X of those hours immediately outside an individual building; application of individual risk to passers-by needs further consideration.

Levels of tolerable risk may be modified for different types of people or building use, for example to take a more precautionary approach for sensitive buildings such as schools and hospitals, as is currently built into the NBS definitions. To some extent vulnerability should already be taken into account in estimating individual risk (as more vulnerable people will typically be at somewhat higher risk – applying a universal individual risk criterion will thus be inherently more restrictive on buildings where vulnerable people are involved).

If intolerable risk thresholds can be established for all three classes of stakeholder (occupiers/users, neighbours and passers-by), then the acceptable frequency of building collapse (the damage state which dominates life risk for all building types) would then be based on whichever group gave the lowest answer, taking into account the different occupancy rates involved[20].

An alternative approach might be to focus on the building rather than the individual and establish guidelines on the tolerable frequency with which a building may cause a fatal accident. This would have the advantage of naturally being less restrictive on buildings with lower occupancy

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[20] If the probability of death for an individual in each category who is present at the time of building collapse is P_o, P_n or P_p for occupants, neighbours and passers-by respectively, the tolerable risk threshold for each group is R_o, R_n or R_p, and the proportion of the time spent in at-risk locations by each group is O_o, O_n or O_p, then the threshold of tolerable frequency of building collapse would be the minimum of $R_o/(P_o.O_o)$, $R_n/(P_n.O_n)$ and $R_p/(P_p.O_p)$.

and around which fewer people spend less time, but could be permissive of very wide differences in building design standard for buildings with different numbers of occupants. Given the relative ease with which a tolerable collapse frequency can be related directly to individual life risk criteria, I consider it preferable to work back as shown in Figure 26, from

- Tolerable individual risk to different stakeholder groups, to
- Tolerable frequency of building collapse, to
- Specification of a maximum design earthquake (e.g. the frequency of the ULS event)

As illustrated in Figure 26, it would be straightforward to allow communities to apply additional constraints reflecting, for example, the amenity or heritage value attached to particular buildings. It is loss of the use of a building (rather than collapse per se) which creates the adverse impact, so we would be working back from tolerable scale/frequency of loss to tolerable frequency of loss of use of a building. Imposition of such constraints (over and above the requirements of ALARP) might be linked to the community sharing in the cost of compliance, to prevent communities making sweeping demands on building owners to provide unlimited safeguards regardless of cost

4.3.2 Applying the ALARP Criterion

A possible framework for applying the ALARP criterion is illustrated in Figure 27.

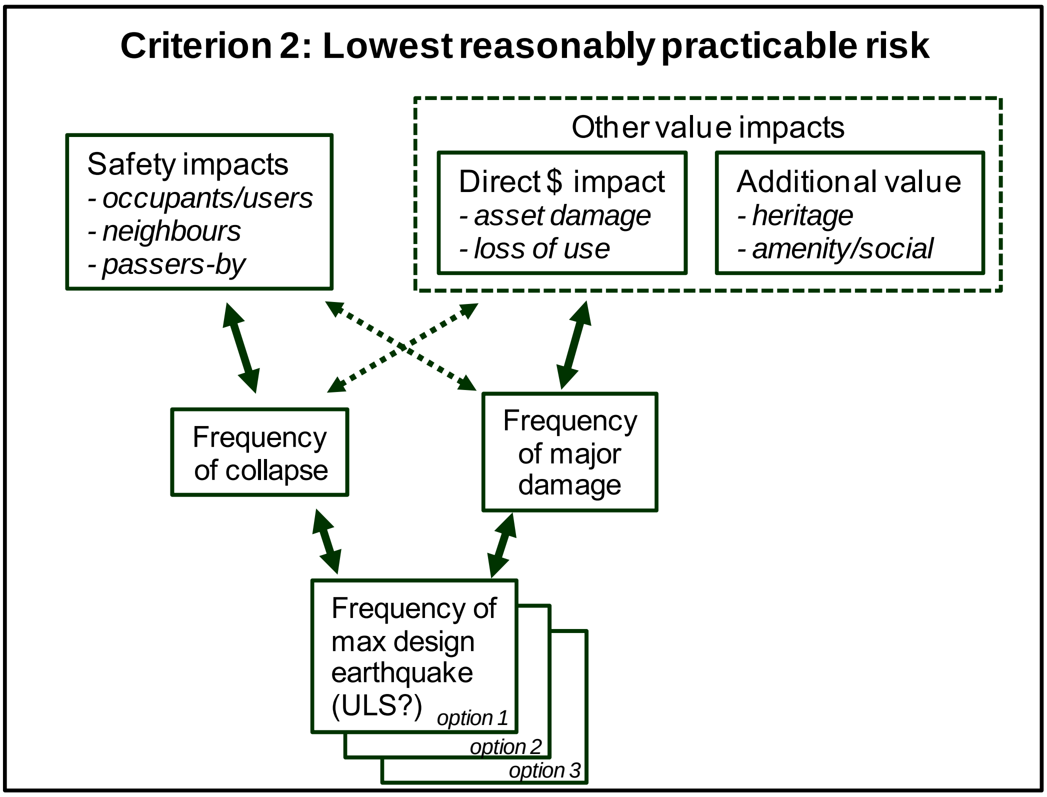

Figure 27: Application of Lowest Reasonably Practicable Risk Criterion

Figure 27 shows a number of options for risk control at the bottom of the figure. These are analysed to derive outcomes at building level (frequencies of different damage states) and thus frequencies and severities of ultimate adverse outcomes for stakeholders. These outcomes are aggregated over everyone involved, rather than being individually based. Thus we would be looking at total expected fatalities and injuries, and at overall social/heritage/amenity losses, rather than normalising those totals pro rata to populations or numbers involved. These aggregate outcomes can then be annualised and the set of outcomes and the costs of achieving them can be compared across options. The arrows are shown as 2-way, indicating the iterative nature of the process – exploring outcomes and varying inputs in light of the findings.

Exploration of options and comparison of their expected impacts, costs and other advantages and disadvantages is at the heart of demonstrating ALARP. The lowest reasonably practicable safety risk option is then that which provides the lowest reasonable safety risk, taking into account all the other factors (cost and other advantages and disadvantages) that are relevant. It cannot be left to the market to decide its own basis for determining what is ALARP; this would be a recipe for chaos. Government needs to make clear the basis on which it expects the determination of ALARP to be made. This can be done in a number of ways; commonly used approaches include:

1. Requiring duty holders to follow an established Code of Practice which explains the good practice risk controls appropriate in different circumstances,
2. Using cost-benefit assessment on a case-by-case basis, with key values (e.g. the value of preventing a fatality) centrally decided, to arrive at a case-specific optimum point of balance, or
3. Using cost-benefit assessment centrally as part of a one-off exercise to identify broad categories of circumstance for which different controls are appropriate.

An example of (1) is the current situation where NBS specifies requirements, but where there is no direct link at present to the safety and other outcomes being sought (what is controlled is the frequency of the ULS design earthquake, not the risk to people or property). Numerous hazardous industries and their regulators use cost-benefit assessment, but this can be a very demanding process to apply on a case by case basis and leaves open, particularly where assessments are subject to large uncertainties, the possibility of widely differing interpretations of what is "reasonably practicable" depending on precisely how the assessments are carried out and with what assumptions. This can all too easily shift decision making about risk from being a consultative, participative process to one which is determined by complex calculations carried out by experts in isolation from the interested and affected parties.

In the current New Zealand context, the 3rd of the options above provides the most attractive way forward in my view. This would enable standards and guidance to be retained in a relatively familiar format (similar to that presently used in NBS), but with a clearly established link between the requirements of the standard and the ultimate outcomes sought. In particular, I would expect there to be some very clear safety-driven minimum requirements, along with options for communities to modify requirements taking into account particular local values and concerns on issues such as amenity and heritage.

4.3.3 Developing Risk Criteria

Much work has been carried out in the past 12-18 months to develop advice for Christchurch City Council on intolerable risk thresholds for householders in the Port Hills at risk from rockfalls. Something similar needs doing to establish safety criteria and values at national level for earthquakes generally. Such an exercise would need to provide both criteria and guidelines on how to apply the "reasonably practicable" overarching criterion. Since this would set a precedent for other hazards; it would make a great deal of sense to carry out such an exercise for natural hazards in general (or indeed for all building-related hazards), not just for earthquakes in particular.

In developing risk tolerability criteria, comparisons with other risks are inevitable. The type of comparisons provided in Section 3 above should ideally be extended for such a purpose to include other buildings-related hazards (e.g. fire, leaky roofs). Substantial effort is also warranted on translating between risk levels, building collapse (and other damage state) frequencies, and design earthquakes such as the ULS, for a representative range of building types. Setting criteria will then normally involve a compromise between what would ideally be desirable (zero risk) and the real-world issues (cost, technical complexity, difficulty) that make zero risk undeliverable, with some confidence that the levels chosen will be broadly appropriate in comparison with other relevant risk levels that people face.

In developing an ALARP approach, two parallel streams of work are suggested:

1. Risk Assessment – Existing Buildings/Standards. This would involve assessing risks for a range of representative buildings, strengthened to different %NBS, using the framework of Figures 26 and 27 (i.e. to start from existing buildings and work upwards to assess risks and impacts in life and other terms). This exercise should bring together much existing work already carried out in New Zealand and can draw on work overseas (e.g. under the US ATC58 programme[21]).
2. Towards Risk Criteria. This would involve a programme of work to develop thinking on metrics and thresholds for intolerable life risk, and the core values that should be applied in judging when risks are as low as reasonably practicable. While this will require appropriate specialist expertise, it is vital that such a programme should engage stakeholders more widely; the ultimate decision on what criteria to adopt is a political, not a technical one.

These two streams of work would then need to be brought together before making firm decisions on appropriate criteria and values – such criteria can only be established once their practical implications in terms of building design and cost (which would emerge from the first workstream) are known.

4.4 Risk vs Building Features

One of the major difficulties in taking a risk-based approach to building safety in earthquakes is that the state of the art of risk assessment for buildings is developing rapidly, and is far from mature. The evidence collected from Christchurch data alone should help transform several aspects of the process, including:

[21] An overview is provided at https://www.atcouncil.org/Projects/atc-58-project.html; this is further discussed in Section 6.

a) assumptions to be made as to frequency of earthquakes near population centres,

b) likelihood of a given shaking/MMI given a particular earthquake,

c) likelihood of given building damage for a given shaking,

d) likelihood of death/injury outcomes for a given degree of building damage, and

e) dependence of (c) and (d) on building type and on nature/degree of strengthening.

Because all of these issues are subject to large uncertainties, current ability to assess and predict future risk with the current policy settings is limited. GNS Science have done a large amount of work over the past year to carry out risk assessments for slope collapse in the Port Hills which correctly (albeit very roughly) model risk from the whole spectrum of possible earthquakes. However, many "risk assessments" I have seen for earthquakes and other natural hazards, in New Zealand and elsewhere, make confused associations between return periods, consequences for a given return period, and risk. The confusion between building standards and implied risk requirements is discussed further in Section 5.2.

An important conclusion from this is that at present there is no possibility of setting high-level standards in risk terms and then leaving it to local authorities, building owners and engineers to translate them into building requirements. Instead, risk assessment should be carried out centrally and used to inform the setting of standards in terms more familiar to buildings owners and other stakeholders. It should not be concluded that because risk assessment is uncertain and immature it is not vitally useful – it is far better to work with clarity of overall approach and transparency in exposing uncertainty than to work "blind" to the risk implications of standards. And the adoption of a risk-based approach will itself promote the research and analysis necessary to reduce the uncertainties, and to enable them to be targeted on the areas where improved knowledge will make most difference to the results.

4.5 Identification of Earthquake-Prone Buildings

A major issue revealed by the failures of the PGC and CTV buildings in Christchurch is that buildings of relatively modern design and construction may have failure modes, particularly when subjected to more severe shaking, which were not identified and addressed during their design, consent and construction processes. The PGC building was estimated in discussion at the Royal Commission Inquiry to be between 30 and 40% NBS (a borderline EPB).

Given the observations in Section 3.2 about the importance of severe shaking events for overall earthquake risk, and the greater potential lethality of large concrete buildings than of older buildings should they collapse, it is important that any process for identifying and addressing EPBs needs to include some mechanism for identifying "High risk buildings that don't stand out as being obviously earthquake-prone". This is discussed further in Section 4.7.

4.6 Evaluating What to Do about Earthquake Prone Buildings

In reading the DBH guidance document for Local Authorities provided at the outset of this work[22] and the transcripts of Royal Commission hearings into the buildings whose failure caused

[22] DBH, Earthquake-prone Building Policy Reviews 2011: Guidance Material for Territorial Authorities, November 2010

fatalities in the Christchurch 22/2/11 earthquake, it is clear that there is a great deal of confusion about “How far is far enough?” to strengthen a building once it is identified as earthquake-prone.

Just as it seems unlikely (4.4) that it would be workable to define criteria for safety risk and then leave it to building owners, local authorities and engineers to apply them, so it seems unlikely that it would be workable to adopt a purely risk-based “reduce risk as far as reasonably practicable” policy and leave it to those same stakeholders to work out how to do this.

The solution is likely to be a mixture of simple minimum levels (such as are effectively provided in the current Building Act and Regulations requiring upgrading to 100% NBS on a change of use, or to 33% of NBS by a due date) along with clear, centrally produced guidance on what else needs to be done to ensure risk is as low as reasonably practicable.

The selection of appropriate minimum levels for upgrade should reflect the risk involved. There is little point requiring a building involving very low risk uses to be upgraded to 100% NBS. If research now in progress confirms the observations in Section 3.3 (Summary point 6) that the safety benefits are substantially greater in getting from below 33% to 33% NBS than in progressing further to 67% or 100% NBS, then it may be inappropriate for legislation to require strengthening to 100% NBS for changes of use generally.

Changes both to the end point for upgrading on change of use, and to the definition of an EPB, should in my view await better evidence on the risk implications of such changes. In the meantime there are other issues to be tackled (sorting out the barriers to attaining the planned benefits of upgrading within current definitions) which can and should be progressed.

4.7 Evaluating Real Risk Reduction

Risk reduction measures adopted by regulators have in very many cases failed to achieve their full intended benefits for a wide variety of reasons. In the Christchurch 22/2/11 earthquake, 178 of the 185 fatalities were associated with building failure. These are broken down in Figure 28 (numbers of fatalities shown in lilac boxes; specific buildings involved in purple italics) in terms of the different ways in which EPB policy failed to address them. There is no implication here that EPB policy was in any way “to blame” for any of these fatalities; simply an observation as to the mechanism by which the policy goal of reducing harm from EPBs was compromised in this particular case – entirely to do with other system issues rather than the actual %NBS adopted for the EPB policy setting.

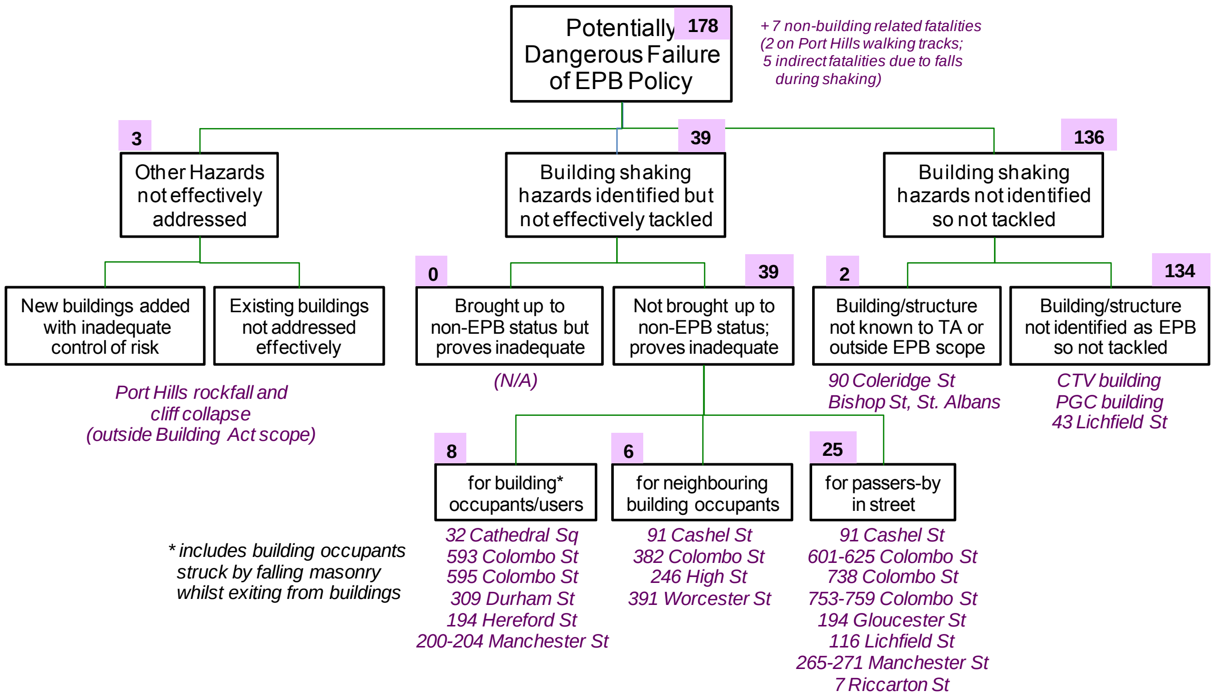

Figure 28: Mechanisms by which Christchurch Fatal Building Failures bypassed EPB Policy
(based on reading of Royal Commission hearings, pre-publication of the Royal Commission report)

The blocks on the right hand side of Figure 28 involve failing to identify at-risk buildings, which has been discussed in Section 4.5. The blocks on the left involve hazards other than shaking, which would have involved more fatalities in comparison with the other blocks had the earthquake occurred outside business hours. In the middle are all the buildings that were potentially identifiable as earthquake-prone prior to the 22/2/11 earthquake. For a wide variety of reasons (many of them linked to the Council's passive EPB policy, requiring strengthening to be done only when a planning application involving a change of use was submitted) these buildings had not been strengthened, or had been strengthened to less than 33% NBS.

It is worth considering how the pattern of fatalities would have changed on this picture had the 22/2/11 earthquake not been preceded by the 4/9/10 event. On the one hand, no buildings would have been red or yellow placarded and no cordons would have been in place, which might have been expected to lead to considerably more casualties. On the other hand, the extent of building damage on 22/2/11 may have been partly attributable to prior weakening in the 4/9/10 event.

The point of this picture and discussion is to bring home the importance of considering all the ways an EPB policy might fail – not just in the earthquakes recently experienced in Christchurch, but also in all other earthquakes that might occur in New Zealand. There is much current debate about whether the threshold for defining an EPB that requires strengthening should be moved from 33 to 67% or higher of NBS. Of greater concern in my view are the possibilities

a) of other hazards than building shaking,

b) of missing high-risk buildings among the stock not readily identifiable as earthquake prone, and

c) of long delays in the time it takes to get from today's situation, with a large population of buildings not strengthened to 33% NBS, to a better situation where most buildings are strengthened to at least a minimum 33% NBS (see also Sections 5.3 and 5.4).

EPB policy options need to be evaluated systematically against all the ways, in the real world, in which they might fail to deliver their intent. As a matter of principle such evaluation of effectiveness should always involve

a) identification of those segments of risk the proposed measures do/do not address

b) evaluation of the maximum effectiveness of the proposed measures against each of the mechanisms by which the segments of risk addressed could come about, assuming each measure works consistently and permanently exactly as intended, and then

c) evaluation of all the ways in which the policy options might fail or produce unintended consequences.

5. Observations on Current EPB Policy

This section is organised under headings matching the issues that DBH requested this paper should address:

- The stock of existing buildings and their uses
- The Building Code, New Building Standard and current EPB definition (33% NBS)
- How adequately current EPB policy settings control risk
- The role of local authorities in administering and enforcing policy
- The adequacy of information and guidance from DBH to local authorities, and
- The adequacy of information and guidance from DBH to building owners and occupants.

5.1 Existing Building Stock and Uses

The current approach to defining EPBs (33% NBS) takes into account the nature and use of the building in that the NBS requirement is matched to the Importance Level of the building as shown in Table 2 below.

Import-ance Level	**Definition**	**Examples (abridged)**	**Design earthquake** return period
1	Structures presenting a low degree of hazard to life and other property	Farm buildings, fences, masts, walls, in-ground swimming pools	100 yrs
2	Normal structures and structures not in other importance levels	Hotels, offices, apartments < 15 storeys, car parking buildings, shopping centres <10,000m^2 gross area	500 yrs
3	Structures that as a whole may contain people in crowds or contents of high value to the community or pose risks to people in crowds	Emergency medical facilities, airport terminals, main railway stations, prisons, educational buildings. Hotels, motels, apartment buildings, offices > 15 floors Public assembly buildings, museums, galleries >1000m^2 Shopping malls >10,000m2 Grandstands for >10,000 people	1000 yrs
4	Structures with special post-disaster functions	Major infrastructure - power stations, air traffic control. Civil emergency centres, emergency services (police, fire, medical)	2500 yrs
5	Special structures	Dams, extreme hazard facilities	(out of scope)

Table 2: NBS Importance Levels (from tables 3.1 and 3.2, AS/NZS 1170.0:2002)

The design earthquake is tailored to the location by defining it in terms of an expected return period, so that whatever its risk implications are (see 5.2 for discussion of this) they will be the same wherever the building is sited. The importance level takes into account both the number of people at risk and the special value of particular building uses and users. In broad terms, this appears a very sensible approach, though it contains some potential anomalies when viewed from a risk perspective, in particular

a) The lowest importance level includes "walls", which are potentially much higher hazard to people other than building users (e.g. passers by, neighbours) than the other structures in this group.

b) The distinction between levels 2 and 3 takes no account of the proportion of the time for which buildings are in use – a 14 floor apartment block might have hundreds of people spending a large proportion of their lives there, while a 20,000 seat grandstand might be occupied at this level for a few dozen hours per year.

c) No distinction is made between structures putting their users at risk, and structures which put other people at risk. It might be argued that building users more or less accept a degree of risk when entering a building whereas passers-by and neighbours do not – but in practice we are all in and out of, outside and next-door to so many buildings for so much of our time that this distinction may not be worth making. What should not be the case is that we treat neighbours and passers-by as of lower significance than users (as effectively happened in some cases in Christchurch during the 22/2/11 earthquake when some red/yellow placarded buildings collapsed killing people outside or next-door to them).

A risk-based approach might use a similar "ladder" of defined levels of ground shaking, where a particular building would be located on the ladder based on individual risk to building users (this would take into account the proportion of time for which a user might be present), then adjusted up or down based on risk to others, number of people at risk, and special sensitivity factors. The end result would be to provide a similarly straightforward design level for each building, but with those design levels more closely tailored to building use, occupancy and numbers at risk.

A further advantage is that consistent policy could also be applied to hazards other than building failure due to ground shaking, which (based on my experience with rockfall and cliff collapse issues in the Port Hills and on a number of other locations in New Zealand where buildings have been sited in locations at high risk of other natural hazards) are not well-controlled by current planning arrangements in New Zealand.

Turning now to the existing building stock, it is clear that New Zealand has a large population of older buildings which have not yet been brought up to a good standard of resilience to ground shaking under current EPB policy. There is almost certainly a smaller but potentially significant population of newer buildings which are not identified as EPBs but have undetected flaws. Further buildings of various ages are located in places exposing them to high risk of slope collapse (or other hazards not involving building failure due to shaking). Two important issues to be addressed in addition to the %NBS definition of an EPB are:

- The timeliness of getting clearly deficient buildings up to a reasonable standard, and
- Bringing high-risk buildings not currently tackled by EPB policy within that policy scope.

5.2 Building Code, NBS and EPB Definition

The basic hierarchy of a Building Code, NBS laying out the design requirement for different buildings, and an EPB definition accompanied by an obligation for local authorities to identify and do something about EPBs seems a good one. It also seems a good idea to define the requirement buildings must meet (in order to address building failure due to ground shaking) in terms of a measure of ground shaking corresponding to a given return period.

What seems much less clear, and creates a great deal of confusion, is what the requirements of buildings laid out in the Building Act, NBS and NZS1170.5 imply in risk terms.

The Commentary Section C2.1 of NZS1170.5 (Standards NZ, 2004) states:

> *"Internationally, an accepted basis for building code requirements is a target annual earthquake fatality risk in the order of 10^{-6} (ISO 2394:1998). In design terms it is generally accepted that fatality risk will only be present if a building fails, i.e., collapses. The maximum allowable probability of collapse of the structure is then dependent on the probability of a person being killed, given that the building has collapsed. This conditional probability will be dependent on structural type and other factors and is likely to be in the range 10^{-1} to 10^{-2}…. Acceptable annual probabilities of collapse might therefore be in the range 10^{-4} to 10^{-6}."*

The commentary then points out that it is not practical to design for a collapse limit state. Instead, design is for a lower level of earthquake motion, for a level of structural performance that can be more reliably predicted. This limit state is referred to as the Ultimate Limit State (ULS). For normal use buildings, the ULS is usually associated with 500-year return period motions. The intent is clearly to achieve associated probabilities of collapse and fatality that are much lower than 1/500 per year, but the relationship between what is designed for at the ULS and what is to be achieved in terms of probability of collapse under shaking at different levels greater than the ULS is not specified.

The NBS requires that at the ULS the building should

- Avoid collapse of the structural system
- Avoid collapse or loss of support to key parts that could create hazards to life inside or outside the structure, and
- Preserve operability of systems necessary for emergency building evacuation.

Going beyond the ULS, the commentary on NZS1170.5 states

> *"It is inherent within this Standard that, in order to ensure an acceptable risk of collapse, there should be a reasonable margin between the performance of material and structural form combinations at the ULS and at the collapse limit state. For most ductile materials and structure configurations it has been assumed that a margin of at least 1.5 to 1.8 will be available. This is intended to apply to both strength and displacement."*

This approach provides some confidence that collapse will be significantly rarer than the ULS designed for, but does not assure that any particular quantified level of risk will be delivered. In particular:

a) the point of collapse above the ULS is not specified, and indeed is very difficult to specify,

b) the risk to be contributed from scenarios below the point of collapse (no real world building is every 100% safe within its design limits – poor construction, poor maintenance, design errors, unplanned modifications etc all erode intended performance) is not specified, and

c) although there is a clearly expressed intent in risk terms it is not translated into any specific requirements for the combination of [frequency of collapse] x [probability of death].

While the Code and NBS provide for consistency of risk treatment across different locations, it is thus not at all clear what level of safety risk they would actually deliver, to building users or others. It may be the aspiration of the NZ standard that designing to the ULS for a given event return period will control risk to an AIFR of 10^{-6} per year, but there is no assurance at all that such a design requirement will control risk to this or any other level. It is entirely possible that two Code-compliant buildings could deliver quite different risk profiles, potentially orders of magnitude different in safety risk.

Buildings designed and built to comply with NZS1170.5 should incorporate the margins referred to above between ULS and collapse which provide significant (albeit unquantified) assurance as to the low likelihood of collapse. Older buildings with low %NBS values are unlikely to embody the principles of toughness and ductility inherent in structures designed to NZS1170.5. When subjected to shaking above their evaluated capacity they are thus likely to exhibit higher probabilities of collapse and of death for occupants than would new buildings.

Much work has been carried out in the USA and elsewhere to develop a more quantified approach to interpretation of building requirements in terms of risk, probability of collapse and probability of death in the event of collapse. The current NZ approach recognises the inherent difficulties in specifying the point of collapse and thus its probability. The NZS1170.5 commentary states:

> *"Given the current state of knowledge of the variables and the inherent uncertainties involved in reliably predicting when a structure will collapse, it is not currently considered practical to either analyse a building to determine the probability of collapse or base a code verification method around a collapse limit state."*

To be able to have confidence in the relationship between building requirements and risk in terms of life and other ultimate outcomes, substantial further work will be needed. The good news is that

a) the evidence available from the Canterbury earthquakes is being extensively researched and should enable significant steps forward to be made in a specifically NZ context,

b) considerable progress has been made in the USA and elsewhere to develop the necessary risk assessment processes, and

c) the same risk assessment processes that will enable the risk from a given building to be estimated across the whole spectrum of possible earthquakes will also enable criteria expressed in risk to be translated back into practical building requirements to provide for genuine assurance that risk is being controlled to a given level.

Figure 29 (based on the US ATC-58 methodology report[23] Figure 1-1) illustrates a performance or risk-based approach to building design.

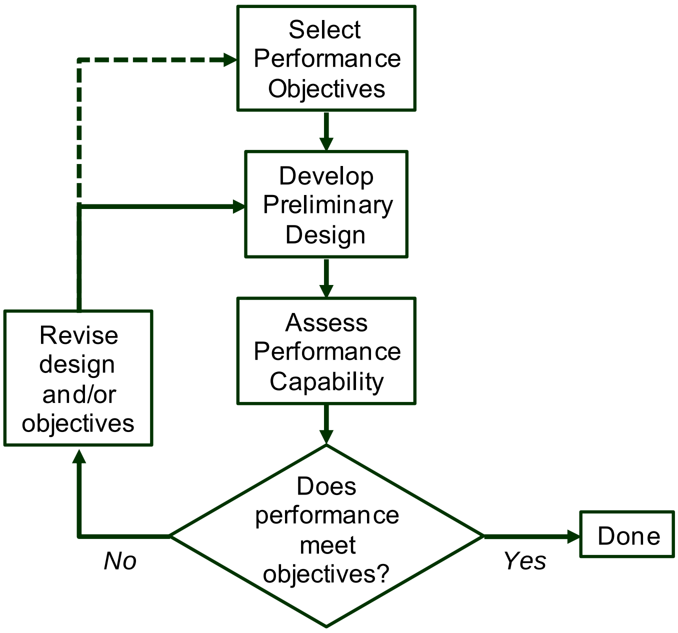

Figure 29: Performance-Based Design Approach (from ATC-58)

The difference between this and the current NZ approach is that the latter establishes design requirements which then become the basis for a similar process. But the link to performance objectives at the top of the diagram is not established. If New Zealand wishes (as I believe it should) to establish safety and other performance requirements in their Building Code which underpin the design requirements of NBS and related documents, then the assessment of risk, and thus of the likelihood and consequences of building collapse as well as of other less severe damage states will be essential to that process.

The approach I consider would best suit New Zealand is illustrated in Figure 30. Rather than moving entirely to a performance-based approach such as that developed in ATC 58, this would retain clear design requirements laid out in terms not dissimilar to those currently contained in the Building Code and NBS. What would be different would be that those design requirements would be established via a process that involved both the development of risk criteria and the assessment of buildings meeting a given set of design requirements against those risk criteria.

[23] Seismic Performance Assessment of Buildings, Volume 1 – Methodology, ATC-58-1 75% Draft, Applied Technology Council, California USA, May 2011

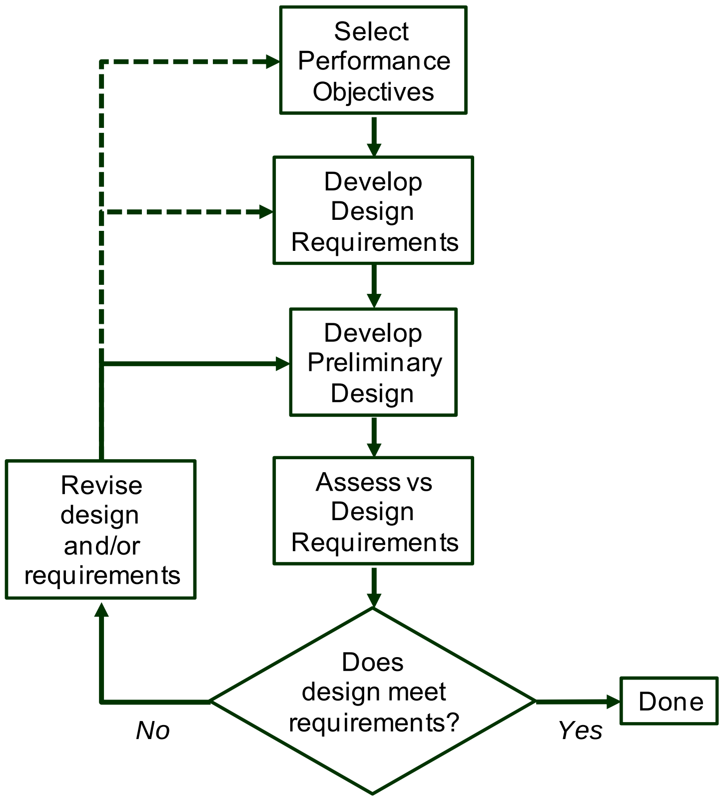

Figure 30: Proposed New Zealand Risk-Based Design Approach

What is missing in New Zealand is the top part of this figure, without which debates about what EPB and other policy settings to adopt are taking place without good evidence as to what levels of performance the policy settings are delivering, and whether those levels of performance are optimal. The primary recommendation of this report is for work to fill this gap.

5.3 How well do Current EPB Policy Settings Control Risks?

The answer here, based on the documentation of Local Authority progress provided by DBH (see e.g. Section 5.4 below) and on my discussions with stakeholders in the course of preparing this report, seems to be a fairly clear "Not very well at all". This is because of slow progress in implementation, rather than because of the EPB definition itself. Most Local Authorities seem to be slow to gain traction with their EPB programmes, and even the leaders are finding it slow and heavy going (see Section 4.6 and DBH reference therein). Difficulties include

- Identifying and assessing at-risk buildings
- Adoption of passive policies by many Local Authorities (allowing vulnerable buildings to continue in use indefinitely unless a change of use is proposed)
- Determining "how far is far enough" to strengthen EPBs, and
- Agreeing programmes of work and timescales with building owners.

An important question posed by DBH is "How much difference would it make to change the EPB definition from 33% to 67% NBS?" This depends on the balance of benefits and disbenefits associated with each policy option. Clearly the latter would involve greater cost, but what about the safety benefits? Following the advice of Section 4.7 consideration is needed in turn of:

a) what segments of the risk this change would address

b) the effect it would have if universally and perfectly implemented, and then

c) the likely real-world erosion of that effect by delays and imperfections in implementation.

As regards (a), the change would not address buildings that fall outside the set we identify as EPB, so (unless accompanied by some other changes) would not have addressed the CTV/PGC building type issues.

As regards (b), two views are possible as discussed in Section 3.2.2. It is clear there would be some benefit in reducing the likelihood of URM buildings suffering severe damage, but not clear that there would be a significant reduction in the likelihood of total collapse, which is where most of the risk to life lies. While it is difficult to quantify and to generalise from the URM research done post-22/2/11 to other earthquakes and buildings, I consider it likely that the safety benefit in moving from 33% to 67% NBS overall would be substantially less than that in moving from well below 33% to 33% NBS.

As regards (c), if the barriers to timely and effective implementation of current policy were not tackled it seems likely that moving to 67% would add to the difficulty in securing consensus about what needed doing to buildings to bring them up to scratch, and further slow down the process of getting from State A (current EPB buildings) to State B (EPB buildings improved as we would wish).

While the safety benefits of moving from 33% to 67% NBS as the basis for definition of EPBs remain uncertain, this should in my view be a lower priority than

a) accelerating the process of getting the large stock of <33% buildings up to 33%, and

b) bringing high-risk buildings that would not currently be captured by EPB policy (whether because presumed to be Code-compliant or via hazards other than ground shaking) under control.

5.4 Role of Local Authorities in EPB Risk Management

Local Authorities have a pivotal role to play in current EPB arrangements, in

- Establishing policy
- Identifying EPBs, and
- Progressing resolution of EPB status with building owners.

It seems vitally important that Local Authorities should have a substantial role in EPB policy and its administration. They are closer to the building stock, closer to the building owners, and closer to the community whose preferences should be reflected in policy; it would be unthinkable not for them to have a major role.

Leaving policy setting and implementation to Local Authorities means, though, that there is considerable variability in approach across New Zealand. This is illustrated in Figure 31.

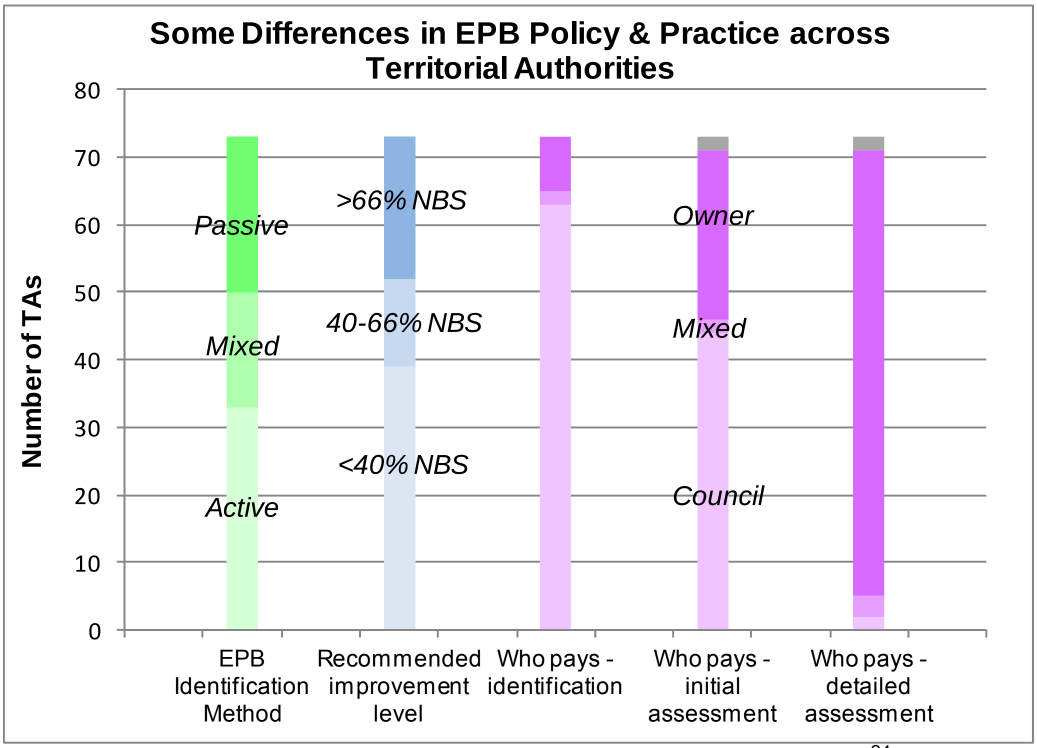

Figure 31 – Variations in Local Authority Policy & Practice (DBH data[24])

As Figure 31 makes clear, there are significant difference in how far buildings are recommended to be strengthened, in who pays for identification and assessment, and in selection of approach (a passive approach is one where the Local Authority reviews EPB status as and when planning applications are submitted in relations to buildings, whereas an active approach involves going out and assessing them to an agenda set by the Authority). The figure does not show the complex variations in time frames established both for assessment and for strengthening actions, which depend on building types which themselves are classified differently across Authorities.

Another important issue for many Local Authorities is that the expertise and resources needed to identify and assess EPBs are scarce and are in heavy demand. Some larger Authorities have in-house expertise but for most there is a reliance on consultants and contractors. Having seen some examples of risk assessment processes being proposed by Local Authorities, I anticipate that there could be a great deal of variability between Authorities in what gets defined as an EPB, arising from differences in risk assessment approach and interpretation rather than from any differences in policy.

Assuming these issues of EPB assessment capability could be tackled, there would remain substantial differences in circumstances between different districts and regions, in terms of

- Age profiles of buildings
- Materials commonly used in construction
- Geological conditions, and

[24] http://www.dbh.govt.nz/UserFiles/File/Building/information%20for/ta-earthquake-prone-building-summary.xls

- Seismicity and associated likelihood of earthquakes of different severities.

The result is that the numbers of EPBs, and the costs of dealing with them, are likely to vary widely across the country. This variation is unlikely to arise neatly in proportion to the resources of Local Authorities to evaluate their EPBs, or to the capacity of local economies to fund what is needed to meet any sort of common safety objectives. Consideration may thus need to be given to national Government assistance to some councils/communities if reasonable consistency of national safety objectives is sought.

5.5 Adequacy of Info and Guidance from DBH (MBIE) to Local Authorities

While Local Authorities generally appear keen to maintain their role in and influence over EPB policy and implementation, there are some real issues of consistency of both policy and implementation, and of capability at Local Authority level. The most obvious way to address these would be through improved guidance from DBH (now MBIE) on issues such as

a) What constitutes a minimum acceptable timeframe and level of strengthening for improving EPBs' resilience to earthquakes

b) What constraints/discretion is available for special (e.g. heritage) buildings

c) Reporting progress to central government

d) How to screen out potentially high risk buildings

e) How to assess risk at potentially high risk buildings, and

f) Evaluation of proposed strengthening measures.

The first three of these are matters of policy. The latter three are all to do with capability. While guidance is an important first step, it may be that something rather more is needed to support Local Authority capability. Pilot/demonstration assessments should form part of this, but it will also be important for MBIE centrally to monitor progress. If there is not a significant step forward in both timeliness and effectiveness of local action, it may be necessary to consider further capability support (e.g. establishment of a small central unit to advise, facilitate and mentor people working in this area in Local Authorities).

5.6 Adequacy of Info & Guidance for Building Owners & Occupants

It is clear reading the transcripts of Royal Commission hearings on buildings that caused fatalities on 22/2/11 that, while most building owners had some sort of awareness of the Council having an earthquake prone building policy, several either had no idea what it was, were unsure whether it applied to them, or were waiting to be told what to do by the Council. There is clearly scope for improving awareness of EPB policy among building owners, but this is secondary in my view to sorting out Local Authorities' role and capability to implement it. The primary and most effective way of letting building owners know the requirements of them in respect of EPBs is likely to involve someone from the Council contacting them and speaking to them. Building owners should not need particular knowledge of how to strengthen their buildings as this would generally form part of the advice they receive from the engineering community, among whom good practice on building strengthening post-Christchurch should be shared in a timely way.

As regards building occupants, users and neighbours, there is an important issue here of letting people know if they are at particular risk in or from EPBs. This both lets them use their influence to speed up resolution of EPBs, and provides a starting point for helping them to manage their own risk. Many people in URM buildings in Christchurch on 22/2/11 put themselves at great risk trying to escape from buildings and running into falling facades and parapets – if building occupants and users were more aware of the nature of the hazards associated with the particular buildings around them they might be better prepared to manage their own risk.

6. Conclusions and Way Forward

My conclusions are as follows:

1. Earthquakes stand out from other hazards in New Zealand in terms of the frequency of very large impact events and the individual risk they present to people in high risk locations. But averaged over the whole population and long periods of time they have a lower impact than some other hazards such as road accidents.
2. Building risk from shaking has been the largest contributor to damage and lives lost in NZ earthquakes to date, but is not the whole picture. Had the 22/2/11 earthquake happened at night fatalities due to slope collapse in the Port Hills may have exceeded those in the CBD.
3. Earthquakes are unusual relative to most other hazards in that most of the overall time-averaged risk from earthquakes is associated with very severe, rare events. This is because, as shaking increases, its likelihood gets lower but its consequences get worse. For a given increase in shaking the effect of increasing consequence outweighs the effect of decreasing likelihood, so that overall risk (in terms of likelihood x consequences) gets bigger as shaking increases.
4. Important implications of earthquake risk being greatest for rare, severe events include
   a) NZ earthquakes since the 1850's may under-represent long-term average risks, and
   b) Care is needed to ensure that measures designed to protect against medium levels of shaking do not make things worse in the more severe events that dominate the risk.
5. Earthquake risk is distributed amongst different people in a complex fashion, for example:
   a) In smaller earthquakes economic risk is well aligned with building owners and users. But the wider social and economic impacts of major earthquakes are unlikely to be attributable to specific owners/users; governments typically play a major part in addressing these issues (and bear a significant share of associated costs).
   b) Life risk is greater for neighbours and passers-by than for occupants of some older buildings, and
   c) Heritage conservation may be completely disconnected from building ownership and use.
6. The definition of limit states in ground shaking terms in the NBS provides a practical and consistent way of controlling risk due to building damage from shaking, but the relationship between shaking and risk is complex. This relationship has not been well characterised to date in New Zealand but much work has been carried out in the USA and elsewhere to develop methods enabling life and other risks to be assessed.
7. The Building Code and NBS do not control earthquake risk to any specific level because
   a) they do not specify performance requirements of buildings below, at and above the ULS, (the risk for two compliant buildings could be very different) and
   b) they do not address other hazards than building damage due to ground shaking.
8. The primary objective of public policy in relation to EPBs should be to control life risk to the lowest reasonably practicable level – balancing reduction in risk with the cost of doing so, subject to the constraint that tolerable life risk thresholds are not exceeded.

9. Additional constraints to safeguard other highly valued assets (e.g. heritage buildings or buildings of strategic importance) may readily be added in to such an approach, but should be subject to safeguards that they do not unduly over-ride life safety.
10. In comparing the benefits of strengthening to 33%NBS vs 67% NBS or some other level, there is a "window" of shaking within which benefits would be significant. At lower levels, there is no difference as either level would ensure minimal damage; at higher levels there is no difference as neither would prevent very severe damage. In terms of safety benefits, the experience of the Christchurch 22/2/11 event suggests that the shaking threshold above which there would be significant benefits of moving from 33% to 67% NBS is quite high (there were no fatalities involving buildings that had been strengthened to 33% NBS or better). In terms of economic benefits, the Christchurch 22/2/11 experience suggests that this threshold would be lower (the proportion of buildings which suffered severe damage short of total collapse was significantly lower for buildings strengthened to 67% or better compared with those strengthened to 33% NBS).
11. There can be high confidence that other measures would have a greater impact in reducing safety risk associated with buildings in earthquakes, in particular
    a) reducing delay in getting identified high risk buildings upgraded
    b) bringing high risk buildings not readily identifiable as EPB within the EPB framework, and
    c) extending the scope of building-related measures to provide equivalent risk control over other life hazards from earthquakes.
12. The state of the art of building risk assessment in earthquakes is insufficiently mature to contemplate setting building standards in risk-based terms. An improved risk assessment framework for buildings in earthquakes could, though, provide a more direct link between building controls and risk than is available at present.
13. The benefits of such a framework would be considerable, in particular in providing
    a) assurance of risk control across the whole range of ground shaking severity
    b) a more consistent, outcomes-focused basis for aspects of NBS such as building importance definitions
    c) a firm foundation for policy settings in relation to EPB and other matters, and
    d) a clear line of sight between safety policy goals and the measures intended to deliver them.
14. Local Authorities play an important part in determining, implementing and enforcing EPB policy, but this leads to considerable local variation in policy and significant practical difficulties for the majority of Authorities who do not have relevant in-house expertise.

My recommendations are:

1. **Policy Goals and Building Requirements:** MBIE in conjunction with other departments and agencies as appropriate should progress work to develop a risk-based framework which connects building requirements laid down in the Building Code, NBS and related documents directly to the safety and other outcomes they are intended to deliver. This will involve

   a) developing proposals for national criteria and values for life risk in relation to earthquakes and other natural hazards, as part of a broader framework of objectives and decision making on building performance in earthquakes to underpin national and local policy decisions,

b) collecting and applying available risk assessment methods and information to establish the life and other risks associated with different building types, and the sensitivity of those risks to building characteristics,

c) bringing together (a) and (b) to establish national outcome criteria and decision processes related to building risk from earthquakes in the knowledge of their implications for existing and new buildings,

d) reviewing Building Code, NBS and EPB policy settings in light of those criteria and of the implications of building design for performance,

e) adoption of any new policy settings for both new and existing buildings, and

f) ongoing evaluation of assessed and actual building performance in comparison with the outcome goals established, along with continued development (maximising learning from the Canterbury earthquakes of 2010 and 2011 and taking advantage of ongoing research and development overseas) of the methods and evidence needed to assess the risk implications of building features.

The approach is illustrated in Figure 32.

2. **Interim Priorities**: In the short term (ideally until the linkages shown in Figure 32 can be established) DBH should give priority to addressing the issues identified in Conclusion 11 above rather than to changing the definition of an EPB from 33% to 67% NBS or some other value.
3. **Local Authority Involvement**: The role of Local Authorities in EPB policy development, implementation and enforcement should continue but with an enhanced level of oversight and support from DBH to provide
a) for consistency of policies with high-level national safety policy objectives, and
b) greater guidance, support and if necessary capability to assist Authorities with this work.

Tony Taig
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12 November 2012

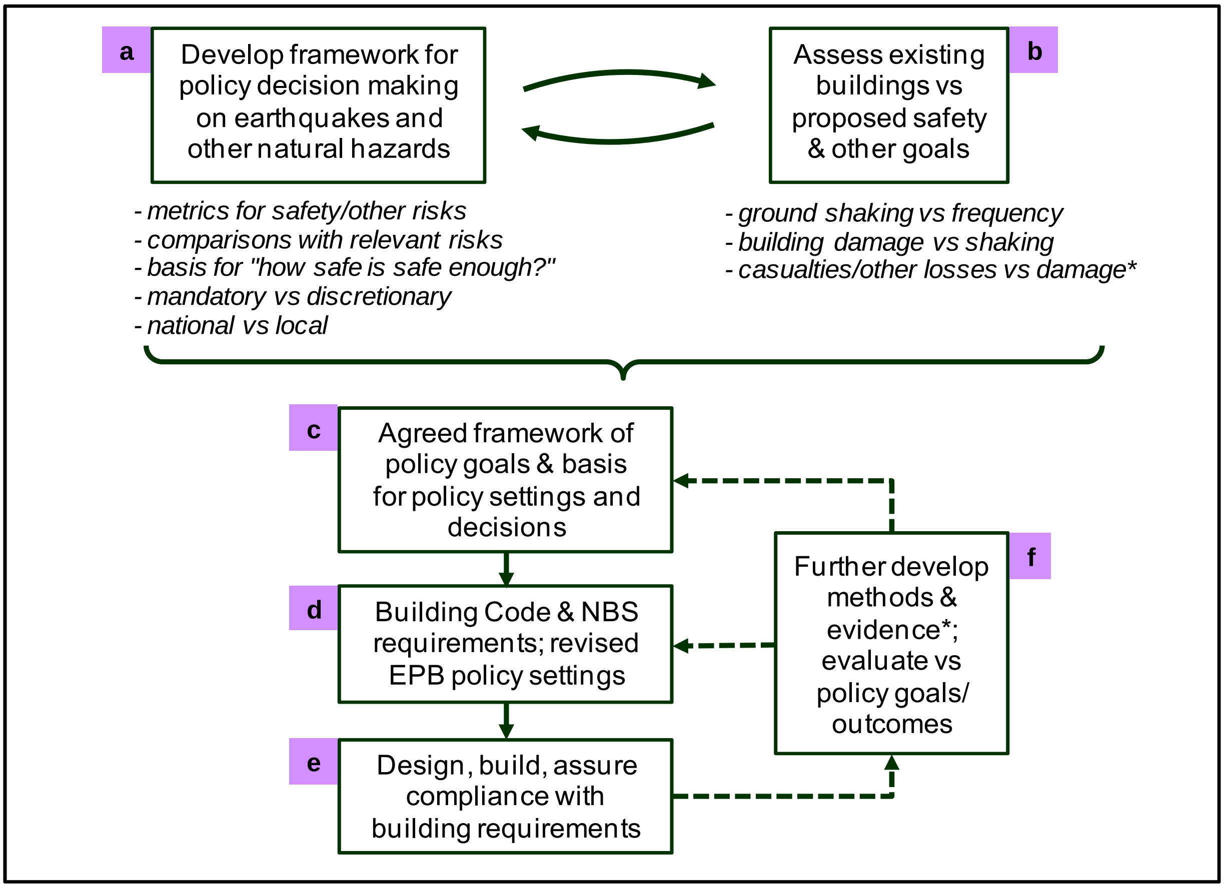

Figure 32: Towards a Risk-Based Framework for Earthquake Policy Settings

* More knowledge of risk to life in the event of building collapse should be obtainable via the 22/2/11 tragedy. Casualties have been well researched, but parallel information is needed on where people were at the time in order to understand the risk from collapse – this is not to my knowledge being pursued at present.