Risk thresholds and the built environment

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ABSTRACT

Engineering design inherently deals with risk. But risk is rarely—if ever—explicitly considered. Most building design in Aotearoa New Zealand (i.e. to B1/VM1 NZS1170) targets an annual individual fatality risk (AIFR) of $1x10^{-6}$, or 0.0001% chance of dying per year in a typical building from collapse or damage due to an earthquake. This paper contextualises that risk threshold by comparing it to risks associated with other common activities in New Zealand. The comparison reveals a lack of established risk thresholds, a wide range of experienced fatality risks, and inconsistent application and terminology where risk thresholds are used. To address this, we share thinking from a Discussion Paper (in draft) on a proposed national risk threshold framework. Creating a coherent, hazard-agnostic risk policy setting will help contribute to challenging opportunities such as RMA reform, climate change adaptation, implementation and update of the Building Act, and other national and sub-national mechanisms.

1 INTRODUCTION

This paper contextualises levels of risk in the built environment with other commonly experienced risks in New Zealand society. Understanding the level of risk associated with 'code' buildings, how those risks are described, and how they compare to other levels of risk can help inform how buildings are designed in the future, as well as risk reduction efforts now. Additionally, comparing risks can help to understand whether risks from various hazard sources are being considered appropriately in relation to each other.

A broad-brush approach is taken to approximately quantifying levels of risk. The statistical methods used herein are far from flawless, but they provide reliable estimates for comparison, with the order of magnitude more important than the digits.

Much of the thinking for this paper came from the Toka Tū Ake EQC *Natural Hazard Risk Tolerance Discussion Paper* (Toka Tū Ake EQC, in draft).

2 A BRIEF DISCUSSION ON RISK

2.1 Risk

The term ‘risk’ is often used in the built environment, and rightly so. However, it is often used incorrectly to refer to what should more rightfully described as ‘hazard’. Notably the Building Act 2004 clause 133AD defines 'low, medium, and high seismic risk’ by tying the terms to the Z factor from *NZS1170.5:2004*, which more accurately notes it as the ‘hazard factor’.

‘Risk’ can be described as ‘the effect of uncertainty on objectives’, where an effect is any deviation from the expected and can be positive, negative, or both (ISO, 2018). In New Zealand, the Civil Defence Emergency Management Act 2002 defines risk as ‘the likelihood and consequences of a hazard’. Risk can therefore be expressed in terms of probability, magnitude, or some combination thereof.

2.2 Risk Tolerance

Determining a consistent risk metric—e.g. fatality risk for building design—allows risks from different hazard sources to be ranked or compared alongside one another. Intuitively, lower risks are more palatable, and higher risks at some point become unbearable, with a transition period between. This is represented in Figure 1, below, with thresholds between each region also indicated.

The terminology used in Figure 1 is used throughout this paper. An Unacceptable risk is self-explanatory; however, Tolerable and Acceptable may be seen somewhat interchangeably. Tolerable is used to describe a risk that is undertaken because the benefit gained by taking on the risk outweighs the potential consequences of the risk. An Acceptable risk (‘Broadly Acceptable’ in Figure 1) describes a risk where no further attention or effort is required for reduction. Acceptable risks should, however, be monitored to ensure that either the risk does not increase, or that the benefit gained from the risk does not significantly decrease.

Figure 1 also introduces the principle of ‘ALARP’, or ‘as low as reasonably practicable’. The concept was introduced in 2001 by the UK Health and Safety Executive (HSE) and considers the effort or resources required to reduce a risk by a given amount. If it can be shown that there is a ‘gross disproportion’ between the reduction in risk and the effort or resources required—with the reduction being insignificant compared to the effort—then the risk is considered to have met the ALARP principle (HSE, 2001).

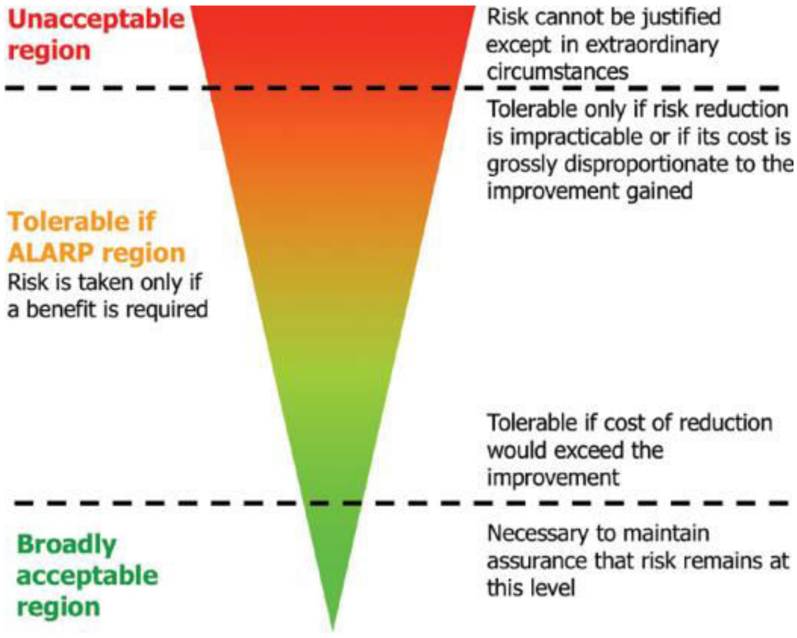

Figure 1: Tolerability of risk (Risktec, 2018)

3 ‘CODE’ BUILDINGS

For the purposes of this discussion, a ‘code’ building is one built to the Building Act 2004, satisfying the New Zealand Building Code, and following Verification Method B1/VM1, i.e. NZS1170.

Keeping in mind the terminology in Figure 1 above, consider that *NZS1170.5 Supp 1:2004* C2.1 General Requirements specifies ‘code’ buildings are designed such that ‘fatality risk is at an *acceptable* level’ (SNZ, 2004, emphasis added). This implies buildings are designed so the fatality risk is reduced so significantly that no further justification is required. Perhaps it should instead specify ‘fatality risk is at a *tolerable* level’, reflecting that the associated fatality risk is not insignificant and could be reduced further at additional cost, but the collective benefits of building use at decreased costs to society are prioritised instead.

If fatality risk for a code building is actually Tolerable (rather than Acceptable), would it be closer to the Acceptable or Unacceptable region? That is, which threshold are our buildings designed to? A building which just meets code minimum is only *just* better than one which is Unacceptable. Therefore, it follows that a code building is designed for the risk threshold between the Tolerable and Unacceptable regions, further reason why ‘tolerable fatality risk’ would be more appropriate than ‘acceptable fatality risk’.

Does the idea of code buildings only slightly better than being deemed Unacceptable match society’s expectations of our built environment? Building safety is generally taken for granted, with society expecting not only life safety but also increasingly for the built environment to enable social and economic recovery following an earthquake, while minimising environmental impact (Brown et al., 2022). Public response to recent events suggests that better performance (lower risk) is expected from the built environment.

4 RISK COMPARATORS

Comparing risk associated with common activities to the seismic risk associated with a ‘code’ building can help contextualise current seismic risk thresholds, and perhaps indicate whether they could be changed. This section picks a few examples from New Zealand and quantifies levels of risk.

To remain consistent with the life safety risk focus of code buildings, annual individual fatality rates (AIFR) are compared here. That is, the probability of an individual dying each year. Where specific risk thresholds or targets are set or used, they are referenced. Otherwise, or additionally, actual fatality risk is derived from historical data for the relevant activity.

4.1 NZ Inherent Risk

From 1999-2022, New Zealand experienced over 26,000 deaths per year, accounting for all ages, causes, and other factors (StatsNZ, 2023). Considering population growth in that time, the average annual individual fatality risk associated with simply living in New Zealand has been approximately $6x10^{-3}$. The average person in New Zealand faces a 0.60% chance of dying each year. This is obviously heavily skewed by elderly persons or those facing terminal illnesses. The majority of people in New Zealand can expect to experience a fatality risk between 10^{-8} and 10^{-7} per day (Taig, 2020), or approximately 10^{-6} and 10^{-5} annually.

Workplace fatality risk may be taken for granted, perhaps depending on one’s occupation. Annual fatality risk for office-based workers typically falls between 10^{-6} to 10^{-5} (0.0001% to 0.001%) (Taig, 2020). This can be further broken out by occupational sectors:

- Education; retail; finance; IT; communications: 10^{-6} (0.0001%)
- Healthcare; professional services; manufacturing; public administration; real estate: 10^{-5} (0.001%)
- Construction; transport; warehousing: $5x10^{-5}$ (0.005%)
- Agriculture; forestry; fishing; mining; utility services; arts & recreation: 10^{-4} (0.01%)

4.2 Seismic Fatality Risk

NZS1170.5 Supp 1:2004 C2.1 states ‘an accepted basis for building code requirements is a target annual earthquake fatality risk in the order of 10^{-6}’ (SNZ, 2004). That is, the average person faces a 0.0001% chance of dying in an earthquake in a ‘code’ building each year.

It is unclear whether the Building Code actually controls seismic risk through this risk threshold. Performance objectives are specified for SLS and ULS level shaking intensities, and presumably the referenced 10^{-6} target fatality risk applies for ULS level shaking. However, no performance objectives—or associated fatality risk thresholds—are specified for other levels of shaking. It is also uncertain how or how much a designer can tangibly affect a structure’s fatality risk level through individual design decisions.

Interestingly, New Zealand has mostly met the current life safety threshold, even accounting for buildings built to older codes. Considering fatalities in all earthquakes in New Zealand since 1840, the historic fatality risk associated with buildings in earthquakes is approximately $6x10^{-7}$ (0.00006%). However limiting the scope to 1935 when seismic design codes were first introduced, the historic seismic fatality risk is closer to $5x10^{-7}$ (0.00005%). The fatality risk has not exceeded the current 10^{-6} threshold since 1935.

Of course, large deadly earthquakes are relatively rare events, so the measured individual fatality risk jumps whenever one does occur (e.g. 1931 and 2011). Also, mathematically speaking the longer we go without another large, deadly earthquake, the lower the empirical fatality risk appears to be (more earthquake events and years without additional deaths), which of course is misleading.

4.3 Driving Risk

Another activity people may take for granted—or at least, readily tolerate despite significant risk—is driving. Numbers of registered vehicles on New Zealand roads and vehicle kilometres travelled have increased significantly over time, even outpacing population growth rates (ITF, 2021). Road deaths, accounting for deaths caused or involving someone driving an automobile, peaked at over 800 in 1973, and have generally declined since then (MoT, 2020).

Road deaths in New Zealand have reduced drastically since 1990, despite increases in numbers of vehicles, drivers, and vehicle kilometres travelled. Accounting for traffic collisions and resulting deaths between 1990 and 2021, the annual fatality risk associated with driving in New Zealand is approximately $8.5x10^{-5}$. The average person faces a 0.0085% chance of dying each year from being involved in a traffic collision.

The fatality risk presented above for driving is a measured level of risk, not a target. New Zealand’s *Road to Zero* road safety strategy (MoT, 2019) ambitiously sets a vision where ‘no one is killed or seriously injured on our roads’. That is any fatality risk is Unacceptable, but Tolerable or Acceptable risks are unknown.

4.4 Drowning Risk

Though perhaps not something New Zealanders take for granted nor encounter daily, drowning is the leading cause of recreational death in Aotearoa (ACC, 2021). National fatality statistics for drowning deaths are regularly in news cycles—especially following summer holidays—and are considered a ‘national disaster’.

Drowning statistics from 1980-2021 are available from Water Safety New Zealand’s DrownBase™ (Water Safety NZ, 2021). In that time, New Zealand has seen a long-term downward trend in the numbers of drowning deaths, bringing the annual total down from over 200 to around 100.

Drownings occur in a range of activities, including swimming (pool, natural waters), boating (powered, non-powered, oar/paddle craft), diving (SCUBA, snorkelling), and fishing (on-water or land-based). Information on the number of people engaging in aquatic activities, and the frequency with which they do so, can be extrapolated from the Active NZ Survey by Sport New Zealand (Sport NZ, 2015; Sport NZ, 2020) following a similar process to Taig (2020).

The average person in New Zealand faces an annual fatality risk from drowning of 2.6×10^{-5} (0.0026%). Like the road safety strategy, the only indication of a risk target for drowning comes from strategic vision documents with purpose statements such as 'to lead a step change in New Zealand so people don't drown' (Water Safety NZ, 2018). Again, this essentially indicates any drowning fatality risk is Unacceptable, with no accompanying Tolerable or Acceptable thresholds.

4.5 COVID-19 Risk

Another comparator that is (unfortunately, still) timely is fatality risk due to COVID-19. But, determining annual fatality risk from the relatively short history of COVID-19 in New Zealand is perhaps inappropriate. Additionally, COVID-19 was a risk that New Zealand society threw its collective might at thwarting ('flattening the curve'), invested significantly in reducing vulnerability (vaccinations), and at times drastically disrupted peoples' lives to minimise their exposure (lockdowns). A similar scale of response to seismic risk is hard to imagine, but engineers may dream.

Beyond the first month of COVID-19 infections in New Zealand, the minimum annual fatality risk due to COVID-19 was approximately 3.4×10^{-6}, or a 0.00034% chance of dying from COVID-19 per year (circa October 2021). Accounting for the cases and deaths up to the first weeks of 2023, the COVID-19 fatality risk has climbed to 1.6×10^{-4}, or a 0.016% chance of dying from COVID-19 annually for the average person in New Zealand. This is its highest level since the pandemic began.

COVID-19 warranted markedly different national responses over time. The initial national response strategy to COVID-19 was elimination, shutting international borders, introducing Managed Isolation and Quarantine (MIQ), and the Alert Level system. This clearly set any fatality risk as Unacceptable.

In August 2021, New Zealand's strategy shifted from elimination to promoting vaccination, replacing the Alert Level system with the COVID-19 Protection Framework ('traffic light system'), and vaccine mandates. Shifting away from elimination meant some fatality risk was now considered Tolerable, or alternatively that the investment (and impacts to New Zealanders) required to maintain an elimination strategy was no longer practicable. This is an example of the 'ALARP' principle.

In October 2022, the government revoked the Epidemic Notice issued March 2020, removing several 'special powers' and signalling that the effects of COVID-19 were not expected to continue significantly disrupting essential government or business activity. This was a further Acceptance of the risk. Figure 2 below shows how AIFR has varied since the pandemic began and includes the national response strategy that was in effect. Specific points are indicated as follows:

1. AIFR when the Elimination strategy ended and transitioned to the 'Traffic Light System': 3.6×10^{-6}
2. Minimum (non-zero) COVID-19 fatality risk since beginning of the pandemic: 3.4×10^{-6}
3. AIFR when the 'Traffic Light System' ended, and government further reduced powers: 1.5×10^{-4}
4. AIFR at time of writing, also the highest since the pandemic began: 1.6×10^{-4}

These points may indicate *de facto* risk thresholds. For example, at (1) it can be argued that where previously the Elimination strategy meant any fatality risk was Unacceptable, switching to the 'Traffic Light System' indicated that a fatality risk of 3.6×10^{-6} was Tolerable, if not Acceptable. And New Zealand's risk tolerance shifted again at (3), where further reductions in controls were made despite even higher levels of fatality risk of 1.5×10^{-4}, which again must be considered at least Tolerable, if not Acceptable.

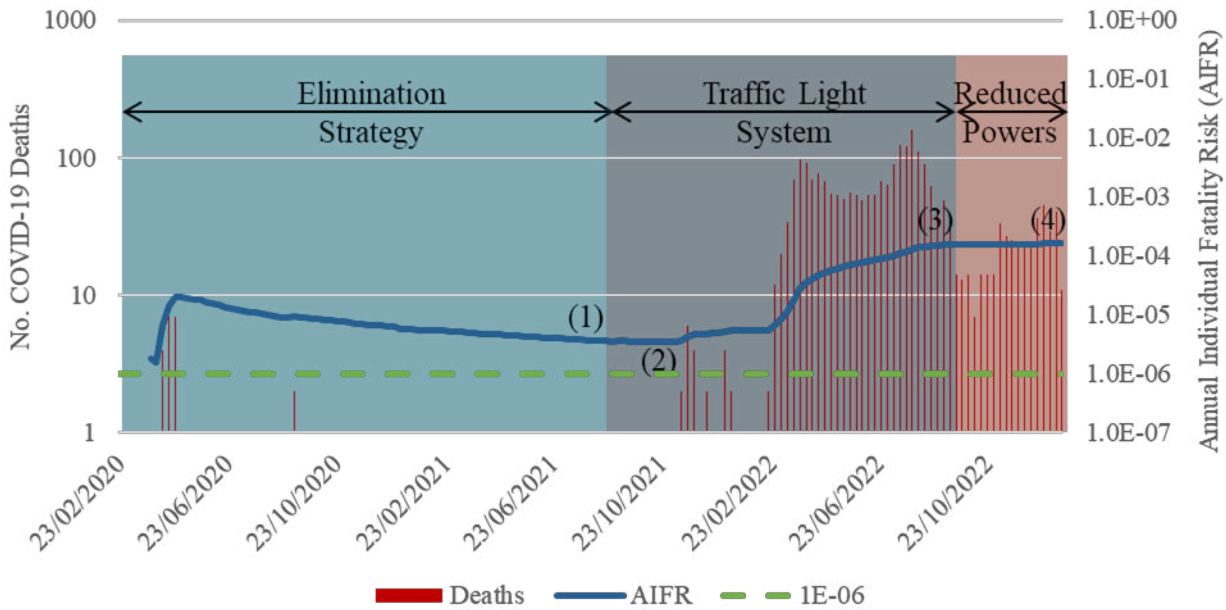

Figure 2: COVID-19 deaths and annual individual fatality risk, with national response strategy periods

4.6 Further Examples

Life safety risk thresholds from elsewhere around New Zealand—mostly from land-use planning—are presented in Table 1 below. They are considered more fully in the Toka Tū Ake EQC *Discussion Paper*.

Table 1: NZ fatality risk thresholds

Location	Context	Threshold(s)	Decision maker (year)
Christchurch	Port Hills Slope Instability (district plan)	Unacceptable: > 10^{-4}	Christchurch District Plan Independent Hearings Panel (2012)
Otago	Regional Policy Statement (proposed) – New Development	• Acceptable: < 10^{-6} • Tolerable: 10^{-6} – 10^{-5} • Significant: > 10^{-5}	Otago Regional Council (proposed 2021)
Otago	Regional Policy Statement (proposed) – Existing Development	• Acceptable: < 10^{-5} • Tolerable: 10^{-5} – 10^{-4} • Significant: > 10^{-4}	Otago Regional Council (proposed 2021)
Bay of Plenty	Regional Policy Statement Appendix L	• Low: < 10^{-5} • Medium: 10^{-5} – 10^{-4} • High: > 10^{-4}	Bay of Plenty Regional Council (2014)
Matatā	Change to Whakatane District Plan	High (for fan head): > 10^{-5}	Whakatane District Council (2021)

4.7 Comparison

From the examples presented, it can be shown that the fatality risk associated with 'code' buildings in earthquakes is relatively low compared to some other common activities in New Zealand. This is reassuring for how we design buildings to safeguard life.

Beyond contextualising seismic fatality risk, this discussion should make it evident that there is little to no consistency in terminology or methodology for testing, setting, or evaluating risk thresholds. For example since 1951, more people have died each year on New Zealand roads than the number of people who died in New Zealand's deadliest earthquake. The 1931 Hawkes Bay earthquake promptly led to the first seismic design codes, signalling the damage and loss of life was Unacceptable. Where is the proportionate response every year to road deaths? Similarly, New Zealand has increasingly reduced controls for COVID-19 despite its fatality risk climbing above the others presented here aside from New Zealand's total mortality rate.

Figure 3 below collates the levels of risk for comparison. For instances without a green bar ('Acceptable'), there was not a risk threshold specified between Acceptable and Tolerable, so instead only the threshold between Tolerable (amber) and Unacceptable (red) is shown. Several only depict Unacceptable (red) bars, indicating that any fatality risk is Unacceptable. Where fatality risk was derived from actual data, the hatched blue bars show the calculated result.

Figure 3 should demonstrate the wide range of risks experienced (and generally accepted) by New Zealand society, as well as the range in thresholds that do exist. Thresholds describing the same level of risk can span multiple orders of magnitude or are inconsistent with their terminology.

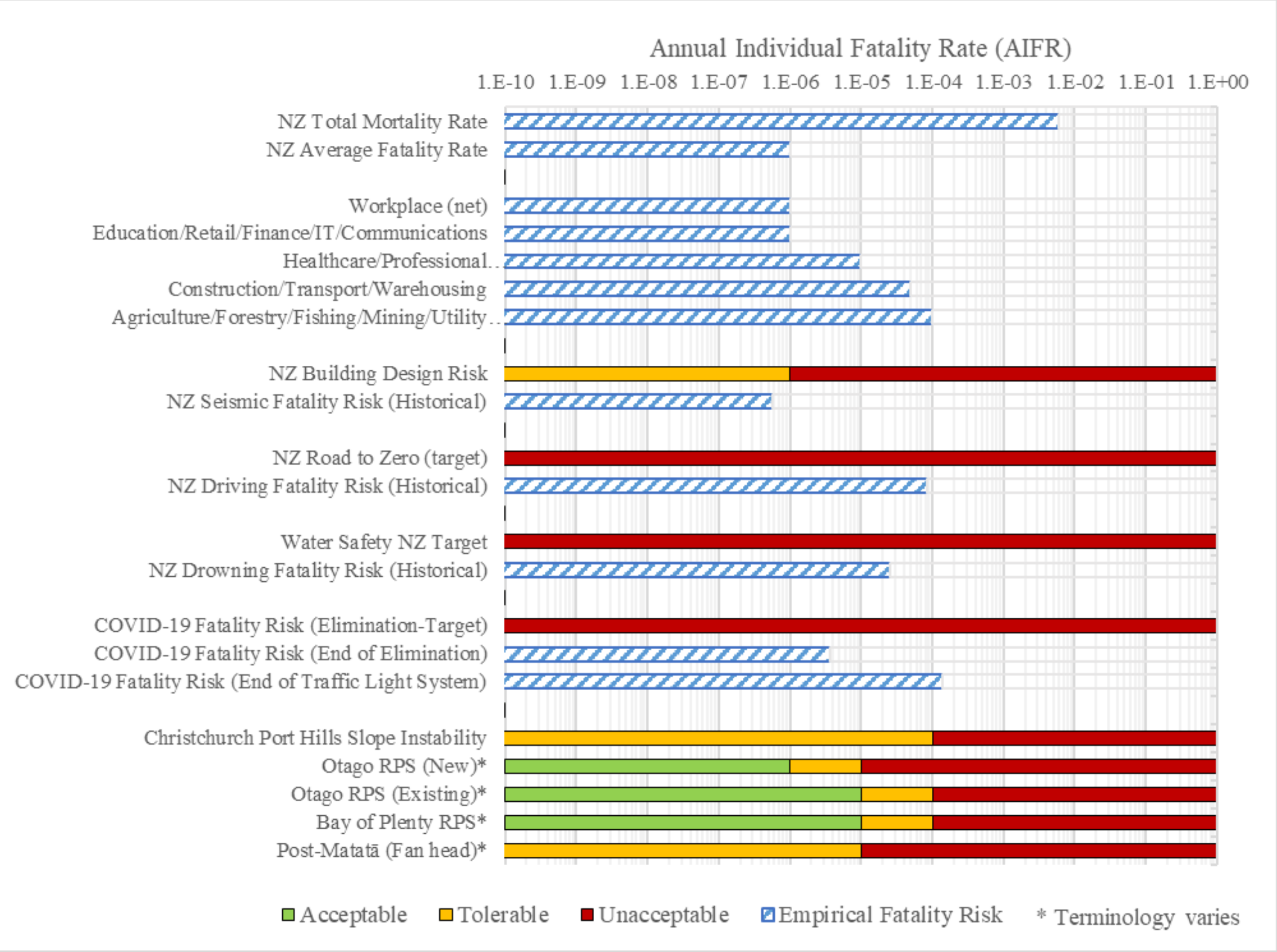

Figure 3: NZ fatality risk comparison

5 THE CASE FOR CONSISTENCY

The range of risk thresholds discussed demonstrate the variability in determining and accepting risk. Neither public opinion nor professional practice describes, considers, or treats risk in a consistent manner. Understanding risk tolerance is a critical part of managing and reducing. Currently, New Zealand does not have an agreed local, regional, or national approach to assessing risk tolerance or risk acceptability.

Toka Tū Ake EQC is interested in this to proactively support risk reduction to reduce the Crown's liability, and so we propose a nationally agreed and adopted approach to assessing and determining risk tolerance, including risk terminology. A consistent approach would help guide ongoing challenges like the RMA reform, implementation and update of the Building Act, climate change adaptation, and other national and sub-national mechanisms. Components of a risk tolerance assessment process are discussed below.

5.1 Risk analysis outputs that directly feed into a risk tolerance assessment

Risk management in Aotearoa New Zealand relies on robust risk analysis processes that provide a strong evidence base. Sectors and agencies already have established risk analysis methodologies in use. Different risk analysis methodologies are available and used for different hazards and to serve different purposes. This allows the most appropriate risk analysis methodology to be used. The risk analysis process should be documented and result in a clear output level of risk or impact that directly inputs to the risk tolerance assessment.

5.2 Time Horizons

risk is a temporal phenomenon and can vary over time due to changes in exposure, hazard, or vulnerability. A risk may be bearable in the present but can become unbearable in the future. Additionally, the nature of some hazards (earthquakes, for example) causes their impacts to grow exponentially with increasing timeframes. The scaling of timeframes therefore does not necessarily directly (linearly) correlate with a scaling of impacts or risk. A risk tolerance assessment should be able to capture this by indicating a risk is presently one classification but will change for a different timeframe.

5.3 Impact Domains

Hazards can impact groups in different, and multiple, ways. Impact Domains are important to provide context for the consequences of a hazard. Especially where hazards result in a range of consequences across different domains of society, it is vital to be able to evaluate them in relation to each other. The impacts of a hazard should be benchmarked against the possible range of outcomes in the specific Impact Domain (e.g., human, social, political, environmental, economic, cultural, etc.). The severity of impact in each specific domain is then considered against pre-set risk threshold criteria.

5.4 Pre-set risk tolerance criteria

The risk tolerance assessment should rely on pre-set risk tolerance criteria, or risk thresholds, for various timeframes. Risk criteria (e.g., numbers of injuries of fatalities, damage repair costs, natural habitat irreparably altered) across environments (e.g., human, economic, environmental) are used to determine risk thresholds (e.g., 'acceptable', 'tolerable', or 'intolerable'). They should be established independently of the Risk Assessment for the given risk, at the national, regional, and local levels. Engagement with groups and communities who experience the risk, but will also live with any risk treatment outcomes, must be a guiding principle in determining risk thresholds. The pre-set risk thresholds allow consistent comparison of varying hazard risks, leading to more consistent Risk Management outcomes.

5.5 Risk treatment through clear policy levers

The result of the risk tolerance assessment should be a clear classification of the risk (i.e., 'acceptable', 'tolerable', or 'intolerable'). This risk tolerability classification directs the appropriate risk management response, which is supported by specific policy levers. Engagement on the implementation options should again drive this process. National, regional, and local policy options should be developed or adapted to align with the risk classifications. For example, an 'intolerable' risk should directly trigger regional or local policies that enable the appropriate response, such as avoiding or controlling the risk.

6 SUMMARY

The seismic fatality risk we design most of our buildings to appears to be reliably low compared to other risks New Zealand society encounters, and seems to match the average building user's expectations of building safety. This suggests that code buildings subjected to earthquakes lead to desirable outcomes. Realistically, this can only truly be said in a life safety sense. Past experience indicates that while code buildings overall sufficiently protect life, the resulting damage and psychosocial, cultural, environmental, and economic disruption are Unacceptable.

This suggests risk thresholds for metrics besides fatality risk are needed to inform building design across different levels of shaking beyond SLS and ULS. And, setting those thresholds should be done via a nationally consistent, robust process. The proposed risk tolerance assessment process outlined herein is a starting point for a wider conversation on consistent risk management outcomes, and national direction on defining, describing, setting, using, and evaluating risk thresholds.

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