Position Paper

Advice on Decisions on Occupying Earthquake Prone Buildings

Background

Building owners and leaseholders have been pushed into obtaining an IEP to give them a %NBS, in spite of not really knowing what either of these acronyms mean. They usually know that they have something to do with the seismic rating for the building. Once they have a %NBS, they're unlikely to know what to do with it, and need further advice from Structural Engineers. Some local authorities have questioned whether a building with a seismic rating below a certain %NBS value should be occupied. This is over-simplistic and will inevitably lead to buildings being closed unnecessarily – losing the amenities they provided.

What they really want to have explained to them in plain English is "*what's going to happen to my building in an earthquake?*" The honest answer is "*nobody really knows for sure*". We're dealing with events that may happen, but we don't know when, and behaviour that's difficult to predict with any certainty. There is only one certainty in life: in spite of centuries of medical advances, life is ultimately fatal in 100% of cases. The only uncertainties are when and how.

What is an Earthquake Prone Building?

An earthquake prone building is defined as one in which the building or part will have its ultimate capacity exceeded in a *moderate* earthquake and if the building or part were to collapse, the collapse would be likely to cause injury or death to persons. Note, a *moderate* earthquake is one with third of the 'power' of an earthquake for which new buildings are designed.

An earthquake prone building presents a risk to occupants of approximately 10 to 25 times that of an equivalent new building that just meets the minimum life safety requirements in the New Zealand Building Code. The expected performance of buildings subject to shaking having differing levels of seismic rating is illustrated in Figure 1.

You need to put that in the context of the seismic risk we expect of new buildings. The target for new buildings is around 1 in 1,000,000 chance of a fatality – a very low level of risk.

Old verses New

We hold new buildings to a higher standard than existing buildings. If we take the design working life of 50 years for 'normal structures', and a 10 percent probability of exceedance in the life of the structure, then the wind and earthquake loads applied to normal structures will have an annual probability of exceedance of 1/500. 'Important' buildings such as schools and hospitals are provided with higher levels of safety against structural failure due to their importance to the community, and are designed to withstand loads with an annual probability of exceedance of 1 in 1000.

Most new buildings will have an expected performance above 100%NBS, if properly designed.

Understanding Risk – Real and Perceived

So Structural Engineers have to explain risk to people who do not understand risk.

Risk is the potential for uncontrolled loss of something of value (in this case life safety) resulting from a given action or inaction, foreseen or unforeseen, planned or unplanned. Risk can also be defined as the intentional interaction with uncertainty. Uncertainty is a potential, unpredictable, and uncontrollable outcome; risk is an aspect of action taken in spite of uncertainty.

But people's perception of risk is different from the actual risk. Risk perception is the subjective judgment people make about the severity and probability of a risk, and may vary person to person. Any human endeavour carries some risk, but some are much riskier than others. For example, the risk of death from lightning varies around the world from 1 in 1 million to 1 in 10 million; i.e. a very low risk, but I still wouldn't recommend playing golf in a thunderstorm!

Given the number of people who die on our roads every year (shown in Table 1), driving is one of the riskiest activities you do – yet that's not the perception. We overestimate our abilities and those of other road users, because we think we are in control. We're clearly not in control of earthquakes – but we can do something to mitigate the consequences of an earthquake. In general, earthquakes don't kill people – major structural failures caused by earthquakes kill people.

Think of risk as the flip side of chance. Lotto NZ explains that if you buy a $7 ticket your odds of winning first division are 1 in 383,838[1]. Similarly, your odds of winning Lotto Powerball with a $15 Power Dip ticket are 1 in 3,838,380. So highly unlikely, but not impossible, as testified by the many winners.

Chance perception (am I feeling lucky) is also the flip side of risk perception. If there's a risk of something bad happening, we think- ''it'll never happen to me''; if there's a chance of something good happening, we think – ''it could be me''.

Tolerating Risk

The UK's Health & Safety Executive developed the concept of 'Tolerability of Risk' for the safe operation of high hazard industries and expect operators to reduce risks to 'As Low As Reasonably Practical' (ALARP). This defines a broadly acceptable risk of a fatality to an individual member of the public of less than 1 in a million (i.e. with an annual probability of exceedance of 10^{-6}), and an unacceptable risk as 1 in 10,000 (i.e. with an annual probability of exceedance of 10^{-4}). In conjunction with the UK's Department of Transport, the HSE also developed a range of risk criteria for consideration when transporting hazardous material. This brings into the number of fatalities into the equation, considering time at risk. For comparison, the two approaches are illustrated side by side in Figure 2.

Meaning of earthquake-prone building

A building or a part of a building is earthquake prone if, having regard to the condition of the building or part and to the ground on which the building is built, and because of the construction of the building or part,—

(a) the building or part will have its ultimate capacity exceeded in a moderate earthquake; and

(b) if the building or part were to collapse, the collapse would be likely to cause—

(i) injury or death to persons in or near the building or on any other property; or

(ii) damage to any other property.

For example, if we're designing for a 1 in 1000 year event (as we would for a typical school), and the probability of (catastrophic) failure on demand is 1 in 1000, then the risk of a fatality is considered negligible.

The difficulty for Structural Engineers is determining the probability of failure on demand (PFD); a concept from the mechanical engineering discipline where devices are used many thousands of times, and tests can determine a PFD. In contrast, a building structure is likely to be subjected to an extreme load only once in its lifetime. For an existing building, we're looking at a moderate earthquake, which is nearer a 1 in 100 year event for an ordinary building. If we take a PFD of 1 in

[1] In contrast the odds of winning the top prize in Euro-millions is 1 in 139,838,160

100, the probability of the event is 1 in 10,000, which could be considered an unacceptable risk if the consequences are fatal.

It should be noted that a 1 in 100 year event could happen tomorrow; as could a 1 in 1000 year event. The 1 in 100 year event is just more likely to happen. High consequence incidents usually have a low probability of occurrence.

Structural failure does not always result in death. So Structural Engineers have to consider the consequences of failure of a structural member; an exercise known as Failure Modes and Effects Analysis (FMEA). Seismic assessment is primarily about life safety, although damage to adjacent buildings needs to be considered too. A decision on whether to occupy an Earthquake Building is all about life safety. If a building falls down without killing anyone, then the risk of structural failure is acceptable (unoccupied buildings may fall into this category). On the other hand, the more occupants in a building, the greater the potential for fatalities.

Meaning of ''moderate earthquake''

Moderate earthquake *means, in relation to a building, an earthquake that would generate shaking at the site of the building that is of the same duration as, but that is* ***one-third as strong*** *as, the earthquake shaking (determined by normal measures of acceleration, velocity, and displacement) that would be used to design a new building at that site if it were designed on 1 July 2017*

For example, if the design basis earthquake (1 in 500) requires a structural element to carry 100kN, but analysis shows that it is only capable of carrying 33kN, then it could be deemed to have a seismic rating of 33%NBS. Although the rating of the building is determined by the weakest element, it does not necessarily mean that the building is earthquake prone. We have to consider the consequences of that failure. Just because a structural element has exceeded its theoretical ultimate capacity does not mean it will simply fail catastrophically. The mode of failure is important: brittle failure is sudden – elements will fail without warning. Ductile failure, on the other hand, is progressive giving visible warning of its impending failure.

Table 1: Road Fatality Statistics for NZ & UK for 2016

Country	Road fatalities per 100,000 people	Road fatalities per 100,000 vehicles	Road fatalities per billion vehicle km	Total Fatalities in latest year	Year
New Zealand	7.8	10	7.2	364	2016
United Kingdom	3.1	5.7	3.4	2,019	2016

How many people are at risk?

When assessing likely fatalities, we have to assume that the building is normally occupied; for an office we would assume that there is one person at each desk and each chair in a meeting room; for a sports stadium, we would assume that there is one person in each seat; for a residential property, we would assume at least 1 person per room or living space.

Thus, the more people in a building, the higher the risk of fatalities resulting from structural failures and the greater the need for ALARP arguments to reduce those risks to acceptable (or at least tolerable) levels.

Robustness

Then we have to consider robustness, alternative load paths, and the ability of the structure to redistribute loads to other elements in the event of the failure of one element.

If the consequences of failure a particular element does not lead to death or serious injury, then it can be justifiably ignored. If the load it was carrying can be redistributed to other elements without them failing, then again, it can be justifiably ignored. Even when a structural element has exceeded its theoretical ultimate capacity, loads can often be carried in different ways. For example, after failing in bending, a beam can act as a catenary so long as it is effectively tied in at the supports; a masonry wall can act as an arch if it has sufficient lateral restraint.

If, on the other hand, failure of one element leads to the failure of another element (because it cannot take the increase in loading) and so on, we have a lack of robustness and the potential for progressive collapse. To borrow another phrase from mechanical engineering, this would be seen as a 'single point of failure'. A robust building would have multiple redundancies and alternative load paths, should one element fail.

In cases where the failure of a single element threatens the overall stability of the building and could precipitate a wider building collapse, it is recommended that the building as a whole is not occupied, until works are carried out to make it safe.

If the consequences of this failure are out of proportion to the original cause (i.e. the earthquake load) then it would be considered to disproportionate collapse; small earthquakes should not cause an entire building to collapse, loss of roof tiles would be more proportionate.

It is more likely that the building has local weaknesses, which do not threaten the overall stability of the building, but are likely to cause local damage to a limited area. In such cases, local propping and/ or isolation may be sufficient to temporarily address the situation and enable continued occupancy. Once repairs are made to the affected areas, the building may be restored to full use.

The collapse of an unreinforced masonry (URM) wall or chimney in an occupied building is likely to lead to death or serious injury to one or more of the occupants. If that wall supports a floor above it, a portion of that floor is likely to collapse.

Life safety hazards that could arise from failure of individual (usually secondary) structural elements include:

a) Parapets or cladding panels toppling or falling, particularly over public spaces, access points and egress paths;
b) Heavy suspended ceilings or other elements that may fall on occupants.
c) Blockage of exit routes by for example falling stairs, trapping people in the building;

If the hazard is limited to an area that may be effectively isolated, limited use may be recommended if:

a) The areas to be occupied are protected from risk of collapse from other areas of the building, and
b) Fire egress is not compromised by loss of the inaccessible area, and
c) The safe use of the building is not otherwise compromised by the collapse of the affected area.

Recommendations on building occupancy must therefore be based on a holistic assessment of the building and surroundings, and how the building is currently being used. A proposed guide to making these decisions is illustrated in Figure 3.

It is suggested that recommendations with respect to occupancy be expressed under the following categories:

- Continued normal occupancy with no restriction
- Continued occupancy with partial access restriction
- Not to be occupied pending further investigation and/or repairs.

Parting Thoughts

It's important to bear in mind that:

- ❑ Many buildings remain in service many years after their design life has expired
- ❑ Many buildings have suffered periods of little or no maintenance
- ❑ The total cost of strengthening may exceed the cost of a new building
- ❑ The value of a building may not justify the cost of a full structural appraisal and intrusive investigation to determine an accurate %NBS

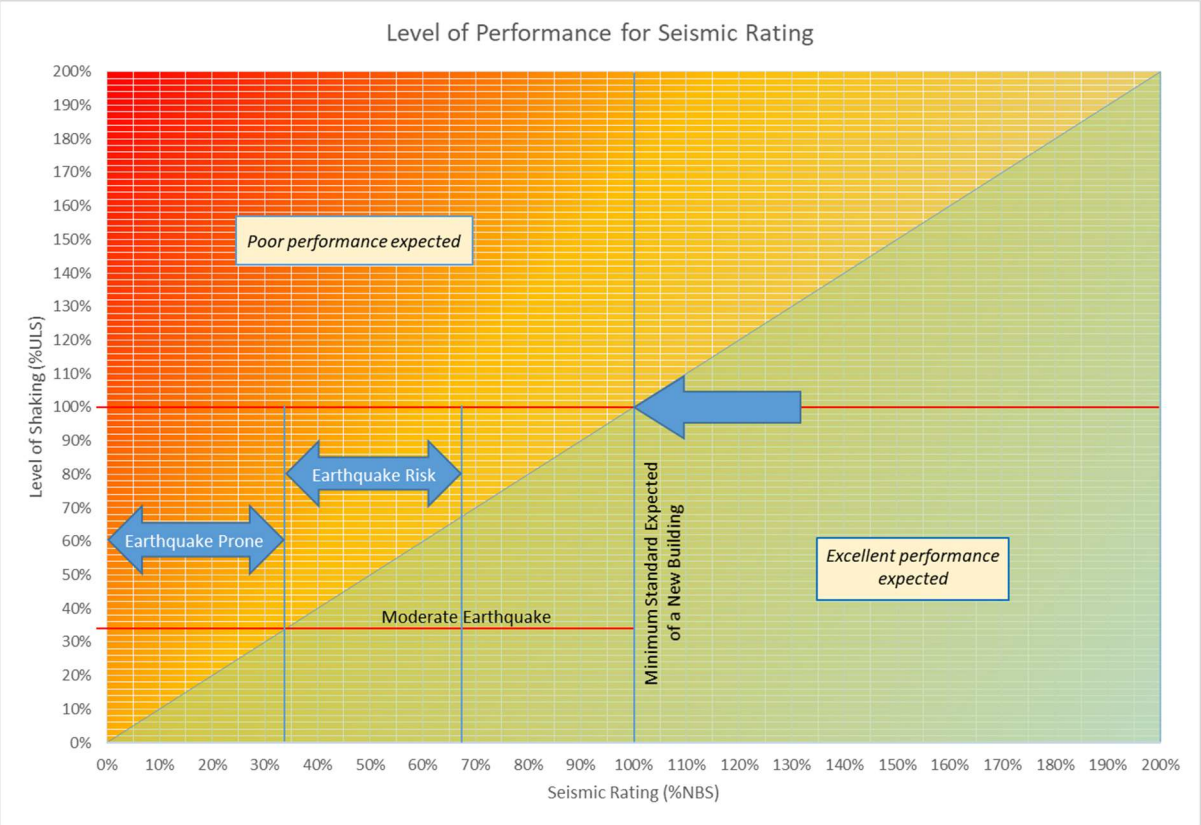


Figure 1: Expected Levels of Performance for different Seismic Ratings

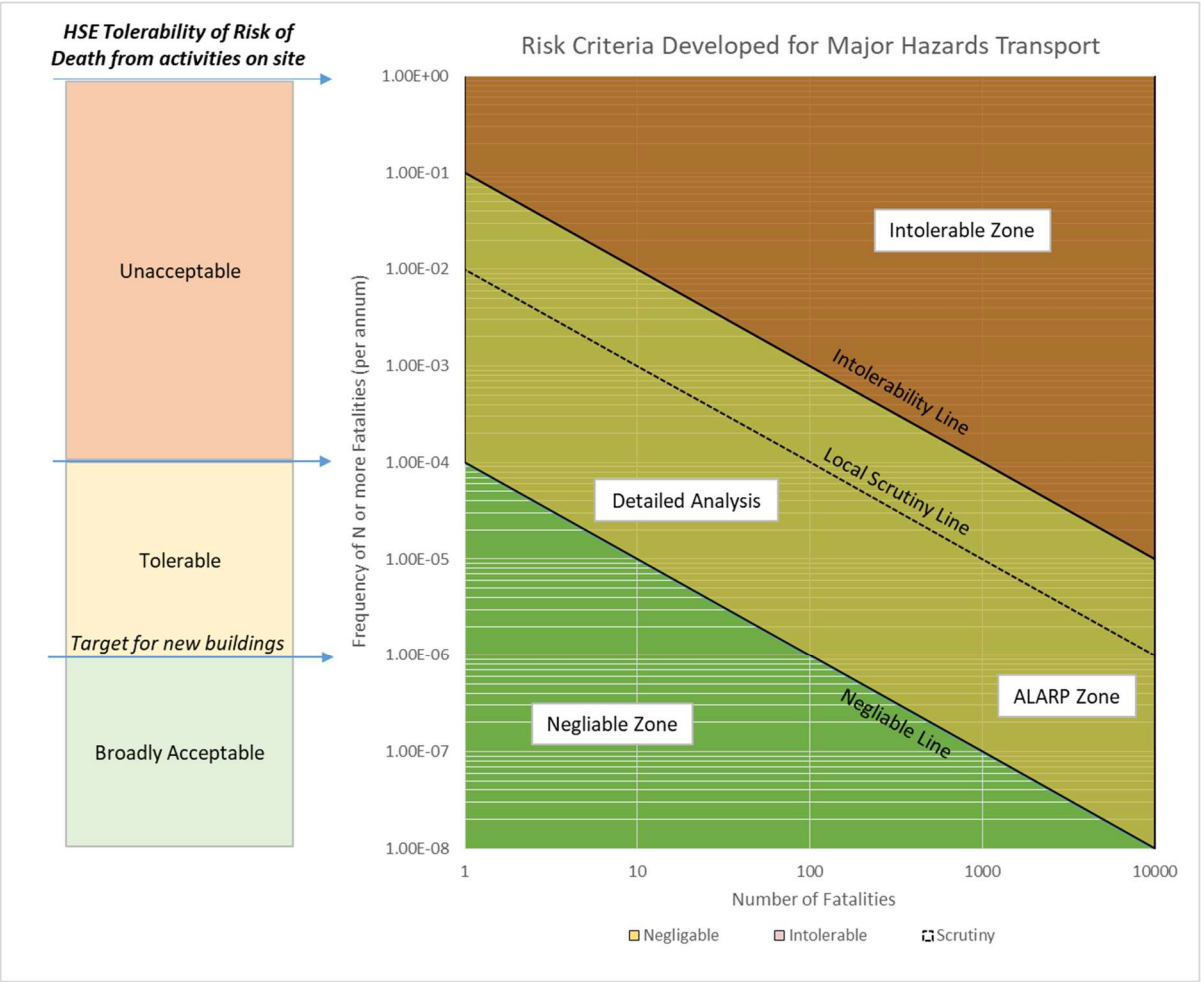


Figure 2: Tolerability of Risk for High Hazard Process (left) and Transport of Hazardous Materials (right)

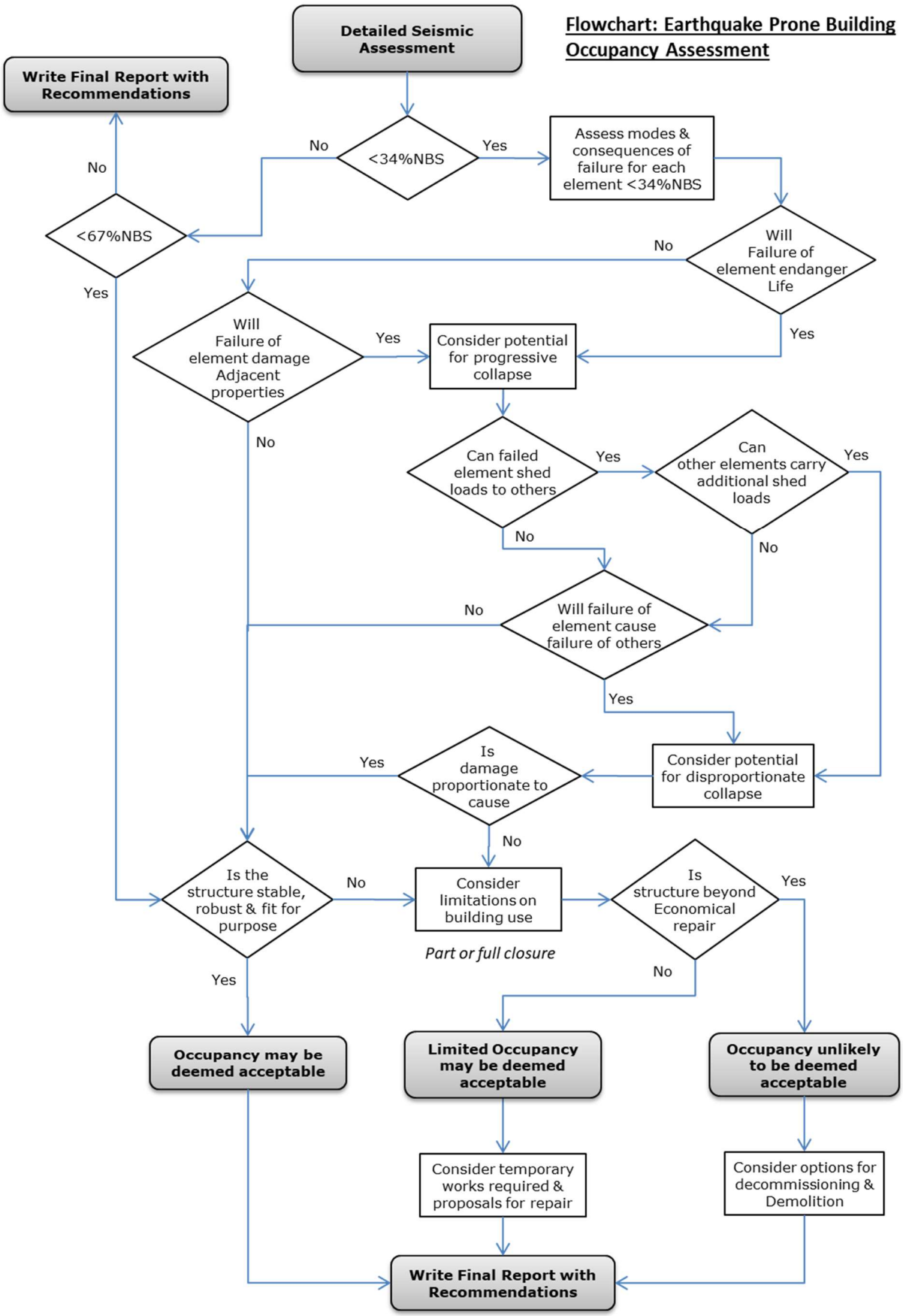


Figure 3: Proposed Flowchart for Deciding whether Earthquake Prone Buildings may be occupied.