

Why do we still tolerate buildings that are unsafe in earthquakes?



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Abstract

Earthquakes continue to kill thousands of people and make hundreds of thousands homeless. Within a few seconds they destroy infrastructure that was developed over decades. To a degree, we have the means and knowledge to stop this happening. But painfully, we are unable to do this because we tolerate unsafe buildings. In this paper, we explore why we are unable to stop this – from engineering and socio-cultural / economic perspectives. We look into both issues together, because these are related from a seismic safety point of view.

Not tolerating unsafe building means having a sound engineering definition and a sound implementation strategy. From an engineering perspective, we looked at the common concepts / terminology we use in engineering to describe safe buildings and the procedures we use to satisfy ourselves as designers that we are doing the right thing. However we find there are many paradoxes (i.e., conflicts with expectations) in our common procedures and explanation when we try to define safe. These are because interpretations vary between people and cultures. We authors (each coming from a very different culture) have debated over many years our appreciation of risk. It is clear that a definition of safe depends both on how we define risk, and on how much risk we are prepared to accept.

From an implementation point of view, there also seem to be many myths and fallacies in our concepts. We believe that a good seismic standard enforced with legal means could solve the problem, but when developing a strategy for implementation of safer buildings, we overlook that safety is a socio-cultural and economic issue. This is because different cultures perceive and interpret risk in very different ways, and then there are economic reasons not to implement safer buildings even though people know they are living in a unsafe one.

Introduction

The theme of this conference is “Why do we still tolerate buildings that are unsafe in earthquakes?” This is an opportunity to explore the fundamentals of why we are not able to implement what we know for our own safety or, more importantly, why we accept these unsafe buildings. Although the question is simple, it raises many complex and conflicting issues, both technical and socio-economic / cultural. Often, we find the approach we have adopted to resolve the problem is full of paradoxes.

The question “Why do we still tolerate buildings that are unsafe in earthquakes?” assumes that we know what “safe” is. But really, what is “safe”? By definition, any building that meets the requirements of the current building standard is “safe”. However, how certain are we of the requirements defined by these standards which are ever changing? Then there are uncertainties associated with the tools we use to analyse or design a building, or the construction materials we use. If we are uncertain about the requirements, how can we assure others of the safety of a building? We say that these documents are based on a reasonable or acceptable level of risk decided by consensus. Words such as “reasonable” and “acceptable” indicate subjective rather than objective targets.

Moving towards seismic resilient building means implementing something new, and that means change. One of the questions then would be: “why are we not able to change?” This question is much more difficult and complex from a human perspective. We need to look deeply into human nature and our perspective and acceptance of realities. These depend on one’s cultural background, geography, acceptance of fate, approach and, more importantly, philosophy of life. These issues have been raised over time immemorial. The question has always been asked, “Why do we have so much inertial to resist the change?” But it is just inertia against change, or more than that?

It is universally accepted that earthquake safety is an engineering problem which can be solved by engineers through proper implementation of engineering concepts through legal means. As discussed earlier, once the issue of change arises, it involves one’s mindset. To change a mindset, risk communication and promotion is required. It requires intensive communication

skills and negotiation. The change, even if accepted, cannot be implemented free of cost. It requires money, and a cash flow. These issues make earthquake safe buildings a multi-disciplinary subject rather than just an engineering one. This issue has hardly been debated in earthquake engineering circles. Of course, historically, earthquake engineering has been led by engineers interested in earthquake safety, and in the last 50 years or so its horizon has expanded tremendously. However, still there are big gaps which have practically hindered earthquake safe buildings, and we are tolerating the buildings which we say are unsafe. The problems are multi-fold - starting from the definition of a safe building to approaches adopted to implement it. They are full of paradoxes. This paper explores these paradoxes that have led us to tolerate unsafe buildings.

What is safe?

By definition, any building complying with current building standards is a safe building. The word "current" implies that the standards are changeable, and indicates that we are not confident about these standards. Over the last 70 years, the seismic loading Standard of New Zealand has changed at least six times (Table 1), most times increasing the demands on the structure, and practically implying that buildings complying with the preceding standards are less safe. Thus, a building that was safe a day before could be deemed unsafe the next day because of the new Standard and its requirements. It is nothing to do with the building, its structure or its use. It is also nothing to do with the actual seismic hazard, as that is also same. It is the definition, interpretation, or maybe our knowledge, and our acceptance level that have changed. It shows the paradox of a "safe" building.

Table 1. Seismic Coefficients for Wellington

Year	Cd (ULS) ¹	Remarks
1939	0.1	Uniform distribution of lateral load over the height
1955	0.1	Triangular distribution of lateral load over the height
1965	0.15	Triangular distribution of lateral load over the height
1976	0.38	Triangular distribution of lateral load over the height
1992	0.39	Triangular distribution of lateral load over the height
2004	0.42	Triangular distribution of lateral load over the height

¹ The design seismic coefficients are for Ductility, $\mu=2$; Fundamental time period, $T_1=0.4$ sec; Subsoil Type: C (Shallow Soil); Building Occupancy Type 2.

The engineer or earthquake scientist says that it is not his fault that knowledge has increased. The perspective of a building owner who has abided by the law and strengthened his building, only to find that after a year the same building has been deemed unsafe, will be similar. He has spent good money for strengthening his building to comply with the law, and today we are asking him to do more. What should he do now?

How much risk is acceptable?

Before we discuss "Why do we still tolerate buildings that are unsafe in earthquakes?" we have to define what our tolerance limit is, or how much risk is acceptable. As discussed earlier, the definition of "safe" is related to the acceptable level of risk. The fundamental questions are therefore "How do we define risk?", and "What is the basis for defining its acceptable levels?", or alternatively we can ask "How do we define vulnerability?", and "What is the basis for defining its levels?" It is because risk depends on seismic hazard and building vulnerability. Obviously, we cannot change hazard, so what we can change is only vulnerability. Further, have we ever thought what could be its implication on the public? These fundamental questions need to be debated.

The definition of seismic risk is directly related to the interpretation of hazard. In an engineering sense, the magnitude of hazard depends on how we define it, and it is closely related to the return period of the earthquake that we consider appropriate for the design. The interpretation of the word "appropriate" differs from person to person, community to community, or region to region. Why for design or assessment of a building structure should a 475-year (10% chance of exceedance in 50 years) return period earthquake be considered? Why not a 1000-year or 200-year return period earthquakes?

Then, there is the question of low risk/high consequences, or high risk/low consequences. For example, shelving in a supermarket is considered a temporary structure, so these could be designed for a 25-year return period earthquake as advised by BRANZ's design guideline (2007), but what would happen if a moderate earthquake strikes on Sunday when people are busy shopping in these malls. Although we perceived the risk to be low, the consequences would be grave. So, the question is not just about temporary or permanent, it is more an issue of magnitude of the consequences.

Acceptable risk paradox

As discussed earlier, acceptance of a safe or unsafe building is based on rational of “acceptable risk”, which is a paradox in itself. It is unclear whether it should be “acceptable risk” or “desired level of safety”. How should this acceptable level of risk be defined? How much risk is too much risk? Who is to define these thresholds? It is accepted that society should define it and it should reflect the societal perspective. However, what constitutes a society or societal perspective is easy to answer in the abstract, but hard to pin down in specifics (May, 2001). The perspective of acceptable risk would differ depending on stakes of a member of the society in the society. So the question is “Who makes this perspective; a politician, a building owner or leaseholder, insurer or reinsurer, an expert?” In society there are extremes: one person might say they would not tolerate “any” risk and another would say “If that happens, let it happen”. The dilemma is, “Where is the balance and how should we decide it?”

At least in the engineering community, it is accepted that acceptable seismic risk for building safety is defined by our building standards in general and seismic standards in particular, because these are based on a consensus of experts. However, these documents present the opinions of experts rather than of a broader society. The issue of seismic safety is public, which provides a public safety rationale for government actions for addressing earthquake risk. If asked, a politician as office bearer would always say that they have zero tolerance for any risk, including seismic. However, a budget allocation for implementation of seismic safety will always show a fatal gap in commitment and action. Is it an issue of political risk, confusion, lack of understanding, or priorities? The question could also be, even if budget is allocated and a policy environment created, can we afford to claim zero risk, or does it exist at all? May (2001) has discussed these issues in his paper on the fallacy of acceptable risk from a very interesting perspective.

Code paradox

The definition of what is a seismically safe building is based on matching its strength (and ductility) and the code level seismic demand on it. For defining the seismic demand, probabilistic seismic hazard assessment (PSHA) is a widely used method these days. Seismic demand defined by the New Zealand seismic standard is also based on PSHA (NZS, 2004). The method has its own limitations and poses uncertainties. A few of these are discussed below.

The uncertainty in PSHA emanates from a lack of understanding or knowledge when defining or selecting source and attenuation models (SSHAC, 1997). Ground motions predicted by PSHA are not expected to match the ground motion from a particular earthquake, irrespective of its recurrence period. A PSHA combines the effect of all possible earthquakes in the region. However, a single earthquake cannot be expected to combine so many earthquakes (Wang et al, 2003). And then there is always a probability of the prediction being exceeded. What it means is, we are designing for something that we don't know exactly. Furthermore, the PSHA does not define a worst case scenario. Whatever we calculate from a PSHA has to pass through the scrutiny of “good engineering” judgement which differs from person to person.

Although New Zealand uses state-of-the-art standards for the design of buildings, the standards are now long and complex, and many engineers have difficulty following them (Spencer, 2007). Furthermore, there is a growing trend to follow the standards as if they were a Bible, rather than understanding the philosophy behind them.

Analysis paradox

How do we estimate demands and building capacity? What we actually do is: construct an analytical model where we input material and structural properties, loads and other parameters based on our past experience. In the process, we try to simplify (over simplify?) the model. We are uncertain about the material properties, its content, even imposed loads (including dead or live). Of course, then there are human errors. From all of these, we use good judgement to predict performance of the building or, conversely, try to interpret whether the building complies or not with our building Standards? The next moment, we opt to use a sophisticated analysis, and attempt to be accurate, but forget the enormous approximations involved in seismic design (and analysis). Other sources of uncertainties and inaccuracies are discussed by Priestley (1993) in his milestone paper.

All this analysis has then to go through the scrutiny of good engineering judgement. It is not wrong, but once human judgement comes on the scene, it introduces subjectivity. So there is the potential that a building could be condemned as unsafe when it would have been deemed safe earlier by another professional or vice versa even under same loading conditions. It is difficult to say what the effect would be on our result of the assumption we have made, whatever sensitivity analyses we do. With this uncertainty, it is extremely difficult to say which building is safe or unsafe. After every earthquake we see the unexpected and learn lessons. Learning lessons is not wrong, but it also means our knowledge is still incomplete. Therefore, our prediction regarding safe or unsafe is doubtful.

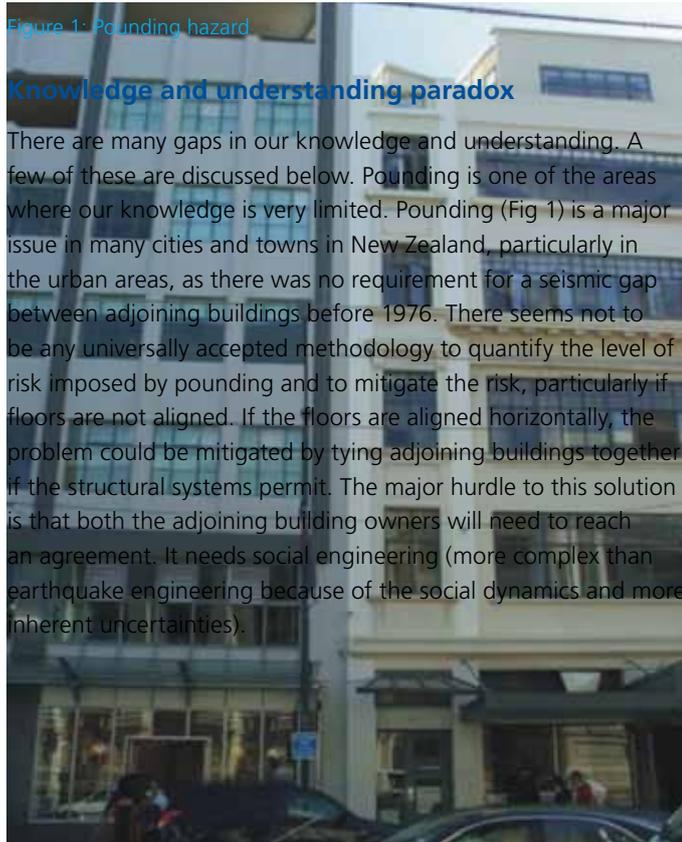


Figure 1: Pounding hazard

Knowledge and understanding paradox

There are many gaps in our knowledge and understanding. A few of these are discussed below. Pounding is one of the areas where our knowledge is very limited. Pounding (Fig 1) is a major issue in many cities and towns in New Zealand, particularly in the urban areas, as there was no requirement for a seismic gap between adjoining buildings before 1976. There seems not to be any universally accepted methodology to quantify the level of risk imposed by pounding and to mitigate the risk, particularly if floors are not aligned. If the floors are aligned horizontally, the problem could be mitigated by tying adjoining buildings together if the structural systems permit. The major hurdle to this solution is that both the adjoining building owners will need to reach an agreement. It needs social engineering (more complex than earthquake engineering because of the social dynamics and more inherent uncertainties).

Interestingly, many of the unreinforced masonry buildings in Wellington are strengthened with steel structures (Fig 2). This technique is easy and fast to implement. However, it would be interesting to observe the progressive damage under an earthquake due to incompatible systems: flexible steel and rigid masonry structures. Due to the high flexibility of the steel structure, by the time the steel structure starts carrying load, the masonry will probably have suffered significant damage and lost most of its strength and stiffness.



Figure 2: Strengthened masonry building

“Modern is safe” fallacy

It is accepted in both engineering and by the public that buildings constructed of modern materials and skills are safe. However, the damage and destruction suffered by different building types during the 2005 Kashmir earthquake show a total anomaly. Dhajji-dewari (Fig 3) (a traditional building construction system in the area), performed far better than its modern counterparts (Bothara & Hicyilmaz, 2008). Even after its superb performance, engineers were reluctant to accept dhajji-dewari on the ground that the system was not tested. What type of test is needed if it has been tested in the open lab and proved its adequacy? After the earthquake, engineers and academicians were lobbying to restrict all form of stone masonry construction (including dhajji-dewari) and to bring in cement-based reconstruction although the latter is not suitable in many parts of the earthquake-affected areas (Mumtaz et al, 2008). It shows our reluctance to learn from history.



Figure 3: Comparing performance of modern and traditional construction in the 2005 Kashmir earthquake

Risk perception and interpretation

Understanding the human mind is of the utmost importance when implementing seismic safety measures. It is one of the most missing and least researched pieces of the jigsaw puzzle of seismic safety. Implementing seismic safety demands a change in human attitude. The attitude and measures adopted by an individual or community to mitigate a seismic risk depends on how they interpret and perceive the risk. Culture, religion, race, ethnicity, faith, literacy, gender, education, and experience influence a person's or community's interpretation and perception of risks and benefits. Risk interpretation and perception also depends on the way risk information is presented. We earthquake professionals work more as protectors and consider our role is to warn people about the earthquake risk that they do not know about or neglect in. We wonder why people are so uninterested in their own safety, and regret that there is not enough policy or not enough money being spent to mitigate the risk. It frustrates us. However, in the process, we forget our role as promoters who should convince people, and promote the technology (and not only develop it!). If we want to not tolerate unsafe buildings, we must break this barrier.

Once people start thinking that they cannot do anything to protect themselves, they slide into surrender and fatalism. With a changed scenario (such as having experienced an earthquake) people perceive risk in a different way. With increased affordability and better education, peoples' perceptions change (Naeem & Okazaki). This was true in the 2005 Kashmir earthquake in Pakistan for reconstruction.

Experts and people interpret risk in very different way, and there are conflicts between these two. Sjoberg (1999a) conducted a study to understand perception of risk among experts and people for nuclear risk which has similarities with seismic risk.

We know we cannot present risk in a meaningful way to a common person. The general public is more interested in consequences (Sjoberg, 1999b). For example, we say that the probability of collapse of a normal building is 10% in 50 years. However, it does not mean anything to an ordinary individual. It is too complicated for him. What he wants to know in very plain words is whether a particular building would collapse or not, and then he would think, if the building is to collapse anyway, why should he spend more money to make it earthquake resilient. Here, firstly, the message is not clear and, secondly, we presented risk in negative sense. Maybe we should say that the chances of survival are 90% provided the building is designed and constructed according to the Standard? Further, the experts' disagreements about the magnitude of the risk or vulnerability give them an excuse not to mitigate the risk.

Fallacy of affordability

A weak economy or a lack of resources are always offered as excuses and considered as hurdles for not implementing seismic safety. These are only partly true. It has been observed that increased affordability does not always result in investment for seismic safety. Once people have more money, they spend it on more comfort or visible things rather than safety.

Without money, people can neither procure professional advice nor can they buy materials, so they cannot construct an earthquake safe building. Not tolerating existing unsafe buildings means buildings have to be strengthened. By mid 2008, the Wellington City Council (WCC) completed the initial seismic assessment of some 1,100 buildings of which around half the buildings have turned out to be potentially earthquake prone (Bothara et al., 2008). Unless the benefits of strengthening these unsafe buildings are communicated properly, no one would be prepared to invest money in these buildings. Many Territorial Authorities have used a lack of resources as an excuse for not implementing an active earthquake prone building policy. The issue will be further complicated by the present economic recession.



4a) photograph from the Bhuj earthquake 2001



4b) A photograph from Kathmandu, Nepal

Increased affordability and education also do not mean increased seismic safety. In an economic boom, building regulations are quietly brushed away (Hodson, 2000). The losses to middle-class housing in Ahmedabad in the 2001 Bhuj (India) earthquake highlighted how increased affluence resulted in increased luxury rather than in safer buildings. Fig 4a presents a picture of a collapsed building, where people constructed a swimming pool on top of the existing building rather than strengthening it. Fig 4b shows a photograph of unusual structures constructed on top of a four-storey building in Kathmandu, Nepal. The owner opted to construct these vulnerable structures on top of the building rather than investing in a safer building.

Socio-cultural realities

Socio-cultural issues are major players in risk perception, and thus in the implementation of safer buildings. A few cultures perceive risk higher than others. It could be something to do with cultural philosophies. A study conducted in the US by Fairlie & London (2008) shows higher rates of health insurance among people of European origin than Asian or Afro-Americans. If the same applies to NZ, then the question would be why do people of European origin buy insurance more often than their counterparts? Is it an issue of risk perception, expectation of guaranteed future, low acceptance of risk, or just an economic one?

In a few cultures such as Islam, earthquakes are perceived in a different way to other natural hazards in meaning, significance, and risk perception. According to Paradise (2008), seismic-related forecasting, construction, architectural standards, and/or related education are haram (prohibited). He further elaborates that less educated people often think that Allah would protect the devout, and consider most scientific assessments as futile since they are related to forecasting (also haram). New construction and building standards are considered as a waste since only the kafir (non-Muslim) or munafiq (hypocrite) are at risk to death or injury from earthquakes. The first author had similar experiences and had to struggle to break these barriers when working in Islamic countries on the promotion of earthquake resistant construction. The opposition was more from traditional communities. However, a breakthrough is possible. It requires cultural understanding and sensitivity, patience, and significant negotiation skills.

There are certain social norms and customs that are helping to increase seismic vulnerability. Fig 5 shows two photographs, which present a common scene in Kathmandu, Nepal. Both the photographs present the effect of land fragmentation. According to Nepalese law (now superseded) and social customs, all sons have equal right to inheritance, so land and other property have to be equally divided among sons. The first photograph shows that one of the sons demolished his part of the original traditional house and replaced it with a slender, reinforced concrete building. Similarly, in the second photograph, one of the sons has added two new storeys on top of his part (in the front corner) of the inherited building. These modifications have made the buildings more vulnerable. This trend is increasing.

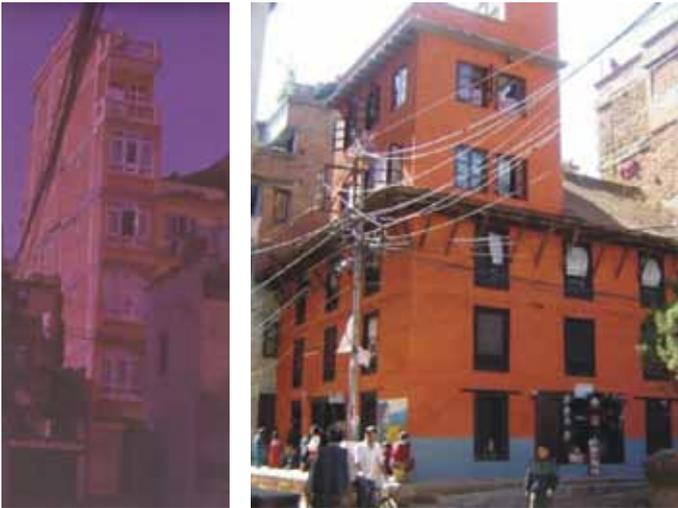


Figure 5: Added vulnerability in Kathmandu due to social norms and customs

In NZ, there are examples of how not abiding by the law has become an incentive, and those abiding by law are left in the cold. Many unreinforced masonry buildings that were previously strengthened to two-thirds of NZSS 1900, Chapter 8 (NZSI, 1965) as required by previous legislation and regulations are being deemed earthquake prone buildings in Wellington. Owners of these buildings had spent significant sums to strengthen their buildings to comply with previous legislation. It is disappointing for them to know that the building which was strengthened just a few years before is again an earthquake prone building and they have to spend yet again a significant amount of money to revoke this status. It has effectively become an incentive for those who did not abide by the law at that time.



6a) An irregular building configuration

Communication gaps

There is a fatal communication gap at all levels of the community, including engineers. Tehran is located in a highly seismically active area of Iran, and has suffered destructive earthquakes in the past. The first photograph in Fig 6 is of an irregular multi-storey building constructed in steel with masonry infill. The building does not abide by even the most fundamental requirements of seismic construction: simple and uniform structure. The second photograph shows a reinforced concrete multi-storey building under construction. All the stirrups in the beams and columns are open. Iran has good universities, and earthquake resilient design is taught. It raises the question of where the gap is in our education system. How poor are we in communication or in following the rules? The same gap can be observed everywhere: starting from policy makers down to grassroot levels.

Whose responsibility is it?

One of the missing pieces of jigsaw puzzle is who is responsible for assuring the safety of a building in an earthquake and, if it is not safe, who is responsible for making the building owner aware? Discussions with building engineers show a variety of attitudes. Some would say that the building complies with building standards, but would not say whether the building is safe or not because of various issues. In this scenario, how can a layman (from a safety point of view) know whether his building is safe or not?



6b) Reinforced concrete frame with open stirrups

Figure 6: Failure of earthquake engineering education

The way out?

There seem to be many pieces of the jigsaw puzzle of earthquake safe buildings missing. Unless these pieces are found and fitted into the puzzle, we will be tolerating unsafe buildings. We must accept that we can reduce the tolerance to unsafe buildings; however, we cannot culminate it forever as it is associated with the perception and there is nothing like an absolute answer to it. The following are a few of the identified measures for reducing tolerance to unsafe buildings:

Communication: There seems an interface between technology and people is missing which should be filled by communication. Communication in various aspects of risk and its mitigation options and awareness raising in end-user's language are the keys for reducing tolerance towards unsafe buildings.

Research: For better communication, substantial research in risk perception, awareness and communication is required to strike the problem and break the barriers of communication.

Role: We have to change the role of engineers and earthquake scientists from protector to promoter. They can create an interface between technology and people. To do this job, they need the understanding of the community's perception and the importance of communication.

Carrot and stick: Incentives for those who want to strengthen their buildings or mitigate earthquake risk would be desirable - accompanied with legal enforcement system.

Viability of technology: There are many grey areas in what we propose for improving safety. These need to be investigated and resolved.

Conclusion

The paper has opened discussion on why we continue to tolerate unsafe buildings from engineering, socio-cultural and economic perspectives. It has identified the paradoxes in our engineering definitions and exclusion of socio-cultural and economic issues when developing strategies for safer construction. It is suggested that we are either pre-occupied with fallacies and myths or we do not understand the importance of socio-cultural and economic issues the implementation of seismic safety. Unless we understand the cultural aspects, we can not effectively implement seismic safety because risk perception and interpretation vary from culture to culture. The paper has also identified the vital gaps in our communication with the people who depend on us for an interpretation of safe. These issues need further debate and research so that we can better deliver to the public so that they do not tolerate unsafe buildings.

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