Disaster Risk Reduction and the Earthquake Code – A Disconnect

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ABSTRACT

The application of current earthquake engineering knowledge through structural design codes has greatly reduced the loss of life from earthquakes in countries where the use of such codes has been normal practice for several decades. However it has not had a commensurate effect on disaster risk reduction as was clearly demonstrated in Christchurch by the Canterbury earthquakes. Although the great majority of lives which were lost were the result of the failure of just one modern building – which evidence suggests was from poor design and not a code problem – many modern buildings, while performing well in terms of life safety, were nevertheless damaged beyond repair imposing major economic and social costs on the citizens of Christchurch in particular and, through greatly increased insurance premiums, New Zealand generally. This paper describes the disconnect between the nature of disaster risk reduction and current structural earthquake engineering design philosophy which arises because disasters are a function of community size as well as building vulnerability, whereas current design philosophy is focussed entirely on the safety of individual buildings. It draws on ideas jointly developed with the late Paul Grundy and is presented as a tribute to his major contribution to this field.

Keywords: earthquake design, disaster risk reduction, socio-economic risk, human safety, insurance

INTRODUCTION

The United Nations International Strategy for Disaster Reduction (UNISDR) defines a disaster as:

> *A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources. A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk*. (UNISDR, 2004)

It is generally assumed that a principal objective of earthquake structural design codes is disaster risk reduction. However although their use does reduce the magnitude of disasters, especially in relation to loss of life, they do not take into account one of the fundamental characteristics of disasters. The magnitude of disasters is a function not just of the vulnerability of buildings relative to the magnitude of the hazard but also of the cumulative impact on the whole affected community of the event giving rise to the hazard.

An underlying principle behind our current structural design codes is that they are concerned solely with the performance of individual new buildings over an assumed design life, and in respect of strength the primary concern is building safety in respect of structural failures that would create a significant risk to life or serious injury.

Several consequences arise from this in regard to disaster risk reduction.

- It fails to take into account the non-linearity of disaster impact whereby the loss of a hundred lives in one event on average every 10 years has a much greater impact on the community than the loss ten lives on average every year from separate individual events.
- It takes no account of economic losses, which make a significant contribution to the total impact of disasters on the community, as a consequence of which generally only those elements of a building whose failure has the potential to pose a risk to human safety are the subject of structural design.
- It takes no account of the fact that the actual life of buildings is generally much longer than the assumed design life.
- It takes no account of the short comings of older buildings designed to obsolescent criteria by providing no criteria for upgrading them to meet current criteria. Nor does it take into account that the current criteria may be obsolescent by the time current new buildings are exposed to a catastrophic event.

The magnitude of a disaster arising from an earthquake is a function of the performance of all buildings subjected to the earthquake, old and new, and of both the human cost and the financial cost, which in combination with other factors affecting the resilience of a community such as the performance of infrastructure, emergency services, social services, and insurance, determine the overall social impact on the community of a major event. It is this social impact which primarily determines the magnitude of a disaster and to which the term ‘disaster risk reduction’ is applied. Design focussed on disaster risk reduction would recognise this holistic nature of disasters.

An additional related factor is that there is an underlying acceptance by many designers that if a building experiences a hazard greater than that specified in the code, then because of the rarity of such an event any consequential impact on the community including the effect of loss of life will be acceptable. To be truly focussed on disaster risk reduction, attention must also be directed at the maximum credible event and how the performance of the building being designed will affect the overall disaster impact.

This paper addresses the implication of these issues for earthquake codes. It is based on a similar paper presented at the last International Conference on Wind Engineering (Walker et al, 2011) of which Paul Grundy was a co-author. Reducing the risk of major natural disasters using the professional expertise and skill of engineers was an issue that was very much on Paul Grundy's mind following the Great Indian Ocean Tsunami in 2004 and the widespread destruction and loss of life which resulted from it. From then until his death in January this year he devoted much of his effort to trying to change attitudes towards this issue within the engineering profession. The paper is written as a tribute to his selfless devotion this cause and an endorsement of the principles he espoused.

HUMAN SAFETY CONSIDERATIONS

In respect of human safety the current structural codes appear to be achieving their objective as far as relatively new construction compliant with these codes is concerned. Deaths from natural disasters, while fluctuating widely from year to year, have not shown a marked increasing or decreasing tendency over the last 40 years (Swiss Re, 2011), with the long term average remaining relatively stationary at about 50,000 deaths globally per year, despite a significant increase in the global population in that time. Most of the deaths have occurred in developing countries, generally as a consequence of inadequate design codes. In developed countries loss of life as a result of the performance of buildings meeting current design criteria in major natural hazards is no longer a major concern.

However this is not due to a focus on disaster risk reduction. While human safety is a stated objective of building codes the real objective appears to be individual building safety. Otherwise the design life of the structure would not be a factor, as it is only relevant in respect of the lifetime economics of an individual building. If human safety is the primary objective, the design lifetime of the structure would not be relevant to the risk of failure. The critical risk factor for human safety in respect of structural safety is the risk of a person experiencing a building failure during their lifetime – not the assumed minimum lifetime of a building. Assuming an average human lifetime of the order of 80 years and earthquake design criteria based on the estimated 500 year return period earthquake ground motion,, a person living in such buildings all their life will on average be exposed to the risk of the ultimate design criteria being exceeded of the order of 15%. On the other hand if the person spent their life in so-called temporary accommodation units designed for a 100 year return period they would be exposed to a risk of exceedance of the ultimate design criteria of 55%, which does not make sense from a human safety point of view. Design criteria based on individual human safety would be expected to produce similar levels of risk during a human lifetime irrespective of the lifetime of the buildings which people occupy.

The non-linearity of disaster impact is highlighted by comparison with vehicle deaths. The estimated annual number of deaths from vehicle accidents in 2004 alone was of the order of 1.2 million (WHO, 2004), which is over 20 times the annual average loss of life from natural disasters. This was five times the estimated loss of life of 220,000 in the 2004 Great Indian Ocean Tsunami (Swiss Re, 2011) in the same year. The latter was of major international concern, yet the vehicle deaths were hardly noticed by the community at large. The reason is that the motor vehicle deaths are the result of a large number of small independent events occurring relatively randomly in time and place. While each one is a personal tragedy for those close to the deceased, local communities are usually well organised to cope with such emergencies. Only when such an event produces a large number of fatalities such as a bus crash is there a significant impact on the community, but this is nothing like the impact of several hundred fatalities from a hurricane or typhoon, or several thousand from a major earthquake. The reason is that a large number of deaths at once create severe strains on a community in terms of the provision of emergency, health and social services which small events do not.

A significant consequence of the focus on building safety is that design codes tend to be focussed primarily on load bearing elements of the building structure – the so-called structural elements. The rest of the building elements are designated as non-structural and of lesser importance in respect of building performance.

ECONOMIC CONSIDERATIONS

Unlike deaths from natural disasters, economic losses from natural disasters have increased tenfold since the 1960's from a 10 year average annual loss of less than USD10 billion to the order of USD100 billion in the first decade of the 21st century when adjusted to present values (Munich Re, 2011). Furthermore this increase is as pronounced in developed countries as it is in developing countries. While raising the level of design criteria has undoubtedly reduced overall economic losses from what they would have been if no change had been made, they have not been nearly as effective in reducing economic loss as they have been in reducing the risk to life. As a result economic losses from disasters are assuming much greater importance relative to loss of life than in the past, a trend which is expected to continue unless checked by appropriate mitigation measures.

The major reasons for the increase in frequency and magnitude of disasters when expressed in terms of economic loss are two generally complementary aspects of global demographic change (Pielke et al, 2007):

- The increasing urbanisation of society resulting in an increasing number of large concentrations of population, which are increasing in area and concentration with time.
- The increasing wealth per person of those living in urban environments.

In the developed world the urbanisation began earlier and is starting to plateau, but in developing countries it is occurring at a rapid rate (UN, 1996). In both the developed and under-developed world the wealth per person continues to increase, as does increasing dependence on increasingly complex systems of infrastructure which is also at risk from major natural hazards. Natural disasters are a consequence of the interaction of natural hazards and concentrations of population so it follows that unless this expansion in size and wealth of urban concentrations is not accompanied by increased mitigation measures then the magnitude of economic losses from disasters will continue to increase. This is as true for earthquakes as it is for weather related events which in addition may also be subject to the effects of climate change (IPCC, 2007).

As with deaths the impact on the community per person increases with the size of the economic loss. In a small event if private property is well insured and damage to infrastructure is small, the local community may be able to cope with the repair and reconstruction. The larger the overall damage costs the greater the financial burden placed on the community, which is exacerbated if the level of insurance of private property is low. Large disasters in developed countries often produce losses beyond the capacity of local and state governments to fund them, even allowing for insurance, and in developing countries it is not uncommon for national governments to have to seek assistance in the form of loans from international organisations such as the World Bank. The impact of these sudden demands can cause economic consequences that are far greater than would be predicted by simple linear extrapolation from the impact of small events. This is reflected in insurance. The reinsurance premium to cover a fifty billion dollar loss with a frequency of exceedance equivalent to a return period of 200 years will be significantly more than 5 times the reinsurance premium to cover a ten billion dollar loss with the same frequency of exceedance (Walker, 2008).

The economic impact of major disasters can disrupt communities and the lives of their citizens to the extent that socio-economic development can be severely retarded. As a consequence there is increasing global recognition that disaster risk reduction is an essential component of sustainable development. The United Nations through its International Strategy for Disaster Reduction (www.unisdr.org) is playing a major role in encouraging government action around the world to embrace disaster risk reduction for both humanitarian and economic reasons, ably encouraged by the World Bank concerned at the increasing demands being placed upon it for disaster related funding. Individual countries such as Australia (AusAID, 2009) have responded by having their own strategies. An important component of these strategies is building standards and their implementation, but they will need to be focussed on disaster risk reduction not just building safety.

It is probably no coincidence that the underlying design philosophy of current codes was developed in the 1960's and 1970's when economic losses were not so significant. In the meantime the socio-economic environment in which they are applied has changed, and if they are to meet the expectations of the wider community in respect of disaster risk reduction they need to address the reduction of the economic impact of disasters more effectively than they are doing. Failure of so-called non-structural elements within a building such as internal partitions, ceiling systems, and those associated with services such as electricity, gas and water systems, which disrupt the function of the building, are a significant cause of economic loss. In respect of individual building design, codes have been increasingly recognising some these factors, but their importance in respect of disaster mitigation is probably not fully recognised by many of those who use them. The Serviceability Limit State is often intended to limit minor damage costs, but the return periods associated with this design are orders of magnitude less than those usually associated with earthquake events causing major disasters.

There is a precedent for the use of criteria based on disaster risk reduction in the design criteria for large dams (ANCOLD, 2003).

OBSOLESCENCE AND EVENTS BEYOND THE CODE

Natural catastrophic events are no respecters of human assumptions. When catastrophic disasters arise it is not uncommon for the return periods associated with the events to be much greater than those used in design. The earthquakes in Christchurch and Japan in 2011 are a good example of this. Although it is commonly assumed by the community that it is only old buildings built to much lower standards that are at risk, from a disaster perspective all buildings are at risk of experiencing events beyond those envisaged at the time of design. Consequently design for disaster risk reduction requires that consideration be given to the performance of all buildings if subjected to events beyond the codes and regulations current at the time of their construction, and especially the consequences for the community as a whole as well as for the occupants of the particular building. This issue is closely associated with the issue of obsolescence of design codes.

The design of all buildings by and large reflects the acceptable level of risk of failure within the community at the time of construction. With the passage of time the acceptable level of risk within communities tends to decrease, indirectly reflecting to some extent that as communities grow they need to be safer, even if the criteria is then applied irrespective of community size. As a consequence, relative to today's standards, much older construction is now regarded as non-code compliant and the community assumes that while buildings built to current codes will be adequate, the older ones may be of some concern. However if there continues to an increase in wealth and its concentration in real terms it is inevitable that the level of acceptable risk will continue to decrease over the real life of most buildings. The types of events that cause major disasters, and to which codes and disaster risk reduction strategies are directed, are rare. If buildings built in accordance with the current codes are exposed to such a major event in the future it is quite likely that by this time our current codes will also be obsolescent.

A design philosophy focussed on disaster reduction needs to take both these issues into account. In addressing this situation Paul Grundy drew inspiration from the ideas put forward by Whitman (1984). Whitman postulated that there was an acceptable level of risk which is the desirable level on which to base normal design performance, but the consequences of events exceeding this level should also be considered and criteria developed for coping with them. However he suggested that the latter criteria should be based on a marginally acceptable level of performance by the community recognising both the extreme rarity of the event but also the consequences if it occurred. He proposed that acceptance at this level be based on the ALARP principle –maintenance of the performance 'As Low As Reasonably Possible'.

The ALARP principle has both structural and non-structural components. The structural component includes concepts of redundant load paths, safety compartments, etc. The non-structural components include community resilience factors such as early warning systems, designated evacuation routes and refuges, robust emergency communication systems, emergency power supply, emergency response planning and drill. Both components are usually necessary. Whitman only considered the performance of single buildings independent of the performance of other buildings, but the concept can be extended to consideration of disasters, particularly in respect of buildings non-compliant with current codes, and events beyond those on which current code criteria for the rigorous design of buildings is based.

Paul Grundy coined the term Disaster Limit State to describe criteria focussed on the design of new buildings for events beyond those catered for by the Ultimate Limit State criteria at the time of design, and on the upgrading of existing buildings for which their design criteria is obsolescent (Grundy, 2008). An alternative term consistent with this objective is Resilience Limit State.

IMPLICATIONS FOR EARTHQUAKE DESIGN

Some of the implications of directly addressing disaster risk reduction in design codes can be summarised as follows:

- Design return periods for the Serviceability Limit State should relate to the return period of the types of events that can cause significant economic losses from this limit being exceeded.
- Design Return Periods for both the Serviceability and Ultimate Limit States should reflect both the present size of the community, and its likely growth in size during the expected life of the building – as opposed to some arbitrarily assumed design life – as well as the resilience of the community. They should also be based on the return period for the whole community, not at a point location. These criteria would be based on normally accepted levels of structural performance levels at the design levels.
- Design criteria should encompass all elements of a building whose failure may give rise to economic loss, not just the load bearing elements whose failure poses a threat to life.
- An additional limit state known as the Disaster Limit State or Resilience Limit State should be introduced to provide criteria for handling buildings whose design criteria is obsolescent, and to provide additional criteria for the design of new buildings which takes into account the maximum credible event to which the communities in which they are located is exposed. These criteria would be developed using the ALARP principle.

CONCLUSIONS

Current earthquake design does not directly address disaster risk reduction because of its focus on a single building, and on human safety only. Disaster impact is the result of a holistic combination of many factors which can be summarised in terms of human safety, economic loss and community resilience. Earthquake design focussed on disaster risk reduction would incorporate all these factors. A major consequence of doing this would be design criteria that were a function of community size and its resilience, took into account both human safety and economic loss, required consideration of the maximum credible event, and also addressed buildings designed for obsolescent criteria. An additional limit state known as the Disaster Limit State or Resilience Limit State is proposed for dealing with obsolescence and the maximum credible event.

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