Earthquake resilience through early integrated urban planning and practice

P. Brabhaharan

Opus International Consultants, Wellington.

2013 NZSEE Conference

ABSTRACT: Early focus on earthquake resilience is important to achieve a resilient urban environment. The Canterbury earthquakes have underlined the importance of achieving this in our practices ranging from urban planning to individual developments.

Planning measures provide a valuable mechanism to develop land in a sustainable manner and to achieve resilience. These measures range from hazard mapping, dissemination of hazard information, consideration of hazard effects in zoning land for development, and putting in place district plan rules to guide earthquake resilient development. Different approaches are necessary for land already zoned and developed, compared to new areas of development. Urban planning measures are illustrated through a number of case studies illustrating good practice from around New Zealand.

Integrated practice of professionals is also fundamental to achieve good earthquake resilience of developments. This requires that various professionals work together and provide early focus on resilience to ensure that good earthquake resilience can be achieved in a sustainable and cost effective manner. The Canterbury earthquakes have also underlined the importance of such integrated practice.

1 INTRODUCTION

Natural hazards such as earthquakes can cause severe damage and loss of life, as amply illustrated by the recent 2008 Wenchuan earthquake in China, 2010-2011Canterbury Earthquakes in New Zealand and the 2011 earthquake and tsunami in Japan. These events highlight the importance of enhancing the resilience of society to natural hazards such as earthquakes.

In New Zealand, the local authorities have significant responsibilities to identify, provide information and manage the risk from natural hazards, primarily under the Resource Management Act 1991 and the Building Act 2004. The Civil Defence Emergency Management Act 2002 also requires local authorities to individually and collectively take proactive measures to manage the risks from hazards.

We have often placed emphasis on design standards for our buildings, without developing and putting in place effective planning measures to improve our long term resilience to such hazards. An integrated suite of measures extending from land use planning, building controls, design and construction to emergency response planning are important to effectively improve our resilience to earthquakes and other natural hazards.

After past earthquakes causing significant loss of life, we as a society had rightly focussed on designing buildings to prevent collapse and loss of life. While there has sadly been loss of lives in the recent Canterbury earthquakes, we as a profession need to move forward to ensure our resilience in earthquakes. This requires consideration of not just life safety, but also performance of our facilities to ensure the ongoing functionality of society. This needs to be considered in a manner that is economic and acceptable to society.

To achieve resilience in an economical and sustainable manner, it is vital that we work together in an integrated manner and provide early focus on resilience. This would enable us to develop buildings and facilities that are resilient, in a sustainable manner.

2 WHAT IS RESILIENCE?

Resilience is the ability to recover readily and return to its original form from adversity. The Community and Regional Resilience Institute (2013) defines resilience as *the capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change*. From an infrastructure and building perspective, this requires us to develop our built environment in a way that reduces damage and the consequent loss or reduction in its functionality, and enhances the ability to recover quickly from such reduction. Brabhaharan (2012) adapts this concept for resilience for the built environment as conceptually illustrated in Figure 1.

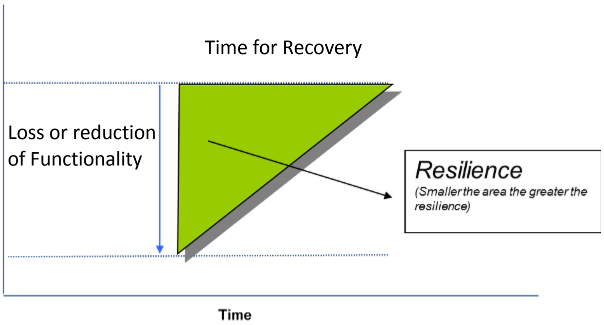

Figure 1. Concept of Resilience of Built Environments

Resilience of our built environment can be maximised by early focus on minimising the green triangular area in the figure by:

a) Reducing vulnerability of our built environment to loss or reduction in functionality in an event, and

b) Developing our built environment so that it is able to be quickly returned to functionality.

Creating a resilient society requires focus on the functionality of our developments after events, by reduction in the loss of use and enables early recovery after events. To achieve a more resilient society, we need to go beyond our focus on life safety from earthquakes, and consider the resilience of the built environment. This requires focus on how a loss of functionality can be minimised, as well as achieving a form that is conducive to quick return to functionality.

3 LEGAL FRAMEWORK

Let us first focus on legislation relating to land use planning for natural hazards.

<u>The Resource Management Act 1991</u>

The primary piece of legislation is the Resource Management Act 1991 (RMA), which governs the use of natural and physical resources, including water and land. Local authorities prepare plans that ultimately provide the policy framework for the decisions to be made about managing risks associated with natural hazards. The local authority functions include controlling the actual or potential effects of the use, development or protection of land to avoid or mitigate natural hazards (s.31(b)). The regional councils have a role, which is to control land use for the purpose of avoiding or mitigating natural hazards (s.30(1)(c)(iv)).

<u>Civil Defence Emergency Management Act 2002</u>

The act requires the preparation of a national strategy and regional civil defence emergency management plans. It focuses on the promotion of the 4'R' of managing risk through reduction, readiness, then response and recovery. The act place responsibility of civil defence emergency management groups and their members to:

- Identify, assess and manage hazards and risks
- Consult and communicate about risks
- Identify and implement cost effective risk reduction.

Other legislation which may affect management of natural hazards and the implementation of measures include the Building Act 2004 which addresses earthquake prone buildings.

Glavovic et al (2010) identify the role of various national, regional and district level agencies and stakeholders with an interest in land-use planning for natural hazards.

4 RISK MANAGEMENT MEASURES

4.1 Generic Measures

The risk from natural hazards can be managed through a number of measures, some of which are more appropriate than others depending on the vulnerability of society, the nature of existing development and the available funding.

The Australia/ New Zealand Standard on Risk Management AS/NZS 4360:2004 (Standards Australia, 2004) summarises generic risk management measures. These together with possible application in this context are presented in Table 1.

Table 1. Risk Management Measures

Risk Management Measures	Application for the Built Environment
Avoiding risk	eg. land use zoning to exclude high vulnerability activities in areas of high hazard.
Reducing frequency of occurrence	eg. using stop banks to reduce frequency of flooding.
Reducing consequences	eg. raising buildings above flood levels or designing foundations to reduce damage from liquefaction, or buildings resistant to earthquake shaking.
Transferring risk	eg. through insurance.
Financing risk	eg. accumulation of funds for repairs following an earthquake.
Accepting risk	eg. Recognising risk and addressing residual risk through emergency response planning.

Different risk management measures may be appropriate in different contexts. The selection of appropriate measures would require consideration of environmental effects, economics, sustainability and the views of the community affected.

4.2 Land Use and Planning Controls

Land Use Planning

Land use controls can be used to keep inappropriate future development away from high-hazard areas, and remove existing high vulnerability developments in high hazard areas. Land use controls should be formulated and resolved within the context of political, social, economic, sustainability and environmental priorities.

Figure 2 illustrates examples from the 2008 Wenchuan Earthquake in the Sichuan Province of China (Yong et al, 2009), where the risk to development would have been impractical to design against, and land use zoning to avoid the area may be appropriate.

There are examples from Christchurch, where land use planning would have been valuable.

a) Liquefaction Damage in Eastern Christchurch: There was extensive damage to the built environment from liquefaction and lateral spreading in some parts of Christchurch and Kaiapoi. In these situations, while design against earthquake damage would have been feasible, it is not economic or sustainable use of resources to develop these hazardous areas.

b) Landslide Damage in the Port Hills: There were landslides that destroyed or threatened buildings that were built close to cliffs, both above and below (Figure 3). Appropriate land use planning controls would have avoided the use of these areas for construction of buildings.

Figure 2. School destroyed by landslide (left); Collapsed school building across ruptured fault (right)

Figure 3. Damage to Buildings from Landslides (left) and Liquefaction (right) in Christchurch

<u>Hazard Maps</u>

Brabhaharan (2010) describes the characterisation of earthquake hazards, and emphasises the importance of mapping the hazard effects in a way that is useful for land use planning as well as for assessment of the consequences to the built environment. An example of a hazard map for Western Bay of Plenty in Figure 4 shows potential liquefaction ground damage from earthquakes, and is more useful for land use planning and damage assessments rather than a map just showing liquefaction.

Hazard maps can be used to manage risk by:

1. Provision of information to the community, to enable them to take self-action to manage the hazards.
2. Use of hazard maps in land use zoning to minimise the risk to the community from hazards.
3. Influencing the mitigation of risk in developments, through rules attached to hazard zones in the District Plan.

The hazards were well known in Christchurch, and they could have been better represented showing ground damage hazards, and been used more proactively for land use planning.

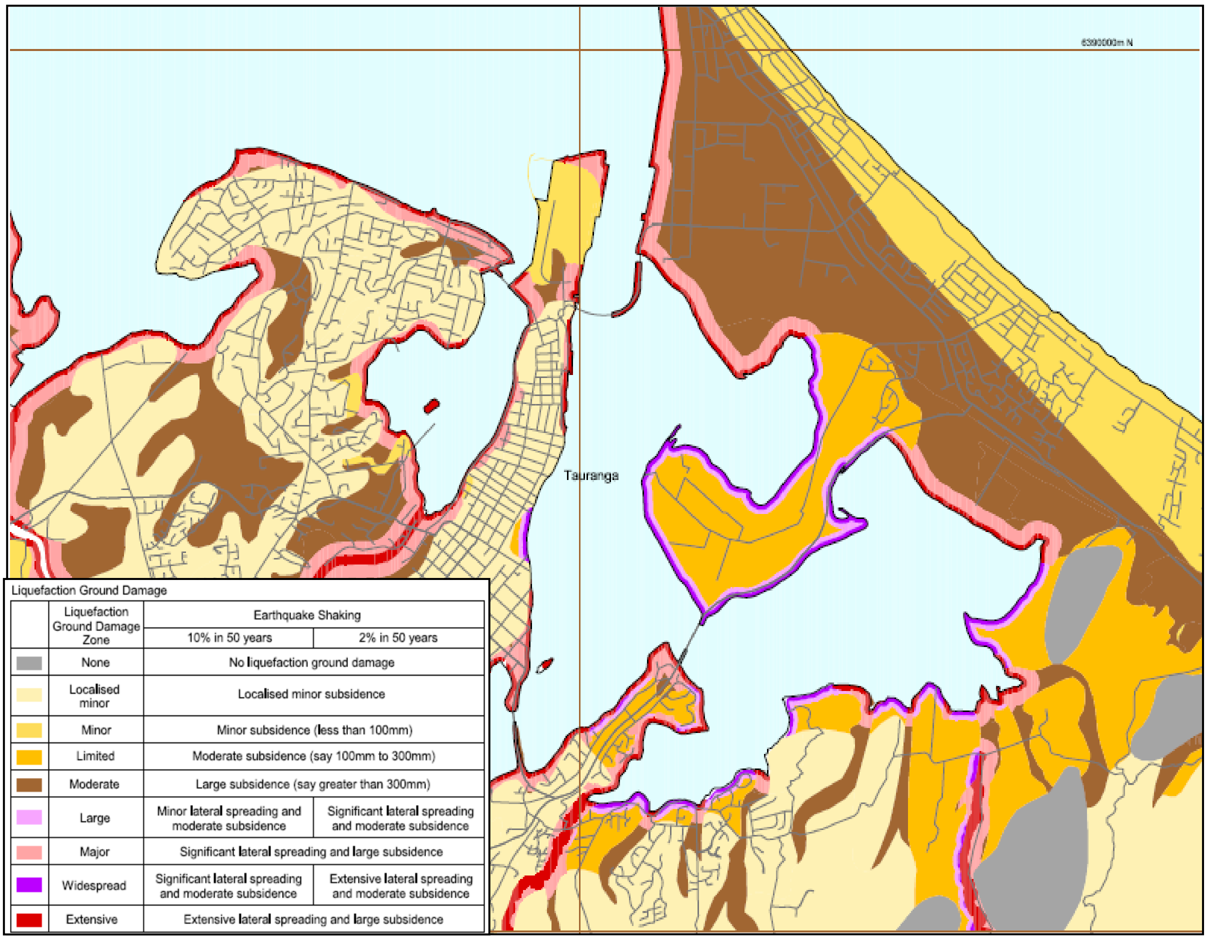

Figure 4. Liquefaction ground damage map extract for Western Bay of Plenty

<u>District Plan Rules</u>

District plans are a useful mechanism to identify hazards, and where appropriate, control the location and standards of development in hazard areas.

<u>Resource Consent Process</u>

The resource consent process can be used to manage land use so that the risks from natural hazards can be avoided or mitigated, through measures such as:

- Requiring information such as a site specific technical report on the effect of hazards on the proposed development.
- Consideration of the risk from natural hazards in the consideration of resource consent applications.
- Specifying conditions to reduce the risk from hazards as part of conditions imposed on resources consents.

The granting of a subdivision application is specifically restricted where land is, or is likely to be subject to material damage by specified natural hazards, or where the subsequent use of the land is likely to accelerate, worse or result in material damage to the land, other land or a structure.

<u>Building Controls</u>

Building controls are conditions that can be attached to building within hazard areas, and aim to reduce the risk to the building and its occupants from hazards.

In relation to floods, this could be the floor level of buildings. Minimum floor levels are currently defined by the Building Act 2004, with a 1 in 50 year standard set. The Resource Management Act has been used to set higher standards.

Section 36 entries on the Certificate of Title can also be used by a consent authority where it considers that the building work will not exacerbate or result in a specified hazard, but the land is subject to, or is likely to be subject to hazards, and where other requirements are met. The entry serves as a warning to potential purchasers.

Building Consents

Buildings consents must be obtained for certain building work including site work. There are restrictions on granting building consents for work on land subject to or likely to be subject to a number of specified hazards, or where building work is likely to accelerate, worsen or result in those specified hazards on the land. The hazards specified are erosion, avulsion, falling debris, subsidence, inundation or slippage. It is noted that not all hazards are listed, for example earthquakes, volcanic eruption or windstorms.

As a general matter, a territorial authority must have "due regard" to natural hazards when exercising specific powers under the Building Act.

4.3 **Earthquake Resilient Buildings**

Earthquake resilience involves the design and construction of buildings with appropriate details or materials such that damage to the structure of the building itself (structural damage) is minimised when the building is exposed to the hazard. For example, a building may be designed to resist a higher level of earthquake hazard than required in the codes of practice. Although design can minimise structural damage, the residents and their possessions may still be adversely affected.

Earthquake design can be considered for enhanced performance of buildings rather than design for life safety alone. This will need to consider the balance between additional costs of construction and performance in relatively low probability earthquake events. However, by considering resilience at an early stage, it may be possible to select more resilient structural forms and enhance performance at little additional cost.

4.4 **Voluntary Actions**

Voluntary actions by private or public individuals or organisations may be appropriate for protecting at-risk properties or reducing the residual risk in areas to be protected by physical measures such as stop banks. These are appropriate in hazards areas where it is impractical to mitigate the hazard. Voluntary actions may include providing information on hazard effects and ways to reduce impacts.

4.5 **Emergency Management**

Emergency management has typically been a service provided to at-risk communities during hazard events. Recent reform has extended this to include reduction, readiness, response and recovery, and aims to build resilient communities.

Emergency management is an integral part of enhancing resilience to hazards through preparedness and being able to recover quickly after events.

4.6 **Physical Measures**

These measures involve constructing physical works designed to contain the hazard. These more traditional tools for reducing the risks associated from hazards include measures such as stop banks, to protect people and assets from floods, or rockfall barriers to protect communities from rock fall hazards.

Such physical measures are valuable to reduce the risk from hazards and allow people to live in areas prone to hazards that have already been developed.

5 EFFECTIVENESS OF EXISTING URBAN PLANNING MEASURES

The extensive damage from liquefaction to residential property from the 2010-2011 Canterbury earthquakes raises the issue of whether the existing urban planning measures have been effective in managing the risks from natural hazards such as earthquakes. They also highlight the vital role land use planning has in enhancing resilience to natural hazards.

Although effective hazard maps have been prepared and published in a number of regions of New Zealand, their uptake in translating this knowledge of hazards into effective land use planning has been limited. In other regions, there is also the need to develop and publish effective hazard maps. The level and scale of hazard maps and their usefulness is described by Brabhaharan (2010).

The 2010 Darfield earthquake in particular, clearly demonstrated the difference in performance of our built environment depending on ground damage hazards. Comparatively modern construction performed well in areas of low ground hazards even when exposed to high level of earthquake shaking (eg in the epicentral areas and in western parts of Christchurch), whereas the performance has been considerably poorer in the areas with poor ground and liquefaction induced ground damage hazards. This highlights the fact that land-use planning has a very important role to play in building resilient communities.

Glavovic et al (2010) explore the setting, and identify four barriers to land-use planning as:

- Hazard risks are secondary to short-term public concerns;
- Well intentioned policies and laws encourage local communities to discount hazard risks;
- Co-ordinated hazard risk reduction is difficult to achieve given diverse and divergent stakeholder interests;
- Economic growth including development in at-risk areas, is prioritised over community safety and sustainability.

They identify four burning issues and associated priority actions as:

1. Improve understanding about nature of hazards
2. Prioritise risk avoidance (reduction) measures
3. Provide national guidance for communities exposed to repeat events and address issue of relocating at risk communities;
4. Mainstream climate change adaptation.

These highlight the need to take effective action to improve land-use planning measures.

The current climate after the recent spate of earthquakes has heightened the awareness of communities to natural hazards and their devastating impacts on communities. This awareness provides an ideal opportunity to engage with the communities and authorities to make changes in the way we manage the risks from natural hazards.

Local authorities will also benefit from practical examples of the way the risks from earthquakes (and other natural hazards) can be translated into land use planning and other urban planning measures.

6 FOCUS ON PERFORMANCE OF THE BUILT ENVIRONMENT

6.1 Design for life safety

One of the fundamental premises of our building codes and standards is life safety. While life safety has been a major source of concern, and remains so, focus solely on this aspect does not help improve the resilience of our communities in the aftermath of hazard events such as the recent earthquakes in New Zealand. It is unclear whether society is adequately aware of the design standards for life safety in modern earthquake engineering practice, or whether there is a gap in the expectations of society and the philosophy adopted in our building codes. It is important that we engage with society to inform and adopt a philosophy consistent with community expectations.

6.2 Design for performance after events?

Resilience requires more than life safety, with an added ability to recover quickly after significant earthquake events. Increasingly performance after events rather than just collapse-prevention, is an important consideration in the design and maintenance of lifeline infrastructure, which is fundamental to response and recovery after hazard events. This has, by and large, served our society well for example in the performance of our road infrastructure and telecommunications lifelines in the Christchurch earthquakes of 2010-2011. Should our built environment also reflect this approach of design for performance rather than only life safety?

Currently design for performance is limited to a relatively low level of earthquake actions used for Serviceability Limit States. Ultimate Limit State design has a singular focus of life safety. In the large Christchurch earthquake event, there are many examples of good performance of our buildings including houses. A study of the comparative performance of our buildings would help us better understand, and adopt types of buildings that can perform better in earthquakes. It is alos important to consider how they would perform in different earthquakes – for example an Alpine Fault earthquake with a lower level of ground shaking but a longer duration of shaking. The buildings that performed well did not necessarily cost more to build, or did they? Such a comparison will enable us as a profession to understand what makes our buildings more resilient and whether they cost more.

It is important to understand the economic ramifications of adopting a more performance based design approach, as it may not be prudent to substantially increase the cost of our built environment to perform in relatively low-recurrence events. Consideration of the performance and costs will enable us to adopt an appropriate performance based design philosophy that would help improve the resilience of our communities to earthquakes. This will also provide a basis to engage with the community on our design approach.

6.3 Early focus to enhance earthquake resilience

Early focus on land use is critical to enhance resilience. For example should we be building in areas of high liquefaction or landslide hazards and accept damage, or be more selective and focus high intensity and high vulnerability urban development on more secure areas and achieve a more resilient built environment, and use the more hazardous areas for less intensity and lower vulnerability land uses? A more informed choice of land use does not cost society as a whole. But this requires a very early focus on resilience at land use planning stage.

Early focus of building form will also help enhance resilience without a significant increase in the construction cost. Brabhaharan (2009) illustrated this through the Transmission Gully highway case study where an early focus on resilience enabled the selection of road forms that gave increased resilience, actually with a substantially reduced cost. This illustrates that improved resilience does not necessarily mean increased costs. This enhanced resilience required focus on resilience at the very early stages of the planning of the project.

For example, taking residential dwellings, building with thin unreinforced concrete slabs have performed poorly in the liquefied areas in the recent Canterbury earthquakes, and are not amenable to be readily repaired. In comparison other types of houses have performed better, and or can be more easily repaired. Adopting house foundations that are less prone to damage or can be quickly repaired would provide a more resilient outcome. This requires a focus on resilience, but may not necessarily cost more.

The need for early focus on resilience during land use planning and engineering practice in building developments is discussed further in Sections 8 and 9.

7 SUSTAINABILITY

Sustainability principles require us to use the earth's resources in a more considered and prudent manner. Damage such as we have seen in recent earthquakes requires a lot more resources, both material and energy, for reconstruction. More resilient built environments will be more sustainable in the long run. Building in hazardous areas such as areas prone to liquefaction and lateral spreading, and rock fall are possible, but will consume a lot more resources (and cost more) either in terms on initial engineering and construction costs, or in terms of reconstruction after hazard events. Therefore a prudent approach to the use of land, and resilient construction will lead to greater sustainability.

The Canterbury earthquakes also produced a lot of debris from demolition and waste that had to be disposed of, and represents wastage of scare resources, which is not sustainable in the long term.

8 EARLY INTEGRATED FOCUS ON RESILIENCE IN LAND USE PLANNING

Early integrated focus on land use planning by town planners and geotechnical engineers is important to ensure that the hazards and consequences to the built environment are taken into consideration in zoning and for urban development. Brabhaharan (2012) cites the example of land use planning in Blenheim as part of Marlborough District Council (2012)'s urban growth strategy. The land initially considered for urban growth was assessed for geotechnical hazards and liquefaction. The assessment identified some of the areas as being prone to liquefaction and lateral spreading, and these were excluded from the growth strategy. The assessment also identified potentially less hazardous alternate land close to the town as being more suited for development based on the geology and geomorphology, and is being considered for urban development. Such an early focus on resilience to hazards helps avoid land subject to significant hazards where alternate land is available. The development of the less hazardous areas leads to less use of resources and the built environment will be more resilient, both of which contribute to sustainable use of resources.

9 EARLY INTEGRATED FOCUS ON RESILIENCE IN BUILDING DEVELOPMENTS

To achieve greater resilience, it is important to focus on resilience at an early stage. The Transmission Gully example above highlights the need for early focus when the siting of buildings and building forms can be influenced. This requires the early integrated working together of the professionals involved in the building process. Brabhaharan (2012) highlights the current process of engagement in the building process, and the integrated relationships necessary for achieving a more resilient building development, as shown in Figure 5.

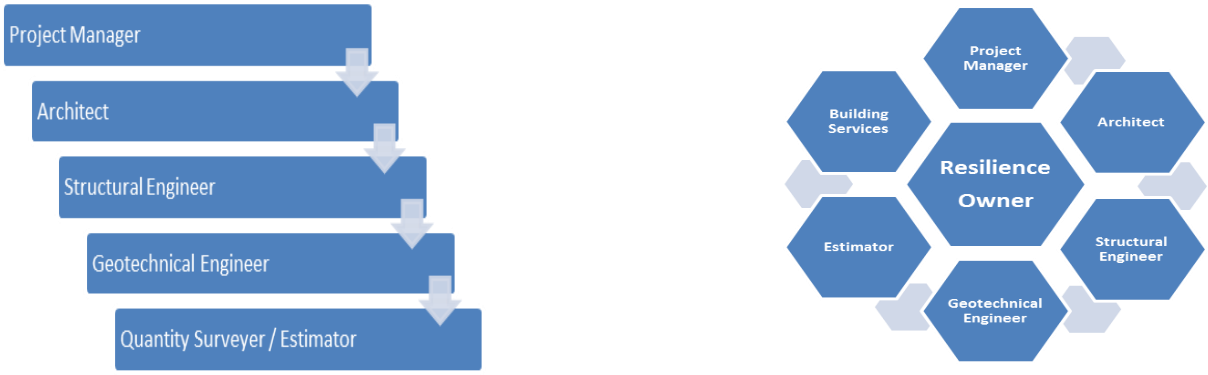

Figure 5. Current Process of Engagement (left); Integrated early relationships necessary for resilience (right)

Based on the common approach above, the building developer or owner perhaps in conjunction with a project manager or architect may make a decision on the site, which may be prone to severe hazards – say liquefaction, even though alternatives may have been available at this early stage.

The architect may be engaged at this stage, and may make decisions on the location of the building within the site, perhaps close to a river with potential for liquefaction induced lateral spreading. He may also decide on a form for the building without recognising the liquefaction hazards or the high potential for ground shaking at the site. The structural engineer may then be engaged at this stage, who is constrained by the building form, and has to come up with a structure that is complex (and less resilient) to suit the building form that has been set, and has a set sub-structure requirement.

A geotechnical engineer may be engaged at this stage, who is constrained by the location of the building in a lateral spread zone, the building form that is vulnerable, and a substructure that is less flexible and therefore develops ground improvement and deep foundations to cater for the restraints at that stage. The cost estimator may then be engaged and comes up with a high cost to account for the complex structure and high foundation and ground improvement costs.

At each stage decisions may have been made that are difficult or embarrassing to change that leads to a high cost and still a lower resilience, as the focus is then to design to a minimum code level to reduce costs. Compromises then may need to be made – focussing on where there aren't strict code requirements – and some flexibility, such as on the ground improvement and performance. All this could potentially lead to a less resilient and more costly building.

If all the professionals are engaged from a very early stage, they would have the opportunity to work as an integrated team, and perhaps select a less vulnerable site, or locate the building away from the river or where there is less liquefaction hazard, or come up with a building form that is sympathetic to the specific earthquake hazard issues or develop a sub-structure that takes into consideration soil-structure interaction to develop a building scheme that is more resilient and less costly to build.

It is therefore of paramount importance to reform our building process, and encourage all of us in the building industry to work together from a very early stage, if we as building professionals are to achieve greater resilience and possibly lower cost buildings. Early identification of hazards from records by the geotechnical engineer at an early stage, and involvement in site section is important.

10 **CONCLUSIONS**

Recent earthquakes in Canterbury and elsewhere have caused significant damage and loss of functionality in addition to loss of life. This also leads to the consumption of a lot of the planet's resources for reconstruction, and severe inconvenience to society. It is important that we consider resilience in our urban planning, site selection, building form and design if we are to achieve resilience in a sustainable manner.

While life safety was a noble cause to focus in the past, and still requires consideration as we still face loss of life in earthquakes, we also need to look forward beyond life safety, and focus on resilience. A focus on resilience requires consideration of functionality after events and the ability to quickly recover after major events. This requires further development of our current design philosophy and building codes beyond the current ultimate state and serviceability state design. We also need to engage with society on the design philosophy so that we come up with an approach consistent with the expectations of society.

Land use planning and zoning of less hazardous land for urban development, and more hazardous land for less intensive land uses such as farms and parks is important to enhance resilience in a sustainable manner. Once land is zoned for development, it then encourages less resilient, less sustainable development which also necessarily costs more. Prudent land use zoning requires early integrated practice between town planners and geotechnical engineers.

More resilient infrastructure and building developments require an early focus on resilience to select a less hazardous location, careful siting within the selected or available land to minimise hazards (eg. lateral spreading), and development of building or construction forms that are more resilient to earthquakes. These considerations can then be integrated into the proposed architectural, structural and foundation concepts. This requires change from the current linear form of engagement in the building industry, to an early integrated and collaborative form of engagement between the building professionals and the owner. An integrated focus on resilience will enable us to collectively contribute to a more sustainable and resilient society.

Acknowledgements

The permission of Opus to publish this paper is also acknowledged.

REFERENCES:

AS/NZS 4360: 2004. Standards Australia 2004.

Brabhaharan, P. 2009. Performance focussed Conceptual Design to enhance Route Security, Transmission Gully Highway, Wellington. NZ Society for Earthquake Engineering Annual Conference. 3-5 April 2009. Christchurch.

Brabhaharan, P. 2010. Characterisation of Earthquake Geotechnical Hazards for Engineering and Planning in New Zealand. 11th IAEG Conference. Auckland.

Brabhaharan, P. 2012. Lessons from Ground Damage in the Canterbury Earthquakes for Engineering Practice. SESOC Conference 2012. From Theory to Practice. 2-3 November 2012. Auckland.

Community and Regional Resilience Institute (2013). http://www.resilientus.org/about-us/definition-of-community-resilience.html

Glavovic, BC, Saunders, WA and Becker, JS (2010). Land-use planning for natural hazards in New Zealand: the setting, barriers, 'burning issues' and priority actions. Natural Hazards, Vol.54. pp679-706.

Marlborough District Council (2012). Blenheim Liquefaction Report. August 2012. http://www.marlborough.govt.nz/Environment/Natural-Hazards/Earthquake/Blenheim-Liquefaction-Report.aspx

Yong, P, Yu, J, Reid, S, Brabhaharan, P and. Meng, P (2009). The Ms 8.0 Wenchuan Earthquake of 12 May 2008 Reconnaissance Report. NZSEE Bulletin. Vol. 43. Issue 1.