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ESTABLISHING THE LINKAGES BETWEEN STRUCTURAL ENGINEERING AND RISK MANAGEMENT

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ABSTRACT

A structural engineering background provides an excellent platform for undertaking a wide range of risk management activities. One of the most valuable and unique skill elements is the ability to visualise damage impacts resulting from earthquake and other natural and man-made hazards.

This paper explores the linkages between structural engineering and risk management. The many activity strands of structural engineering are expressed in terms of the fundamental steps in the risk management process of *risk context*, *risk identification*, *risk assessment*, *risk treatment* and *risk communication*. It is concluded that the linkages between the disciplines are more direct than is often appreciated by many structural engineers.

The importance of professional engineers understanding the wider context of their activities is highlighted. This includes awareness of recent legislation beyond the customary building regulatory frameworks, with particular reference to the Civil Defence and Emergency Management Act 2002. One of the changes brought about by this Act is to place greater emphasis on the consequences of hazard events on infrastructure and communities. For engineers, this involves moving beyond identifying the impacts of an event into the area of addressing the community consequences.

Engineers play a key role in *risk communication* in a variety of different situations. The need for engineers to be proactive advocates to asset owners and operators for a more holistic approach to risk management is emphasised.

BIOGRAPHICAL NOTE

David established his career as a structural engineer during the building boom of Wellington, Auckland and Sydney in the 1980's. He was fortunate to be based in Sydney at the time of the 1989 Newcastle earthquake, and was involved in the initial impact assessment and subsequent recovery process for the following two years. He also undertook reconnaissance of the 1993 Guam and 1995 Kobe earthquakes, and led the New Zealand Society for Earthquake Engineering team to Taiwan following the 1999 Chi-Chi earthquake.

His observations from these events have led to his active involvement in emergency management planning.

David is the Immediate Past President of the New Zealand Society for Earthquake Engineering, and is a member of the National Urban Search and Rescue Steering Committee. He is also the National Lifelines Engineering Co-ordinator, and has been the Project Manager of the Wellington Lifelines Group since its establishment in 1993. He is one of the two IPENZ nominees on the board of the Building Research Association of New Zealand Incorporated.

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1 INTRODUCTION

A structural engineering background provides an excellent platform for undertaking a wide range of risk management activities. One of the most valuable skill elements is the ability to visualise damage impacts.

This paper explores the linkages between structural engineering and risk management. The many activity strands of structural engineering are expressed in terms of the fundamental steps in the risk management process of *risk context*, *risk identification*, *risk assessment*, *risk treatment* and *risk communication*.

Understanding the risk context of a structural engineering task or project and the ability to communicate the complexities of earthquake risk are of vital importance to all practising structural engineers. Once these fundamentals have been grasped, structural engineers are able to work effectively in a wider array of related disciplines such as Lifelines Engineering and structural collapse rescue.

2 THE ESSENCE OF STRUCTURAL ENGINEERING

Structural engineering is essentially the design of buildings and other structures to withstand the effects of gravity and other imposed actions. This involves understanding the physical impacts of the various hazard drivers that can give rise to extreme loadings (eg. wind, snow, earthquake). Each of these hazards typically has an assessed probability of occurrence.

The design forces associated with the common hazard events are applied to a structure as external actions. From this, deformations, internal actions and stresses are assessed. Deformation is of course the key physical effect for a designer to take into account in proportioning the elements individually (responding within defined strain limits) and collectively (overall structure responding within total deformation limits). Successful structural design involves the awareness of deformation compatibility whilst maintaining complete load paths.

The detail of this step is increasingly undertaken by computer analysis. The verification of most sophisticated computer structural models however comes down to the question 'is the structure deforming as we might have expected?' It is this intuitive appreciation of structural behaviour in terms of deformations that is arguably the most important skill that is learned by a structural engineer.

One of the most thought-provoking and challenging lectures that many of experienced during our undergraduate years at the University of Canterbury was given by Tom Paulay at the end of the Second Professional year. This tutorial was actually a test (in more ways than one!), in which a series of statically indeterminate structures were provided, each with a different imposed force. As students we simply had to sketch the deformed shapes and indicate the key locations to be reinforced, with only rudimentary calculations being required. This was an early exposure to real engineering judgement! This tutorial remains a key ingredient of the Department's undergraduate programme today.

3 THE RISK MANAGEMENT PROCESS

The Australia and New Zealand risk management standard, AS/NZS 4360:1999:4, defines the process of risk management as *'the systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risk'.* This process is illustrated in Figure 1.

The traditional heartland of risk management is the risk assessment step. However the key to successful implementation of a risk management process is establishing and understanding the wider context, along with the ability to effectively communicate the risk and the associated treatments.

The direct parallel with structural engineering is that for many projects, success as perceived by clients and end users typically doesn't revolve around the accuracy of calculations at the individual member level. Those technical aspects of the process are of course important, but are typically taken for granted. The broader judgement of success by clients and end users tends to relate to how cost-effectively the compliance requirements and amenity objectives are met.

4 RISK CONTEXT

4.1 Hazard and Risk Perception: Earthquakes

Earthquakes are low probability but high impact (or consequence) events. Both of these aspects are well appreciated by the earthquake engineering fraternity, whereas property owners and the operators of critical infrastructure seem to only register the former!

Figure 2 shows that there have only been 4 earthquakes of magnitude M_w greater than 7 in the past 60 years, and that none of these affected a significant urban area. It is thought-provoking to realise that only 9 lives have been lost in earthquakes in New Zealand in the past 70 years.

This 'good fortune' corresponds to a lack of experience of the reality of earthquakes in New Zealand. This in turn has led to a lack of urgency towards earthquake mitigation and preparedness work, particularly for business and organisation leaders. It is an important layer of *context* that surrounds all earthquake engineering endeavours, and at times represents an appreciable obstacle.

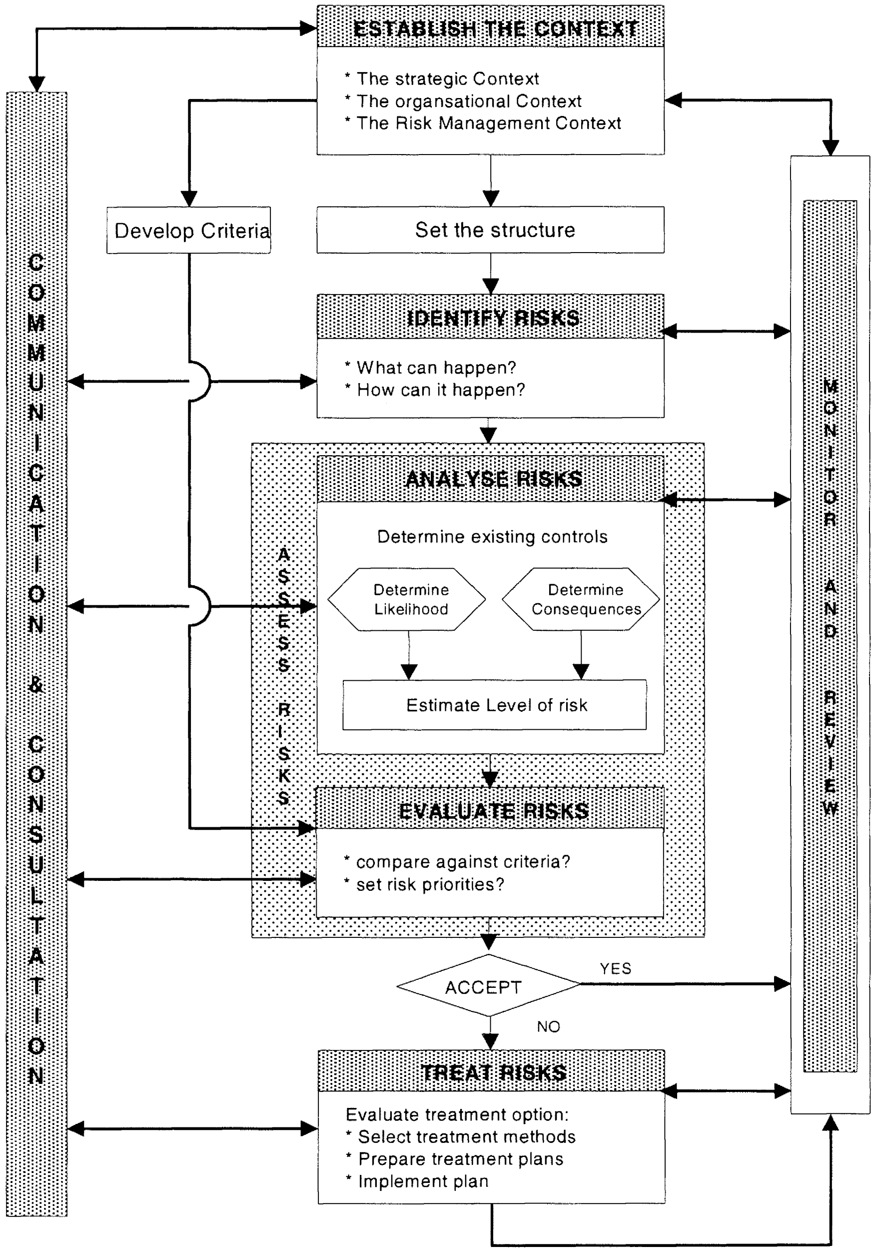

Figure 1. The Risk Management Process (AS/NZS 4360:1999).

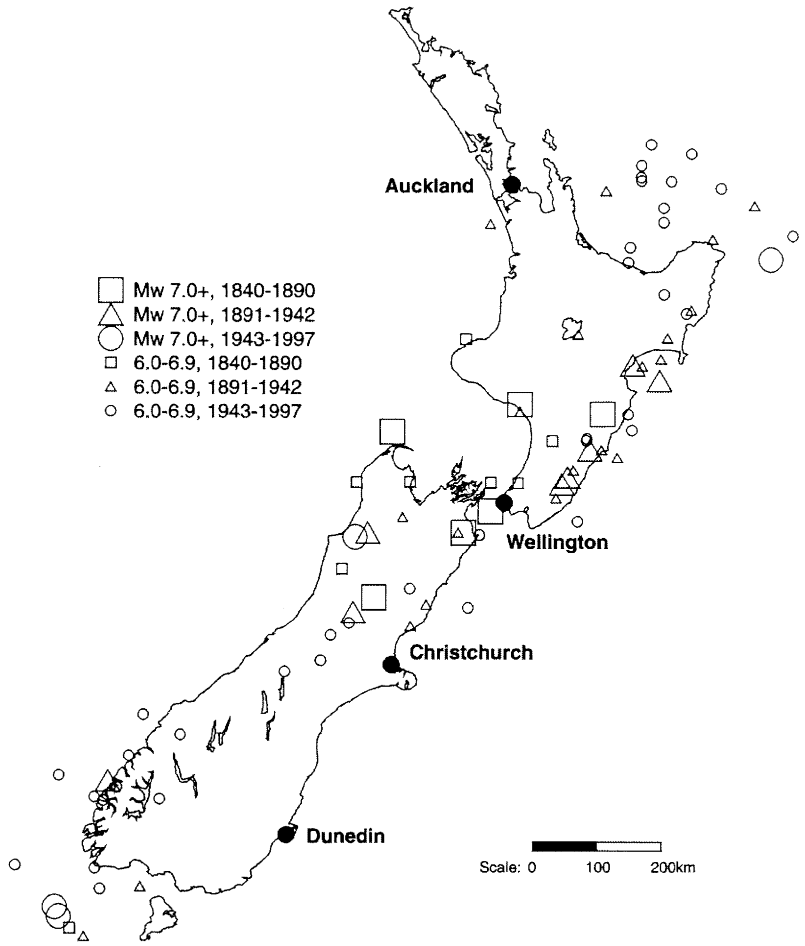

Figure 2. Large Historic Earthquakes in New Zealand *(adapted from Dowrick & Cousins, 2003).*

5 LEGISLATIVE CONTEXT

5.1 Earthquake Risk Buildings

Currently in New Zealand the only regulatory requirement for seismic assessment and upgrading relates to early unreinforced masonry buildings. Even with a specific clause on earthquake prone buildings (ie. URM structures) in the Building Act, the reality is that many territorial authorities have to date taken what could best be described as a passive approach to dealing with this manifest community risk.

Considerable effort has been put in by the New Zealand Society for Earthquake Engineering (NZSEE) over the past two decades to move both awareness of building vulnerability and the regulatory framework to encompass early reinforced concrete and structural steel buildings.

In November 1998, the Building Industry Authority submitted to government draft new provisions for defining 'dangerous' buildings from a structural perspective. Under these proposed provisions, any building found to have less than 33% of the capacity of an equivalent new structure would be able to be declared unsafe in earthquake, and will be required to be upgraded. The level of upgrading required is to be addressed on a case-by-case basis, with the 'as nearly as is reasonably practicable to that of a new building' provisions applying.

While these provisions have yet to receive parliamentary support, they represent the future direction of earthquake risk reduction regulations. At the time of writing this paper, it is understood that these earthquake provisions are to be included in the proposed changes to the Building Act aimed at addressing concerns relating to the weathertightness crisis. The definition of the threshold level however is still to be set by the new regulatory authority that is yet to be formed.

5.2 Civil Defence Emergency Management

On 1 December 2002, new Civil Defence Emergency Management (CDEM) legislation was enacted (CDEM Act, 2002). Under this Act, CDEM Groups will form across each region to integrate and co-ordinate hazard risk management planning and emergency management activity. CDEM Groups are essentially a consortia of local authorities, emergency services, lifeline utilities and others delivering emergency management within regional boundaries. The thrust of the Act is the building of more resilient communities, with the associated goal of greater self-reliance.

The Act requires that a risk management approach be taken when dealing with hazards. In considering the risks associated with a particular hazard, both the *likelihood* of the event occurring and the *consequences* must be considered. Past research has tended to focus on our understanding of the hazard processes. There has been less emphasis on the consequences of the hazard events on infrastructure and communities.

The Act defines lifeline utilities as key agencies, including airport authorities, port companies, gas production, supply and distribution companies, electricity generators and distributors, providers of networks for water and waste-water, telecommunications, rail and road, and producers or distributors of bulk petroleum energy products. The emphasis is on providing continuity of operation, particularly where their service supports essential CDEM activity (e.g. a hospital).

Key principles underpinning this requirement are that risk management and continuity planning are core business – responsibility cannot be transferred to customers or contractors, and that integrated planning across and between sectors will be required.

To meet the requirements of the Act, there will need to be greater emphasis on and commitment to the key elements of emergency preparedness across the 4Rs of *reduction*, *readiness*, *response* and *recovery*.

6 EXPRESSING STRUCTURAL ENGINEERING IN RISK MANAGEMENT TERMS

The generally understood objective of structural engineering is essentially to design structures to not collapse under any foreseeable loading. More correctly, the objective is to *minimise the risk of collapse*, recognising that both the loading and hazard drivers have a probability distribution associated with their occurrence, as do the material properties of the resisting structural elements. The process of structural design does not guarantee the absolutely safe building in all circumstances that the general public perceive it to be.

Structural engineering is therefore an exercise in *risk minimisation* for the more extreme (rare) loading events.

With respect to Figure 1, in the case of the design of new buildings, structural engineering is essentially *risk treatment*. It involves specifying minimum material strengths, providing adequate overall stiffness and providing separations that in most cases preclude interference by other structures. There is relatively little *risk assessment* involved, as the risk parameters are largely prescribed in loadings and material standards. This aspect is addressed in the standard development process.

Life for the structural engineer however gets more complicated when he or she gets asked to assess an existing building, especially for earthquake. They will be faced with a raft of unknowns, particularly if the building was designed prior to modern seismic design codes, and additionally so if reliable construction documents are not available. These unknowns include aspects such as the influence of secondary elements such as infill panels and integral stairs on the performance of the primary structure (which in itself is invariably a hybrid combination of walls and frames), and the materials strengths in the elements.

This process is therefore much more an exercise of *risk assessment*.

A structural engineer working on a new structure is essentially *designing the structure not to fail*. Contrast this with one of the initial steps in working on an earlier existing structure, which involves *establishing the point at which failure would occur*. These are quite different processes, with the second being significantly knowledge-based.

With reference to Figure 1, before an engineer can knowledgeably tackle the task of assessing an existing building, they must understand the *risk context*. This involves a clear appreciation of the legislation and regulations and their application (or not) in a given district or city, along with property management issues (capital investment and return, commercial tenancy processes). These tend to dominate over seismological and structural response aspects in the minds of the owners and building officials!

The broader risk debate for engineers associated with assessing the performance of an existing building relates to whether the building represents an *acceptable* or *unacceptable* risk. The spectrum of possible seismic performance of buildings is illustrated simplistically in Figure 3. It can be seen that buildings in the 'High Risk' category represent an *unacceptable risk* to the community. While a building with a seismic risk profile in the 'middle third' (a new expression for a familiar engineering term!) still represents a moderate risk, consideration of economics deems that it be regarded as an *acceptable risk*. This is a prime example of taking the risk context into account.

Setting the threshold performance criteria at the level of one third of current code seeks to address the most vulnerable of the concrete and steel buildings up until the mid-1970s, and follows the principle of establishing the 'unacceptable level of risk' posed to the community by such buildings. Buildings in this category are likely to perform poorly in even a moderate earthquake.

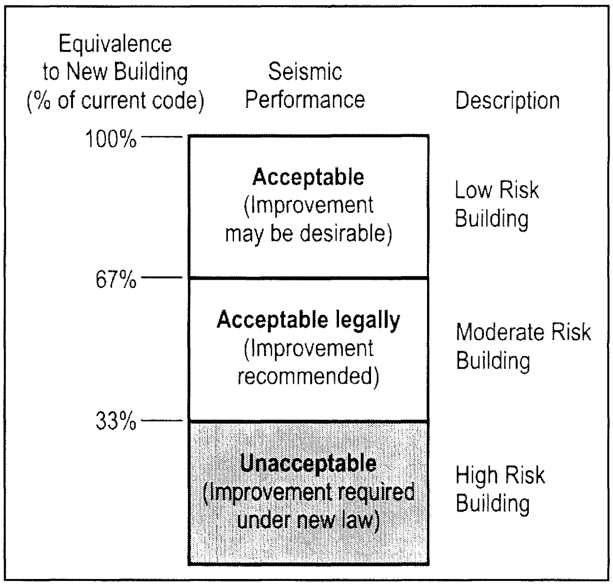

Figure 3. Seismic Performance Categories and Acceptable/ Unacceptable Risk

(adapted from NZSEE, 2003).

The first stage of this work led by Bob Park in 1994 recommended that the level of 'two-thirds current code' be set as the threshold below which strengthening was required. Subsequent economic analysis showed that this figure could not be justified from a wider community perspective. This led to the Society's Study Group (perhaps without realising it at the time) giving more specific consideration to *what is an unacceptable risk*. While a number of engineers are uncomfortable that this threshold has been lowered to the 'one-third current code' level, the context of political reality is important – without taking this into account, a distinct possibility was for there to be no support for change in the current regulatory environment.

It should be appreciated that this perception of *acceptability/ unacceptability of earthquake risk* is very likely to change after the next damaging urban earthquake involving loss of life in New Zealand!

As part of this work, the New Zealand Society for Earthquake Engineering has developed a Building Grading Scale which expresses the anticipated seismic performance on a broad scale from A to E. An 'A' grade building is one that has been designed to current (post-1976) standards, whereas an 'E' grade building would be an unsafe unstrengthened brick building. A 'C' grade represents a 'pass' in terms of the proposed new provisions. Early concrete and steel buildings typically vary from 'D' grade to 'B' grade, depending on their structural configuration.

The purpose of the scale is to inform the owners and users of buildings as to the level of relative risk they face, and to promote an ongoing awareness of earthquake risk in the community. Through this mechanism, it is hoped that mitigation of earthquake risks will, to some extent, be driven by market forces.

This is of course an exercise in *risk communication*.

7 LIFELINES ENGINEERING

Lifelines engineering in New Zealand began as a separate discipline with the Lifelines in Earthquakes: Wellington Case Study project. This project was initiated, produced and largely funded by the Centre for Advanced Engineering, and was completed in 1991 (CAE, 1991). This project has provided the impetus and a point of reference for all subsequent lifelines work in New Zealand.

There are currently Lifelines Projects or Groups either planned or underway in virtually every region of New Zealand. The focus of lifelines work in New Zealand is on regional scale hazard events that are beyond the ability of individual organisations to respond to and control. Projects currently underway in the remaining regions face the challenge of adapting the metropolitan methodologies to suit smaller and more dispersed centres with much less dense and/ or widely spread utility networks.

The New Zealand Lifelines engineering process is essentially a qualitative risk assessment, and is based on the methodology encapsulated in AS/NZS 4360:1999. The key technical engineering step is the vulnerability assessment stage ('determine consequences' in Figure 1). While this can involve detailed assessments of specific structures, it typically involves a knowledge-based appraisal of a segment of utility network or facility. It requires an understanding of the potential weaknesses of typical forms of construction from different seismic code eras (both primary structure and major plant items), and an appreciation of how they are likely to deform, along with the associated operating risks. For earthquake, it is the equivalent of a rapid assessment of individual buildings. As with buildings, the context of a qualitative risk assessment is quite different from specific detailed engineering advice.

A prime example is pipes attached to bridges. In many cases, irrespective of the performance of a bridge in a major earthquake, pipes supported in or from the bridge can be expected to experience distress where they pass through the bridge approaches due to differential movement of the ground and the bridge structure. In bridges in older estuarine areas, the prospect of liquefaction adds to this problem.

The reality of this process is that mechanical, electrical or chemical engineers are rarely seen undertaking this aspect of the process. Structural engineers have the training and experience in understanding earthquake-induced movements. In many cases this theoretical understanding has been greatly enhanced by observing earthquake damage whilst being part of international earthquake reconnaissance missions.

There has been a range of physical mitigation undertaken by the various utility sectors over the past decade. While some of this work was or would have been initiated by the respective individual utility asset management plans, the lifelines process has provided a sharper focus and often a greater sense of urgency in the 'toughening' of networks. Structural engineers have been involved in many aspects of this work, most notably with respect to the seismic upgrading of reservoirs, bridge structures and buildings. Lifelines engineering exposes structural engineers to a range of players and disciplines that extend well beyond the built environment.

With heightened awareness of the threat of terrorism, Lifelines Engineering is starting to move from its natural hazards base. Internationally, this work comes under the heading of Critical Infrastructure Protection. In addition to *utility services and transportation networks*, critical infrastructure includes key facilities such as hospitals, police, fire and ambulance stations, emergency management Emergency Operations Centres. The United States events of September 2001 have made critical infrastructure operators realise that 'anything goes' in terms of physical and organisational attacks. The particular lesson for operators is the potentially prolonged nature of the response and recovery phases – not unlike that for earthquake.

Engineers typically advise operators of critical infrastructure on risk mitigation (or *Reduction)* measures. There is however a need for engineers to convey the message to those operators that there are also basic preparedness measures across the *Readiness*, *Response* and *Recovery* phases that need to be given specific consideration.

8 URBAN SEARCH AND RESCUE

Urban Search and Rescue (USAR) involves the location, rescue and initial medical stabilisation of victims trapped in confined spaces following a structural collapse. Search for the injured and rescue of those trapped are among the most important and urgent post-earthquake activities. Those conducting USAR activities can themselves become victims, as a high level of risk is associated with these activities.

The international post-earthquake reconnaissance visits organised by the New Zealand Society for Earthquake Engineering have played a significant part in highlighting the need for New Zealand to have such a capability. Information on USAR in New Zealand can be obtained from the website www.usar.govt.nz, with the background to the development of New Zealand's USAR capability being provided by Angus et al (2003).

Structural Engineers are a key part of a USAR response. They have a critical role to play in providing technical advice for rescue teams. This includes assessing the overall stability of a partially or wholly collapsed structure, monitoring the structural stability and the development of temporary shoring arrangements.

Engineers involved in USAR activities need to be comfortable dealing with high-pressure situations and able to make rapid decisions. A familiarity with disaster environments and the procedures of specialist rescue task forces needs to be developed. This familiarity requires specific prior training and engagement with emergency service agencies.

A two-level USAR training system for New Zealand engineers is being developed with the objective of providing a specialist engineering response capability at both regional and national levels. The training includes specific courses for engineers and courses involving participation with members of the emergency services (Brunsdon, et al, 2003). There are two components of training engineers in USAR – (i) *familiarity with how emergency services operate*, and (ii) *specialist engineering skills for collapse situations*.

For all but very few experienced and trained engineers, involvement in structural collapse situations is very unfamiliar territory. It therefore requires a systematic risk management approach that is undertaken on one's feet. Conveying critical safety information to rescue personnel in dynamic risk situations is once again an exercise in *risk communication*.

9 DEVELOPING CLOSER RELATIONSHIPS BETWEEN ENGINEERS AND THE EMERGENCY MANAGEMENT SECTOR

Traditionally, engineers have had the greatest impact in the area of *risk reduction*. This involvement however is predominantly with building owners and asset managers rather than emergency managers. It is also typically on a task-by-task basis, with little opportunity to have input into a planned risk management programme.

People working within the emergency management sector are the flagbearers for promoting more effective mitigation and preparedness across a range of sectors. As outlined in Section 4, the new CDEM Act requires interaction between Emergency Managers and utility asset managers and network operators. There is both a need and an opportunity for engineers to work more closely with Emergency Managers, particularly in regard to conveying the *likelihood* and *consequences* of a major event such as earthquake. Engineers who are both knowledgeable about all of the steps of the risk management process and have a good grasp of the principles of modern emergency management can use this opportunity to establish vital linkages and hence increase their involvement.

Participation in the regionally-based Lifelines Groups is another example of where engineers can make a significant contribution, and learn from their involvement with scientists, planners and utility managers.

The most obvious example of such a linkage for structural engineers is to encourage utility asset managers to consider the functionality of their operating facilities after an extreme event. Ensuring the continued operationing of key facilities typically requires going well beyond simply meeting the minimum performance requirements inherent in current structural design codes. The same of course applies to Civil Defence Emergency Operations Centres (EOCs). And yet how often do structural engineers get asked to design or assess a building in terms of its ultimate limit state performance only, and in the form of an isolated task or request?

There is an associated need to promote the vital role of engineers in the aftermath of a major emergency. The key characteristic of a post-earthquake situation is overloaded and ineffective communications, and disrupted access. In this context, engineers represent a scarce technical resource that will not be used effectively without prior planning. Accordingly, the operators of essential post-earthquake facilities and critical infrastructure need to establish Priority Response Agreements (NZSEE, 2002) with engineers in order to address two key objectives:

- *Ensuring the availability of designated engineers and/ or technical personnel who are familiar with their facilities*; and
- *Minimising the response time of the designated engineers by defining in advance the specific actions they are to undertake.*

However on the flip side of the opportunities for engineers in terms of establishing 'response relationships' with key organisations, there is a professional obligation to raise our individual and organisational abilities to respond. The leaders of consulting practices should provide a briefing for staff on what their initial response should be following a major earthquake in terms of both their various key clients and local emergency management agencies. Any priority commitments entered into should be carefully thought through, and must avoid over-commitment of resources, given that not all staff will be available to respond to any given situation.

Professional engineers need to give specific thought as to how they would respond to a major earthquake in their region, what individual resources they may need at short notice and how they should prepare their families for their absence once they have attended to their immediate needs.

One specific consideration for earthquake is the need to understand how the post-earthquake building safety placarding arrangements (NZSEE, 1998) will work in the context of a significantly disrupted region. This is a classic interface between structural engineers (as technical implementers), building control officials (as process managers) and emergency managers (as process communicators) that must be established in each region *before* the event. Engineers need to be able to advise building owners as to what the placards mean in functional terms, and know how to best assist their clients' businesses become rapidly operational after the event.

There is potential for a wider usage of the *green*, *yellow*, *orange* and *red* placards in everyday terms. Where different levels of structural upgrade are under consideration, these placards could be used to illustrate to owners the likely seismic performance outcomes for given levels of earthquake effects. In many cases this may prove more effective than talking probabilities, return periods and code levels!

10 CONCLUDING OBSERVATIONS

There are direct linkages between the disciplines of structural engineering and risk management. The nature of these linkages are however not always appreciated by structural engineers, who tend to focus on *risk assessment* and *risk treatment* activities, nor are the opportunities that they present. Understanding the wider *risk context* of structural engineering is considered to be of particular importance, as is the role engineers play in *risk communication*.

It is therefore recommended that greater emphasis should be given in undergraduate courses on understanding the elements of risk management and their fundamental relationship with 'day-to-day' engineering practice. This should extend to a basic appreciation of the Civil Defence Emergency Management Act, which provides an important backdrop to the daily risk mitigation work of professional engineers.

At a technical level, the structural engineering training with a strong earthquake component provides an excellent platform for appreciating the potential physical and operational impacts of a major event. The ability to visualise damage impacts resulting from earthquake and other natural and man-made hazards is a unique knowledge base. The wealth of experience gained by the NZSEE-led reconnaissance missions to the scenes of major international earthquakes over the past two decades has also provided many engineers with the knowledge base to consider the wider risk management issues, and also in terms of the CDEM planning phases of *reduction*, *readiness*, *response* and *recovery*.

Engineers play a key role in *risk communication* in a variety of different situations. These can include specific technical engineering commissions (ie. on a project basis), participation in wider and ongoing regional Lifelines Engineering projects or conveying critical safety information to rescue personnel in structural collapse situations. Engineers however need to be more proactive advocates to infrastructure asset owners and operators for a more holistic approach to risk management, particularly with respect to basic response preparedness measures.

All critical infrastructure operators need to have direct relationships with earthquake engineering advisors in order to have dependable assistance for assessment of their facilities for re-occupancy following an earthquake. Professional engineers and consulting practices need to give specific thought as to how they would respond to a major earthquake in their region, and make appropriate personal and organisational preparations.

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