CRITICAL INFRASTRUCTURE AND EARTHQUAKES: UNDERSTANDING THE ESSENTIAL ELEMENTS OF DISASTER MANAGEMENT

DAVID BRUNSDON,
NATIONAL LIFELINES CO-ORDINATOR, WELLINGTON, NEW ZEALAND

AUTHOR:

David Brunsdon is the Immediate Past President of the New Zealand Society for Earthquake Engineering, and is the National Lifelines Co-ordinator. He is Director, Risk & Emergency Management Planning of Spencer Holmes Ltd, a consulting engineering, surveying and planning practice, and a member of the NZ Urban Search and Rescue Steering Committee.

ABSTRACT:

The effects of earthquakes upon critical infrastructure, and hence the community, are significant. The need to take appropriate planning steps is apparent to earthquake engineers, but not always to the managers of critical infrastructure in the face of many competing time and financial demands. This is particularly the case in regions of low and moderate seismicity.

This paper considers the essential earthquake preparedness elements for critical infrastructure across the 4Rs of Emergency Management - *Reduction*, *Readiness*, *Response* and *Recovery*. The role of earthquake engineers working in conjunction with emergency managers to promote more effective risk management by critical infrastructure operators with respect to earthquake is outlined.

It is concluded that earthquake engineers are well-placed to facilitate the risk management process from which the appropriateness of these preparedness elements for individual infrastructure operators can be assessed.

1. INTRODUCTION

The effect of earthquakes upon critical infrastructure, and hence the community, are significant. The need to take appropriate planning steps is apparent to earthquake engineers, but not always to the managers of critical infrastructure in the face of many competing time and financial demands.

This paper considers the essential earthquake preparedness elements for critical infrastructure across the 4Rs of Emergency Management - *Reduction*, *Readiness*, *Response* and *Recovery*. The role of earthquake engineers working in conjunction with emergency managers to promote more effective risk management by critical infrastructure operators with respect to earthquake is outlined.

2. DEFINITIONS, CONCEPTS AND CONTEXT

Critical infrastructure and *disaster management* are broad subject areas that mean different things to different people. The concepts involved need definition, and to be placed in an appropriate context. Similarly, while *earthquakes* are well appreciated from a technical perspective, they need to be put in context with respect to other emergency events.

Critical Infrastructure

Critical infrastructure comprises the essential services and facilities on which communities depend. These can be further subdivided as follows:

- *utility services* - water, wastewater, power, gas and telecommunications
- *transportation networks* - roading, rail, ports and airports
- *critical facilities* – hospitals, police, fire and ambulance stations, emergency management Emergency Operations Centres

The physical elements of critical infrastructure include buried services (pipes and cables); overhead cables; switchyards, exchanges and control rooms; roads; bridges and buildings.

Earthquakes

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

Two key points put earthquakes in context for critical infrastructure and the community:

1. Earthquakes affect all elements of critical infrastructure across a region simultaneously and to an extent greater than any other emergency event (with the exception of volcanic activity)
2. The most significant influence on the ability of an affected community to recover is the rate of restoration of utility services and transportation functions

The direct impact of earthquakes upon key utility services from the community perspective is best represented by the service restoration curves from the 1995 Kobe earthquake (Figure 1).

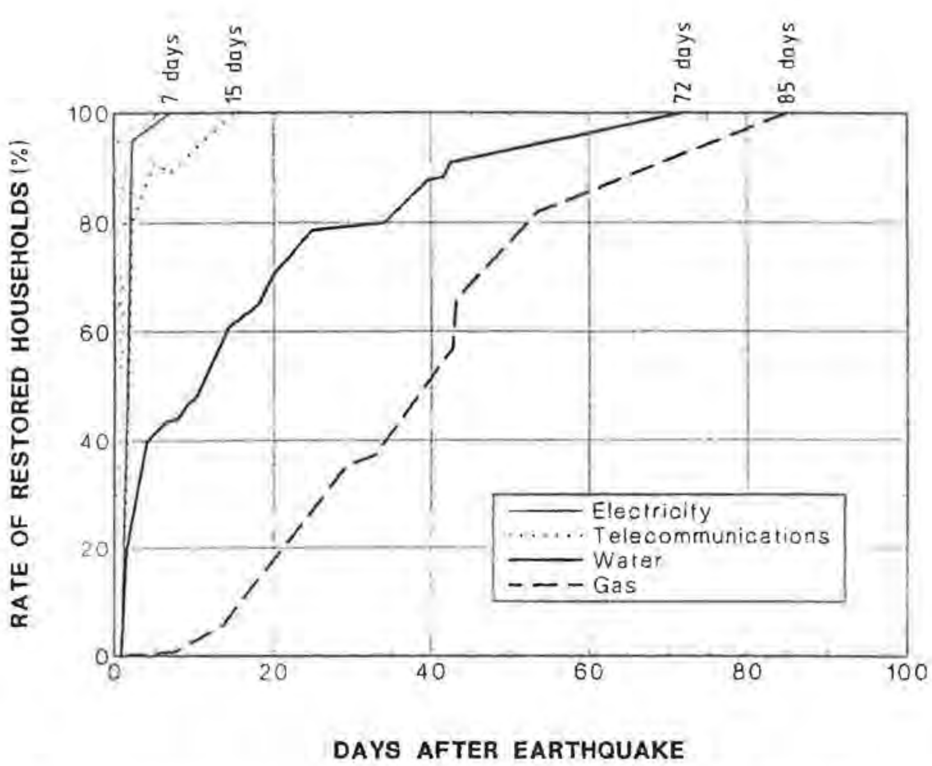

Figure 1: Service Restoration Curves From Kobe (WELG, 1995)

This hierarchy of restoration times is essentially the same as observed following the Northridge and Taiwan earthquakes. Water is clearly the critical service – in addition to the real difficulties for households struggling without water over extended periods, businesses cannot operate. The ability of businesses to resume even limited operations is one of the key determinants of the overall community recovery.

Disaster Management, Emergency Management and Risk Management

Disaster Management is the aspect of Emergency Management which addresses extreme emergencies. To many, it only involves planning the response to such an event. It is however important to consider the broader facets of Emergency Management, which can be defined as:

> *A range of measures to manage the identified risks to a community before, during and following an event or disaster*

This involves consideration of the 4Rs of *Reduction*, *Readiness*, *Response* and *Recovery*. It is also integrally tied to the process of risk management, as encapsulated in AS/NZS 4360:1999 (SA & SNZ, 1999).

In New Zealand, the Lifelines Engineering process has been developed to assist utility and transportation network operators in their planning for regional scale emergencies. It is based around the following risk management steps (Brunsdon, 2001):

- Identifying the *hazards* which could affect each lifelines network

- Compiling common *inventories* of the various utility and transportation networks
- Assessing the *vulnerability* of the lifeline network to those hazards (the *potential damage* to and *consequences for* each network)
- Identifying and implementing practical *mitigation* measures
- Facilitating the preparation of comprehensive *emergency response* plans

All critical infrastructure operations undertake risk management to varying degrees. In many instances however, this still tends to be internally focused. The response of a utility organisation after a major emergency is heavily influenced by the performance of other utilities. The regionally-based Lifelines Engineering process provides the much-needed external perspective by systematically highlighting the *interdependencies* involved.

3. RECENT INFLUENCES ON CRITICAL INFRASTRUCTURE PREPAREDNESS FOR EARTHQUAKE

It is the view of the author that a number of critical infrastructure operators are not as well prepared for earthquake events as they might be. This is believed to be the case even in higher seismicity areas such as in in central New Zealand. In evaluating the current level of preparedness of critical infrastructure for major events such as earthquake, there are a number of recent influences to be considered.

Privatisation and Associated Restructuring

The utility and transportation sectors have undergone considerable transformation over the past decade throughout Australasia. Privatisation has led to a greater commercial focus, particularly for those with revenue directly at risk. The dividing up of some utility sectors into component pieces (eg. generation, transmission and distribution for electricity) and highly competitive sectors working within anti-competition legislative frameworks (telecommunications and energy) has led directly to a 'silo' approach for emergency response. This clearly has an adverse influence on the ability of these sectors to develop integrated plans to respond to a major event such as earthquake. Studies of the 1995 Kobe earthquake highlighted that the effective response of utilities such as Kansai Electric Power Company was due to their integrated nature, covering generation, transmission and distribution (WELG, 1995).

Restructuring has also led to extensive outsourcing for design and maintenance, with a resulting heavy dependence of many utility organisations on contractors, some of whom are shared with other organisations. While maintenance contracts place a heavy influence on 24 hours/ 7 days a week response as part of 'business as usual', they need to be subjected to more careful scrutiny to ensure that the procedures will also be effective for extreme events such as earthquake. For example, the ability of external contractors to carry out the critical initial impact assessment immediately after a significant earthquake is open to question.

Also, while the restructuring has led to significant advances in financial risk management, the heavy emphasis on economic justification for capital development and other activities creates a real obstacle for earthquake mitigation. Feeding the low annual probabilities of damaging earthquake events into a Net Present Value calculation typically results in an unfavourable outcome. This is usually the case even in high seismicity regions, and inevitably the case for regions of moderate and low seismicity.

The development of a consistent economic framework for justifying investment for mitigation and preparedness for low probability/ high impact natural hazard events remains a significant challenge for the earthquake engineering fraternity.

General Asset Condition

The IEAust 2001 Australian Infrastructure Report Card (Yates, 2001) revealed that the average age of many of the infrastructure sectors is increasing, with the lack of both capital and maintenance funding being of concern. The absence of long-term integrated planning was also highlighted. For water supply, it is noted that the amount currently being spent on rehabilitation is not sufficient to keep pace with the rate of asset deterioration. The ageing nature of electricity infrastructure was also commented on.

These observations underscore the inherent physical vulnerability of key utility networks, which typically have only nominal (if any) provision for the effects of strong ground shaking.

Legislative Drivers

The new Civil Defence Emergency Management legislation in New Zealand requires key lifeline utilities to be actively involved in regional and national emergency management planning. This legislation places particular emphasis on utility organisations having a plan to respond to foreseeable emergency events, including earthquake. A copy of the Ministry of Civil Defence and Emergency Management information guideline for lifeline utilities (*Working Together: Lifeline Utilities and Emergency Management*) can be downloaded from www.civildefence.govt.nz.

It is understood that there is no equivalent legislation in place or proposed for Australia.

Heightened Awareness of Terrorist Potential

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.

4. KEY ELEMENTS OF EARTHQUAKE PREPAREDNESS

The appropriate level of earthquake preparedness by critical infrastructure operators can only be established following a comprehensive risk assessment. However, essential elements of critical infrastructure earthquake preparedness can be summarised across the 4Rs as follows:

Reduction

- Identify seismic vulnerabilities for major assets and facilities, and prioritise mitigation measures based on assessment of possible impacts and what is needed to provide minimum acceptable short and medium-term service
- Incorporate high priority seismic mitigation measures within asset renewal programmes
    - *eg. for water supply, priority measures are the installation of automatic shut-off valves for key reservoirs, and upgrading key mains leading down from reservoirs and brittle mains in soft ground*

- The bracing and tying down of control cabinets and computers in control rooms is well proven as a low-cost but highly effective mitigation measure. Consideration can be given to increasing the level of pipes and fittings held for emergency repairs, and the method of storage (eg. horizontal storage of critical and brittle spares to minimise damage)
- Essential post-earthquake facilities such as hospitals and civil defence and utility emergency operations centres must be situated in seismically robust buildings, with alternative locations. Seismic evaluation of key buildings must be undertaken.

Readiness

- Ensure appropriate mutual aid agreements are in place for key utility sectors such as water and energy
- Ensure that operators of critical infrastructure have dependable access to technical resources such as engineers
  - *Critical facilities and utilities to have Priority Response Agreements with engineers*
  - *Consideration to be given to the establishment of a register of engineers*
- Upgrade the level of emergency water supplies retained by critical facilities (eg. hospitals)
- Hold exercises to test preparedness and effectiveness of response plans and communications processes

Response

- Ensure that response plans have appropriate emphasis for earthquake with respect to
  - *the role of external contractors (prepare additional Standard Operating Procedures where necessary)*
  - *inter-agency communications*
  - *the mechanics of distributing core community supplies such as emergency water over an extended period of time*
- Clarify currently available resources for impact assessment and initial repairs
- Establish hierarchy of critical supply points
  - *eg. hospitals as a priority for the restoration of water supply, electricity*

Recovery

- Identification of contractors who could assist with repairs and reconstruction of specialist equipment and facilities
- Strategy for management of mutual aid over an extended period of time

5. THE ROLE OF ENGINEERS IN PROMOTING BETTER PREPAREDNESS

Engineers typically advise operators of critical infrastructure on risk mitigation (or *Reduction)* measures. There is however a need for earthquake 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.

Earthquake engineers need to be pro-active advocates for the range of earthquake preparedness measures outlined in the previous section.

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, critical infrastructure operators need to establish Priority Response Agreements 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.*

More information on Priority Response Agreements can be found in a recent NZSEE Working Party discussion paper (NZSEE, 2002) which can be downloaded from www.nzsee.org.nz

6. CONCLUDING OBSERVATIONS

In considering the range of earthquake preparedness measures that critical infrastructure operators could implement, the following key observations are made:

- District or regionally-based lifelines engineering processes for utility and transportation operators should be actively encouraged, having due regard to the risk profile of each area. This process enables the vital interaction between different agencies, leading to a better understanding of the interdependencies involved, as well as providing a 'safe' platform to cut across commercial considerations
- Emergency Managers are the flagbearers for promoting more effective mitigation and preparedness by critical infrastructure operators. Earthquake engineers must work more closely with Emergency Managers, particularly in regard to conveying the *likelihood* and *consequences* of a major earthquake
- Designated Emergency Operations Centres for lifelines, critical facilities and emergency management agencies need to be capable of functioning after a major earthquake
- 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. This should be addressed in their Business Continuity Planning.

The need for some of the measures outlined in this paper across the 4Rs may not be as great in low and moderate seismicity regions as for high seismicity locations. However it is argued that critical facilities in even low seismicity locations need to have basic preparations in place for earthquake. Critical infrastructure operators need to be made aware that low seismicity does not mean that only weak earthquake shaking can be expected – it just means that strong earthquakes occur even less frequently. Also, a number of the items involve relatively low cost measures (eg. the seismic restraint of control cabinets, etc).

The appropriateness of these various measures for individual infrastructure operators needs to be judged in the context of the physical and operational risks. Earthquake engineers are well-placed to facilitate this risk management process.

References

Brunsdon D R, 2001. *Lifelines Engineering in New Zealand: Moving Into the Second Decade*, Proc. Australian Earthquake Engineering Society Annual Conference, AEES, Canberra, Australia.

New Zealand Society for Earthquake Engineering, 2002. *The Response of Professional*

Engineers to a Major Earthquake: Priority Response Agreements and a Register of Engineers, NZSEE, Wellington

Standards Australia and Standards New Zealand, 1999. *Risk Management AS/ NZS 4360*, Sydney and Wellington.

Wellington Earthquake Lifelines Group, 1995. *1995 Report*, Wellington Regional Council, ISBN 0-909016-37-2, Wellington

Yates A. 2001 Australian Infrastructure Report Card, Institute of Engineers Australia, Canberra, 2001

INVESTIGATION OF LIFELINE INTERACTIONS USING A GEOGRAPHIC INFORMATION SYSTEMS

D. JOHN PRABAHARAN AND DR. BERT VEENENDAAL
DEPARTMENT OF SPATIAL SCIENCES, CURTIN UNIVERSITY OF TECHNOLOGY

AUTHOR:

D. John Prabaharan is a postgraduate student at Curtin University of technology. He completed his M.Tech in Remote sensing from India and M.Phil in GIS and Remote sensing from Cambridge. He received awards from *Overseas Development Authority* and *Cambridge Common Wealth Trust*, England. He is also the recipient of the *IPRS* and *Department of Spatial Science* scholarships.

Dr. Bert Veenendaal is a senior lecturer at Curtin University of Technology and has been instrumental in the development of the teaching and research program in Geographic Information Science since its inception in 1988. Dr. Veenendaal has several awards, scholarships and grants to his credit, together with over 40 publications in his areas of interest. He is the recipient of the prestigious 1998 AISIST Award as well as a Curtin Innovative Practice Teaching 2000 award. Currently, he is Project Coordinator for the 2001-2003 Learning Effectiveness Alliance Program (LEAP) Spatial Sciences Project as well as for projects utilising GIS in risk management and rural health development. Dr. Veenendaal has recently been elected as president-elect of AURISA, the spatial information association.

ABSTRACT:

Electricity, water supply, sewerage, gas and liquid fuels, transportation and communication systems are generally referred to as lifelines. Lifelines are important infrastructures for social and economic activities. They act as arteries for the delivery of services to society. Lifeline systems are often interconnected and interdependent and their interactions are very complex. Due to natural disasters, the failure of lifeline network systems at vulnerable segments can affect the functioning of a network system and other associated systems. For example, damaged powerlines can interrupt power supplies, which in turn affect automated home technology, water supply, telecommunication systems and related services. This study examines the interactions within and between lifeline network systems. The interaction within the system is examined using the hierarchical holographic model, and vertex, edge and length ratio methods. Interactions between lifeline network systems are investigated using logic tree and interaction ratio methods..

1. INTRODUCTION

Lifelines are grouped into six principal systems: water supply, electricity, transportation, gas and liquid fuels, communication and waste water systems. The common characteristics of lifelines are: spatially distributed in various types of geographic areas; large-scale systems with numerous diversified components, interconnected and interdependent; multiple constituencies and multiple functions. Most social and economic activities are dependent on lifeline network systems without which the standard of living, and social and economic development would be jeopardised (O'Rourke, 1998; Brown, 2001; Haimes, 2002). Due to a natural hazard, failure at a vulnerable component in a lifeline network can affect the functioning of that network system as well as those that interact with it. Effects can include physical and functional damage spread, recovery interruption, occurrence of lifeline-induced fire, and so on (Nojima, 2002).

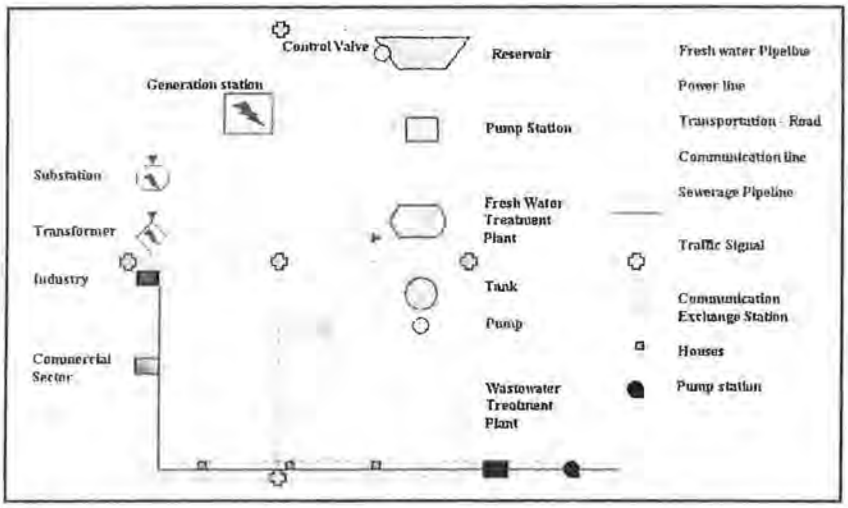

Figure 1. Illustration of lifeline network systems interactions

Lifeline interactions can be grouped into three classes: a) interaction within a system, b) interaction between lifeline systems and c) interaction with socio-economic activities and the environment. These interactions can be further classified into direct and indirect interaction. Figure 1 shows an example of direct interactions among various lifeline network systems and interaction with social and economic activities (interaction with the environment is not shown). An example of interaction within a system, the failure of an electricity sub-station (a point in the network) can affect electricity supply in a whole sub-network within the system.

Failure of one lifeline system can directly affect the other system's functionalities. For example, electricity failure can cause disturbance to water supply pumping systems, electric rail systems, road signals, airport activities, sewerage pumping systems, supply of gas and liquid fuels and communication systems. Furthermore, interruption to the electricity and water supply systems may have socio-economic effects, causing disruption in day-to-day activities and business transactions, which can further lead to economic losses. In addition, transportation and communication systems are essential infrastructures during a disaster response and recovery process; failure of these systems can hamper relief and emergency activities (Schiff, 2001; Scawthorn, *et al.*, 2001).

Collocation of lifelines can also lead to the propagation of disruption from one system to another. For example, gas pipe leaks, downed powerlines or damage to water mains can result in road closures, especially when these failures are in the vicinity of a road network (Chaker, 2001). Failure of one-lifeline component can induce certain types of hazards and, as a consequence, these hazards can also affect other systems. For example, electric and gas generated fires resulting from an earthquake can affect communications systems (O'Rourke, 1998). Lifeline interactions can have major consequences far beyond their immediate location. For example, the capacity of an airport can be reduced because air traffic controllers and passengers have difficulty reaching the airport due to the failure of a surface transportation system. These types of interactions are referred to as indirect interactions (Chacker, 2001).

This paper explores direct interactions within and between lifeline network systems. This is important because modelling interactions within and between lifeline network systems allows lifeline management methods to be established in relation to the networks' performance. This can assist in the preparation for potential natural hazard crises, and it is useful for the development of efficient and corporative emergency plans.

2. TECHNIQUES AND RESULTS

In this study, lifelines are modelled as network systems. Edges and vertices are used to represent lifeline linear features such as: pipeline; power line; road and point/polygon features such as transformers; sub stations; and pump stations. Failure of vertices or edges can affect associated edges and vertices in a network system. The interaction within a network system was examined using the *hierarchical holographic model* and the *network model* with *ratio methods*. Interactions between lifeline systems were investigated using the *logic tree* and *interaction ratio* methods. Techniques adopted for lifeline network systems interaction analysis and results are discussed in the following sections. Lifelines within the Perth metropolitan region were selected and used to explore these methods in a geographical information system (GIS) environment.

2.1 Interactions within the system

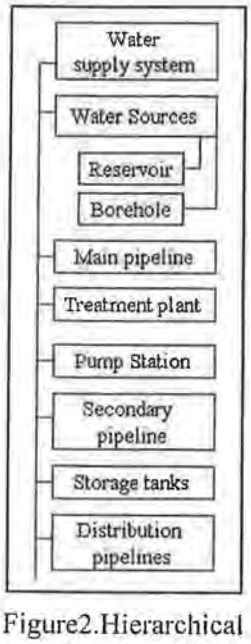

Figure2.Hierarchical Model for water supply system

Functionality of lifeline systems is generally provided by the operation of combinations of equipment and/or human actions. The hierarchical holographic model (Haimes, 2002) is one of the methods that enables the identification of component interactions within a system. This model can indicate system functions in relation to its components. Figure 2 illustrates a simple example of the hierarchical holographic model (HHM) for a water supply system. In this hierarchical model, water sources are located at the highest level followed by main pipeline, treatment plant, pump station which occupy the subsequent lower levels. The secondary pipeline and storage tanks are located further down the hierarchy. The lowest level in this hierarchical model is the water distribution pipeline. Failure of any individual component in the main link can affect the functioning of the system as a whole. In some cases there may be redundant components within a lifeline system such as alternative pipelines, which provide full or partial operation during a component failure. The HHM can show the network components and associated links, and demonstrate network disruption due to failure of individual components.

However, the quantitative and/or qualitative and spatial representation of lifeline network disruption, due to the removal of a non-functional lifeline segment, is essential for network system management, especially during a natural hazard crisis period. This representation can be achieved using vertex, edge and length ratio methods (Prabaharan and Veenendaal, 2002). These methods indicate overall network disruption caused by the removal of non-functional edges and/or vertices. Formulae 1, 2 and 3 are related to vertex, edge and length ratio. These ratio methods were tested for the water supply pipeline network system.

Vertex Ratio (V_r) = $\sum v_u / \sum v_t$ -------- (1)

Edge Ratio (E_r) = $\sum e_u / \sum e_t$ -------- (2)

Length ratio (L_r) = $\sum l_u / \sum l_t$ -------- (3)

Where
e_u - Number of edges in use
e_t - Total number of edges in the network system
v_u - Number of vertices in use
v_t - Total number of vertices in the network system
l_u - Length of the lifeline in use
l_t - Total length of the lifeline

In a water supply network system (Figure 3), main pipelines are referred to as first order edges and the components linked to this main pipeline are referred to as first order vertices. The secondary pipelines are referred to as second order edges and related vertices are referred to as second order vertices. The distribution pipelines and related components are referred to as third order edges and vertices respectively. The water flow direction is from point A to B and A to C. Failure at first order edges/vertices can cause wide spread disruption than at second order edges/vertices where there are no alternative components to support the edges/vertices. To understand these effects in the spatial manner, consider the water supply network illustrated in Figure 3. Assume that failure at location D can affect the water supply in its associated pipelines. This disruption effect can be captured by vertex, edge and length ratios. For example, in an intact network, all the vertex and edges are functional and therefore calculated ratios are 1 (see Table 1.). After the removal of inoperative edges and vertices from the calculation, the vertex, edge and length ratio are 0.913, 0.875 and 0.955 respectively. In this particular scenario, the calculated ratio values reveal that the water supply network system disruption is low due to failure at location D. These ratio values can be used to identify the vulnerability of each link. For example, the removal of a link at location D can cause low disruption in the network system and therefore the vulnerability of this link is low. However, this may vary according to the location of the link and number of associated features supported by the link.

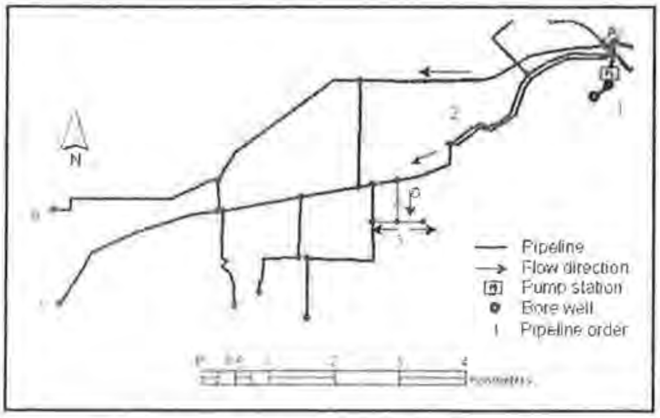

Figure 3. Part of a water supply network system

Table1. Ratio values and network disruption

Ratio Values	Network disruption
1	Fully functional
0.75 – 0.99	Low disruption
0.50 – 0.74	Moderate disruption
0.25 – 0.49	High disruption
0.10 – 0.24	Extreme disruption
0	Non functional

2.2 Interactions between lifeline network systems

The interactions between lifeline systems can be examined using the logic tree method. This method uses *Boolean logic* to express system interactions and interrelationships, as well as the overall successful functioning of systems (Scawthorn, *et al.*, 2001). Figure 4a shows the logic tree model for a functional water supply system. The logic tree model can accurately identify the components which most critically affect the ability to supply water. For example, the functioning of a water supply system is dependent on components such as water sources, pump station, treatment plant, storage tank and pipelines. These components are linked by AND logic, indicating that they are all required for the proper functioning of the system. Failure of any one of these components will affect the functioning of the water supply system. In addition, the functioning of the pump station is dependent on the power supply system. Failure in the power supply system also affects the functioning of the water supply system. Redundant or backup components are represented by OR logic. For example, the pump station can utilise either the electricity grid or the power backup for its operation.

The interaction between lifelines can also be examined using the interaction ratio method. This method demonstrates the disruption in direct interaction points in the network systems. The interaction ratio can be calculated using formula 4.

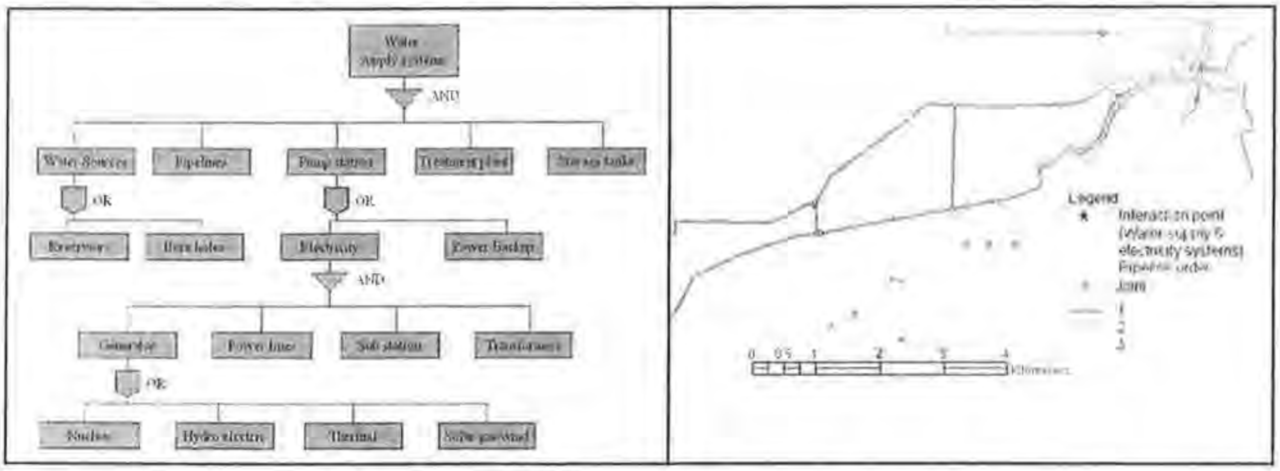

Figure 4a. Logic tree model for water supply system, Figure 4b. Electricity and water supply system interaction points.

$$\text{The interaction ratio} = \sum iv_u / \sum iv_t \quad \text{--------} (4)$$

where

iv_u – Number of interlinked vertices in use;

iv_t - Total number of vertices interlinked with other lifeline network systems.

In the study area, there are around 149 vertices in the water supply system, which require electricity supply for its operation. The interaction points are mainly pump stations at bore wells, reservoirs, tanks and treatment plants. If all the interaction points are functioning then the interaction ratio is 1. Failure of the electricity system can affect the electricity supply to these interaction points. In Figure 4b, it is assumed that a power failure at location D may affect 2 power supply points in the water supply system. After removal of these two vertices from the calculation, the calculated interaction ratio value is 0.987. This calculated value reveals that there is disruption at interaction points. The availability of power backup or alternative power sources may reduce these disruption effects. The interaction ratio method will only provide an overall idea about the disruption at interaction points. However, the water supply disruption due to failure of these interaction points can be found by vertex, edge and length ratio methods.

CONCLUSIONS

Lifelines can be modelled as a network system using vertices and edges in a GIS environment. The hierarchical holographic model can help to understand network disruption within systems when non-functional lifeline segments are removed. This model focuses on a specific aspect. Therefore, it is difficult to represent within a single model to cover all important and critical aspects of the system. The vertex, edge and length ratios can be used to examine the network disruption within the system in a GIS environment. The logic tree method represents the interaction between lifeline systems. However, the development of the logic tree model should be completed in a step-by-step manner before proceeding to the next level. The interaction ratio method provides an overall idea about the disruption at interaction points; however, it cannot capture the network disruption due to failure of interaction points. The spatial representation of interaction points and their failure effects can be identified using a network model and by combing a network model with vertex, edge and length ratio methods.

REFERENCES

Brown, T. (2001) Assessing Infrastructure Interdependencies: The Challenge of Risk Analysis for Complex Adaptive Systems, A Workshop on Mitigating the Vulnerability of Critical Infrastructures to Catastrophic Failures, VA, USA, September, http://www.ari.vt.edu/workshop/papers.htm

Chacker, A.A. (2001) Improving The Disaster Resiliency Of Transportation Systems, A Workshop on Mitigating the Vulnerability of Critical Infrastructures to Catastrophic Failures, VA, USA, September, http://www.ari.vt.edu/workshop/papers.htm

Haimes, Y. (2002) Strategic Approach to Risk, Centre for Risk Management School of Engineering and Applied Science, University of Virginia, USA, http://www.sys.virginia.edu/risk/

Nojima, N., 2002, Towards the New Era pf Lifeline Earthquake Engineering – after the 1995 Hyogo-ken Nanbu earthquake, Japan, Department of Civil Engineering, Gifu University, Japan, 6 pp.

O'Rourke, T.D. (1998) An Overview of Geotechnical and Lifeline Earthquake Engineering, Proceedings of Geotechnical Earthquake Engineering and Soil Dynamics – III, Dakoulas, P., Yegian, M. and Holtz, B. (eds.), University of Washington, Washington, USA, August 3 – 6, pp. 1392 – 1426.

Prabaharan, J. and Veenendaal, B. (2002) Lifeline Network System Performance Analysis Using Geographic Information Systems, Proceedings of the AURISA and Institution of Surveyors Conference, Adelaide, November, Canberra, Australia, In press.

Schiff, A.J. (2001) Documenting Damage, Disruption, Interdependencies, and Emergency Response of Power and Communication Systems after Earthquakes, A Workshop on Mitigating the Vulnerability of Critical Infrastructures to Catastrophic Failures, VA, USA, September, http://www.ari.vt.edu/workshop/papers.htm

Scawthorn, C., Johnson, G.S. and Porter, K.A. (2001) Critical Equipment Functionality – Mitigating Natural Hazards Vulnerability, A Workshop on Mitigating the Vulnerability of Critical Infrastructures to Catastrophic Failures, VA, USA, September, http://www.ari.vt.edu/workshop/papers.htm

SOME IMPLICATIONS OF EARTHQUAKE IMPACT FOR THE PORT ADELAIDE ENFIELD COUNCIL

WALTER (WALLY) IASIELLO

AUTHOR:

As Director of Technical Services for the Port Adelaide Enfield Council, Wally Iasiello is responsible for the engineering oversight of civil works including, traffic management, survey and design and construction and maintenance of footpaths, drains, roads, sporting facilities and parks and gardens.

2.57
.15
3.12

BACKGROUND

The Port Adelaide Enfield Council embraces 95 square kilometres of metropolitan Adelaide. With 470 employees and an $80m annual budget, it serves a population of 101,000 people. Over 40% of Adelaide's industry falls within its boundaries. Included in such industries are three power stations and major port facilities.

The Council's services include the maintenance of infrastructure such as roads, footpaths, stormwater drains, sport and recreation sites, libraries, development control, waste management, traffic management, health services, community buses, home and community services, tourism and foreshore maintenance.

AGEING INFRASTRUCTURE

Like other areas within South Australia, the Port Adelaide Enfield Council is confronted with the challenge of ageing critical infrastructure within its boundaries. A recent report has flagged that for South Australia, over the next twenty years, the rate of expenditure on such infrastructure will need to increase by a factor of four.

ENGINEERING CHALLENGES

Possible consequences of earthquake impact would include an overwhelming call on building inspectors to deal with damaged premises. Following this would be an extraordinarily large number of applications for building modifications.

The Council's recovery operations in its area would need to be coordinated with those of utilities such as water, sewerage, electricity, gas and telecommunications. The Council would also need to work in concert with State-based Community Health and Welfare agencies.

There are numerous heritage buildings, particularly in the old Port Adelaide area and issues such as, who determines what is demolished and what should be restored, would need to be addressed.

DEMANDS OUTSIDE THE COUNCIL AREA

All of these activities would arise against a back-drop which might include similar needs in other areas right across the entire Adelaide metropolitan area. In such a scenario, which would most likely see the implementation of the State Disaster Plan, not only might the Port Adelaide Enfield Council be calling on State resources, but as well, the State could be calling on Council resources, depending on what tasking priorities arise.

BUSINESS CONTINUITY

There would be a need to maintain business continuity, not only for the Council itself but for the Community at large. Business continuity would involve maintenance and restoration of information technology systems, other critical infrastructure and the physical environment.

SUMMARY

Because of its close day-by-day interaction with the local community, Local Government is not only well poised, but also a key player, in ensuring the safety and well-being of the public. A coordinated approach, involving all stakeholders, needs to be in place to ensure that efforts to mitigate, prepare, respond and recover from hazard impacts of all types, including earthquakes, are maximised.

RECOVERY FROM DISASTER: WITH PARTICULAR REFERENCE TO ENGINEERING RESPONSIBILITY

BARRY J GREAR AO, FIEAUST, FIPENZ, FACE, FAICD

AUTHOR:

Past National President of the Institution of Engineers, Australia.
Chairman, South Australian State Disaster Committee
Chairman, Australian Red Cross S A Tracing and Disaster Services Committee
Chairman, Steering Committee for Disaster Recovery Manual, of Emergency Management Australia

Barry Grear has been involved in disaster arrangements in SA and Nationally since being responsible for drought relief in 1977, then being responsible for Recovery after Ash Wednesday in SA and then involved in Recovery policies and Emergency Management Arrangements currently.

ABSTRACT:

The potential for a Disaster of either Natural and Technological origin is increasing dramatically in the major cities of the world. The role of engineers in highlighting the potential events, in assisting in the development of mitigation initiatives, in ensuring appropriate design and construction and then in directing the recovery operations, is a new responsibility for the profession. This paper comments on the importance of measures to be undertaken to increase community safety in disaster events and gives practical information and advice for those who are charged with the responsibility of getting communities back to normal operation.

KEY WORDS: disaster, engineering, earthquake, recovery

INTRODUCTION

The development of Emergency Management arrangements around the world supports a concept that disaster events can be managed in four phases which will always occur in relation to a particular event or group of events

These phases are:
Prevention – Those measures which can be taken to prevent or minimise the effects of the impact of an event. In recent times there is a greater attention to Risk Assessment Principles and subsequent attention to Mitigation measures to make considered decisions about the best prevention methods.
Preparedness – the arrangements that ensure full and effective utilisation of all resources and services for disaster response and recovery.
Response – those actions taken to minimise the effects of an impending or actual disaster.
Recovery – those actions that assist the community to successfully adapt to the effects of disaster after its impact is over.
This paper asserts that PREVENTION and RECOVERY are the phases where a greater involvement and intervention by engineers will reduce the loss of life in a disaster situation.

PREVENTION

Natural hazards to which many cities are commonly vulnerable include tropical cyclones, floods, earthquakes, landslides, volcanic eruptions and tsunami.

In recent years, however, the increase in technological disasters seems to be increasing. These include chemical spills and leaks, radiation leaks and the collapse of bridges, buildings, dams, communication systems, etc.

SOME MAJOR DISASTERS OF THE WORLD IN TWO RECENT DECADES

1997	Earthquake, Iran, 1 560 dead	1990	Earthquake, Iran, 60 000
1996	Flood, China, 1 200	1989	Landslide, China, 2 000
1995	Flood, India, 1 479	1989	Earthquake, Newcastle, Aus, 13
1994	Typhoon, China, 1 174	1988	Earthquake, Armenia, 25 000
1993	Earthquake, India, 9 782	1984	Gas Leak, Bhopal , 2 350
1992	Earthquake, Indonesia, 2 500	1982	Volcano, Mexico, 1 700
1991	Cyclone, Bangladesh, 125 000	1978	Earthquake, Iran, 25 000

In recent years there have been many disasters that have resulted in a devastating loss of life in cities and heavily populated areas. However, despite the above list, there appears to be little commitment to ensuring that mitigation methods and the possibility of shifting cities or limiting future growth in the high-risk disaster areas to reduce the future impacts on life and property are considered and undertaken.

The cost of these disasters is very high. In Australia, a relatively low density and low risk country it is about $1.5 Billion per year.

Substantial advances in reducing this figure will not be achieved until those concerned about the health; welfare and environment issues generate more public debate.

Policy makers and governments need to seek the help of interdisciplinary teams; to have risk assessment analyses applied to the infrastructure of all of our cities. These analyses are becoming known as "lifeline" projects. There needs to be a new approach to the way we manage the development and redevelopment processes applicable to any densely populated area.

RECOVERY

The dynamics at work in a community when the people become aware of an impending disaster, immediately a disaster occurs and when recovering from a disaster are very complex. Those responsible need to be aware that they will face issues, which are unique to each situation, and that they often have to make decisions in very short timeframes compared to the normal activities in which they are involved.

Often in smaller or remote communities those responding and their families may be personally affected. The priority for their immediate family has to be balanced with the needs of the community that they serve.

While it is accepted that not all engineers can give the priority for extensive training in disaster management it is appropriate that all are aware of the principles of emergency management and have a checklist of key people who have had experience and where information can be made available.

For those on the front line there will be competing demands and conflicts which will have to be resolved. Human behaviour must be expected to be different than that which occurs in a normally operating community. There will be demands for instant information and an expectation that answers can be given in areas outside normal responsibilities. Information is of course vital for everyone, it will need monitoring. Financial estimates will be demanded for both immediate and long-term requirements.

As soon as possible, a program of work needs to be documented. However, people involved need to be aware that it will be flexible as it will have to take account of new information which will be gathered on a daily basis. It will be difficult to do this with the normal precision. The estimates must cover, cleanup, disposal of waste, assistance with the provision of temporary infrastructure, the rehabilitation of existing infrastructure and the building of new infrastructure and a variety of miscellaneous tasks.

In clean up, priority will have to be given to, safety of the community, health of the community, establishment of communications and restoration of access.

COMMUNITY

Understanding the community is very important. Its history, locality, dependencies, common interests and time. Be prepared to listen to older people.

Having assessed the situation and the amount of recovery work needed it is important for the community to be told.

If, of course, there has been an exodus of population and there is only a low likelihood of them returning, then the recovery program will be quite different to the situation where the community has stayed and is demanding full restoration of services immediately.

ROLE OF THE ENGINEER

The community will depend on the engineer to assess the physical damage and then take significant control of restoration and reconstruction.

There will be excessive demands on the engineering team.

Legal considerations may become immediate and critical. What is my duty of care and legal liability? Undertaking a wide variety of tasks with time pressures that do not always allow due consideration of all aspects. Professional judgement in decisions regarding the protection of persons and property will become more focussed than normal. Make sure that you record every decision made and the basis for making it.

The organisational arrangements may have to be changed.

What is my authority? This may be an important question, which needs answering.

How am I coping, behaving and reacting? These are questions that need to be asked of a mentor.

Will there be conflicts with my professional ethics? There will be pressures to exceed the limits of approved funding and possibly change previously agreed priorities.

Another challenge is that community leaders and politicians may not understand operational priorities and can often make inappropriate and competing demands for the use of available resources.

Keep thinking, keep revising and keep reporting.

VOLUNTEERS

The use of volunteers in recovery is essential for prompt attention to the many tasks required to be carried out, but control may be difficult.

You will have varying numbers and their attendance will be irregular. They will have other commitments. There must not be a lack of appropriate tasks or their motivation and effectiveness will be diminished. Send them away with a time and place to return if there are no current tasks.

Be aware that untrained volunteers may make incorrect judgements if authorised persons do not vet decisions. Try to not have the volunteers briefing their replacements.

Be aware as well that there may be conflict between volunteers if contractors get paid for work initially done by volunteers.

MEDIA

Politicians and the media work together on a daily basis. It is worth all involved to be briefed about these relationships. My belief is that during a disaster event that linkage should be used and all involved should use the media adviser to make all arrangements when giving information and when giving radio or television interviews.

Those involved such as engineers, should not express opinions but provide hard, factual information. Develop a reputation for giving accurate, well-informed and useful information that the community requires.

FINANCIAL MANAGEMENT

No matter what freedoms are available during a disaster event there is one important matter, which must not be forgotten. "The auditors will come".

It is often the case that when the busy phase of a disaster is over, many things will be in disarray, including the organisation, the office and daily personal interests. Your colleagues may be dispirited and exhausted and now the clean up and rebuilding process may be estimated to be years.

Apart from having good documentation there are now some new issues.

Is the funding for the work guaranteed or only promised.

What are the sources of new funds?

Are there different controls on the spending?

Are the accounting requirements different from the normal requirements in my own organisation?

INSURANCE

Insurance companies have a major influence on disaster recovery. The assessment of the insurable portions, the release of funding, the leaning towards litigation. Will governments make up any shortfalls?

THE ENGINEERING TASK

Clean up can be a major task. I have mentioned priorities earlier, but it is timely to comment that this is a matter which needs careful consideration during the planning phase as dump sites are not always readily available and the road system may not have been designed for the new traffic demand because or weight or volume. The separation of the different types of waste is critical. Remember where the waste was put. Photographs are very useful.

Can I utilise private property is an issue.

Is special equipment required?

Toxic chemicals, dead animals and insects may present special problems.
Waste food, oil, sewage, and noxious weeds

Do I have to help in food deliveries, eg. refrigeration?

Security and communication.

CONCLUSION

Despite all of what I have said, which may sound daunting, my experience and study has demonstrated two things.

The actual efforts of all involved will exceed their own expectations.

There will always be things that are learnt from each incident.

Finally, I honor all who have been at the frontline in any disaster event and believe that you will have made a significant contribution to your fellow citizens.

ACKNOWLEDGMENTS

I acknowledge the input given to me by many colleagues and students involved in disaster management, particularly through the courses and workshops held at the Australian Emergency Management Institute, Mount Macedon, Victoria, Australia.

AN INTRODUCTION TO SEISMIC RISK ASSESSMENT OF BRIDGES IN SOUTH AUSTRALIA

PHIL MOLLOY B.ENG (CIVIL)

AUTHOR:

Phil Molloy is a Senior Design Engineer with the Structural & Geotechnical Section of Transport SA. He has over 20 years experience in the design and assessment of highway bridge structures. Currently he is responsible for the assessment and load rating of existing bridges, and is involved in establishing and assessing all types of bridge loadings.

ABSTRACT:

Transport SA is responsible for the management of approximately 1500 bridges on main roads in South Australia. Recent significant seismic events throughout the world - and their effects on bridges - are briefly examined and an assessment of seismic risk in SA and implications of likely future earthquakes on SA bridges is discussed.

1. INTRODUCTION

Transport SA is responsible for the management of approximately 1500 bridges on main roads in South Australia. Most are small span structures, representing a small risk of failure during a likely seismic event. Many are medium to large span bridges which represent not only a risk of loss-of-asset and loss-of-life, but also the loss of a critical link in the post-disaster response network. AS1170 Part 4 [10] stipulates minimum earthquake loads for the design of new structures, but the real risk of failure lies within the bridge inventory that has been constructed prior to the present era, before the consideration of seismic effects. Just what is the risk of a bridge failure during a likely seismic event in South Australia? The fact that there has been no reported damage to any road bridge from a seismic event in Australia may give us some reassurance, but have we just been lucky?

2. BRIDGE PERFORMANCE DURING EARTHQUAKES

Traditionally, Australia has followed the lead of other countries (chiefly the USA, Canada and the UK) with regard to loading and detailing requirements for bridges. Bridges have typically been designed throughout the world to similar loading requirements and standards, at least up until about 1972. In more recent times, countries with higher earthquake risk (USA, New Zealand, Japan) have introduced more stringent seismic criteria into their bridge design codes.

In predicting likely damage to bridges from an earthquake in South Australia, it is instructive to look at recent significant seismic events throughout the world and observe their effects on bridges.

Well-known high-risk earthquake locations throughout the world generally occur at or near well-defined boundaries between continental tectonic plates (eg. New Zealand, Japan, California). Australia, however, experiences "intra-plate" earthquakes [2,8], occurring within the confines of the continental plate mass. Typically, intra-plate seismic events are shallower, exhibit higher frequency characteristics, and are of shorter duration than inter-plate earthquakes. They also do not necessarily coincide with the location of known fault lines and may occur in locations thought of as stable and having little or no seismic risk - like the 1989 Newcastle event [4].

Although intra-plate earthquakes do not release as much energy (often reported as the Richter magnitude M) as inter-plate earthquakes, they have the potential to cause considerable damage due to their shallow depth [2]. Hence, in comparing damage between inter-plate and intra-plate earthquakes, it can be more useful to adopt the Modified Mercalli Intensity (MM), which is a subjective scale related to the severity of ground shaking, rather then the Richter magnitude. A description of the Modified Mercalli scale can be found at reference (6).

It is particularly relevant to observe the performance of older bridges in significant overseas earthquakes, as bridges designed and constructed in Australia in the same period could be expected to perform similarly.

2.1 San Fernando 1971 [5,7,9]

This earthquake in the US state of California (M6.5, MM XI) caused major damage to bridge structures, and the aftermath saw a new impetus to overhaul bridge seismic specifications and construction details. It heralded a new era in terms of designing and assessing bridges for earthquakes. It is interesting to compare bridge failures from this watershed seismic event with failures in more recent earthquakes.

Bridge failures in the 1971 San Fernando earthquake were typified by:

- spans dropping off supports
- separation of deck joints and collapse of suspended sections
- columns pulling out of footings
- shear in support column bases due to failure of confinement reinforcement

Much of the subsequent overhaul of seismic design specifications dealt with superstructure restraints at span supports, column confinement reinforcement and adequate anchorage of main column reinforcement in plastic hinge zones.

2.2 Loma Prieta 1989 [5,7,9]

This Californian earthquake (M6.9, MM IX) saw the catastrophic collapse of the Cypress Street Viaduct with the loss of 35 lives (over half of the total number of earthquake victims). The loss of such a critical structure - the Oakland Bay Bridge could not be used for one month - and its impact on the post-disaster response exposed the vulnerability of key bridges and their importance in disaster-relief operations. As a result, an importance factor was subsequently introduced into the criteria for the design and retrofit of strategically critical bridges.

Bridges designed to seismic criteria introduced after the 1971 San Fernando event generally performed well, with restraining systems preventing decks separating at joints and supports, and piers exhibiting ductile behaviour with well-confined plastic hinge zones in columns. It was a clear demonstration that the revamped seismic provisions had been effective in preventing major bridge failures.

Seismic retrofits to older bridges typically also performed well, but many bridges designed to pre-1972 specifications had not been strengthened and suffered similar damage to that observed in the 1971 Loma Prieta event, viz loss-of-support and column ductility failures.

The Cypress Street Viaduct was somewhat of a unique structure, and its collapse can be attributed to a lack of understanding or appreciation of seismic performance in its design (1950's). Aside from deficient structural details however, one of the main causes of collapse was the dynamic response of its deep soft foundations - up to 150 m of mud lay between the bedrock and the bridge. Loss of lateral resistance in soft foundations (and potential for liquefaction) can highly magnify lateral seismic accelerations, and the 1989 Loma Prieta event illustrated this effect and demonstrated the need for it to be considered in future design and assessment procedures.

2.3 Northridge 1994 [5,7,9]

Occurring only 5 years after the Loma Prieta event, this Los Angeles earthquake (M6.7, MM IX) demonstrated that seismic strengthening efforts were on the right track, with almost all bridges that had been retro-fitted sustaining no detectable damage.

Again, pre-1971 bridges suffered with the same problems identified in the 1971 and 1989 events, though retrofit priority-setting methods employed by Caltrans ensured that most vulnerable bridges survived without collapsing. Four of the six bridges that did collapse were designed to pre-1971 specifications and were scheduled for retrofits. The other two bridges were subject to high vertical ground accelerations (faulting directly under bridge), combined with particular bridge geometry effects.

Bridge features which caused problems were typified by:
- high skew and support columns of different stiffnesses
- surface treatments implemented after bridge construction changing pier column fixity boundary conditions
- architectural treatments (eg. flared columns) increasing column stiffness

2.4 Kobe 1995 [3,7]

This devastating Japanese earthquake (M6.5, MM XI) caused widespread damage and disruption - all major roads and railways crossing Kobe were closed because of damaged or collapsed bridges, severely hindering post-disaster response. Most collapsed bridges were designed to pre-1971 specifications, though even 1995 Japanese designs did not implicitly require ductile performance, so failures tended to be sudden and catastrophic. Ductility design is now mandatory in Japan.

Most bridge collapses occurred because of support structure failures, specifically reinforced concrete pier columns suffering from the same deficiencies observed in the reported Californian earthquakes, viz
- inadequate column confinement reinforcement & inadequate lapping details
- curtailment of main column reinforcement in regions of anticipated plastic hinging
- inadequate support lengths for superstructure(s), especially for skew bridges

2.5 Turkey 1999 [7]

The Kocaeli earthquake in Turkey (M7.6, MM X) saw bridges perform well, except at a site where faulting occurred directly under a bridge and collapse occurred.

Some concrete shear keys (seismic restraints to prevent excessive lateral movement) at supports were inadequately reinforced and failed, causing superstructure dislodgment from bearings.

Several road overpasses sustained minor damage in the form of pier tilting arising from ground movement, and approach fill settlement. Such damage did not substantially impair the use of the main highways or the road overpasses.

2.6 Taiwan 1999 [7,11,12]

This major earthquake (M7.7, MM X) was evidenced by major vertical displacements due to faulting (up to 6 m) and approximately 10% of the bridge inventory suffered moderate to major damage. All damaged bridges were older structures not designed for seismic forces.

Bridge failures were again similar to those observed in the earlier Californian earthquakes, viz

- unrestrained spans collapsing off supports
- major column failures due to shear and ground movement

3. EARTHQUAKE RISK IN SOUTH AUSTRALIA

Past significant (recorded) earthquakes in SA [2,6] were of a level between MM VII and VIII (Table 1), though the peak ground shaking usually was restricted to a relatively small area, perhaps affecting only a handful of bridge structures at most. Intensity contours for these SA earthquakes can be seen at Reference (6).

Event	Magnitude (& Mercalli Intensity)
1897 Kingston-Beachport	M 6.5 (MM VIII)
1902 Warooka	M 6.0 (MM VII, peak at VIII)
1954 Adelaide	M 5.5 (MM VII, peak at VIII)
1989 Newcastle (for comparison)	M 5.6 (MM VI, peak at VIII)

TABLE 1 PREVIOUS SIGNIFICANT SA EARTHQUAKES [2,6]

Previous work [2] has indicated that there is approximately a 4% chance of a MM VIII earthquake occurring in SA in the next 50 years (Table 2) and approximately a 7% chance within the next 100 years.

Probability of being exceeded (%) within period T years				
Period T	Modified Mercalli Intensity (MM)			
(years)	VI	VII	VIII	IX
50	44	14	3.5	0.8
100	69	26	6.9	1.6

TABLE 2 PROBABLILITY OF AN ADELAIDE EARTHQUAKE [2]

4. IMPLICATIONS FOR SA BRIDGES

Bridges are routinely designed for frequent large vertical loads, and the superstructures are typically stiff enough to remain elastic during even large seismic events. It can be seen from observing failures during overseas earthquakes that bridge superstructures generally perform well and do not require specific attention, other than deck joint separation and restraining superstructure movement at support points. Conversely, bridge substructures - particularly reinforced concrete pier columns - are seen to be especially vulnerable to damage, and it is there that most of the risk of failure lies.

As observed in the Northridge, Turkey and Taiwan events, span collapse can be inevitable if ground dislocations are large relative to span support points, though this is unlikely to occur in SA.

The ultimate strength limit state - as routinely used in the design and assessment of bridges (1) - is commonly interpreted to be an event that has a 5% chance of being exceeded in the 100-year life of the bridge. At loads higher than the ultimate strength limit state, collapse may occur. At this statistical probability, an earthquake a little more severe than a MM VIII event could be expected in SA (Table 1) - this then, is the strength limit state seismic event for bridges in SA.

For a strength limit state earthquake (MM VIII) in SA, bridges should perform to the following criteria:

- depending on the importance of a structure, an earthquake of intensity MM VIII should be resisted without significant damage, and the bridge should behave elastically.
- some structure(s) with low importance may sustain damage, which prevents the bridge(s) from remaining open to traffic.

Bridge performance in earthquakes of this intensity has been observed to be very good, with conventional strength requirements and good detailing generally securing good performance - and this is borne out by the fact that there has been no reported damage to any road bridge from a seismic event in Australia. Allowance for movement (or restraint) at supports may require attention, particularly in multi-simply-supported span structures. Overall, it is expected that most bridges in SA would survive such an earthquake with little (if any) damage.

For higher intensity earthquakes (MM IX), performance criteria should be:

- collapse of important structures should not occur. If required, repairs should be able to be performed while the bridge is open to traffic.
- Some structures with low importance may suffer damage and possible collapse.

Earthquakes like Loma Prieta (1989) and Northridge (1994) illustrated the effects of this level of seismic event, though a similar intensity earthquake occurring in SA would be expected to have a shorter duration. This level of earthquake is likely to cause problems for bridges in SA, particularly those designed prior to 1985.

Earthquakes reaching intensity MM X or higher are approximately a 1 in 20,000-year event in SA (2), and damage or collapse of structures with low importance could be expected. Critically important bridges should be able to sustain repairable damage and may become unserviceable, but should not collapse.

In assessing the importance of a bridge, post-disaster emergency use needs to be taken into consideration. Structures that vehicles can bypass may be assigned a lower importance and need not be assessed to the highest standard, or may be rendered unserviceable above a strength limit state seismic event.

5. CONCLUSION

A broad assessment has been made of the likely effects of an earthquake on bridges in South Australia. Designing bridges to the current (and proposed) loading recommendations of Standards Australia [10] and Austroads [1] should ensure that new bridge structures satisfy the required performance criteria for such seismic events.

For existing structures (particularly pre-1985), a risk assessment needs to be undertaken to identify important bridges and implement retrofit strategies (if required) to ensure that they will perform to the required criteria during an earthquake of intensity MM VIII or higher.

The problem areas associated with bridge performance during earthquakes are well documented and can be summarised as:

- excessive superstructure movement at supports
- ductility at hinge locations in reinforced concrete pier columns
- deep soft soil site amplification

Addressing these three critical areas would go a long way - perhaps all that is required - towards safeguarding bridges against a large seismic event in South Australia.

6. REFERENCES

1. Austroads (1992) '92 Austroads Bridge Design Code
2. Greenlaugh, S. and McDougall, R. (1990) Earthquake Risk in South Australia, IE Aust, CE 32, No. 3, pp 106-115
3. Kawashima, K. (2000) Seismic performance of RC bridge piers in Japan: an evaluation after the 1995 Hyogo-ken nanbu earthquake, Prog. Struct. Engng Mater., No. 2, pp 82-91
4. Melchers, R.E. and Page, A.W. (1992) The Newcastle Earthquake, Proc. Instn Civ. Engrs Structs & Bldgs, May, pp 143-156
5. National Earthquake Information Centre (2002) website at http://neic.usgs.gov/
6. Primary Industries and Resources (2002) Minerals and Energy Resources, Mineral Resources Group, Earthquakes website at http://www.pir.sa.gov.au
7. Roberts, J. (2001) Performance of concrete bridges in recent earthquakes, Structural Concrete, No. 2, June, pp 73-91
8. Rynn, J.M.W. (1988) The Assessment of Seismic Risk in North Eastern Australia, IE Aust, Civil Engineering Transactions, pp 45-55
9. Southern California Earthquake Data Center (2002) website at http://www.scecdc.scec.org/
10. Standards Australia (1993) Minimum design loads on structures, Part 4: Earthquake loads
11. Su, N, Lin, D. and Chai, H.W. (2002) Damage to structures and buildings from the Chi-Chi (Taiwan) earthquake, Structures & Buildings, February, Issue 1, pp 51-56
12. Yen, W.H. (2002) Lessons learnt about bridges from earthquake in Taiwan, Public Roads, Jan/Feb, pp 20-23

SEISMICALLY UPGRADED STRUCTURES – TWO ADELAIDE CASE STUDIES

MARK BILLINGER, DAVID COCKBURN, ADRIAN JONES
CONNELL MOTT MACDONALD

AUTHORS:

Mark Billinger BEng (Hons I) PhD, is a senior structural engineer with Connell Mott MacDonald with over 10 years experience in both research and design of structural systems. Mark's research has been based on both high-strength and high performance concretes and their use in structural elements.

David Cockburn BEng (Hons), is a structural engineer with Connell Mott MacDonald with experience in the design, documentation and construction of multi-storey reinforced concrete and steel framed buildings. David also has experience in 3D dynamic earthquake analysis of new and existing structures.

Adrian Jones BEng (Hons), is an Associate with Connell Mott MacDonald and is the head of their structural discipline. Currently Adrian is the President of the Concrete Institute of Australia Southern Division and Adrian is also a member of the Earthquake Code Committee.

ABSTRACT:

With an increased focus on risk management, the largest risk for building structures in Adelaide is from earthquakes, hence building owners have been engaging consultants to assess earthquake building risk and if necessary reducing the risk to an acceptable level. This paper describes two seismic upgrades for two different types of existing mutli-storey buildings within the Adelaide CBD. The first case study is the Public Trustee Building, a 10 storey reinforced concrete structure while the second study is the Hayborough Building, a 3 storey unreinforced stone and masonry structure. For both cases, the paper describes the structure's earthquake inadequacies and the final designs, which have ensured the structures compliance with the relevant current Australian codes and the owner's requirements.

1. INTRODUCTION:

In recent years there has been an increased focus on risk management and ways of reducing risk especially in existing infrastructure by large property groups including state governments and individual owners. Within Adelaide the largest risk for building structures is from earthquakes, hence building owners have been engaging specialist consultants to determine the level of earthquake risk and if necessary to reduce the risk to an acceptable level based on the building's use, cost benefit etc. Hence, this paper summarises two very different case studies of seismic building upgrade in Adelaide.

2. PUBLIC TRUSTEE BUILDING, FRANKLIN STREET:

The Public Trustee Building is 10 storey office building constructed in 1971 with basement, located on the south side of Franklin Street Adelaide. The main building tower is rectangular with dimensions of 15m (east-west) by 51m (north-south). See Figure 1.


Figure 1: Public Trustee Building

The structural form of the building consists of reinforced concrete slabs supported on a combination of precast and insitu concrete columns and walls, with the walls and columns supported on concrete pile caps and piles. The lateral load resisting system consists of 6 precast concrete walls on the higher levels and insitu concrete walls on the lower levels in the east-west direction (short direction) and in the north-south direction by concrete frame action.

In 1998, the South Australian Government through the Department of Administrative and Information Services (DAIS) engaged EQE International to perform an earthquake evaluation of several of the government buildings including the Public Trustee Building.

The evaluation performed by EQE International reported the Public Trustee building to have a high seismic risk based on the following:

- Minimal frame action from precast column columns and flat slabs.
- Columns constructed with high-strength concrete and not detailed with ductility in mind.
- Perimeter columns and spandrel beams may cause a strong-beam weak-column situation, which is not desirable.
- Discontinuities in the floor diaphragms that interrupt the load path to the shear walls.
- Penetrations in shear walls, especially the large penetration in the northern shear wall on Ground Floor.
- Pounding of the 5 storey building to the west which may result in local damage.

Connell Mott MacDonald were commissioned by DAIS to undertake a preliminary earthquake evaluation of the Public Trustee Building, and to develop three options to upgrade the building to comply with AS 3826 (1998) and to comply with DAIS's guidelines.

The starting point of any earthquake upgrade is to determine the classification of the structure and this classification is related to the function of the structure and its value to the community. Structural classification discussions with DAIS, the Public Trustee and architect were performed and it was desired that the Public Trustee Building should withstand 67% of the lateral earthquake loads from AS 1170.4 (1993). This is equivalent to a type III classification in accordance with AS 3826 (1998). This was chosen so that the future flexibility and function of the building was not compromised.

An inspection of the Public Trustee Building was carried to confirm the quality and the general construction of the building and to correlate with the existing structural drawings. From the review of existing drawings and calculations, it was found that the structural members, columns, beams and shear walls were not designed or detailed for earthquake loading.

A three dimensional dynamic analysis of the Public Trustee Building was performed using the ETABS analysis program using the classification type III as discussed above. From the analysis is was found that for an earthquake in the north-south direction, the columns and beams were overstressed in the order of up to 50% and 200% respectively. For the east-west direction, the shear wall system was overstressed at the lower three levels due to the poor detailing of boundary elements. It was also found that the storey drift at fifth floor was excessive which meant that the building could collide with the adjacent building to its west.

Consequently, the Public Trustee Building required an earthquake upgrade so it complied with AS 3826 (1998) and DAIS classification. Three strengthening options were proposed based on the following site constraints;

- Tenants were to remain within the building, due to the large cost to relocate.
- Minimal disruption to tenants in regards to noise etc.
- Existing building built on three of its four boundaries.
- Cost.
- Existing architectural form to remain.
-

- Existing services in the lane way to the east.
- No encroachments into the right of way of the lane way.

The three options were:

- Construct a new concrete shaft in the south-eastern corner of the building with shear walls in both directions.
- Construct an external steel bracing system also on the south-eastern corner of the building.
- Construct a new shear wall to the north-eastern corner of the building and a new shear wall on the southern façade up to level 5.

In considering the three options, the third option was chosen to be the most structurally viable and cost effective solution.

The adopted strengthening of the Public Trustee Building incorporated a new full height shear wall on the eastern façade to attract earthquake loads in the north-south direction, see Figure 2, and a new shear wall on the southern façade (to underside of level 5) to reduce stresses in the existing shear walls in the east-west direction at the lower levels.

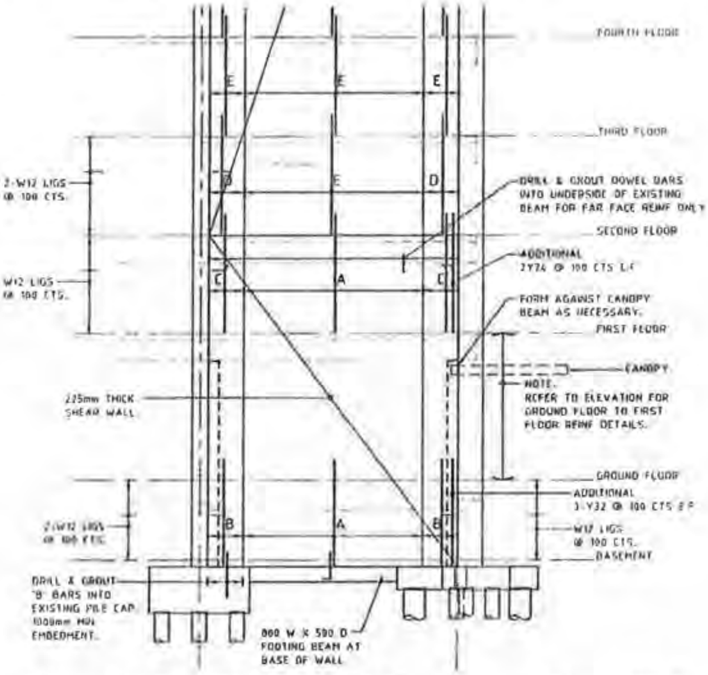

Figure 2: Part Elevation of New Eastern Shear Wall

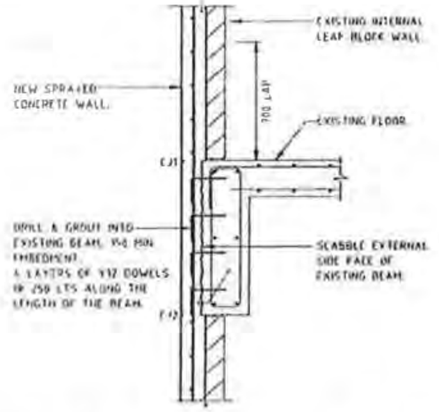

Figure 3: Connection of New Shear Wall to Existing Floors

The earthquake strengthening shear wall system consisted of the following:

- two additional piles and new pile cap to the existing footing system for the eastern façade shear wall only,
- the removal of the external leaf of masonry at the location of the shear wall,
- doweling reinforcement into existing precast concrete columns,
- doweling reinforcement into concrete floors at each level, see Figure 3, and
- concrete spraying new reinforced wall to the internal leaf of masonry.

3. HAYBOROUGH BUILDING, RUNDLE STREET:

The Hayborough building is a three storey unreinforced stone and masonry building, located on the south side of Rundle Street, Adelaide constructed approximately 100 years ago, see Figure 4. Due to a change in tenancy use, the building was required to satisfy the minimum standards for earthquake resistance set out in AS 3826 (1998), 33% of the lateral loads from AS 1170.4 (1993).

Figure 4: Hayborough Building

With construction typical of buildings constructed at the time, the building consists of five stone/masonry walls on a 6m grid running north-south for the length of the building. The edge walls are common with the two adjacent buildings also of similar construction. Timber joists on rebates in the masonry walls support the timber floorboards.

The building did not satisfy the deemed-to-comply provisions of AS 3826 (1998) for two main reasons; the northern side of the building at ground level contained no lateral resisting elements due to the installation of shop front windows and the client's request to remove substantial portions of the interior masonry walls, deleted the regular spacing of walls required. Therefore, at ground level, the building was essentially a three-sided box with walls on the east, west and southern sides.

In order to justify that the exterior walls could be mobilised to resist an east-west earthquake event without excessive deflections, a simple three dimensional model of the building was analysed using the building analysis program ETABS. The model consisted of the building's main masonry walls and flexible floor diaphragms. The threshold load, 33% of AS 1170.4 (1993) loads, was applied at the design eccentricities to AS 1170.4 (1993).

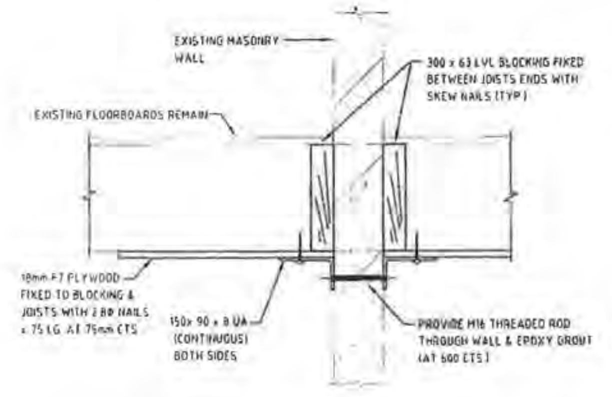

Figure 5: Typical Connection of Floor to Wall

From the analysis, the building exhibited surprising stiffness with theoretical deflections in the order of 10mm (north-south masonry walls are up to 400mm thick). The main assumption of the analysis was an integral floor diaphragm with connectivity to the exterior walls. Details similar to those in AS 3826 (1998) were used that satisfied the code requirements and enabled the timber floorboards to remain as a feature of the building renovations, see Figure 5. The connection tied the floor to the exterior walls and ensured continuity between interior masonry walls. The floor/wall stresses from the model were also able to be adequately resisted by the proposed detail.

4. REFERENCES:

AS 1170.4 (1993) Minimum design loads on structures, Part 4: Earthquake loads, Standards Australia, 54pp.

AS 3826 (1998) Strengthening existing buildings for earthquake, Standards Australia, 55pp.

5. ACKNOWLEDGEMENTS:

We wish to acknowledge our clients of the case studies in this paper:

- Public Trustee Building - Department of Administrative and Information Services (DAIS)
- Hayborough Building - Adelaide Development Company