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Lifelines and Earthquakes:

A Review of New Zealand's Key Vulnerabilities

D. R. Brunsdon

National Lifelines Co-ordinator, New Zealand.

M. C. Daly

Executive Project Manager, Auckland Regional Council.

A. J. W. Lamb

Project Manager, Christchurch Engineering Lifelines Group.

ABSTRACT: Lifelines engineering in New Zealand was initiated in 1989, and is now an established technical discipline. There are now Lifelines Projects and Groups in virtually every region of New Zealand. The Lifelines engineering process represents a very effective regional scale collaborative model which is being viewed by other sectors as a model framework for integrating technical processes with community needs.

While the New Zealand Lifelines process addresses all natural hazards, the considerable risks to infrastructure posed by earthquake throughout the country make it a prime focus of Lifelines work. This paper summarises the findings from Lifelines work to date regarding seismic vulnerability of utility networks. This includes first-hand observations by New Zealand Lifelines Study Tours following major earthquakes during the 1990's. The common earthquake mitigation measures for the key utility sectors are summarised, and a critical appraisal made as to the level of progress with mitigation in each area. The authors' views are given as to where the emphasis should be placed for future earthquake mitigation for utilities given the recent organisational changes in major utility sectors.

1 INTRODUCTION

Lifelines are those essential services which support the life of communities. These are either *utility services* such as water, wastewater, power, gas and telecommunications, or *transportation networks* involving roading, rail, ports and airports.

Significant developments have occurred in the field of lifelines engineering over the past decade both in New Zealand and internationally. In New Zealand, this period encompassed both the beginnings of lifelines activity and its development into being an established discipline across virtually all regions.

The overall objectives of Lifelines Engineering are:

(i) to reduce damage levels following a major disaster event; and

(ii) to reduce the time taken by lifelines services to restore their usual level of service.

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.

Once the many positive benefits from the initial projects became apparent, the regional lifelines model and methodology spread rapidly across NZ in the late 1990's. The Christchurch Lifelines Project commenced in 1992, and developed the multi-hazard approach that has been adopted by all subsequent projects. There are now Lifelines Projects either planned or underway in virtually all of the 14 regions across New Zealand.

2 THE NEW ZEALAND LIFELINES PROCESS

The regionally-based New Zealand Lifelines Engineering process is based around the following risk management steps:

1. Identifying the *hazards* which could affect each lifelines network
2. Compiling common *inventories* of the various utility and transportation networks
3. Assessing the *vulnerability* of the lifeline network to those hazards (the *potential damage* to and *consequences for* each network)
4. Identifying and implementing practical *mitigation* measures
5. Facilitating the preparation of comprehensive *emergency response* plans
6. Communicating the outcomes to key stakeholders and monitoring progress on an ongoing basis

This process is based on risk management methodology encapsulated in AS/NZS 4360:1999 (SA & SNZ, 1999), and is described more fully elsewhere (Brunsdon, 2001).

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 Lifelines process provides the much-needed external perspective by systematically highlighting the *interdependencies* involved. The responsibility however for taking appropriate mitigation and preparedness steps remains with the individual organisations.

With respect to hazards, the focus of lifelines work in New Zealand is on regional scale events that are beyond the ability of individual organisations to respond to and control. While Lifelines Engineering in New Zealand had its origins with earthquake, subsequent work has extended to address all hazards. Earthquake hazard has however been found to present the most significant hazard to utility systems in virtually all of the regions studied to date. The unique backdrop to this work however is that no major New Zealand urban area has experienced a damaging earthquake since the 1931 Napier earthquake which claimed 256 lives. It is this fact that makes the credibility of the risk so hard to convince the decision makers (senior management, elected councillors, board members, etc) to commit funds for mitigation and ongoing work.

The first five key Lifelines steps outlined above typically take from 3 to 5 years to work through for each region, and result in a major report. Reports have been completed by Lifelines Projects in the major metropolitan centres of Wellington (CAE, 1991), Christchurch (CAE, 1997), Dunedin (DELP, 1999) and Auckland (ARC, 1999), and for the Hawke Bay region (HBRC, 2001). The Lifelines process is however an ongoing one, with a review of mitigation and preparedness progress and achievements across all organisations involved is typically conducted on an annual basis in each region. This important step maintains the momentum and information exchange achieved by the earlier work.

The key outcome is of course not the report, but the establishment of a mitigation programme in the asset management plans of the individual Lifeline utilities.

3 LESSONS FROM OVERSEAS EARTHQUAKES

Major earthquakes in Northridge, California (1994) and Kobe, Japan (1995) have also consolidated the momentum of lifelines work in New Zealand. These events generated a number of technical findings and response lessons for those involved with the management of lifelines systems. NZ Lifelines study teams visited each of these areas approximately six months after the respective events, and held detailed discussions with their counterparts.

The key lessons learnt from these events (WELG, 1994 & 1995) were:

- The importance of access and communications for utility restoration; *and*
- The need to have an integrated response plan at national, regional and local levels

Information on the service restoration times from these events has provided a good basis for establishing likely scenarios following a major earthquake in New Zealand. In particular, the impact on communities and other utilities of the likely extended loss of water supply sends an important signal for post-earthquake planning.

4 THE KEY SEISMIC VULNERABILITIES OF NEW ZEALAND'S LIFELINE UTILITIES

The principal seismic vulnerabilities of New Zealand's lifeline utilities are considered in this section under the headings of *physical, organisational* and *operational* vulnerability.

Physical Vulnerabilities

In simple terms, the main physical vulnerability of lifeline utilities to earthquake can be summarised as:

- Parts of lifelines systems located close to active faults or in areas susceptible to liquefaction or landslides
- System elements designed from brittle materials or prior to modern seismic codes

In the utility context, system elements comprise:

– Buried services (pipes, cables)

– Overhead cables

– Switchyards, exchanges & control rooms

– Roads

– Bridges

– Buildings

Organisational Vulnerabilities

Lifeline utilities have undergone considerable transformation over the past decade. The restructuring in most sectors has generated a number of newer utility organisations and a greater commercial focus, particularly for those in sectors with revenue directly at risk. While this has led to significant advances in short- and medium-term financial risk management, many of the newer utilities have not given the same level of attention to mitigation and preparedness for longer return period hazard events. The same can also be said for some from the category of utilities that do not have 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 considerable emphasis 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, the current 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 is inevitably the case for regions of moderate and low seismicity.

Operational Vulnerabilities

Consideration of operational vulnerability to earthquake focuses on maintaining the currency of so-called 'smaller items', which typically fall between major physical elements and organisational aspects. These include:

- Ensuring control and computer equipment continues to be secured against earthquake shaking (annual inspection required)
- Maintaining the ability to operate manually in the event of failure of the normal electronic control systems
- Regular testing of standby emergency plant and equipment (those who will be responsible for implementing the standby methods should do the testing, including running standby plant for a long test period occasionally)
- Ensuring adequate emergency spares for key elements (not depending solely on "just in time" inventories because this will not work in a major regional-scale emergency)
- Continual review of methods for mitigation including the updating of appropriate sections in design and operational manuals
- Staff training for emergency response.

5 NEW ZEALAND LIFELINES ACHIEVEMENTS

New Zealand's achievements in Lifelines Engineering can be considered under the headings of *Mitigation* (Reduction) and *Response Preparedness* (Readiness).

Mitigation

There has been a range of physical mitigation undertaken by the various utility sectors in New Zealand over the past decade. While some of this work was 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.

A sample of generic mitigation projects for each of the key sectors is outlined in Table 1:

Table 1 Lifelines Mitigation Achievements

Water Supply	• Seismic upgrading of reservoirs, often with the addition of automatic shutoff valves • Creation of medium-term (10 to 20 year) mitigation programmes integrated with Asset Management plans
Electricity	• Strengthening or replacement of substation buildings • Upgrading of switchyard facilities, including transformer mountings and switchgear support frames
Gas	• Relining of old cast iron gas mains in the capital city of Wellington with modern PVC mains operating at higher pressures • Improving the ability to isolate gas distribution networks into smaller sectors by the introduction of more valving
Telecommunications	• Strengthening of exchange buildings • Achieving greater route diversity by developing new cable routes
Transportation	• Developing seismic evaluation methodologies for road bridges that take the availability of alternative routes into account • Strengthening of vulnerable road and rail bridges • Introducing more redundancy into the network by identifying alternative routes and ensuring any such route status was factored into Asset Management plans

Virtually all utilities have undertaken programmes to brace and tie down control cabinets and computers in control rooms. Some utilities have developed new systems of equipment and spare parts inventories and storage (eg. horizontal storage of critical and brittle spares to minimise damage).

Response Preparedness

Observing the lessons from major overseas earthquakes has played a major part in increasing the level of utility response preparedness for major earthquakes. Some utilities hold annual response exercises, with Lifelines Groups providing the platform for region-wide exercises in some areas.

In recent times there has been a growing awareness of the implications of dependence of many utility organisations on their maintenance contractors. Maintenance contracts are now subject to more careful scrutiny to ensure that appropriately experienced repair personnel are available on a stand-by basis and, more importantly, they are available on an exclusive basis rather than being shared with other utility companies. This highlights one of the key thrusts of the new Civil Defence Emergency Management arrangements in New Zealand, which is to place greater emphasis on self-sufficiency by key utility organisations.

Observations

- The extent of physical work undertaken to date has varied between organisations depending on the level of priority assigned by senior management
- Many utilities have not made use of the information available from regional Lifelines Projects
- The degree of action taken by individual utilities is still governed by their internal economic perspective, rather than the assessed regional level of risk
- Many utilities are still planning in isolation, without much regard to their dependence on other lifeline sectors

6 THE NEW LEGISLATIVE CONTEXT

On 1 December 2002, new Civil Defence Emergency Management legislation was enacted (CDEM Act). This new Act requires lifeline utilities to function at the fullest possible extent during and after an emergency. 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 lifeline utility earthquake preparedness across the 4Rs of *reduction*, *readiness*, *response* and *recovery*.

With its emphasis on the much-needed external perspective by highlighting the *interdependencies* involved, the lifelines process is likely to become an important area of focus for both lifeline utilities and the emergency management sector in the near future.

7 KEY ELEMENTS OF UTILITY EARTHQUAKE PREPAREDNESS: FUTURE FOCUS

The key elements of lifeline utility earthquake preparedness can be summarised across the 4Rs of *reduction*, *readiness*, *response* and *recovery* 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*
    - *eg. For road networks, ensure that asset maintenance and renewal programmes take account of the priority route status of alternative parts of the network*
- Focus on low-cost/ high benefit items – for example, the bracing and tying down of control cabinets and computers in control rooms, and the introduction of flexible joints at junctions with rigid structures
- Increasing the level of pipes and fittings held for emergency repairs, and improving the methods of storage
- Utility emergency operations centres must be situated in seismically robust buildings, with alternative locations. Seismic evaluation of key buildings must be undertaken.

Readiness

- Hold exercises to test preparedness and effectiveness of response plans and communications processes, ensuring that contractors are directly involved
- Establish hierarchy of critical community supply points
  - *eg. hospitals as a priority for the restoration of water supply, electricity*
- Ensure appropriate mutual aid agreements are in place for key utility sectors such as water and energy
- Ensure that utility operators have dependable access to technical resources such as engineers for impact assessment and the organization of initial repairs

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)*
  - *the mechanics of distributing core community supplies such as emergency water over an extended period of time*
- Improve inter-agency communications and co-ordination processes

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

8 CONCLUDING OBSERVATIONS

The Lifelines Engineering process represents a very effective regional scale collaborative model that is being viewed by other sectors as a model framework for integrating technical processes with community needs. Lifelines Engineering is all about identifying and progressively reducing weak links – both *physical* and *organisational*, and both *within* and *between* organisations.

In the previous section, key elements of lifeline utility earthquake preparedness were identified. In order to continue to make progress in reducing weak links in utility systems, it is considered that the four most critical aspects common to all utility sectors and organisations are:

1. The adoption of a consistent approach towards the integration of earthquake mitigation measures within asset renewal and capital development programmes
2. The development of a consistent economic framework for justifying investment for mitigation and preparedness for low probability/ high impact natural hazard events
3. Conscious improvement of inter- and intra-organisation links to ensure a base level of functionality in a sudden catastrophic emergency event such as earthquake (with particular reference to the role and function of contractors)
4. Commitment of significantly increased levels of staff time to preparedness activities

This work cannot be left to Lifelines Projects and Groups alone, as these are informal groups of interested parties that rely on extensive levels of voluntary input. Furthermore, a number of important lifelines are typically not represented or involved. Individual lifeline utilities need to make a much higher level of commitment (both financial and time) to basic measure that need to be undertaken individually and collectively.

There is also a need to recognise at the governance level of many utility organisations that in the absence of ‘real’ events, specific steps need to be taken to achieve an appropriate level of robustness in order to meet both the community expectation and the requirements of the new CDEM Act regarding service continuity. This is also known as establishing a defensible position.

A quote from the Christchurch Engineering Lifelines Project report *Risks and Realities* is an appropriate note to close on: ‘*Recovery from a destructive earthquake is expensive for everybody, and anything to reduce the cost is worthwhile’*.

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