LIFELINES ENGINEERING - A LONG WAY IN A DECADE

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SUMMARY

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 engineering and its development into being an established discipline of earthquake engineering.

This paper charts the progress of lifelines engineering during this time, outlines the key achievements and critical success factors and discusses current needs and future developments.

INTRODUCTION

Lifelines are those essential services which support the life of our communities. These are either utility services such as water, wastewater, power, gas and telecommunications, or transportation networks. The term civil infrastructure is also frequently used in a similar context to lifelines, particularly in the United States.

The twin overall objectives of Lifelines Engineering are firstly to reduce damage levels following a major disaster event and secondly to reduce the time taken by these lifelines services to restore their usual level of service. This saving in time translates directly into a saving for the community as a result of reduced disruption to homes, offices and industries.

While much of this paper refers to earthquake events, a great deal of the recent work associated with lifelines engineering has embodied an all-hazards approach.

At the start of the decade in question, there was a growing realisation that while considerable effort had been put into understanding the seismic response of buildings, relatively little was known about the likely performance of utility services. Similarly, in the case of transportation networks, while the individual structural response of major elements such as bridges had been extensively studied, the post-disaster performance of the networks as a whole had not been considered in anywhere near the same detail.

THE LIFELINES ENGINEERING PROCESS

The process of minimising the vulnerability of lifelines in seismically active regions involves the following key steps:

- Assessing the *vulnerability* of the lifeline network.
- Assessing the *potential damage* to the network
- Identifying and implementing *practical mitigation* measures.
- Compiling comprehensive *response plans.*

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The first of these steps is in many ways the most significant, as it involves a full seismic hazard assessment. However the benefits of any hazard assessment count for nothing unless the subsequent three steps are worked through in a systematic manner.

Assessment of vulnerability takes account of the *importance* of the lifeline component - that is, the degree of disruption if the element is lost to the network. This aspect typically highlights the redundancy (or lack of) in a system. The assessment of potential damage takes into account of the *impact* of an earthquake - that is, the time and effort which is likely to be required to reinstate the component in addition to the cost.

Traditionally, seismic risk issues have been worked through on an organisation by organisation basis. The key focus, and hence advantage, of lifelines work is the sharing of technical information relating to seismic hazard and mitigation between lifelines organisations.

The relationship between lifelines studies and the broader field of earthquake engineering is illustrated in Figure 1. This diagram indicates how the process of reducing the vulnerability of the community to earthquake is a continuous one. Earthquake events provide lessons which need to be considered when decisions are made on risk assessment and on money to be spent on preparedness measures. It is however not necessary to wait for the actual events, as a third path of learning is available through research of hazards, risks and physical mitigation.

The *preparedness* aspect of lifelines engineering is embodied in the third and fourth points. A prime example of a practical mitigation measure is the installation of automatic shut-off valves at water supply reservoirs, to stop the loss of vital water through broken mains. This is not simply an engineering exercise, as it requires prior consideration of the post-earthquake response of the fire service, and consultation with them.

The planning of disaster response essentially involves establishing frameworks for organised and immediate responses to such situations. A great deal of emphasis is placed on co-ordination between the many organisations involved following a disaster.

ESTABLISHMENT, CONSOLIDATION AND EXPANSION

The timeline of lifelines engineering development in New Zealand is presented in Figure 2. This diagram presents the establishment, consolidation and expansion phases described in this section.

Establishment

Lifelines engineering in New Zealand began as a separate discipline with the undertaking in 1989 of the *Lifelines in Earthquakes: Wellington Case Study*. This project was initiated, produced and largely funded by the Centre for Advanced Engineering, and was completed in 1991 [2]. This project was unique internationally in both scope and approach, and has provided the impetus and a point of reference for all subsequent lifelines work in this country.

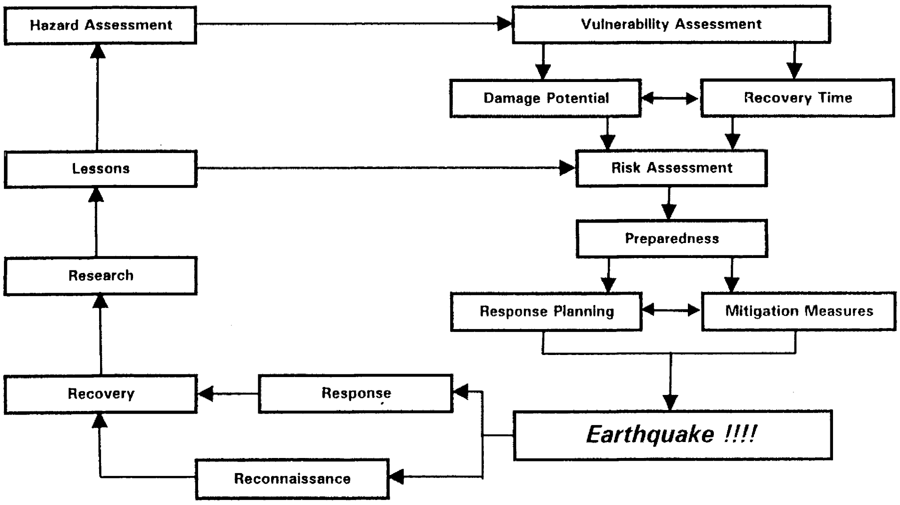

FIGURE 1. *The Earthquake Risk Reduction Cycle [1].*

	1989	1990	1991	1992	1993	1994	1995	1996
Earthquake Events	Loma Prieta					Northridge	Kobe	
Phase 1 Work *Project Establishment, Hazard Identification and Vulnerability Assessment*		Wellington Project (CAE)				Christchurch Project		Auckland Wairarapa Timaru Dunedin Southland
Phase 2 Work *Mitigation Work and Response Planning*						Wellington Earthquake Lifelines Group		Christchurch

FIGURE 2. *Timeline of Lifelines Engineering Development in New Zealand.*

The principal output from this project was the identification of a series of possible mitigation measures that operators of lifelines could undertake to reduce the risk from a major earthquake. The concepts of *interdependence* and *critical areas* were also identified: interdependence relates to the effect of the outage of one utility service (eg. power) on the time taken by another to recover (eg. water supply requiring power for pumping), whereas a critical area is one where a number of lifelines are highly vulnerable in one location (eg. a bridge carrying water, gas and power in addition to roading).

Of greater significance however beyond the technical content was the heightened awareness of this work created by this project amongst utility services providers both in Wellington and elsewhere in New Zealand.

The value of the project was enhanced by the involvement of four United States experts in lifeline earthquake engineering. Don Ballantyne, Dennis Ostrom and Ian Buckle contributed directly to the project by attending a special three day workshop in Wellington in September 1990, with Thomas O'Rourke also providing valuable input via corrrespondence. This involvement has created a continuing conduit for the exchange of information on lifelines work between New Zealand and the United States, and has led to the participation of key New Zealand lifelines engineers in joint United States-Japan technical meetings.

Consolidation

Lifelines engineering in New Zealand was consolidated by two developments in 1993.

Firstly, the establishment of the Christchurch Engineering Lifelines Project. This project was similar in nature to the CAE Wellington Case Study, but with the enhancement of an all-hazards approach. This project considered not only earthquake, but also severe flooding of the Waimakariri River; a severe rain storm causing a local flood hazard (Heathcote, Avon and Styx rivers); a severe windstorm, a tsunami on the coast, a heavy snowstorm and slope hazards causing damage to surfaces on the Port Hills. The need to take specific account of critical community facilities such as hospitals was also highlighted by this project.

A major workshop on the Christchurch project was held in September 1994. International input was provided by Ron Eguchi of the United States.

The second of these developments was the establishment of the Wellington Earthquake Lifelines Group. This group operates under the auspices of the Wellington Regional Council, and contains representatives of each of the national, regional and local utility srvice and transportation providers involved in the metropolitan area, along with consulting engineers and scientists.

As well as further developing the preparedness of lifelines operators for major earthquakes, one of the key areas of emphasis of this group is to create and maintain awareness of the importance of lifelines to the community at large. It has been set up as an ongoing organisation rather than as a finite project. The Wellington Earthquake Lifelines Group has involved related disciplines and organisations beyond the engineering and scientific origins of the initial lifeline work. Project groups have been established to build on and take further the key findings of the original project, including rationalisation of the original list of mitigation measures into a shorter list with emphasis on cost-effectiveness and affordability. A great deal of effort has also gone into the generation of response plans.

This work is referred to as the second phase of lifelines work, following on from the first phase work which involved hazard identification and vulnerability assessment.

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. Study teams comprising representatives from both the Wellington and Christchurch lifelines groups visited each of these areas appproximately six months after the respective events and held detailed discussions with their counterparts. These events also generated a high level of interest amongst the general public, particularly because they were separated by only 12 months. It is this level of community interest and concern which has formed a vital backdrop to lifelines work in New Zealand.

Expansion

With the continuum produced by the first and second phase work outlined above generating clear benefits, other lifelines groups have been formed in New Zealand. 1996 saw five new groups established (Auckland, Wairarapa, Timaru, Dunedin and Southland), and several others mooted.

This rapid expansion highlights the major progress made over the past decade.

OVERSEAS DEVELOPMENTS

Lifelines engineering had its origins in the United States where the major impetus to examine seismic design procedures for lifelines facilities came from the 1971 San Fernando earthquake. This led to the formation of the Technical Council on Lifelines Earthquake Engineering (TCLEE) in 1974. This organisation was formed to address issues regarding the state of the art and practice of lifeline earthquake engineering in the United States. Contact with TCLEE members during the early and mid-1980s generated considerable interest amongst key New Zealand earthquake engineers regarding lifelines work, and was a leading factor in the establishment of the CAE Project. Immediately preceding the decade which is the subject of this paper, the National Centre for Earthquake Engineering Research (NCEER) was formed with the objective of addressing socio-economic issues related to the seismic performance of lifelines systems. This centre has brought together researchers from many different technical disciplines to focus on multi-dimensional issues.

The Loma Prieta earthquake in San Francisco in 1989 significantly heightened awareness of lifelines concerns. The two dominant images from this event were the failures of a number of components and sections of the transportation networks in the city, and the disruption to water supplies in the San Marino district with near disastrous consequences for fire fighting activities.

One of the most significant developments in the United States in this decade was the passing in 1990 of Public Law 101-614 (reauthorisation of the national earthquake hazards reduction programme). This law required the director of the Federal Emergency Management Agency (FEMA) to submit to Congress a plan for developing and adopting seismic design and construction standards for lifelines. This is an ambitious programme, and while draft standard documents for both new and existing lifelines services have subsequently been compiled, it is understood that difficulties are being experienced in the adoption of these standards given the significant cost (and hence political) implications.

The January 1994 Northridge, Los Angeles earthquake was the most significant lifelines event in the United States during this ten year period. Current estimates of lifeline damage as a result of this earthquake are in excess of US$2 billion [3]. While this amount may appear to be low relative to other types of costs (eg damage to buildings), it only reflects those costs associated with the repair of damaged lifeline systems. Other related costs such as business interruption due to lifelines disruption may be many times as higher as this basic repair cost.

Closer to home, the Tasmanian Lifelines Project was established in 1995, and with the benefit of appropriate backing has also made very good progress in a short space of time.

KEY NEW ZEALAND ACHIEVEMENTS

In the relatively short period of time that lifelines engineering has been actively undertaken in New Zealand, there have been a number of key achievements. At a general level, probably the most significant has been the level of acceptance of the discipline of lifelines engineering and the rapid spreading of this work throughout the country.

The following specific key achievements are selected from project considerations. The criteria adopted in listing these achievements is principally that the work involved would not have been undertaken without the focus that lifelines engineering provided. While most of them relate to projects undertaken in the Wellington Region, this is simply a reflection of the progression of lifelines work in that area following the initial CAE study.

- ***Thorndon Overbridge retrofitting***

  The CAE study identified the Thorndon area as being the most critical area in the Wellington Region, due to the combination of proximity to the Wellington Fault, the extent of early harbour reclamation, and the proliferation of lifelines that pass through this narrow strip of land. Such was the emphasis given to this area in the CAE project, that Transit New Zealand commenced a study into the likely seismic performance of the Thorndon Overbridge, which is the main highway entrance to the city and which also crosses the main trunk railway in the Wellington railway yards. This overbridge was designed progressively through the 1960s and early 1970s to design standards that are now recognised as not being as comprehensive as those of today. The study undertaken on behalf of Transit New Zealand has identified structural shortcomings, and the first stage contract to rectify these problems has recently been let.

- ***The Kaitoke Flume Bridge***

  This concrete aqueduct carries half of the daily water supply to the Wellington metropolitan area across a deep gorge and was designed in the late 1950s. An engineering assessment was commissioned immediately after the CAE Wellington Case Study Project, and this identified that the strength of the supporting structure was less than a quarter of that required by current standards. A retrofit to full current standards resulted, for a completed cost of approximately $250,000. Given the major task of reconstructing this key element of the water supply network should it fail, this project demonstrates a very high inherent value for money.

- ***The Hutt Estuary Bridge Assessment***

  In addition to the primary traffic function, this bridge carries five other lifelines; two regional council watermains (the remaining half of the water supply to the Wellington Metropolitan Area), the Hutt Valley main trunk sewer, a medium pressure gas main, 11kV power supply and 6 Telecom duct lines. The bridge was designed and constructed in the early 1950s, and recent studies have shown the bridge to be situated in an area that is known to have a high potential for liquefaction.

  As a result of the identification of this element as being the second most critical lifelines area in the region by the Wellington Earthquake Lifelines Group in 1993, sufficient encouragement and financial support was given by the affected lifelines operators that the seismic assessment of this bridge was brought forward by the Hutt City Council several years ahead of its programmed date.

- ***Learning lessons from the Northridge and Kobe Earthquakes***

  The study teams sent by the Wellington and Christchurch groups following each of these events brought back valuable lessons for New Zealand lifelines operators. These lessons were conveyed by various means, including the *1994 Report* and the *1995 Report* produced by the Wellington Earthquake Lifelines Group [4], [5]. The key lessons learnt from these events were firstly the importance of re-establishing transportation links as quickly as possible and secondly the need to have an integrated response plan at national, regional and local levels. The third aspect was the indications of the time taken to restore the various utility services in each of these events. The rate of restoration for Kobe is shown in Figure 3, and is similar to that observed after the Northridge event. Whilst only indicative in nature, these curves give a good basis for establishing likely scenarios following a major earthquake.

- ***Development of the Response Planning Process***

  Response Planning acknowledges that full physical mitigation is unattainable for most lifelines, and represents the vital first step in ensuring a rapid restoration of service. A response plan defines the physical sequences to be followed in the event of a

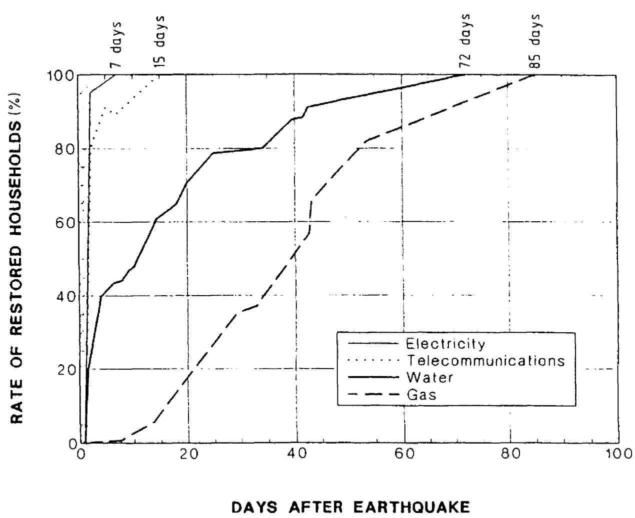

FIGURE 3. Restoration Curves for Utility Services after the Kobe Earthquake [5].

significant earthquake, and defines the roles, responsibilities and authorities of key personnel involved. Response Planning has been the main area of emphasis in Phase 2 lifelines work in New Zealand.

The two key benefits of Response Planning are:

(i) The process identifies work to be done individually and collectively by organisations; and

(ii) A clearer set of priorities for mitigation and preparedness results.

The four key response aspects that a well prepared organisation should have in place are:

- a high level of awareness of all personnel of hazard issues
- appropriate mutual aid agreements in place
- a programme of mitigation and/or preparedness underway
- a comprehensive response plan

The work on response planning undertaken in Wellington has culminated in the holding of an Earthquake Response Exercise for all lifelines organisations in May 1996. This exercise [6] has given all of the participants a wider appreciation of the issues associated with response in an emergency.

In the process of planning this exercise, it became apparent that there was no practical mechanism for co-ordinating the response of lifelines at a regional level. A unique co-ordination mechanism was therefore created, and its effectiveness demonstrated in the exercise. A central feature of this mechanism is a Regional Lifelines Centre, which is a place where lifelines information can be co-ordinated, analysed and directed to where it is needed. Plans are underway for the establishment of a Regional Lifelines Centre for Wellington as a co-operative effort between emergency management agencies and the Wellington Earthquake Lifelines Group.

CRITICAL SUCCESS FACTORS

In analysing the developments and achievements in the field of lifelines engineering over the past decade, a number of critical success factors are apparent.

- ***The linkage between scientific and engineering interests and Emergency Management (Civil Defence) and insurance sectors.***

  With lifelines engineering being somewhat more an applied field than theoretical, a close linkage has been formed between engineers and scientists and emergency managers and the insurance industry respectively.

- ***Lifelines engineering has a practical face that the public can relate to***

  A key benefit of lifelines studies is the generation of a much clearer picture of what the real situation is likely to be following a major earthquake. This work is capturing the imagination of communities very effectively; people react to the thought of being without water or sewerage facilities for a week far more readily than the threat of being injured by a damaged building.

- ***Lifelines engineering has a practical face that politicians can relate to***

  In the same way as for the public, politicians are also more sensitive to the implications of utility failure. Ultimately they have a degree of accountability to the ratepaying public if a local authority is found after an event not to have taken appropriate steps to mitigate vulnerability.

- ***Lifelines engineering has a practical face that management of private sector organisations can relate to***

  Reduced disruption to utility services and also access has a clear benefit to managers of private sector organisations and insurers in terms of reduced business interruption.

- ***Technological developments***

  There have been a number of technological developments that have enhanced aspects of the lifelines engineering process during this period. The most significant of these is the increased availability of Geographic Information Systems (GIS) mapping software which has greatly facilitated the overlaying of infrastructure networks on seismic hazard maps. This very simple process remains one of the cornerstones of the lifelines engineering process.

The latter years of the decade in question have seen other favourable influences on lifelines activities. These include changes to the earthquake insurance scene in New Zealand and requirements for improved asset management at both local authority and private sector levels.

FUTURE DEVELOPMENTS AND NEEDS

Lifelines engineering is likely to become an even more integral part of the overall process of preparing the community to respond to disaster events.

It is anticipated that engineers and scientists will continue to work more closely with emergency management offices in the future. These agencies are accustomed to presenting technical information to the general public in a straightforward, clear and concise way.

Support for lifelines activities is becoming increasingly embodied in semi-statutory policy documents such as the *Earthquake and Geological Hazard Mitigation Strategy* produced by the Wellington Regional Council in 1996 [7].

The flip side however of the current success and expansion that lifelines engineering in New Zealand is experiencing is a range of co-ordination needs. The three prime considerations in this respect are:

(i) Procedures and Standards

As indicated above, the initial procedures for lifelines studies follow a generally established pattern, and advice along these lines for the new groups would minimise the extent of wheel re-invention. While assistance is freely provided by the established groups, there are no national guidelines or standardised procedures to be followed.

(ii) List of Contacts

There is a need to establish and maintain a reference directory of principal lifelines contacts in New Zealand, particularly with respect to the different disciplines involved within each group. Similarly, contact with international organisations and key people should be managed so as to ensure that firstly, the information that is obtained from overseas contacts is shared effectively around the New Zealand groups, and secondly that repetitive or overlapping requests are not made from New Zealand to these key contacts.

(iii) Funding

The history of lifelines work in New Zealand has seen a strong voluntary contribution by many of the people involved. With the changes in the workplace environment of many utility organisations in the past few years resulting in increased work pressures at all levels, less input of this kind can be depended on. There is also the associated question of the appropriateness of this work being done on such a basis. While the strong financial contribution by the Earthquake Commission and key national utility providers should be acknowledged, there is clearly a need for a more consistent and rational funding basis for the range of lifelines groups.

Consideration is being given to how these needs can be satisfied without creating unnecessary organisational structures.

Of considerable significance is the Emergency Services Review currently underway in New Zealand. This process, while aimed at rationalising and improving the process of emergency response and recovery, is attempting to take appropriate consideration of all steps, including that of hazard assessment. Those involved in this review have signalled their support for activities such as those undertaken by the lifelines groups being a central policy-led requirement for all regions to undertake. To this end, the objectives of the Emergency Services Review are supported by lifelines groups, as it will both facilitate hazard assessment on a national basis, and necessitate the application of consistent standards and approaches to the hazard assessment process.

Another need is for the establishment of a standardised approach for the economic justification of lifelines work. Previously projects could be undertaken essentially at the recommendation of the engineer in charge (in either the private or public sector context), based on his or her appreciation of the risk issues, implications of failure and cost of the project. However, irrespective of the nature of the organisation, projects involving either staff or physical resources are now typically subject to detailed economic analysis. This is one of the major changes through this decade, and has brought sharply into focus the need for a comprehensive and consistent approach to economic benefit-cost analyses appropriate to the various stages of lifelines projects. There are two levels at which benefits and costs need to be considered; firstly on a single organisation basis, and secondly on a multi-organisation basis extending to involve a community or region.

The Wellington Earthquake Lifelines Group has recently commenced a project to develop a universally applicable economic evaluation procedure.

CONCLUDING OBSERVATIONS

Lifelines engineering in New Zealand has made tremendous progress in the past decade, and equally important developments are anticipated.

The level of interest in lifelines engineering is currently very high, as evidenced by the recent establishment of a number of new groups around New Zealand. This expansion is likely to continue, for although the lifelines process follows a general pattern as outlined earlier in this paper, every area has its own set of lifelines systems in their unique geological and seismic setting.

The key to the success of lifelines work in New Zealand lies in its ability to portray the wider view of seismic risk. The main product of lifelines studies is the generation of a much clearer picture of what the real situation is likely to be following a major earthquake. A balanced but informed scenario is a fundamental tool in seeking community involvement.

Internationally, New Zealand's lifelines work is considered to be at the cutting edge. This is due to both the seriousness with which this work is taken at a local authority and corporate level, and the close technical co-operation between the various organisations involved which cuts across commercial aspects.

In the September 1990 workshop held as part of the CAE Wellington Case Study Project, the objective of the project was restated as *"Making the best possible use of available information and technology so that in, say, 20 years we can look back at money well spent on reducing the earthquake risk to lifelines"*. Based on progress made during this decade, there is every reason to believe that this objective will be comprehensively met.

ACKNOWLEDGEMENTS

The progress and achievements outlined in this paper have resulted from efforts made by a wide range of people, with much of this input being on a voluntary basis.

These efforts are gratefully acknowledged, as is the financial support provided by a number of loyal organisations.

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