

## RESEARCH REDUCES RISKS

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Presented at the Conference on  
INFORMATION NEEDS OF THE EARTHQUAKE INSURANCE INDUSTRY  
held in Christchurch, November 1989

### SUMMARY

The role of research in earthquake engineering is examined, particularly its contribution to reducing overall risk. Aspects of the built environment which are at risk are outlined, as an indication of worthwhile research areas. The importance of research in resolving the differing requirements of function, economy and safety is highlighted by reference to building design. Principal research areas in earthquake engineering are reviewed, and specific examples of the reduction of risk through research are given.

The overall reduction in damage to buildings with reducing age is graphically illustrated. Nevertheless, there is a need to continue to design and build in accordance with accepted and properly researched methods, and to develop effective ways of using information which is available.

### INTRODUCTION

The purpose of this paper is to outline some of the ways and areas in which earthquake engineering research is contributing to the general stock of knowledge as applied to the design of the built environment, particularly buildings. The coverage is not exhaustive but is intended to give a general appreciation of the wide range of research topics which lie behind the construction of functional, economical and acceptably safe buildings.

Buildings are the visible end result of an ongoing process of

- research
- development
- design
- construction

In its own way any building represents the tip of the overall iceberg of these four elements - what we see is a small part of the whole operation. We see construction taking place. We don't see design; we don't see manufacture; we don't see

materials development; or soils investigations; nor a large amount of basic and applied research into analysis, design, material properties and the like.

Research, development, design and construction each plays an equally important role in producing buildings which are economical, functional and represent an acceptable risk. Because they are not so visible, the roles of research and development are all too easily underrated.

To examine how research reduces risk, it is necessary to look more closely at what is at risk, and at the role of research in addressing these risks.

### WHAT IS AT RISK?

In earthquakes, a whole range of items large and small are at risk, which may be categorised under the following broad headings:

- risk to land stability
- risk to infrastructure
- risk to buildings
- risk to people and their livelihood

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Risk to Land Stability

These may vary from regional effects such as

- major changes in level over the countryside with resulting changes in drainage and run-off
- local effects such as landslips and ground rupture
- site specific effects such as the loss of support due to local soil failure

Risk to Infrastructure

Infrastructure includes many of the most vital systems which support community activities and include

- Roads/bridges
- Railways/bridges
- Airports
- Harbours
- Telecoms
- Postage and courier services
- Water
- Sewerage
- Power supply
- Radio/TV transmission
- Computer networks especially in industry and commerce

Risk to Buildings

This category covers the full range of building types including houses, apartments, offices, hospitals theatres and cinemas, grandstands and sports venues, public buildings, industrial buildings and so on. Each group carries its own consequence of failure. The risk may vary according to the height, shape, location and materials of construction. Buildings with 24 hour occupancy such as hospitals represent a higher risk than those occupied during the working day only. The consequences of an earthquake may range from minor damage to total destruction.

Risk to People

This may be subdivided into three main categories: physical injury, emotional and psychological effects, and the threat to general health. Physical injury can be brought about falling objects, building collapse, consequent fire, or even panic. Emotional effects will include immediate shock, concern for friends and relatives, loss of employment, loss of productivity, loss of routine, effects of separation and lack of communication.

Threats to health include the loss of potable water supply, food shortage, breakdown of sewerage systems and the spread of disease.

Many of these issues may appear to fall outside the general area of normal insurance but it is not hard to imagine how some effects may interact with others, particularly where people are affected. The return to 'normal' following a major earthquake could take some time, even if the workplace is undamaged.

This analysis of what is at risk suggests areas in which research may help to reduce

the overall impact of an earthquake. But how does research reduce risk?

THE ROLE OF RESEARCH

The role of research in reducing risks can be demonstrated by reference to building design. Firstly, on the most basic level, a building design needs to achieve three things:

- function
- safety
- economy

In the 1980's, the demands of function have become increasingly diverse and sophisticated. At the same time, the overall success of engineering designs through the years has pushed up public expectations of safety to near 100% levels. Furthermore, there has been an ever increasing pressure to meet programme deadlines and financial constraints. Indeed there are numerous examples of failures brought about by over-emphasis on these criteria, at the expense of technical quality in design and construction.

Even without changes in the functional requirements, the issues of safety and economy are pulling in opposite directions when it comes to risk. Generally, safety is greater when more material is used - stronger beams or columns. Economy is achieved by reducing the amount of material.

Research and development has a key role in resolving a practical balance between function, safety and economy. Without a continuing supply of up-to-date information, designers and contractors would find it impossible to resolve this balance satisfactorily, especially in the face of continuing changes in attitudes and expectations.

To further illustrate the point let us examine what holds a building up! Refer to Figure 1. The three sections of the chain are vital in providing support, and equally the links within each are vital in supporting the building as shown. There can be no missing links and furthermore no link should be significantly weaker than any other - attention must be paid to each link. There is no point in spending money and effort in reinforcing one link if it is already stronger than the weakest one. It is the weak links which must be strengthened. When the problem is illustrated in the form of Figure 1, this is a very simple concept to grasp. It is however not always as easy to see which are the weak links when dealing with reality. The exact composition of the chain is not so obvious. Weak links may not be conspicuous - but large earthquakes have a habit of finding them all too easily.

Research and development provides the means to strengthen the links in the chain and this will always be a continuing process. The clever part of course is to identify those most in need of strengthening at any particular time.

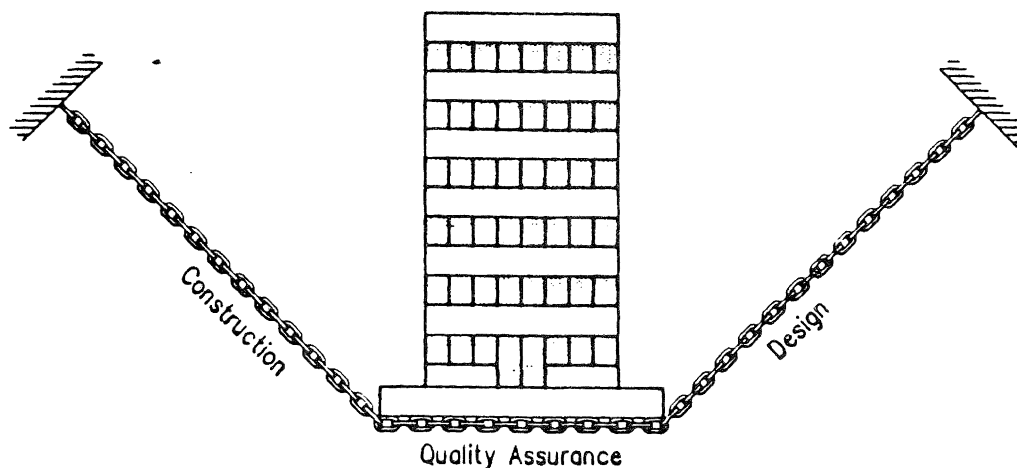


FIGURE 1 WHAT HOLDS A BUILDING UP

So what are some of the links in these chains?

In construction this includes:

- fabrication of materials and component parts
- assembly of parts to make sub-assemblies
- erection and assembly to form whole buildings
- knowledge of construction techniques
- development and use of appropriate construction tools.

In the design area these links include:

- knowledge of loads such as earthquake, wind, gravity and snow
- knowledge of foundation conditions
- knowledge of materials
- knowledge of analysis and design techniques
- knowledge of acceptable performance criteria.

Under the broad heading of quality assurance, the following links may be identified:

- codes of practice for design
- codes of practice and regulations for construction
- management of design and construction
- supervision of construction
- peer review and approval of design and construction proposals.

Without adequate knowledge and provisions in the above areas, the balance between safety and economy cannot be satisfactorily achieved. Research must continue to be applied to keep the chain intact - rust never sleeps!

#### RESEARCH AREAS IN EARTHQUAKE ENGINEERING

The principal research areas of 'earthquake engineering' may be categorised as follows:

- land stability
- site characteristics
- building structure characteristics
- non-structural elements
- machinery and equipment
- public utilities
- transport systems
- communication systems
- social factors

The diversity of the overall research effort required is evident from a closer look at each of these categories and at some of the research results which have been successfully applied in reducing risks.

A more detailed breakdown of these categories and a list of some of the research areas is included in Appendix 1. While many of the research areas have a clear and direct relevance to the design and construction of buildings to resist earthquakes, there are numerous others which are at first sight totally unrelated. However it is the results from this research which form the input into the ever changing jig saw puzzle of relevant knowledge. The challenge is to find and use the pieces as effectively as possible in day-to-day design and construction.

#### Land Stability

To start with a rather obscure example, the study of fossil magnetism played a significant part in developing the concepts of plate tectonics. The dating of fossils coupled with observed movement of land forms has enabled estimates to be made of the average movement of plates, and the frequency at which sudden earth movements have taken place in the past [1]. Sophisticated survey measurements now being carried out provide further evidence and opportunities for correlation and substantiation of information from other sources as to the rate of plate movement [2].

The understanding of the nature of earth-

quakes and the way in which the shock waves are propagated from the focus is increasing with the availability of more and more information on the geological background and on soil and rock characteristics. Developments in computer systems have not only brought more information to the attention of more researchers, but have allowed the development of techniques to review this vast array of information. Identifiable trends emerge. It is from considerations such as these that the occasional prediction of earthquakes comes. Researchers are constantly trying out new theories to see how they match recorded events. Each event inevitably throws up a new batch of data which does not fit. Nevertheless, as research continues, better and better information is becoming available, particularly in relation to the intensity of earthquakes. Over the last decade or so, this has allowed the application of some rational risk analysis to the effects of earthquake. For instance maps of earthquake probability for New Zealand have been developed and published, Figures 2 and 3 are maps of earthquake risk derived by Smith and Berryman [3]. It is important to realise however that these maps represent a best estimate of the long term situation. Nevertheless, they form a basis for assessing earthquake risk, where previously there was none.

#### Site Characteristics

A classic example of the benefit of research may be found by tracing the history of soil liquefaction under earthquake forces. In 1964 in Niigata, some large apartment buildings tilted dramatically due to loss of foundation support. Under the earthquake vibrations the underlying soils had liquefied, but structurally the buildings were intact. This catastrophe led to considerable research into soil liquefaction and the development of techniques to identify soils which were likely to liquefy in earthquakes. This in turn led to the development of measures to prevent soil liquefaction. Reduction in risk has resulted.

#### Building Structure Characteristics

A vast amount of research has been carried out in this area. This ranges from research into the nature of ground motion and how it is affected by particular site and foundation-conditions, right through to the ability of small components to resist the resulting forces and movements generated within the building. After all, the force comes from the ground into the building. However soils are notoriously different from one site to another and the

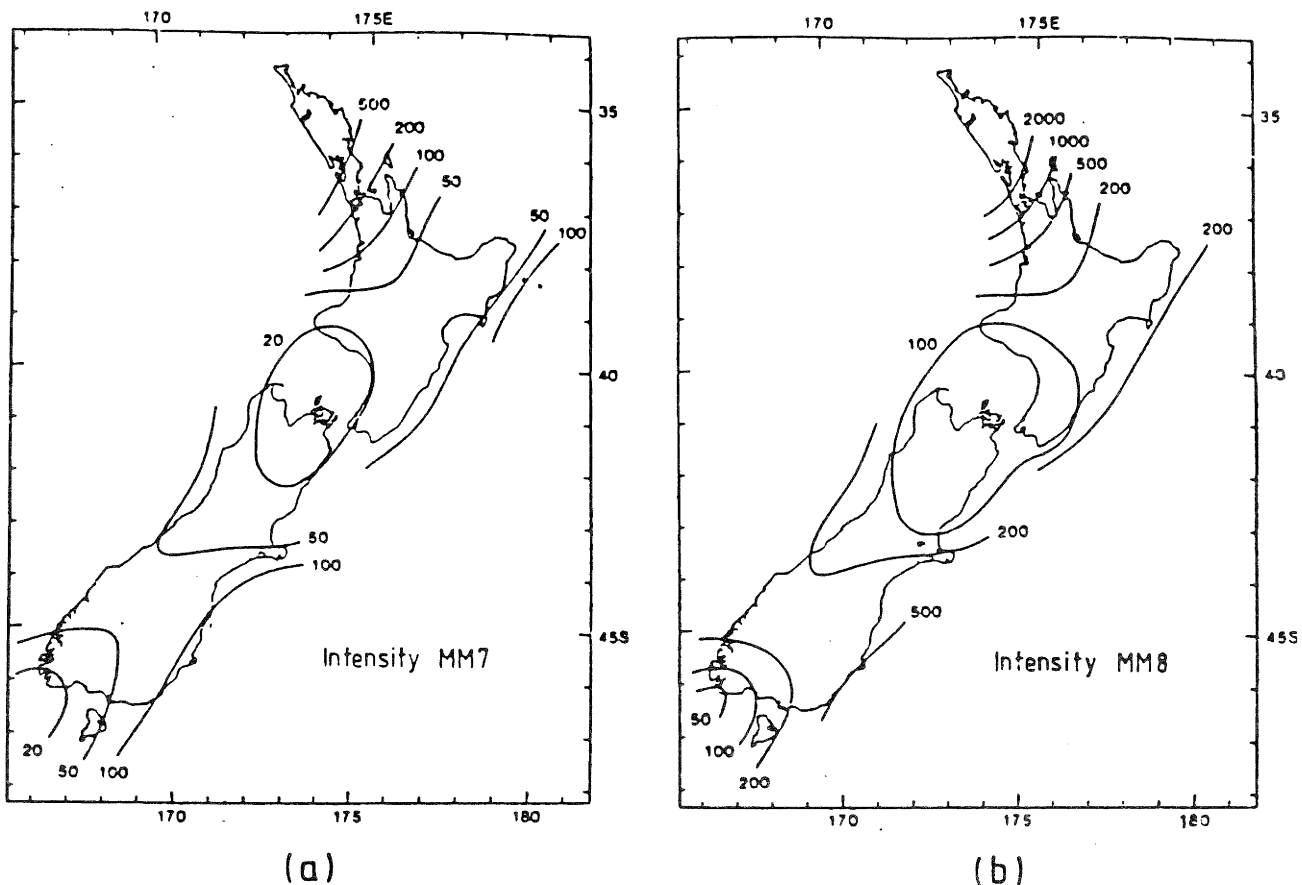


FIGURE 2 MEAN RETURN PERIODS (YEARS) [Reference 3]

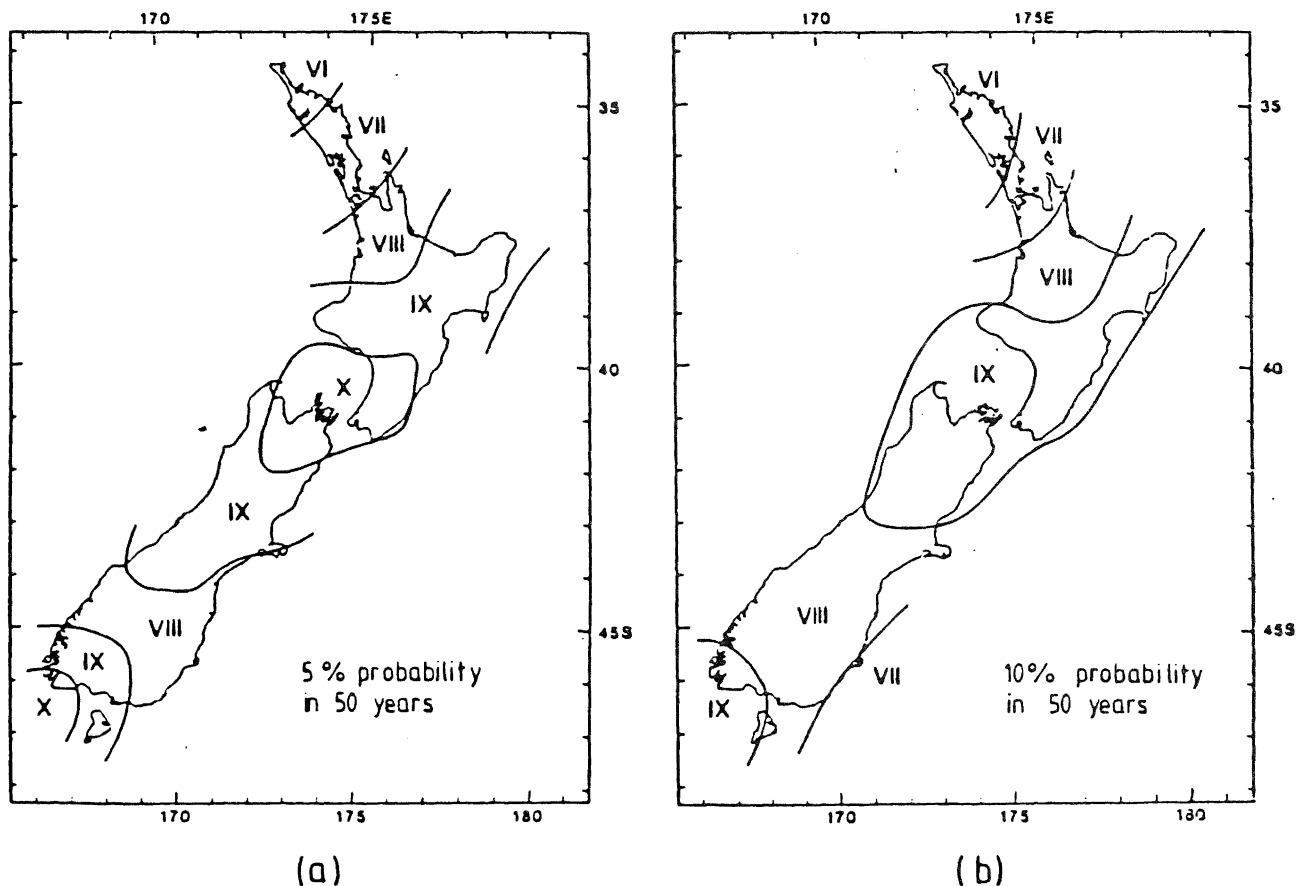


FIGURE 3 INTENSITIES WITH EQUAL PROBABILITY [Reference 3]

development of reliable criteria to take advantage of this possibility requires a great deal more research and development. The topic of soil/structure interaction is one which is frequently put in the "too difficult" drawer, and yet it may yield very large benefits, especially for existing buildings.

Meanwhile structural specialists have developed the ability to analyse just about every conceivable combination of materials and forms under a wide variety of possible ground movements due to earthquake. Again the availability of high-powered computers has enabled such sophisticated analyses to be carried out reasonably economically.

In spite of such comprehensive analyses, the basic earthquake input remains unpredictable and many basic assumptions must be made to allow analysis to be made. The most recent New Zealand structural codes have introduced the concept of capacity design, which is intended to produce a structure which is capable of dealing with just about any credible ground motion. The techniques involves proportioning the structure so that pre-selected elements will absorb the energy of the earthquake and leave other more vulnerable elements relatively intact. In New Zealand almost all major multi-storey frame buildings designed since 1976 have

incorporated the weak beam/strong column concept, a form of capacity design. This is intended to safeguard the integrity of the columns, and so avoid collapse. It is accepted that the structural damage to the beams may be such as to render them irreparable after a major earthquake. Development of this technique has grown out of wide ranging research into related issues including theoretical analysis and laboratory testing of full scale components. It has been possible with sophisticated analysis techniques to try out this design concept on mathematical models of buildings to verify that the design methods produce practical solutions which meet the overall objectives.

Recent developments have seen the production of large computer-driven shake tables capable of simulating actual earthquake motions. Larger and more realistic models of buildings are being tested on these machines, each test helping to develop better design approaches. In the past, structural designers have had little option but to design buildings with the best available knowledge and wait for a major earthquake to tell them whether their methods had succeeded. Now they are able to gain some confidence through the analysis and testing carried out by researchers.

One success story from Edgecumbe earthquake in 1987 [4] was the good behaviour of houses designed and constructed to NZS 3604, a code developed after considerable research into earthquake resistance. An illustration of progress on a broader front is shown in Figure 4. This shows a plot of estimated damage to buildings of different vintages in various levels of earthquake. Prior to 1935 in New Zealand, little or no account was taken of seismic requirements, and many unreinforced masonry buildings were built. After the 1931 Napier earthquake which claimed 256 lives, basic seismic requirements were introduced leading to steel framed and reinforced concrete buildings. These requirements were made more sophisticated in 1965 but it was not until 1976 that the concept of capacity design was introduced in conjunction with code provisions for the detailing of structural materials, especially reinforced concrete and steel. Code developments are the direct result of research and it is clear that progress is being made with passage of time. (Note that the % damage refers to a group of buildings nor to any one building in particular).

Values of damage ratios for groups of buildings have been used to estimate the maximum probable loss in Wellington [5]. This has been quoted as being up to NZ\$20 billion [6].

**Non-Structural Elements**

Recent earthquakes, including that in Edgecumbe in 1987 and Mexico in 1985 [7], highlighted the importance of dealing with non-structural elements in a thorough and logical manner. Contents of shelves were overthrown, ceilings fell out of their grid systems, partitions were racked, services were broken, causing considerable insured losses [8].

Falling objects from large buildings are a well known risk and much has been written about the potential for our main city streets to be covered with glass following a major earthquake. In fact the design of glazing systems to cater for earthquake motions has seen considerable advances in New Zealand over the last two decades. When a building frame sways there is a danger that the structure or the glazing frame will impose large forces on the glass panels and break them. From early

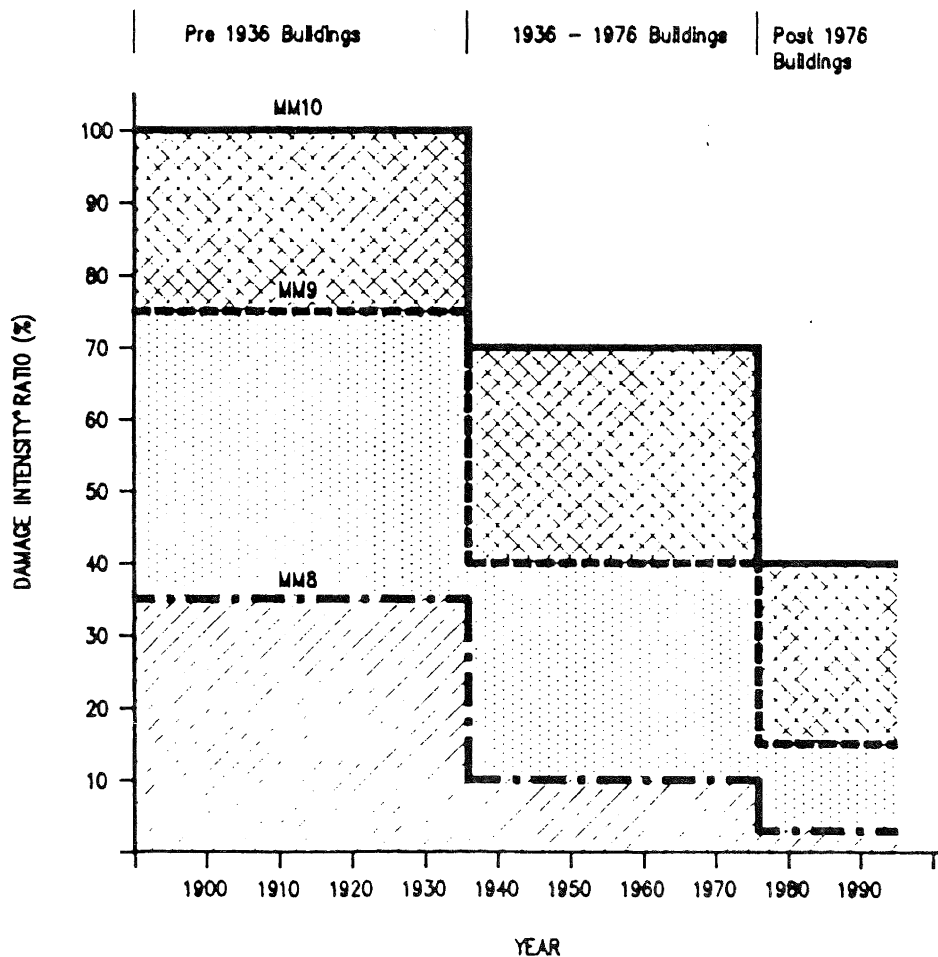


FIGURE 4 DAMAGE INTENSITY VERSUS AGE OF BUILDING

beginnings when special details were incorporated on design drawings to prevent the glass from coming into contact with the building, there has developed a wide appreciation of this need amongst glazing system manufacturers [9]. It is now possible in New Zealand to order "off the shelf" systems which will achieve the necessary separations. For this reason the behaviour of the glass covered buildings which have been popular in recent years is likely to be much better than many people imagine. The shower of glass to the street is more likely to come from buildings of an incorporated. This is another clear case where research and development has dramatically reduced risks. Even so our knowledge of the behaviour of such systems is not great - much more research is needed. In the last year two specially designed rest rigs have been built in New Zealand to test glazing assemblies under simulated earthquake action.

#### Equipment and Industrial Plant

The Edgecumbe earthquake of 1987 has brought home to the New Zealand insurance industry the tremendous impact that an earthquake can have on mechanical equipment and industrial plant. Quite apart from the cost of replacing the equipment and its enclosing buildings, a very considerable cost can result from loss of productivity. This subject would undoubtedly benefit from more analysis and research in order to identify and develop means by which these impacts can be minimised in a manner which balances the risk with the potential costs.

Edgecumbe also provided some good lessons on the techniques for coping with major damage and shutdown, and returning to production [10].

#### Public Utilities

There is a growing awareness that our systems of power distribution, water supply, gas supply and sewerage systems must be protected as far as possible from earthquake damage. This requires research into techniques which start from the basic planning of routes right through to details required to accommodate earthquake forces and movements.

Even so it is recognised that damage and shut-down in a major earthquake is inevitable. Hence a further research area opens up - that of techniques to deal with these breakages and restore services as quickly and as economically as possible. One project in this area is that sponsored by the Centre for Advanced Engineering at Canterbury University - it will examine the vulnerability of Wellington's services in earthquake.

#### Transport

All forms of transport are at risk to varying degrees. The breakdown of any one system could impact very seriously on the community and increasingly, earthquake prone regions are conducting research into ways of mitigating damage and of preparing contingency plans.

#### Communication Systems

Commerce and industry is becoming increasingly dependent upon sophisticated technology and communication systems. The potential losses due to breakdown or interruption of these systems due to earthquake are extremely high and have far reaching consequences. Comparatively little research has yet been done to investigate the vulnerability of these systems and to develop means of minimising the loss and of restoring them following an earthquake. However, there is a growing awareness amongst owners and operators of this problem and some have called for investigations and implementation of preventive measures.

#### Social Impact

Only a small amount of research has been carried out on the social impacts of earthquake. But interest in them is growing and information is starting to become available which in time will enable a closer estimation of the likely effects.

#### CONCLUSION

Advances in the understanding of earthquakes, their nature, risk of occurrence and effects on the built environment, are helping to provide a more rational basis for dealing with the consequences. Researchers have made good progress since Bertero [11] gave a comprehensive summary of research needs. Each earthquake brings with it a batch of surprises which reminds us all of how complex a subject is, and sends the researchers looking for new or revised answers. Over time, considerable progress has been made in reducing risks although it is usually difficult to identify particular research topics which contributed more than others. Given the scope and complexity of the subject, elimination of the unknowns and the surprises is going to take a very long time. Continuing research is needed to ensure that this valuable progress is maintained in reducing them.

To keep on reducing risk we must:

- design and build in accordance with accepted and researched methods
- continue to fund to research into all aspects according to their importance
- strive to maintain a consistent awareness of the threat of earthquakes and our approach to it. For example by providing incentives to owners who have taken the trouble to implement seismic resistant measures
- continue to develop effective ways of using the information which becomes available.

A fitting analogy is shown in Figure 5 - the iceberg of research, development, design and construction is vital for the safe support of our built environment. It must be continuously tended in a balanced manner to keep buildings upright and above water. It will take continued effort and co-operation from all concerned, to stop the iceberg from melting and breaking up.

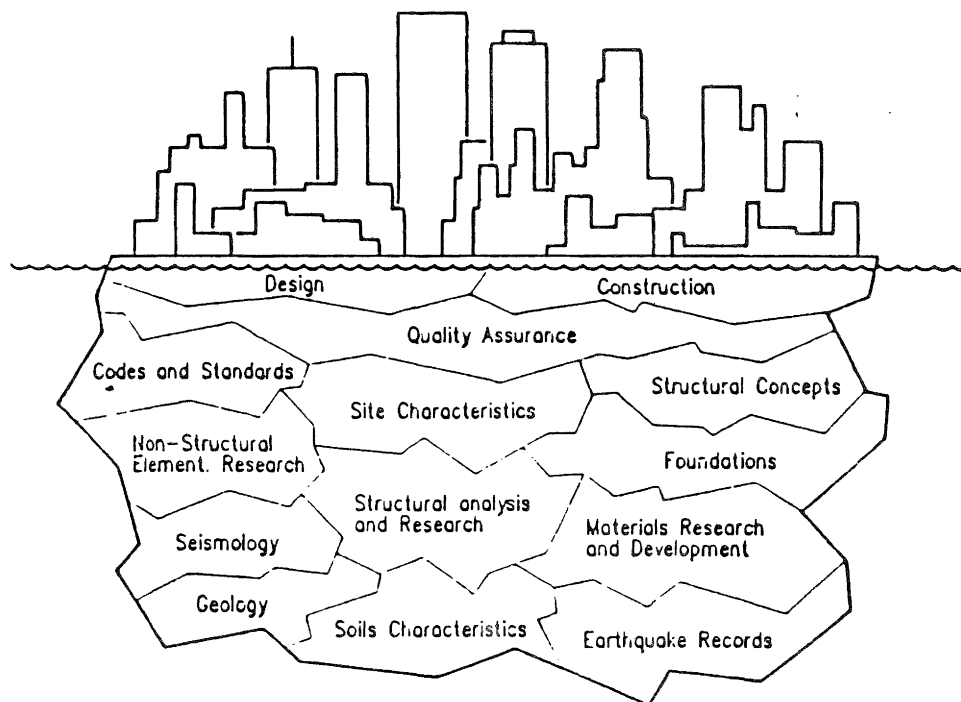


FIGURE 5 WHAT KEEPS OUR CITIES AFLOAT

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APPENDIX 1RESEARCH AREAS AND TOPICS

<u>Category</u>	<u>Examples of Topics</u>
1. Land Stability	Geological interpretation <ul style="list-style-type: none"> <li>- Fossils</li> <li>- Changes in land form</li> <li>- Fault movement &amp; characteristics</li> <li>- Rock and soil properties</li> <li>- Survey measurements</li> <li>- Plate tectonics</li> </ul>
	Seismological <ul style="list-style-type: none"> <li>- Measurement and recording of earthquakes</li> <li>- Wave propagation</li> <li>- Nature of fault rupture and movement</li> <li>- Influence of depth, soil and rock characteristics</li> </ul>
2. Site Characteristics	<ul style="list-style-type: none"> <li>- Nature of foundation soils</li> <li>- Influence of depth to basement rock</li> <li>- Liquefaction</li> <li>- Stability</li> <li>- Techniques for retaining ground</li> </ul>
3. Building Structure	<ul style="list-style-type: none"> <li>- Foundations</li> <li>- Soil/Structure Interaction</li> <li>- Materials Research and Development</li> <li>- Structural Concepts and details</li> <li>- Building response to earthquake</li> <li>- Acceptable performance criteria</li> <li>- Methods of Analysis and Design</li> <li>- Construction techniques and supervision</li> </ul>
4. 'Non-Structural' elements	<ul style="list-style-type: none"> <li>- Participation in structural action?</li> <li>- Glass, partitions, ceilings, precast cladding, contents, services</li> <li>- Separation from structures</li> <li>- Anchoring forces</li> </ul>
5. Equipment & Industrial Plant	<ul style="list-style-type: none"> <li>- Shut-down by earthquake trigger</li> <li>- Securing against forces</li> <li>- Protection of contents</li> <li>- Effects of disruption</li> </ul>
6. Utilities	<ul style="list-style-type: none"> <li>- Power Supply</li> <li>- Water Supply</li> <li>- Gas</li> <li>- Sewerage Systems</li> </ul>
7. Transport	<ul style="list-style-type: none"> <li>- Air - Airports, Radar network</li> <li>- Land - Roads, Railways, Bridges</li> <li>- Sea - Wharves, Port Access</li> </ul>
8. Communications	<ul style="list-style-type: none"> <li>- Telephone</li> <li>- Telefax</li> <li>- Computer Networks</li> <li>- Radio</li> <li>- Television</li> <li>- Satellite</li> </ul>
9. Social Impact	<ul style="list-style-type: none"> <li>- Preparedness</li> <li>- Post-disaster response</li> <li>- Civil Defence</li> <li>- Psychological impact</li> <li>- Disruption to production and routine.</li> </ul>