7 DISCUSSION AND CONCLUSIONS (T. JONES, G. FULFORD AND T. DHU)

7.1 Discussion

7.1.1 Earthquake Hazard

The earthquake hazard calculated for rock foundation in this study for the Newcastle and Lake Macquarie region is higher than the hazard suggested by the Australian earthquake loading standard, AS1170.4-1993. Our techniques to estimate hazard are an improvement over previous techniques used to estimate hazard in the Hunter region (e.g., Gaull et al., 1990). A detailed earthquake source zone model has been prepared that is based both on historical data and on expert opinion from structural geologists and seismologists. More than 10 years of new earthquake catalogue data was available since the assessment of Gaull et al. (1990). The attenuation relation for the decay of peak ground acceleration that was used in this study (Toro et al., 1997) gives similar results to the relation used by Gaull et al. (1990). The calculations were carried out to a much finer scale of resolution than, for example, Gaull et al. The new earthquake hazard results are presented for periods of vibration of 0.3 seconds and 1 second, in addition to peak ground acceleration. The hazard at other periods of vibration of interest can also be generated. However, in this study, considerable allowances were made for variability in the regional hazard model. These allowances will tend to increase the estimated hazard. Whilst we are confident that our methodology and input models are an improvement of the previous work included in the Australian earthquake loading standard, we believe that more testing is needed prior to these values being adopted.

The regolith site class model for Newcastle and Lake Macquarie also produces amplifications of earthquake ground shaking for all regolith sites ‘softer’ than weathered rock that are significantly higher than the specifications in the Australian earthquake loadings standard AS1170.4-1993. For example, for site classes D to H (Figure 4.9) the peak median ground shaking amplification factors range from 2.3 to 2.7 when considering a magnitude 5.5 event with a PGA of 0.25 g (Table 4-4). By contrast, the ‘site factor’ S in AS1170.4-1993 has a maximum value less than 2 for the soil types that compare best with these site classes. The amplification factors for site classes D to H peak at various periods of vibration in the range 0.3 to 1.1 s. These periods of vibration approximate the natural periods of vibration of almost all buildings in Newcastle and Lake Macquarie, and are the periods at which buildings will be most affected by earthquake shaking.

The site amplifications in this study were developed specifically for localised conditions in Newcastle and Lake Macquarie. By contrast, the amplification factors presented in AS1170.4-1993, by necessity, apply generally to all of Australia.

The site classes and period-dependent amplification factors could replace those in Table 2.4 (a) and Table 2.4 (b) of AS1170.4-1993 and the relevant parts of the successor to AS1170.4-1993. AS1170.4-1993 notes (p. 23) that:

> *‘For the purposes of this Standard, it is not intended that a detailed site investigation be carried out for any structure to determine a soil profile over large depths. Most major centres and regional areas have basic information available on the likely strata which should be used to assess the site factor (S).’*

Although the site class maps and related amplification factors produced in this study are generalised to local level and are not specific to an individual building nevertheless, in the absence of a ‘detailed site investigation’, they are an excellent guide to the dynamic properties of regolith in Newcastle and Lake Macquarie, and especially in Newcastle, where the research was mainly directed. The regolith site classes developed in this study are a valuable aid to developers and the two local governments.

7.1.2 Vulnerability of the Building Stock to Earthquakes

The predictions of damage and economic loss depend not only on the parameters that are used in the models, but also on the building inventory database that has been used. Geoscience Australia undertook a comprehensive field survey in order to document the characteristics of buildings in the study region that contribute to the building’s vulnerability during an earthquake. This survey obtained vital information on vulnerability parameters for more than 6,300 buildings in the study region. In addition to surveying a sample of the general building stock, an effort was made to survey all essential service facilities such as hospitals, and ambulance and fire stations. Extrapolations were made from this sample to generate a building inventory for the entire study area. Although we consider that the building inventory we have constructed is a good reflection of the composition of building construction types and usages in Newcastle and Lake Macquarie, differences between our inventory and the actual building stock will cause variations in the estimations of earthquake risk. Our building inventory is probably more accurate for Newcastle than for Lake Macquarie, especially southern and western Lake Macquarie.

The building vulnerability models used to calculate potential damage and losses in this study were developed specifically for Australian building types by structural engineering experts. These models cover 28 structural and 18 usage types of buildings found in Newcastle and Lake Macquarie. The models provide estimates of damage and loss for both the structural and usage types. However, they do not produce estimates of damage to specific structural and non structural sub-components, often related to masonry, such as parapets, gable ends and chimneys. The models also do not predict specific types of failure such as out of plane failure of masonry walls. For low rise structures the models do not differentiate between single storey, two storey or three storey structures.

The field survey team collected information on these sub-component attributes for all of the buildings surveyed. They also collected information on soft storey construction. Some researchers found that these attributes played a significant role in the damage from the 1989 earthquake (Chandler et al., 1991; Murphy and Stewart, 1993). For example, Chandler et al. (1991) found that, in the parts of Newcastle with some of the highest damage, damage to masonry and timber frame structures with two or more storeys was approximately double that for single storey structures.

7.1.3 Earthquake Risk

In this report we have mainly used annualised loss as a measure of risk. This measure of risk is useful as it allows the reader to compare the risk from earthquakes against the risks from many other hazards, both natural and otherwise, that can impact on the community. Other indicators of risk, such as the probability of occurrence and consequence of catastrophic events, are also of interest to communities, politicians, emergency managers and the insurance and reinsurance industries.

The majority of the earthquake risk in the study region is from events that have annual probabilities of occurrence in the range of 0.02 to 0.001. These events have equivalent return periods of 50 to 1,000 years (Table 7-1). The information in this table is derived from Figure 6.8. This suggests that the risk to the region is primarily from relatively infrequent events with low or moderate impacts.

In contrast, very frequent earthquake events, with return periods of 50 years or less, will have low impacts, and consequently they pose little risk to Newcastle and Lake Macquarie. They contribute approximately 15% of the total annualised risk under the model assumptions. The ground shaking levels generated in Newcastle and Lake Macquarie by these events will be mild, and the consequent degree of simulated damage is slight. In real earthquake scenarios with these levels of ground shaking, the restoration cost per building may be of the order of hundreds of dollars or less, and many building owners may not make insurance claims to recover costs. For relatively frequent events such as these, and depending on the insurance deductibles, insured losses are expected to be significantly less than the total damage losses.

Events with return periods of less than 500 years comprise about two thirds of all annualised risk. This return period approximates the return period for loadings for normal buildings in the Australian earthquake loading standard. Events with return periods of less than 1,000 years contribute around 77% of the total annualised risk.

Very high impact events can also occur in the region. However, because these events are rare they only contribute relatively small amounts to the annualised risk to Newcastle and Lake Macquarie. For example, events with impacts at least as severe as the Newcastle 1989 event only contribute about 18% of the total annualised risk. These events have return periods of greater than 1,500 years, and their impacts will be greater than 7.2% of the total value of all the building stock, including contents. Note that these events, with return periods greater than 1,500 years, have a greater than 6% probability of occurring in any 100 year period.

Table 7-1: Percentage of total annualised risk against maximum return period considered. Annualised risk is a percentage of the total value of the building stock and contents. The percentage of the total annualised risk increases as events with increasing return periods are considered

Maximum return period considered (yr)	Annualised risk (%)	Percentage of total annualised risk
10	< 0.001	< 1
50	0.006	15
100	0.013	30
500	0.029	66
1,000	0.033	77
2,500	0.038	87
5,000	0.040	92
> 100,000	0.043	100

The average annualised losses are estimated to be approximately 0.04% or $11 million per year. For an ‘average’ residential building and contents of value $250,000, this annualised loss equates to a figure of approximately $100 per year.

If this ‘average’ building is considered to have a nominal 50 year lifespan, then in its lifetime it is expected to suffer losses of approximately $5,000 in today’s dollars. However, many buildings in Newcastle are at least 100 years old or are expected to reach this age. An ‘average’ $250,000 residential building and contents with a nominal 100 year lifetime is expected to suffer losses approaching $10,000, in today’s dollars, in its lifetime.

Although the annualised risk figures may suggest otherwise, the buildings and people in the study area are unlikely to experience a significantly damaging event in their lifetime. For example, in a 100-year period, events with a return period of 100 years or longer have approximately a 63% chance of occurring (see Chapter 2). The loss for an ‘average’ building from an event with a 100 year return period or greater is approximately 1% of the building and contents value. This percentage is equivalent to a loss of approximately $2,500 for a nominal value of $250,000 for building and contents. This sum may seem an acceptable loss in a 100-year lifetime of a house.

More severe events are much less likely to occur in a nominal 100-year ‘lifetime’. For example, the impact on an ‘average’ residential building from events with return periods of 1,000 years or greater is approximately 5.7% of the total value, or $14,250 for the same ‘average’ residential building and contents. This sum would appear far less acceptable. However, events with impacts with return periods of 1,000 years or greater have only about a 9.5% chance of occurring in a period of 100 years.

The gulf between relatively small amounts of annualised risk, and realisation of that risk in single, rare, events, points out a problem with managing the risk from earthquakes in Newcastle and Lake Macquarie, and in other parts of Australia. The argument also applies to other, intraplate, areas of the world that have similar rates of seismicity to Australia.

The annualised risk may not be realised for many years, not even in the lifetime of many structures and most people. Thus, it is possible for politicians, emergency managers, the finance industry, business owners and householders to be complacent about earthquake risk. There is a good chance that they will not suffer from this assumption. However, even extremely rare, catastrophic events do have a chance of occurring at any time Although this issue is clearly of importance to the insurance and reinsurance industries, it may be less well recognised by the broader community.

Annualised risk varies considerably across Newcastle and Lake Macquarie. It depends strongly on the nature of the underlying regolith. In general, areas that are built on substantial thicknesses of geological sediments having noticeably higher annualised losses than other areas. The annual risk also depends on the building construction types, building usages and total floor areas in local areas. Figure 6.11 shows the annualised risk by suburb.

The suburbs most at risk in Newcastle and Lake Macquarie are shown in Table 7-2 and Table 7-3 respectively. The annualised risk in Table 7-2 and Table 7-3 is expressed as a percentage of the total value of buildings and contents in the suburb. Nine of the ten Newcastle suburbs considered most at risk are situated entirely on the geological sediments near the Hunter River (Figure 6.11). ***The reader should note the many variabilities and uncertainties inherent in the models used to calculate these results (see Chapter 4 and Chapter 6).***.

Lake Macquarie suburbs Estelville, Redhead, Dora Creek, Killingworth, Holmesville, and Toronto also had high estimates of annualised risk, but the results are less reliable for these suburbs because field survey rates were low, and the regolith site modelling in Lake Macquarie is inferior to that in Newcastle.

The annualised risk also varies with building construction type. Brick buildings are estimated to have higher average risks per building than other construction types. Brick veneer buildings and unreinforced masonry buildings have similar average risks per building. Timber frame buildings with timber or fibro wall cladding are estimated to have annualised risks slightly less than half of the risks for brick structures, when considered as a percentage of the value of the building.

Table 7-2: Suburbs most at risk in Newcastle

Newcastle Suburb	Annualised risk (% of value of buildings and contents)
Hamilton South	0.09
The Junction	0.08
Hamilton East	0.08
Carrington	0.08
Stockton	0.08
Hamilton North	0.07
Broadmeadow	0.07
Hamilton	0.07
Warabrook	0.06
Islington	0.06
Wickham	0.06
Maryville	0.06

Table 7-3: Suburbs most at risk in Lake Macquarie

Lake Macquarie Suburb	Annualised loss (% of value of buildings and contents)
Belmont South	0.12
Pelican	0.11
Marks Point	0.10
Blacksmiths	0.08
Caves Beach	0.07
Swansea	0.07
Teralba	0.06

The vulnerability model used for masonry was designed for new masonry compliant with the earthquake loadings standard (engineers workshop, AS1170.4-1993). However, there is plentiful evidence from the 1989 Newcastle earthquake that many masonry buildings did not perform to the expected standards of AS1170.4-1993 because of weak lime mortars, corroded or absent wall ties, and poor restraint of details such as parapets (Page, 1992; Melchers and Page, 1992). Thus, the vulnerability model we have used for unreinforced masonry structures may significantly underestimate the risk to some masonry structures, especially old masonry structures.

The spatial distribution of damage in the simulations of the 1989 earthquake and the estimates of annualised risk would be affected by such variability in the model. Suburbs with significant numbers of masonry buildings, especially old masonry buildings, may have unexpectedly low estimates of annualised risk in relation to other suburbs. Newcastle, Newcastle East and Newcastle West may be three such suburbs.

Our models show that dwellings including houses, hotels/motels and mobile homes have a higher annualised risk than buildings used for retail trade, professional offices, hospitals, medical offices and clinics, heavy and light industrial buildings, government buildings, schools and university buildings in Newcastle and Lake Macquarie. In this context, annualised risk is measured as a percentage loss of all buildings of a particular usage type in Newcastle and Lake Macquarie. The results may not accurately reflect the relative annualised risks to individual buildings.

The following question arises from an analysis of the annualised risk to suburbs in Newcastle. If 11 out of the top 12 suburbs most at risk in Newcastle are located on significant amounts of regolith, why do adjacent suburbs have significantly less annual risk? The suburbs in question are Newcastle West and Cooks Hill, and they are also situated on this regolith. The answer may lie in building usages and in the construction types of the buildings. For example, both of these suburbs contains a relatively high proportion of non-residential buildings that, according to the models, have lower annualised risks than most dwelling types.

The risks of death and serious injury are small. However, the acceptance of death or severe injury due to rare disasters such as earthquakes appears to be lower than the acceptance of more common causes of casualties such as heart disease and vehicle accidents.

7.1.4 Effect of Variability on Results

It should be emphasised that a great deal of variability was included in the models used to generate these results. To some degree this variability was incorporated to account for our lack of knowledge about the various models used in the study. A detailed description of how natural variability has been incorporated into this study can be found in Chapter 4 and Chapter 6.

The effect of high levels of variability is to increase the estimates of risk. Future studies on the earthquake risk in the region should focus on improving the models that have been used. This will allow for the variability in the models to be decreased, which will most probably result in a decrease in the estimated risk.

7.2 Conclusions

We emphasise that this report should be regarded as the best and most recent assessment of earthquake risk in Newcastle and Lake Macquarie. However, we acknowledge that there are limitations in the models and data we have used, and that we have an incomplete understanding of the natural variability inherent in ground shaking and building response.

The results, interpretations and conclusions could change with the incorporation of new data and with different model assumptions.

Therefore, the reader should not take action based on information in this report alone.

Our conclusions from this study are:

- The calculated earthquake hazard in the Newcastle and Lake Macquarie region is higher than the hazard suggested by the Australian earthquake loading standard, AS1170.4-1993;
- The regolith in the study region causes a significant increase in the earthquake hazard, and differences in the regolith thickness can cause quite dramatic variations in the hazard and risk across the study region;
- The annualised loss for the study region is of the order of 0.04% or $11 million per year;

- The majority of the annualised earthquake risk in the study region is from events that have annual probabilities of occurrence in the range of 0.02 to 0.001 (return periods of 50 - 1,000 years);
- Brick veneer buildings contribute about half of the total risk. This is partly because they comprise a large proportion of buildings in Newcastle and Lake Macquarie. Timber frame buildings with timber, fibro and other light wall claddings contribute approximately one-quarter of the risk. A further one-sixth of the risk is contributed by unreinforced masonry buildings;
- Damage to residential buildings contributes the vast majority of the risk (approximately 91%). This is largely because residential buildings comprise the vast majority of all buildings in Newcastle and Lake Macquarie;
- The 1989 Newcastle earthquake had an economic impact with a return period of the order of 1,500 years. According to our models, approximately 82% of all annualised risk in Newcastle and Lake Macquarie is due to events with lesser economic impacts than the 1989 earthquake. Thus, events like the 1989 earthquake, or even more catastrophic events, make only a small contribution to the earthquake risk in the region when considered on an annualised basis. However, rare but catastrophic events are very important to emergency managers and the insurance and reinsurance industries;
- Annualised risk varies considerably across Newcastle and Lake Macquarie. It depends on the nature of the underlying regolith, the composition of the building stock and building usage in particular areas. Our results suggest that the suburbs most at risk in Newcastle, determined by a percentage of the total value of buildings and contents in the suburb, are Broadmeadow, Carrington, Hamilton, Hamilton East, Hamilton North, Hamilton South, Islington , Maryville, Stockton, The Junction, Warabrook and Wickham. In Lake Macquarie the suburbs most at risk are Belmont South, Blacksmiths, Caves Beach, Marks Point, Pelican, Swansea and Teralba. Further research into the building parameters for unreinforced masonry construction types may change these conclusions, especially in older suburbs such as Newcastle, Newcastle East, Newcastle West and Cooks Hill. Other Lake Macquarie suburbs such as Cooranbong, Dora Creek, Estelville, Fassifern, Holmesville, Killingworth, Redhead, Toronto and Warners Bay also had high annualised risk in our results, but the results are less reliable because survey rates were low in these suburbs, and the regolith site modelling is inferior to that in Newcastle;
- Over half of the earthquake risk is from moderate-magnitude earthquakes, with moment magnitudes around 5, that occur less than 30 km from the study area. This conclusion has implications for emergency management in the lower Hunter. It may be appropriate to prepare for the possible impacts of such events rather than on catastrophic events that have an extremely small probability of occurring;
- In general, the risk of casualties from earthquakes is low. However, we do not rule out the possibility that casualties in future events could be caused by damage to a single building, or a small number of buildings. It is extremely unlikely that any event capable of causing widespread casualties will occur in the study region;
- The results also have implications for the earthquake risk facing larger Australian cities such as Sydney, Melbourne and Adelaide. This is due to a number of factors, including similarities between the earthquake hazard in Newcastle and Lake Macquarie and other parts of Australia, and similarities between the urban environments, particularly the composition of the building stock;
- The earthquake risk to Newcastle and Lake Macquarie may be reduced gradually over time by improved building construction practices, attrition of vulnerable building stock such as unreinforced masonry, and by reducing vulnerability of existing buildings through renovations constructed to modern code standards;
- Good building practice may be the single, most important, long-term factor in reducing economic losses and casualties from earthquakes in Newcastle and Lake Macquarie.

7.3 Suggested Mitigation Options

- Newcastle City Council and Lake Macquarie City Council should consider adopting the site class maps and the associated, period-dependent median amplification factors in their land planning regulations. The amplification factors could replace the site factor S in AS1170.4-1993 in determining earthquake loadings for structures in Newcastle and Lake Macquarie. The amplification factors that refer to a peak ground acceleration on rock of 0.25 g from a magnitude 5.5 earthquake (Table 4-4) are appropriate, for normal structures, for earthquake loadings with a 10% probability of occurrence in 50 years.

- Enforce the compliance of all new structures with current earthquake loading standards. Two important areas where improvements could be made are in ensuring that mortar quality and wall tie placement and specifications comply with code specifications.
- Provide adequate insurance against earthquakes. Householders, small business operators and corporations should ensure that their earthquake insurance is adequate. The cost of repair or replacement of heritage buildings can be significantly higher than the corresponding costs for modern buildings and so there is potential for heritage buildings to be underinsured to a greater extent than other buildings.
- Protect facilities such as police, fire and ambulance stations and hospitals, which provide essential services following any earthquake event. These facilities could be examined by suitably qualified engineers on a site-by-site basis to assess their performance under earthquake loadings. The survey of essential facilities carried out during this study found that many of these facilities were built on regolith site classes that dramatically increased earthquake hazard and/or were of vulnerable construction types.
- Review earthquake loading standards. In this study, certain levels of building damage were estimated as a result of certain levels of ground shaking. The levels of damage may be more or less than what engineers would have expected from the input ground motions. If the damage predicted by the models is higher than would have been expected by expert engineers, then design standards may need to be made more rigorous. The damage models need to be rigorous for this review of design standards to be meaningful.
- Collect future post disaster damage, economic, social and insured loss data in a systematic, pre-planned way with a high degree of detail and accuracy so that risk assessments will be improved and the amount of variability reduced.
- Collect information on building parameters that contribute to vulnerability to earthquakes on a systematic basis and maintain databases containing this information. This need not be a tedious task if it is combined with similar related information gathering as for example through development approval processes. The information may also be useful for other purposes, for example, as estimating the vulnerability of the community to other hazards such as fire and wind, and would be valuable to the insurance industry. This long term strategy would assist risk assessments and risk management in the future.

7.4 Future Directions for Earthquake Risk Assessment

Many improvements and additions can be made to improve the techniques used in this study. Improvement can be made through new scientific, engineering and socio-economic research, by expanding the scope of the risk assessment to capture other sources of risk outside of what has been assessed so far, and by collecting, compiling and assessing new information to assist these initiatives. Chapters 4 and 6 each contain a discussion of the sources of earthquake hazard and risk variability.

Some important measures to improve earthquake risk assessment in Newcastle and Lake Macquarie are suggested below. The list is not comprehensive.

In this study, we have assessed direct economic losses due to building damage. Our study has not addressed the direct losses from business interruption or the indirect losses to other communities resulting from earthquakes in Newcastle and Lake Macquarie. An assessment of these losses would give a more complete estimate of the total risk due to earthquakes in Newcastle and Lake Macquarie.

The importance of the impacts of earthquakes on ‘lifelines’ such as electric power and water supply needs to be investigated. In Chapter 5, a preliminary analysis was undertaken of the exposure of sewer and water facilities due to their location on the various regolith site classes. Further investigation is required to assess the risk to lifelines in Newcastle and Lake Macquarie. This investigation needs to address the impact that earthquakes could have on lifeline function, as well as the consequent impact on the broader community due to impaired lifeline functioning.

The socio-economic implications of earthquake impacts on Newcastle and Lake Macquarie also need to be assessed. In the first instance, the simplest socio-economic vulnerability models would relate structural damage to the impact on all community activities and the time taken to restore the community to its normal state. Geoscience Australia has assembled some relevant information that could assist such investigations in future, and is working to develop socio-economic loss models for natural hazards.

The methodology used in the modelling approach is a significant improvement over previously published earthquake risk assessment models applied to Australia. However, Geoscience Australia’s model will benefit from further validation, which will need to be carried out with the support and cooperation of others.

The engineering vulnerability models need to be checked, modified and produced as necessary to make them appropriate for Australian building stock. This requires a long-term, engineering research effort. Models for some construction types including timber frame buildings were developed by GA and structural engineering experts based on Australian design and construction practice were used in this study. Models for other building types such as some steel frame buildings have been adopted without alteration from US models. The efforts to improve the models should concentrate on the construction types that are the most important contributors to risk, as they have done so far. For Newcastle and Lake Macquarie, these are timber frame structures (especially brick veneer structures) and unreinforced masonry structures. Details such as tile or steel roof, masonry gable ends, parapets and chimneys, number of storeys in low rise buildings, soft storey, are important components of the vulnerability models. Other structural types may be important because, even though they are relatively few in number in the study area, such buildings may be classified as ‘important’ buildings or house essential services. Concrete frame buildings are one example of such building construction types.

Part of the assessment process for the building vulnerability models is to examine the degrees of structural, non-structural and contents damage, and economic losses, that are predicted by the models for certain levels of input ground shaking. The vulnerability and economic loss models need to be further reviewed by the structural engineering community to improve confidence in the results produced by them. For example, upon further analysis, the results of our modelling may show that significant simulated economic losses are due to acceleration effects rather than lateral displacements. These outcomes should be compared with the expectations of the structural engineering community and the model parameters adjusted if necessary.

The degree of damage and economic loss predicted by the models can be used to assess the appropriateness of earthquake loading standard specifications. For example, is the economic loss predicted by ground shaking with a 10% probability of occurrence in 50 years acceptable to the loading committee, the insurance and construction industries, and to government?

Sensitivity tests should be run by varying parameter values in the models to give alternative estimates of risk. The results may point to areas where efforts should be made to improve the models or collect new data. Reduced variability in the models will lead to more accurate and reliable estimates of risk.

Assessments of future risk based on projections of changes in building stock and demographics would be valuable to the assist decisions on the development of Newcastle and Lake Macquarie. A cost/benefit analysis of the effectiveness of introducing various mitigation measures would also assist the rational development of the cities. Assessments of future risk, and cost/benefit analyses, would be aided by masonry vulnerability models that accounted for building condition.

7.5 Final Remarks

Geoscience Australia is actively developing new techniques and revising its methodologies. Other workers in planning, emergency management, engineering, the insurance industry, the utility corporations, sociology and the finance industry are also putting increasing efforts into risk management for natural hazards including earthquakes. It is our hope that this study will assist these workers, the people of Newcastle and Lake Macquarie, and the broader Australian community, in reducing earthquake risk.

As a final note it should be remembered that, in the aftermath of the 1989 earthquake, there were many studies and recommendations on what should be done to mitigate the effects of future earthquakes. However, thirteen years on, few of the recommendations have been implemented. We urge the relevant authorities to review the recommendations made in this report and previous reports such as that conducted by the Institution of Engineers (Melchers, 1990) and to take appropriate action, so that ultimately we will have safer and more prosperous communities.