13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2625

Improving the Performance of Existing Buildings in Earthquake Proposed Legislation in New Zealand

DAVID C HOPKINS [1] AND GEORGE F STUART [2]*

SUMMARY

Legislation introduced in 2003 will extend the definition of earthquake prone buildings to cover all existing buildings, except small residential buildings. Studies of cost and benefit were used to support the introduction of legislation and in determining trigger levels for strengthening. Four groups of buildings were examined in 32 cities and towns in New Zealand. Relationships between shaking intensity and damage/loss were used to estimate the benefit of improving structural performance. Values of benefit to cost (B/C) ratio ranged up to 6 but varied considerably around the country. Issues involved in obtaining community commitment to mitigation measures are then discussed.

INTRODUCTION

Since 1968 New Zealand has had legislation requiring owners of buildings made of un-reinforced masonry (brick) to strengthen or demolish them if they fail to meet minimum standards. These standards are roughly equivalent to 20% of that for new buildings, and refer to buildings generally built before 1935 when earthquake requirements were first introduced. In the 35 years since legislation was introduced, progress by various local authorities has been mixed, but, for example, in Wellington, 500 out of a total of 700 buildings have been strengthened or demolished.

Over the last two decades concern has grown amongst New Zealand structural and earthquake engineers that provisions should be extended to cover all buildings, particularly those built prior to 1976 (when capacity design and full detailing for ductility were introduced). Over the last decade the situation has been examined by a Study Group of the New Zealand Society for Earthquake Engineering (NZSEE), supported by the Building Industry Authority. This has seen the development of Guidelines for the Assessment and Improvement of the Structural Performance of Buildings in Earthquake by NZSEE [1]

1. Director, David Hopkins Consulting Limited, Wellington, New Zealand. dhcl@xtra.co.nz

2. Director, Future Impact Limited, Wellington, New Zealand. George@futureimpact.co.nz

and of proposed legislation to require owners of all buildings (except small residential buildings) to improve the structural performance of the building if it falls below a certain percentage of the standard for new buildings (i.e trigger level). The trigger level will be set by regulation, thus allowing more flexibility of application - it will not be necessary to change an Act of Parliament in order to make a change to the trigger level at some time in the future. The NZSEE has recommended that a trigger level of 33% be used. This would target only the worst cases since the 33% trigger level represents about 10 to 20 times the risk involved in a new building. Opinion is divided on the suitability of this value. Some consider it is too high, others consider it is too low. The prevailing NZSEE view was that insistence on a higher level could result in the legislation not being passed, while to reduce it would result in unacceptably slow progress on mitigation.

The NZSEE Guidelines allow for each local authority to set its own approach (active or passive) and timetables for requiring action, indicating typical time frames of around 20 years.

The Guidelines also introduce a recommended Grading Scheme for classifying all buildings according to their assessed performance in earthquake. This is intended to increase awareness of earthquake risk in the community, and to allow market forces to play a part in earthquake risk reduction over time. Owners of low grade buildings will be forced to upgrade if revenues or values fall as a result of market response to earthquake risk.

Legislation was introduced in 2003 and is expected to be passed into law in late 2004. This will require local authorities to identify and take action on buildings falling below the defined trigger level.

Thus the New Zealand approach will be a combination of:

- A grading scheme that allows market forces to drive the pace of retrofitting for most buildings,

  underpinned by

- Legislation requiring buildings of high risk to be strengthened or demolished within a specified time.

A number of background investigations were made to support the case for introduction of the legislation. Amongst these was a study of the cost-benefit of improving structural performance (retrofitting). The description of this study and its key results forms the bulk of this paper. The study used annual probability of earthquake shaking of various levels to estimate the value of benefits over a defined time period, from which benefit/cost ratios were computed.

The use of annual probability as basis is open to question as the most suitable basis on which to assess benefit-to-cost ratios. Nevertheless, the study provided insights into the effect of a wide range of variables on the benefits, or otherwise, of retrofitting.

COST-BENEFIT STUDY

Objective

The objective of the project was to extend previous work on cost benefit analysis by NZSEE [2] to cover locations around New Zealand, different building types and four different legislation regimes.

Four groups of buildings (Pre-1935, 1935-65, 1965-76 and post-1976) were examined in 32 cities and towns in New Zealand. The building groups selected relate to the dates of significant changes in New Zealand's code requirements for earthquake performance. Relationships between shaking intensity and damage/loss were used to estimate the benefit of improving structural performance. Benefits included reduced physical damage, injuries, fatalities, business interruption and social disruption.

Four possible trigger levels were considered: status quo, 33%, 67% and 100% of new building standard. Estimates were made of the net present value of costs of retrofitting and of benefits for each of the 32 locations, for each building group and for each trigger level. The specially developed systems dynamics model for the analysis was used to examine the effects of variables such as discount rate, depletion of building stock with time, retrofit period, and factors governing business interruption and social disruption. Output focused on the costs and benefits for each building group in each location and under each legislation regime, and the resulting benefit to cost ratios.

Model Development and Key Data

The approach used to calculate the cost, benefit and benefit/cost ratios for the range of variables was conceived specially for this application. Table 1 shows key data used for the prototype development, indicates the nature of the model and the way in which the variables were used to compute the benefits and costs of performance improvement.
Development of the mathematical model was based on the *"ithink"* software which enabled calculation of values of all variables at successive time intervals. It was thus possible to track the costs, benefits and benefit/cost ratio at every time interval over any nominated period.
Figure 1 shows the home panel of the model, indicating how the variables may be altered for any run. It also shows a sample output in tabular and graphical form.

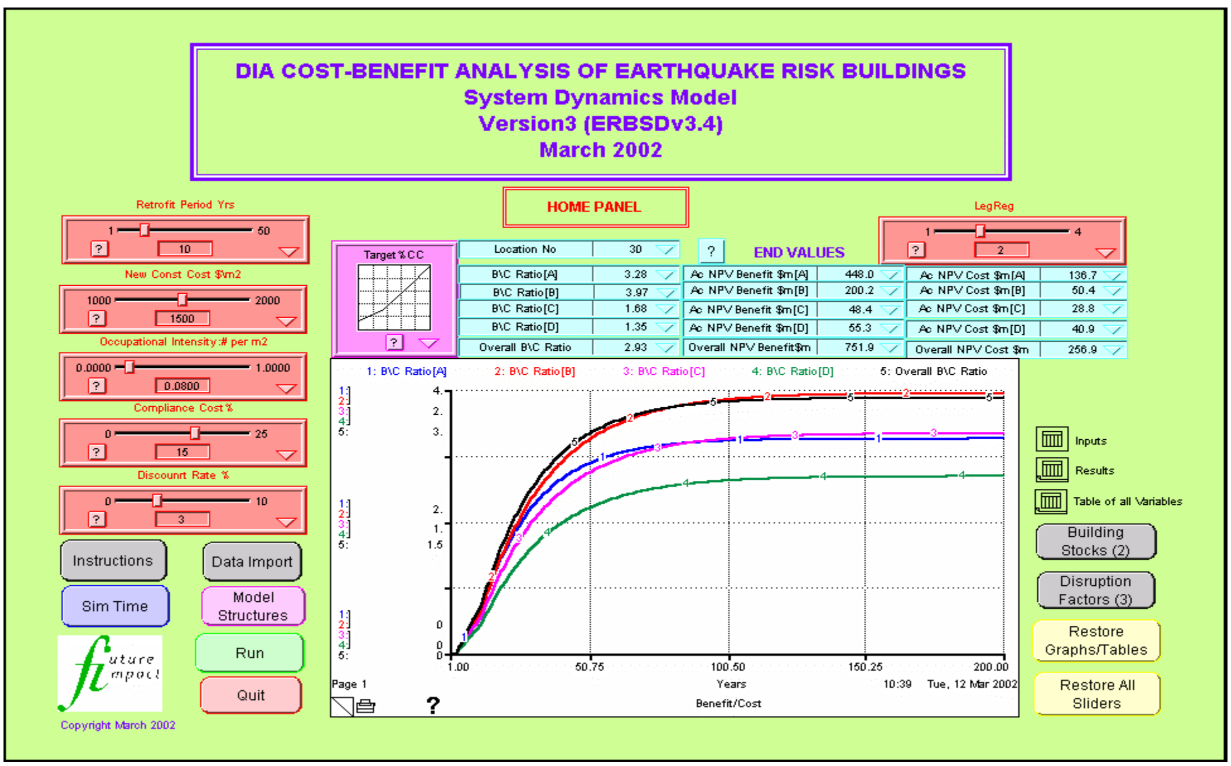

Figure 1 - Home Panel for the "ithink" Systems Dynamics Model

Variables Considered

The following comments give some background to the variables considered:

Legislation Regimes – Defined Trigger Levels: There were four Legislation Regimes (LR), trigger levels for which were status quo, 33%, 67% and 100% of New Building Standard.(Current Code –CC%) This was the level below which the proposed legislation would require earthquake strengthening.

Legislation Regimes – Required Retrofit Levels: The model assumes that these levels are the same as the trigger levels. Buildings falling below the trigger level would be required to be brought up to the trigger level and no more.

Seismicity: Values of annual probability of occurrence of each MM intensity level for each location were provided especially for this project by the Institute of Geological and Nuclear Sciences using the latest available data and modelling.

Total Area of Building: Only the total areas of residential and commercial buildings were used in producing the Key Results. Residential premises were only included if the area of the building was greater than 1000 square metres. This was taken as approximating the intent of the legislation that single and small residential properties would be excluded.

Percentage of Buildings that will be Non-complying (Retrofit %): This is the assessed percentage of the total area of each building type that is expected to require retrofit under the various Legislation Regimes. The model assessed this percentage based on assumed distributions of strength for each building group. These percentages give a measure of the scale of the task in strengthening buildings. The values chosen were based on judgement and general knowledge of the strength of buildings in each group.

Generic Percentage New Building Standard for Building Type: This is the assessed average strength level of the buildings of each type that require strengthening for each Legislation Regime.
The generic values given were adjusted to account for location and vintage. The strength of a building in relation to new building standard depended on the code to which it was designed.

New Construction Cost: This is the assessed cost of new construction of an entire building in $ per square metre. This was used directly to calculate the value of the benefits of reduced damage and indirectly to obtain the cost of retrofit. The same value is used for all locations, but can be varied in the run model.

Retrofit Cost: This is the assessed cost (per square metre) of the structural cost of strengthening buildings to the level required by the Legislation Regime. It was varied according to the seismicity of the location and the amount of improvement in structural performance achieved.

The formula used for retrofit costs included a significant fixed component to reflect the costs of opening up and making good after structural work, regardless of the amount of structural work to be done. Implicit in this assumption is that the structural retrofit work has been imposed by the legislation and that without the legislation, retrofitting would not be done.

Depletion of Building Stock – Existing Regime: The model allows for depletion of building stock over time. A factor was included to represent the rate if depletion if the legislation was not changed, and was expressed as a percentage of the area of buildings for each group.

Table 3 Sensitivity Analysis

Percentage change to Values		Legislation Regime 2				
Results based on Wellington		33% New Building Standard				
City/Town	**Bldg Group =>**	**Pre 1935**	**1935-65**	**1965-76**	**1976-**	**Total All**
	Bldg Type =>	**A**	**B**	**C**	**D**	**Bldgs**
Wellington	B/C Ratio	3.3	4.0	1.7	1.4	2.9
(Standard)	NPV Benefit	448.0	200.2	48.4	55.3	751.9
	NPV Cost	136.7	50.4	28.8	40.9	256.9
Wellington	B/C Ratio	**100%**	**100%**	**100%**	**100%**	**99%**
(50yr Retrofit)	NPV Benefit	47%	53%	53%	53%	49%
	NPV Cost	47%	53%	53%	53%	50%
Wellington	B/C Ratio	**177%**	**173%**	**165%**	**159%**	**174%**
(200%OccInty)	NPV Benefit	177%	173%	165%	159%	174%
	NPV Cost	100%	100%	100%	100%	100%
Wellington	B/C Ratio	**61%**	**64%**	**68%**	**70%**	**63%**
(50%OccInty)	NPV Benefit	61%	64%	68%	70%	63%
	NPV Cost	100%	100%	100%	100%	100%
Wellington	B/C Ratio	**166%**	**196%**	**196%**	**196%**	**178%**
DisRate -2%	NPV Benefit	180%	213%	213%	213%	194%
	NPV Cost	109%	109%	109%	109%	109%
Wellington	B/C Ratio	**71%**	**67%**	**67%**	**67%**	**70%**
DisRate +2%	NPV Benefit	66%	62%	62%	62%	64%
	NPV Cost	93%	92%	92%	92%	93%
Wellington	B/C Ratio	**139%**	**136%**	**132%**	**130%**	**137%**
ConsCost $1000	NPV Benefit	92%	91%	88%	86%	91%
	NPV Cost	67%	67%	67%	67%	67%
Wellington	B/C Ratio	**81%**	**82%**	**84%**	**85%**	**81%**
ConsCost $2000	NPV Benefit	108%	109%	112%	114%	109%
	NPV Cost	133%	133%	133%	133%	133%
Wellington	B/C Ratio	**170%**	**134%**	**134%**	**134%**	**156%**
No Bldg Stock Depln	NPV Benefit	188%	142%	142%	142%	169%
	NPV Cost	111%	105%	105%	105%	108%
Wellington	B/C Ratio	**82%**	**78%**	**72%**	**68%**	**79%**
FB1=FS1=0	NPV Benefit	82%	78%	72%	68%	79%
	NPV Cost	100%	100%	100%	100%	100%
Wellington	B/C Ratio	**95%**	**96%**	**97%**	**97%**	**96%**
FB2=FS2=0	NPV Benefit	95%	96%	97%	97%	96%
	NPV Cost	100%	100%	100%	100%	100%
Wellington	B/C Ratio	**53%**	**56%**	**60%**	**64%**	**55%**
FB3=FS3=0	NPV Benefit	53%	56%	60%	64%	55%
	NPV Cost	100%	100%	100%	100%	100%
Wellington	B/C Ratio	**170%**	**170%**	**171%**	**172%**	**170%**
(FB and FS) x 2 (4,2,2)	NPV Benefit	170%	170%	171%	172%	170%
	NPV Cost	100%	100%	100%	100%	100%
Wellington	B/C Ratio	**89%**	**82%**	**82%**	**82%**	**86%**
Simulation 50 years	NPV Benefit	89%	82%	82%	82%	86%
(Not 200 years)	NPV Cost	100%	100%	100%	100%	100%
Wellington	B/C Ratio	**1498%**	**1186%**	**1186%**	**1186%**	**1380%**
DisRate=0%, Run =200years	NPV Benefit	1892%	1423%	1423%	1423%	1703%
No stock Depletion	NPV Cost	126%	120%	120%	120%	123%
(Earthquake in year after retrofit)						
AUCKLAND	B/C Ratio	**1484%**	**0%**	**1160%**	**1207%**	**1318%**
DisRate=0%, Run =200years	NPV Benefit	**1874%**	**0%**	**1393%**	**1446%**	**1624%**
No stock Depletion	NPV Cost	**126%**	**0%**	**120%**	**120%**	**123%**
(Earthquake in year after retrofit)						

Depletion of Building Stock – New Regimes: This is similar to the depletion described above, but is additional to it. It enables the model to reflect any increase in rate of depletion that results from introduction of the legislation. Values were set at the start of each analysis.

Damage Ratio – Existing: These values form the key to benefits of strengthening. Values for each building group have been derived from a report done by Kingston Morrison, [3]. This modified US data to suit New Zealand building types. Four sets of relationships between earthquake intensity and damage ratio were used, one for each building type. (Refer Table 1 for values). These basic relationships were taken to be the same for all locations. The data sets were extrapolated beyond MM12 in order to enable interpolation of values when running the model.

Provision was made in the model to adjust Damage Ratio values for particular groups of buildings. Modifications were made to account for the fact that the sample of buildings requiring retrofit would have a lower mean damage ratio than the whole sample. This was done by "shifting" the value of MM by an amount corresponding to the difference in strength.

Damage Ratio – Retrofit: The damage ratio after retrofit was assessed by first calculating the reduction in damage ratio between the existing building group in question and a group built to current standards. (Building Type D). Retrofitting to the 100%CC level (LR4) was assumed to reduce the damage ratio from the existing level to that of Type D Buildings. Retrofitting to a lesser Target %CC was assumed to achieve a proportionately lower reduction from the existing damage ratio. Thus the damage ratio difference, and benefit, for any given MM level increased with the trigger levels in successive Legislation Regimes.

Injuries and Fatalities: These were modeled in identical fashion, but with different key data. For both injuries and fatalities a relationship between Damage Ratio and rate of injury or fatality per person exposed is provided. The model then looks up the rate at the existing damage ratio and the rate at the retrofit damage ratio. The difference in these two rates was used in conjunction with the occupational intensity and retrofit floor area to calculate the number of people affected and thus the assessed benefit of reducing the damage ratio.

The relationships used were the same as those used in the previous analyses which in turn were used in a Works Consultancy Services Report to Wellington Regional Council [4]. The cost of an injury for the prototype model was NZ$0.25M and that for a fatality NZ$2.5M. These correspond to values used by Transit New Zealand in assessing the benefit/cost of roading improvements. The quoted figures do not include any social disruption or business interruption elements.

Business Interruption and Social Disruption: Benefits of retrofitting buildings, and reducing the damage to them, results in reductions in Business Interruption (BI) and Social Disruption (SD). In an earlier study [3], the reduction in the cost of physical damage was factored by 1.0 to give BI and by 2.0 to give SD. In this model, provision was made to factor each of the calculated cost benefits due to reduced damage, reduced injury and reduced fatalities to obtain benefits for Business Interruption and for Social Disruption.

Analysis and Retrofit Periods: The model allowed both of these to be varied independently of one another. The retrofit period can be varied to up to 50 years. The model software allows the analysis to proceed for an indefinitely long period.

Discount Rate: Provision was made to adjust the rate at which future values are discounted to obtain present day values.

Compliance Costs: A percentage of retrofit costs was added to account for compliance costs. No provision was made for ongoing compliance costs once retrofit is complete.

Applicability of Model

The model has been developed using reasonable values for variables and has been checked to produce consistent results. However, the values of benefit, cost and benefit/cost ratio could vary immensely according to assumptions and settings made for any particular run. This is especially the case for the differences in damage ratio between the various types and those complying with current codes. Extreme care is thus needed when interpreting results of any particular analysis on the run model.
It is most important to note that the model computes benefit/cost ratios using annual probabilities. For each year the calculated benefits of retrofitting (reduced damage, injuries and fatalities) are multiplied by the annual probability of occurrence for each level of shaking. This takes no account of the prospect of the maximum credible earthquake at any particular location occurring in the first few years after retrofitting is complete. A measure of the benefit of this can be gained by running the model for several hundred years with a discount factor of 0%. For this scenario, benefit/cost ratios rose markedly for all locations.

Key Results

With the large range of variables available, it is difficult to summarise the results of analyses. Much can be learnt from experimenting with the model on screen.
Table 2 shows results of runs for selected cities and towns for Legislation Regime 2 (33%New Building Standard), indicating the benefit, cost and benefit/cost ratio for each building type in these locations, and the values for all building types. Results clearly indicate the way in which seismicity and building areas in these cities and towns influence the key outcomes.

Sensitivity Analyses

Table 3 compares B/C ratios, NPV Benefit and NPV Costs with the reference values using the 'standard' or default settings. Values shown are the percentage movement from the default settings due to the change in variable stated. In all cases, only the variable mentioned is changed from its default value.

Discussion

The wide range of input variables signals the dependence of the output on the input values selected. The most significant variable is clearly the measured seismicity of the location. Building damage, injuries and fatalities all rise with increase in shaking intensity. Increased seismicity compounds this relationship, resulting in a wide range of benefit/cost ratios for the 32 locations. The seismicities used are for average site conditions. Considerable variation in annual probabilities is evident for very soft and for very hard sites, but for groups of buildings, it was considered appropriate to use the average values.

The relationship between damage ratio and shaking intensity is another key variable. Values used in the analyses represent mean values for the buildings groups concerned. For buildings with critical structural weaknesses, damage ratios could reach 100% at relatively low values of MM Intensity. The benefits of

retrofitting such buildings would be several times the benefits of dealing with the average of the group, particularly for post-1976 buildings.
The cost of retrofit was varied from $120 per square metre to over $500 per square metre. These were based on values provided by consultants on the cost of past jobs on mainly unreinforced masonry buildings. (Note that for comparison, the cost of typical new construction was taken as NZ$ 1500 per square metre). The costs are for structural improvement measures only. Consultant records show a wide range of costs and very little correlation between cost and percentage improvement of performance. However, to make sense of the model, some correlation was assumed.

The cost of fatalities and the relationship to damage ratio contributes significantly to the overall result. The value assigned to a human life reflects only the willingness of people to pay to avoid the pain and suffering as well as the direct costs associated with dealing with a fatality. Wider effects such as business interruption and social disruption are not included. (Similar reasoning applies to injuries, though the overall effect in the context of this study is small.)

To allow for Business Interruption and Social Disruption, further factors on damage, injuries and fatalities were applied. There is little definitive data on the added cost of Business Interruption and Social Disruption to the community. The overall effect of a major earthquake on an economy can be significant, such as the case of Kobe Port in Japan. They permanently lost some 20% of business, in addition to the more direct costs and disruption of the earthquake and the influence of reconstruction work. Factors as high as 15 times physical damage have been quoted for business interruption. The standard settings of the model at twice physical damage are believed to reflect a conservative assessment.

Results presented in this study are based on the annual probability of each level of shaking intensity. This provides a slow build up to a long term B/C ratio. However, for low probability, high consequence events, this does not account for the benefits realised if a major earthquake occurs soon after the retrofitting is done. Rough assessments of this effect were made, giving B/C ratios of between 16 and 90 for Wellington, and 0.3 and 2.4 for Auckland.

B/C ratios generally increase with trigger level of the Legislation Regime. Values for pre-1935 and 1935-65 buildings were similar and noticeably higher than for 1965-76 and post 1976 buildings. This reflects the generally lower existing damage ratios of the latter two categories and the fixed elements of retrofit cost.
B/C ratios of between 6.2 (for Wellington) and 0.012 (for Whangarei) indicate clearly that, at least for an annual probability basis, the seismicity of a particular location has a marked effect on the perceived benefit of earthquake strengthening.

Full details of the study are contained an unpublished report for the Department of Internal Affairs [5]

COST-BENEFIT ANALYSIS – THEN WHAT?

The output of the cost benefit analysis provides apparently precise answers and it is tempting to regard them as providing a single definitive criterion for deciding whether or not to carry out retrofitting. But the precision of the process masks the wide range of uncertainty in the values of the many parameters involved. The best that can be said about such cost benefit analyses is that they inform the decision-making process. Exploring the sensitivity of the results to changes in selected parameters provides further insights and information.

Annual Probability versus Conditional Probability

Setting annual probability year by year assumes that earthquake risk is spread evenly over time. This may be a satisfactory assumption for low intensity shaking that occurs relatively frequently, but for the impact of higher intensity shaking that occurs once every 500 years, the annual probability basis does not reflect the possibility of a major event in the short term. The scenario of “What if the earthquake occurs in the first year following retrofitting?” is an example of a *conditional probability*. If the decision to retrofit or not is based on the major event occurring in the short term, then greater justification and benefit-to-cost ratios obviously will result than if annual probability was used. With these higher numbers it may prove easier to make a case that retrofitting is worthwhile.

Conditional probability is at the heart of annual insurance. Premiums provide protection in case the event occurs in the next year. From this standpoint, basing the cost-benefit on annual probability tends to underestimate the justification for taking action. Similarly, assuming that a major event will occur soon after retrofitting certainly overestimates the justification. Somewhere in between is an answer that provides a balance between the two approaches. Exactly where this position is will vary from community to community depending on a number of factors, not least of which will be the overall wealth of the economy, and the perception of the threat of earthquake amongst community decision makers.

The results of the study described above indicate that the requirements that New Zealand engineers have pushed for in legislation are not unreasonable. For locations of high seismicity, the annual probability basis yields satisfactory B/C values. For locations of low seismicity, greater reliance on the conditional probability approach is needed to achieve comparable B/C ratios.

One approach available to local authorities, to account for varying seismicity, is to vary the timetable required for taking action on buildings that do not meet the required standard.

The Decision to Retrofit

There are two basic and distinctly different situations in which this decision needs to be taken:

- An owner’s situation - protecting an investment in one or more assets
- A legislator’s situation – reducing the overall risk to the community

Owner Perspective

The owner’s perspective is more narrowly focused on the fate of a particular asset or portfolio of assets. Improving the seismic performance of, say, an apartment building, may increase its market value, improve its appeal to tenants, reduce insurance premiums, and provide peace of mind that should a major earthquake occur, the value of the asset is better protected. Reduction in physical damage will be a consideration, and so too will the reduction in risk of injury and death.

Some asset owners who consider the merits of spending money to improve the earthquake performance of their asset will adopt a conditional probability approach. When it comes to the final analysis, they argue that, even though the probability of a major earthquake is low, its occurrence would wipe out their investment or business. There will be other owners for whom the low risk of a major earthquake provides all the argument needed to take no action.

As an individual or organization, an owner can decide to take action and within a short space of time achieve the improvement required or sought. Any benefits will thus be fully available not long after the decision is taken to carry out the improvement work.

Legislator Perspective
This is a much more complicated situation since decisions need to be made on behalf of the whole community. These decisions are faced by legislators when setting requirements to reduce the risk represented by a city's or country's building stock. The analysis described above was made from this viewpoint in order to inform the development of suitable legislation.

Whereas an individual owner makes a voluntary decision, a legislator is looking to impose a decision on building owners in general. For the legislator, reduction in risk of injury and death become relatively more important. Reduction in physical damage is a significant consideration since over a whole city or country, the damage bill can be daunting in terms of normal construction capability. Similarly, reduction in social disruption and indirect losses are significant issues for the legislator. Improvement in valuations and reduction in insurance premiums are likely to be less important to a legislator, and more difficult to quantify.

Because their decisions affect a wide range of assets, the question of timescale is markedly different for legislators. Any retrofit programme will need to be applied over many years, probably decades, in order for the required investment on retrofitting to be realistic Much will depend on the perception of the community as to how important it is to address seismic risk, compared with addressing other community priorities. Any community can only afford to spend a limited proportion of its GDP on earthquake risk mitigation. The hard question is how much is enough?

When the NZSEE developed guidelines to assist designers and local authorities with the implementation of the 1968 legislation affecting masonry buildings, the total cost of all retrofit on all buildings in Auckland City was estimated. A reasonable maximum annual spend was then established that would be acceptable in relation to normal economic and construction activity. Recommended timetables for strengthening were around 20 to 30 years.

Istanbul is one city that is endeavouring to address requirements for retrofit from a legislator's perspective. The city is faced with a 65% chance of a major earthquake in the next 30 years. This compares to the 10% chance in 50 years taken as the basis for design of new buildings. Clearly there is a need for action, and considerable analysis of earthquake risk has been undertaken by Istanbul Municipality, [5,6]. The immensely difficult decisions of what to require through legislation – trigger levels, retrofit standards and time scales to complete retrofitting - have yet to be made.

Role of Cost Benefit Analysis in New Zealand Legislation

The development and introduction of the New Zealand legislation was driven by the poor performance of many buildings in major earthquakes overseas, notably Northridge, Kobe and Taiwan in recent times. Buildings with major structural weaknesses (soft storeys, irregular plan shapes, short columns etc) are known to perform poorly. New Zealand is bound to have its share of these and the aim of the legislation is to make a start on addressing the worst cases.

The introduction of the legislation was promoted by NZSEE representatives, and was backed up by the following basic assessments:

- A pilot survey of buildings in Wellington indicated that there was a sufficient percentage of high risk buildings, around 10%, to warrant some action.
- Analysis of benefit-to-cost ratios, even on an annual probability basis, resulted in values well in excess of one in places of highest seismicity.
- Benefit-to-cost ratios were sufficiently high for all parts of the country when some form of conditional probability was introduced.

At the very least, the cost-benefit analysis has indicated that money spent on retrofitting has a good chance of proving worthwhile in strictly financial terms, at least for high risk buildings in regions of highest seismicity.

This lends support to the intuitive view of earthquake engineers that a programme of retrofitting is needed to reduce earthquake risk over time.

It is well known that after a major event, questions are asked in hindsight as to actions that could or should have been taken to mitigate the effects of a major earthquake. This is a reminder to all earthquake engineering professionals that we have a duty to inform the community of the risks, so that reasonable decisions on what to require by way of retrofitting can be made in the face of other demands on the resources of the community.

By informing the community in this way the earthquake engineering profession helps put itself in a *defensible position* when major events are viewed in hindsight. Cost-benefit analyses play their part in providing some of the information necessary.

Acknowledgements
The assistance of Quotable Value New Zealand and the Institute of Geological and Nuclear Sciences is gratefully acknowledged, as is the commitment and skills of Dr George Stuart of Future Impact in developing the *ithink* model. The input of Brendon Whiteman and Steve Gentry in helping to frame the project is much appreciated.

The permission of the Department of Internal Affairs to publish this paper is appreciated.

REFERENCES

1. Kingston Morrison 1993. Confidential report for insurance broker, relating New Zealand buildings to US data.
2. NZSEE (New Zealand National Society for Earthquake Engineering), 2003. *Guidelines for the Assessment and Improvement of the Structural Performance in Earthquake*, Study Group Draft, March 2003,
3. NZSEE (New Zealand National Society for Earthquake Engineering) (1997), *Consolidated Report on Parametric Study,* Project for the Building Industry Authority, September.
4. Works Consultancy Services for WRC (Wellington Regional Council) 1995. *Earthquake Risk Assessment Study*.
5. DIA (NZ Dept of Internal Affairs) 2002. *Report on Cost Benefit of Improving the Performance of Buildings in Earthquake.* David Hopkins Consulting, March.
6. Japan International Co-operation Agency (JICA) / Istanbul Metropolitan Municipality, 2002. *The Study on a Disaster Prevention/Mitigation Plan in Istanbul including seismic microzonation in the Republic of Turkey*, Final Report, December.
7. Metropolitan Municipality of Istanbul, 2003. Earthquake Master Plan for Istanbul, July.

Table 1 - Key Data and Input for Model Development

								Legislation Regime Number		
1	**Legislation Regimes - Defined Trigger Levels (%CC)**						1	2	3	4
	(Bldg Types A, B, C, D)						16*X/Z%	33%	67%	100%
	(Target%CC)		*(Z=Zone Factor from NZS4203:1992)*							
2	**Legislation Regimes - Required Retrofit Levels (%CC)**						16*X/Z%	33%	67%	100%
	(Target%CC)		*(Z=Zone Factor from NZS4203:1992)*							
3	**Location for Prototype: Wellington**				*32 Locations for full model*					
4	**Seismicity for Wellington**			(Prototype only)						
	(MM Prob)		MM Level	6	7	8	9	10	11	12
			Probability	0.0938	0.0213	0.0073	0.0022	0.0004	0.0001	0.00002
5	**Building Parameters (for Wellington)**					Building Type	A	B	C	D
a	**Total Area (m2)(Million)**					Vintage	Pre-1935*	1935-65	1965-76	1976-
	(Total Bldg Area) (Prototype only)						0.5	1	1.5	1
b	**% of buildings that will be Non-complying**					%CC/Type	A	B	C	D
	(Retrofit %)	%CC Base value LR1 =		16	LR1	16	63	9	6	0
	Varies with location according to values of				LR2	33	100	33	25	8
	X, Z, CCi%, Mean and Standard Deviation of				LR3	67	100	79	64	29
	whole building sample (See 5c below)				LR4	100	100	100	100	50
c	**Generic %CC for building type**				**Multiply CCi% values shown:**					
	(CCi%)		For Legislation Regime 1			LR1	8	9	10	10
	Values in table to right		For Legislation Regime 2			LR2	16	20	22	20
	are same for all		For Legislation Regime 3			LR3	25	40	40	45
	locations		For Legislation Regime 4			LR4	25	55	60	65
		Mean for Full Sample (AM%, BM% etc)				All Bldgs	16	55	55	100
			Mean for full sample modified for X.Z				13	46	55	100
					by	**F(X,Z) =**	**1/Z**	**1/Z**	**X/Z**	**1**
			F(X,Z)	>>>>>>>>>>>>>>>>>>>>>>>>>			0.83	0.83	1.00	1.00
			for							
	Z = 1.2 for Wellington		Z=	1.2		Where Z = Zone Factor in Current Code				
	X = 1.2 for Wellington		X=	1.2		Where X = 10 times Coeff from 1965 Code Fig 1(b)				
	For X and Z values for other locations refer Table 2.1					**to give CCi%'**				
6	**New Construction Cost ($/m2)**						1500	1500	1500	1500
	(New Const Cost$/m2)			*Note: Can be varied on Control Panel*						
7	**Retrofit Cost ($/m2)**					For each building type at each location set retrofit cost to be:				
	(Retro Cost$/m2)					= (0.08+(sqrt(DRex'-DRret')/3))* New Construction Cost per m2				
						Where DRex' and DRret' are adjusted values of DRex and DRret				
	Results in different costs with location, and amount					corresponding to a value of MM = 8 + 1.67*Z				
	of reduction in Damage Ratio					(Z= Zone Factor in NZS 4203:1992)				
8	**Depletion of Building Stock - Existing Regime**					Bldg Type	A	B	C	D
	(% per annum of total area for each type)						*Input from Control Panel on Model*			
9	**Additional Depletion of Building Stock**					All LR's	*Input from Control Panel on Model*			
	(% per annum of total area for each type)									
10	**Damage Ratio - Existing (Mean Damage Ratios)**					Bldg Type	A	B	C	D
	(DRex)					MM	Pre-1935*	1935-65	1965-76	1976-
a	**Base Values**					6	5	4	3	2
	(from KM Report)					7	13	8	6	4
						8	30	15	10	6
	These are taken to be the same for all locations					9	49	30	19	12
						10	70	45	30	20
						11	91	60	42	29
						12	112	77	54	40
b	**Scale the Base Values** by allowing for an					LR1	0.7	1	1	1.5
	MM shift of the following, so as to increase					LR2	0.1	1	1	1.5
	the DR values.					LR3	0	0.5	0.3	1
						LR4	0	0.1	0.1	0.5
11	**Damage Ratio - Retrofit**									
	Calculate Shift in Damage Ratio due to Retrofit as follows:									
	i) Calculate DRD, the difference between DRex as above (at MM+shift)and value for Post-76 Buildings at MM.									
	ii) Reduction in DR for this Legislation Regime is equal to DRD*(Target%CC-(%Cci))/(100-%Cci) ***but not less than zero.***									
	Where DRD is difference in DR at relevant MM +shift level, for Bldg type in question and Post-76 Bldg at MM level.									
12	**Injuries and Fatalities**									
a	**People at Risk per 10m2 of area:**					Bldg Type	A	B	C	D
	(Occupational Intensity)		*Same for all building types*				0.8	0.8	0.8	0.8
b1	**Injuries and Fatalities versus Damage Ratio**						Injuries	Deaths		
	(Inj x DRret or DRex)					DR%	Rate %	DR%	Rate %	
	(Interpolates a graph to determine injury rate)					0	0.0000	0	0.0000	
						10	0.1200	10	0.1500	
	Note! Benefit is obtained by calculating					20	0.4000	20	0.4000	
	difference in rates before and after retrofit					30	0.6600	30	0.6000	
						40	0.9000	40	0.9000	
	DRex is obtained for MM+shift					50	2.4000	50	2.7000	
	DRret is obtained for MM without shift					60	4.0000	60	4.7000	
	Applies to all buildings					70	5.9400	70	6.4200	
						80	8.1600	80	7.8000	
b2	Cost of injury =		$ 0.25	Million		90	9.8400	90	9.0600	
	Cost of fatality		$ 2.50	Million		100	11.0000	100	10.0000	
13	**Business Interruption and Social Disruption**						FB	FS		
	Adds the following:		FB1 or FS1 times Physical Damage Benefi				2	2	Default	
			FB2 or FS2 times Injury losses				1	1	values	
			FB3 or FS3 times fatality losses				1	1	shown	
			Note: Values of FB1, FB2 and FB3 can be varied independently on the Control Panel							
14	**Analysis Periods**		Assumed 10 years of retrofitting. Assumed 50 years for model to run							
15	**Compliance Costs**		Adds a defined percentage to the cost of retrofit. (15% for Base Case)							
16	**Refurbishment Costs**			Costs of non-structural refurbishment are not included.						

Table 2 - B/C Ratios Benefits and Costs

Legislation Regime 2 - 33% New Building Standard

Values in $Million

City/Town	Bldg Group =	Pre 1935	1935-65	1965-76	1976-	Total Al
	Bldg Type =>	A	B	C	D	Bldgs
Auckland *	**B/C Ratio**	**0.03**	**0.00**	**0.02**	**0.06**	**0.04**
	NPV Benefit	2.2	0.0	0.3	2.7	5.2
	NPV Cost	65.8	0.0	13.9	47.2	126.9
Christchurch *	**B/C Ratio**	**0.40**	**0.50**	**0.25**	**0.38**	**0.39**
	NPV Benefit	20.2	5.4	2.2	10.2	38.0
	NPV Cost	50.8	10.9	8.9	26.6	97.2
Dunedin *	**B/C Ratio**	**0.08**	**0.00**	**0.03**	**0.11**	**0.08**
	NPV Benefit	1.5	0.0	0.1	1.1	2.7
	NPV Cost	19.4	0.0	3.6	10.2	33.2
Hamilton *	**B/C Ratio**	**0.2**	**0.2**	**0.0**	**0.3**	**0.2**
	NPV Benefit	2.4	0.6	0.0	3.6	6.6
	NPV Cost	10.8	3.7	0.0	13.5	28.0
Hutt City *	**B/C Ratio**	**3.2**	**3.8**	**1.6**	**1.3**	**2.8**
	NPV Benefit	40.6	42.2	10.5	7.0	100.3
	NPV Cost	12.7	11.0	6.6	5.5	35.7
Invercargill *	**B/C Ratio**	**0.19**	**0.16**	**0.00**	**0.26**	**0.19**
	NPV Benefit	0.5	0.1	0.0	0.4	1.0
	NPV Cost	2.8	0.7	0.4	1.5	5.4
Napier *	**B/C Ratio**	**2.4**	**3.2**	**1.5**	**1.3**	**2.3**
	NPV Benefit	64.3	14.0	4.1	4.7	87.0
	NPV Cost	26.4	4.3	2.8	3.5	37.0
Nelson *	**B/C Ratio**	**1.5**	**2.1**	**1.0**	**1.0**	**1.4**
	NPV Benefit	8.9	5.9	1.9	3.4	20.1
	NPV Cost	6.1	2.8	1.8	3.5	14.2
New Plymouth *	**B/C Ratio**	**0.6**	**0.9**	**0.5**	**0.4**	**0.6**
	NPV Benefit	9.8	4.6	1.2	2.7	18.3
	NPV Cost	15.1	5.3	2.5	6.3	29.2
Palmerston North *	**B/C Ratio**	**2.4**	**3.2**	**1.4**	**1.3**	**2.2**
	NPV Benefit	49.0	22.8	8.3	9.7	89.7
	NPV Cost	20.3	7.1	5.9	7.5	40.8
Rotorua *	**B/C Ratio**	**0.8**	**1.3**	**0.7**	**0.7**	**0.9**
	NPV Benefit	3.0	10.2	2.4	5.0	20.5
	NPV Cost	3.6	7.9	3.5	6.8	21.8
Taupo *	**B/C Ratio**	**1.8**	**2.4**	**1.1**	**1.2**	**1.7**
	NPV Benefit	0.1	8.1	1.3	3.9	13.3
	NPV Cost	0.0	3.4	1.2	3.3	8.0
Tauranga *	**B/C Ratio**	**0.6**	**0.8**	**0.5**	**0.6**	**0.6**
	NPV Benefit	2.3	3.6	1.2	3.1	10.2
	NPV Cost	3.7	4.3	2.6	5.6	16.2
Wanganui *	**B/C Ratio**	**1.3**	**2.1**	**1.1**	**1.0**	**1.3**
	NPV Benefit	28.8	5.9	2.2	3.6	40.4
	NPV Cost	21.9	2.9	2.0	3.6	30.4
Wellington *	**B/C Ratio**	**3.3**	**4.0**	**1.7**	**1.4**	**2.9**
	NPV Benefit	448.0	200.2	48.4	55.3	751.9
	NPV Cost	136.7	50.4	28.8	40.9	256.9
Whangarei *	**B/C Ratio**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**