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Evidence Based Seismic Strengthening

Assessment of the Review of the Hawke's Bay Opera House Redevelopment Project 2004-2008 and Subsequent Assurance Reviews

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- The economics of financial regulation
- Advanced capital adequacy modelling
- Stress testing for large and small financial institutions
- Regulatory compliance for financial institutions

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Introduction and key conclusions

We have been engaged by Mr. Mike Butler of Hasting to provide an assessment of the report "Review of the Hawke's Bay Opera House Redevelopment Project 2004-2008 and Subsequent Assurance Reviews" commissioned by Hastings District Council (the Review). The Hastings District Council commissioned the Review after receiving structural reports that concluded that the Opera House and Municipal Buildings were "earthquake prone". Earlier reports had confirmed that the building met statutory requirements. The Council was perturbed that the "low seismic capability" of the buildings had not been identified earlier.

Our assessment of the Review is focused on the assessments of life safety and the strengthening decision, rather than Council and consultants' processes, and is organised as follows:

Section one deals with questions relating to whether the Opera House meets statutory requirements or not. Our key conclusions are:

- The Opera House did meet statutory requirements when the Opera House Project was begun and continues to do so. The Council has no statutory obligation to strengthen the building. The reason that the some consulting engineers believe that the buildings are earthquake-prone is that they have applied the New Zealand's Society for Earthquake Engineering's (NZSEE) percent of new building standard (%NBS) test, which has no basis in law.
- The Review's failure to discuss the legal basis of the earthquake prone building test is a serious omission.
- The discussion of the test was misleading.

Section two deals with the %NBS assessments of the building. Our key conclusions are:

- The discussion in the Review that it is difficult to get a precise fix on the buildings' %NBS estimates is well founded.

- The judgment that the %NBS assessment is likely to be conservative is well founded.

Section three deals with advice given on whether the buildings should be strengthened. Our key conclusions are:

- % NBS targets recommended by the NZSEE do not provide a sound basis for decision-making.
- The original advice given by Loughnan Hall and Thompson (LHT) that it did not make financial sense to further strengthen the building was broadly sound.
- The original advice from LHT that the buildings do not present a material life safety risk was broadly sound.
- The advice given by the Holmes Consulting Group to follow the NZSEE recommendations on strengthening is not sound.
- The suggested risk assessment methodology presented in the Review is not sound.
- Our cost-benefit analysis of the Opera House strengthening options shows that the benefits of strengthening are extremely small compared to the costs (just 0.3%), and that there is no justification for further strengthening.
- The life safety risk to audiences is extremely small. The odds of a concertgoer being killed attending a three-hour performance is about 110 million to one. The odds of being killed in a three-hour car drive is something like 1.5 million to one.

Section four addresses the Council's processes. Our key conclusions are:

- The Council should obtain independent advice on its legal obligations with respect to the strengthening of the buildings and on the earthquake-prone-building (EPB) test it is applying to buildings in its jurisdiction.
- The Council should not rely exclusively on advice from engineers to decide whether the buildings need strengthening and to what level.
- The Council should obtain independent advice on the life safety risk posed by the buildings.

Section one: Is the building earthquake prone?

It is important to be clear that in deciding on the seismic strengthening on the building the Council has to address two separate questions.

1. Are the buildings earthquake-prone as defined in the Building Act 2004 (the Act)?
2. If the buildings meet the legal test and are not earthquake-prone, should the Council still strengthen the buildings? To make this assessment the Council needs understand the life-safety risks and to consider the costs and benefits of strengthening.

This section deals with the first of these questions.

The legal definition of an earthquake-prone building

An earthquake- prone building is defined in s 122 of the Building Act 2004 as follows:

(1) ***Meaning of earthquake-prone building***

> *A building is earthquake-prone for the purposes of this Act if, having regard to its condition and to the ground on which it is built, and because of its construction,*
>
> *(a) the building will have its ultimate capacity exceeded in a moderate earthquake (as defined in the regulations): and*
>
> *(b) would be likely to collapse causing –*
>
> *injury or death to persons in the building or to persons on any other property; or damage to any other property*

A moderate earthquake is defined in the Building (Specified Systems, Change the Use, and Earthquake-prone Buildings) Regulations 2005 as follows:

> *For the purpose of section 122 (meaning of earthquake-prone building) of the Act, moderate earthquake means, in relation to a building, an earthquake that would generate shaking at the site of the building that is of the same duration as, but that is one-third as strong as, the earthquake shaking (determined by normal measures of acceleration, velocity, and displacement) that would be used to design a new building at that site.*

The NZSEE 34% NBS interpretation of an earthquake-prone building

The Review applies the test that an earthquake-prone building (EPB) a seismic capacity assessment of less than 34% of the new building standard (that is 33%NBS or below). This is represented as being consistent with the test set out in the Act and in the Regulations.

This approach relies on a particular interpretation of the Act that is set out in the New Zealand Society of Earthquake Engineering document "Assessment and Improvement of the structural performance of Buildings in earthquakes" released in 2006 (NZSEE 2006), which was intended to provide guidance to local authorities when meeting their obligations under the Building Act.

The 34% NBS interpretation relies on changing the term "ultimate capacity" in the first limb of the definition to "ultimate limit state" (ULS), and ignoring the second limb of the definition that the building would be likely to collapse. NZSEE 2006 states:

> *NZSEE holds the view that the collapse criterion given in subclause 122 (1) (b) of the Act does not relate back to expected performance in a moderate earthquake but rather to an overall expectation. Thus it does not in itself affect the recommendations made in these guidelines.'*

The effect of these changes is to redefine the earthquake-prone-building test in the Act to a test that an EPB exceeds its ultimate limit state at less than 34% NBS.

However, this is not consistent with the definition of earthquake-prone building in the Act.

The Supreme Court, in a judgment issued in December 2014 (Canterbury University vs. The New Zealand Insurance Council), made a very clear statement about the meaning of earthquake-prone building. It said the definition had two limbs and that both must be satisfied for a building to be earthquake-prone. The operative limb that an earthquake-prone building must be likely to collapse in a moderate earthquake cannot be ignored. The Court also settled the issue of whether a Council can require a building owner to strengthen beyond the trigger point set in the Act. Councils cannot do that.

Simply put, the effect of the NZSEE 2006 interpretation is to apply a different, and far stronger test of EPB, than is permitted by law. Under the correct interpretation of the Act, whether a particular building is earthquake prone becomes a matter of fact – the building must be likely to collapse in a moderate earthquake.

While the Opera House and Municipal Buildings may not pass the 34% NBS threshold, they are not weak buildings and the chance that they will collapse in a moderate earthquake is extremely remote (more than 10,000 to one). The reason is that a moderate earthquake is not particularly strong. It is defined has having a force of 0.13 g, and it is well understood that only defective buildings are at a material risk of failure when subject to such a force. It is not possible to credibly argue that the buildings meet the legal "likely to collapse" test.

The Opera House and Municipal buildings are, legally, not earthquake-prone.

The meaning of earthquake-prone building according to the Review

The Review sets out the relevant parts of the Building Act and the Regulations in appendix one and points out the effect of the use of the NZSEE definition. In A2.10 it is stated:

> *The Building Act 2004 defines an earthquake-prone building as one where "its*

> *ultimate capacity is exceeded in a moderate earthquake … and …would be likely to collapse"…. Refer section A1.3 above. However the %NBS that the engineer determines is based on the Ultimate Limit State (ULS) that a new building is designed to, and which is required to have a low probability of failure at the design load Therefore the 33% of the NBS that determines the earthquake-prone trigger point is* ***also based on a low probability of failure*** (our emphasis).

The Review confirms that the NZSEE %NBS test is based on a low probability and not the legal likely test. However, the point that the NZSEE trigger point is inconsistent with the legal test is not made.

In appendix III there is a further discussion of the legislative requirements.

> *similarly government legislation has set a trigger point of 33% to identify earthquake-prone buildings. A building with a earthquake-resistant capacity below this level is assessed as earthquake-prone. Regulations also define a "moderate earthquake" as one that will cause failure of a building with a earthquake-resistant capacity of 33% NBS*

The statement that government legislation has set a trigger point of 33% is not true. There is no reference to a trigger point of 33% in the Act.

The statement that "*regulations also define a "moderate earthquake" as one that will cause failure of a building with an earthquake resistant capacity of 33% NBS"* is also not true. It is clear that the regulations only refer to the size of the earthquake.

The discussion goes on:

> *For the HBOH the recent DSA* (detailed seismic assessment) *assessments have identified the buildings as earthquake-prone. This suggests that a particular earthquake with an intensity of MM7 could cause significant damage to the HBOH building.*

The suggestion that an earthquake with an intensity of MM7 could cause significant damage to the HBOH building could not reasonably have been made. The relationship between earthquake intensity and damage are broadly understood and are set out in the appendix to the Review. The relevant section on the likely impact of a MM7 event is as follows:

> *Unreinforced stone and brick walls cracked. Buildings type I cracked with some minor masonry falls. A few instances of damage to buildings Type II.*

> *Unbraced parapets, unbraced brick gables and architectural ornaments fall. Roofing tiles especially ridge tiles may be dislodged. Many unreinforced domestic chimneys damaged, often falling. Water tanks type I burst. A few instances of damage to brick veneer and plaster or cement-based linings. Unrestrained water tanks (type II) may move and leak. Some windows (type II) cracked. Suspended ceilings damaged*

As the Opera House building can most likely be categorised as a building type III, and at worst a type II, the statement that there would be "significant damage" would have misled a reader into thinking there was some material risk of loss of life in a moderate earthquake. This is simply not true.

Conclusion

The discussion on the earthquake-prone-building status of the buildings was misleading.

Section two: How strong are the buildings?

The %NBS rating

Once it is understood that the buildings is not an earthquake prone on its %NBS, the measured %NBS status of a building becomes less important.

Nevertheless, the question still arises as to why there should be such a gap between the early and later %NBS assessments. This divergence was a central concern to the Council and is addressed in the Review. The discussion is both helpful, and on some points, a little misleading.

The Review poses the following questions:

> *Has understanding and approach changed between 2004 and 2014 in regard to structural assessments, calculations, and regulatory guidance? If so are these changes sufficient to explain the dramatic change in status of the building in terms of earthquake status?*

And provides the following answers:

First:

> *Over the period 2004 to 2014 there were significant changes in the legislative requirements for the assessment of buildings to determine their earthquake proneness.*

This statement is not strictly correct. There have never been legislative requirements for building assessment. Legislation has always been framed in terms of building performance. The Act was changed in 2004 but there were no changes in legislative requirements over 2004-2014.

NZSEE (2006) guidelines do provide guidance as to how buildings should be assessed, but these guideline do not have legal authority. While the NZSEE guidelines were finalised in 2006, an earlier draft was available to LHT and they appeared to have used this guidance in making their assessment.

The guidelines have not been amended since 2006 so it appears that both LHT and the engineers who did the subsequent assessments were working within the same framework.

Second:

> *In addition there was an increase in knowledge and experience of how various buildings respond to earthquake effects and sophisticated tools became more generally available to engineers for the structural assessment of buildings, ….Over this period there has been a remarkable improvement in the ability of structural analysis to provide more accurate solutions for the stresses and strains induced in buildings as they responds to various loadings. However the quality of the output is very dependent on the assessing engineers understanding of the characteristics of the programme and the knowledge and experience with the interpretation of the results for particular types of buildings.*

While this was true it is not clear that there was necessarily a shift in the expected assessment of reinforced masonry buildings.

And third:

> *the Canterbury earthquake sequence over 2010-11 has heightened the public perception of earthquakes and their consequential effects…..earthquake resistant performance of older buildings, the lack of understanding of how earthquake risk is managed, the tendency of everyone to be more risk adverse, buildings are been more closely scrutinized and assessed more conservatively.*
> *All these issues are having a significant effect on how the public views our older buildings and the response of engineers in carrying out the assessment process.*
>
> *With respect to the Hastings Opera house complex the current assessments are likely to have a higher degree of accuracy than the assessments carried*

out through 1998 to 2006 but they will naturally be more conservative…. This is not to call into question the recent work done in reviewing the Opera House and Municipal buildings. That work appears to be robust with conclusions that are supported by relevant structural analysis ….
while the DEE (detailed engineering evaluation) *is conservative it is still likely that the buildings are earthquake prone"*

We conclude that even with more sophisticated techniques different engineers can reach a range of conclusions about the precise %NBS status of an older building. We also conclude that an assessment can still only give a broad indication of the "true" strength, and that it is likely that the recent assessments are biased on the downside.

It is also worth noting that the Strata Group assessment that the Opera House was "earthquake prone" was based on the performance of the masonry walls of the theatre (18% NBS) and that the Review notes that "*the failure of one element of the building does not necessarily lead on to a collapse".* LHT seems to have taken a broader approach to the assessment of life safety risk of the buildings.

Part of the problem here is that the NZSEE framework does not have a solid quantitative anchor. A %NBS rating is not linked to a probability of collapse. If engineers estimated collapse probabilities with respect to design strength earthquakes (and stronger), more sophisticated probabilistic modelling would generate more value and allow a more direct link to life safety assessments. While there would be uncertainty around any central result, the greater transparency and replicability of the processes would be an improvement on an approach where a judgment is made that the building is earthquake-prone, and by implication high risk, because one element of the building is assessed as being below 34%NBS.

The Review suggests that it is "natural" for engineers in the current environment to make conservative estimates. We do not agree with any suggestion that this is appropriate. An engineer's obligation is to make the best-estimate of the %NBS for their client. It is then for a client to make an assessment, based on that estimate and other information, about how safe they want their building to be. It is to not for the engineer to be making that decision for them by embedding conservative assumptions within the detailed calculations or the overall assessment of the building and effectively forcing the owner to strengthen by delivering a low %NBS estimate.

Engineers have their own incentives and biases that may consciously or unconsciously shade their assessment:

- They may be inclined to assess buildings to be earthquake-prone because they may be open to recriminations -- if they say the building is not earthquake prone and if building is subsequently materially damaged in a severe earthquake.
- Many engineers have a philosophy that if a building's strength is below the

new building standard then it should be strengthening almost regardless of the costs and benefits of doing so. This philosophy is embedded in the NZSEE 2006 document and recommendations.

- The earthquake engineering profession stands to gain financially from conservative assessments.

Section three: How strong should the buildings be?

How significant is the 34%NBS standard for life safety?

More important than whether the building is really above 34%NBS or not, is the prior question of the significance of that figure for life safety. Does it really provide a useful dividing line between buildings that pose an “unacceptably” high risk and those that don’t?

The answer to this question is that the 34% NBS benchmark has very little risk significance. In the NZSEE risk grading system these buildings are described as “high” risk, but all this is saying that the building is likely to have a higher risk of collapse than a building with a higher %NBS.

In NZSEE 2006 there is a table that purports to show how risk is related to % NBS. A 34% NBS building is described as 10 times riskier than a 100% NBS building and a 67 % building is three times riskier. But these numbers are not helpful in assessing what matters, which is the absolute level of risk. If the 67%NMS building poses an extremely low risk then it probably won’t matter if the risk of a building rated at, say, 20% NBS building’s risk is five times this extremely low figure. It could be a risk that is not worth worrying about.

A key problem with the NZSEE risk assessment framework is that there is no documented analysis behind it and the 34% NBS trigger point is just an arbitrary number that has taken a life of its own. The NZSEE simply doesn’t know what risk it represents and in our view, should not be saying that buildings below 34%NBS are high risk.

Fortunately, in recent years work has been done by GNS Science (particularly for the Ministry of Buildings Innovation and Employment’s 2012 cost-benefit analysis of seismic strengthening policies) that makes it possible to make a broad assessment of the risks posed by buildings that might typically be assessed as having a %NBS of below 34. We have used this work in the next section to produce a cost benefit analysis of the strengthening proposals.

Should a stronger test be applied to the Opera House?

In the Strata report it recommended that the Opera House should be assessed as a class three building. That is, it should receive a lower new building standard assessment than, say, an office building with the same strength. The justification for this recommendation is that there may be large crowds in the building. This recommendation is supported in the Review.

We think that is a policy judgment and not a technical engineering assessment. That is ultimately for the people of Hastings and their Council to make.

In our view, the Opera House should not receive special treatment. Other factors to be taken into account are that the buildings have a very low occupancy rate so the chances a severe earthquake will strike when there is a well-attended performance is extremely low. Further, the number of people attending a performance is not likely to be much greater than the number of occupants of in many office buildings in Wellington, which are not always accorded a “special” treatment.

Suggestions in the Review

A minimum 67% NBS
In section 11.7 it is suggested that “*consideration be given to an ultimate limit state target level that could be a minimum of 67% though to 100%.”*

This suggestion appears to be based on the NZSEE 2006 document that recommends a minimum 67% NBS level. As discussed above the problem with the NZSEE recommendation is that there is no analysis behind it. It is a one-size-fits-all approach that takes no account of the costs and benefits in particular cases. The NZSEE recommendation should not serve as a basis for the Council’s strengthening decisions.

The advice from the consultant engineers was in a similar vein and should also be ignored. Holmes Consulting Group LP said “*Given the above table and the recommendations from the New Zealand Society for Earthquake Engineers that strengthened buildings should target a minimum of 67% we would recommend investigating the 70-75% and 100% schemes further”.*

In the Review, further advice on how the Council could assess its options is presented in Section 4.

> *..It is important that decision-makers gain a broad understanding of what the various options can achieve in reducing life risk, as well as risk of damage occurring and the associated cost of repair. This information does not require a high level of detail: a broad understanding of qualitative damage and risk of occurrence is all that is required.*

The Review presents a table of the probability of occurrence of the earthquakes of varying intensities for Hastings and the associated damage at each intensity.

From a life-risk assessment the probability-of-occurrence information is essential. But the suggested framework is flawed because the table omits a quantitative assessment of the life safety risk associated with the earthquakes of each magnitude. It is life-safety that concern with the seismic strength of the building is, quite properly, about. Knowing, in qualitative terms, what the building damage could be like for each earthquake type does not help very much.

Relevant quantitative information is available. GNS Science has produced estimates of the likelihood of building collapse and of the probability of death by broad building types for different earthquake sizes. This information was used in the 2012 Ministry of Business Innovation and Employment's cost benefit analysis of various seismic strengthening options.

This information could and should have been used in the Review.

Once life-safety risk is understood in quantitative terms it is a relatively straightforward step to produce a cost-benefit analysis. Given the magnitude of the possible strengthening costs the Review should have recommended that a cost benefit analysis have been conducted.

An illustrative cost-benefit analysis

In this part we present an illustrative cost-benefit of strengthening options for the Opera House. A cost-benefit analysis of the buildings is a relatively straightforward exercise. It is a matter of combining the following information.

1. The probability of earthquakes of different, life-threatening magnitudes.
We have used the probabilities set out in the Review.

Return times:
- MM8 125 years.
- MM9 875 years.
- MM10 14,286 years.

The MM refers to the Modified Mercalli index which is a measure of the "felt intensity" of earthquakes and is a standard way of classifying of the intensity of earthquakes by the damage caused to buildings. An earthquake which is classified as an MM8 or bigger will occur on average every 125 years. MM8 earthquakes will damage to some buildings, but the probability (or odds) that a particular building will be severely damaged or collapse causing loss of life will be quite small (see tables 1 and 2). MM10 quakes which cause much more damage are very are in Hastings and can be expect to occur once in every 14,286 years.

2. The probability of a building incurring significant damage or collapse resulting in loss of life.
This probability will depend on the size of the earthquake and the strength of the building. Here we have used the GNS data discussed above. This data relates to broad classes of buildings, so it is difficult to get a precise fit to the Opera House, which has an amalgam of structural features. Below we present an array of alternative serious damage/collapse probabilities by three building types. There is a material risk of death or serious injury in these damage states.

None of the reports on the Opera House suggests that the building is as weak as a defective un-reinforced masonry building (URM). If it were, it probably would not have survived the 1931 quake. We have rejected this choice for the analysis.

Assuming a sound URM status may also be a little harsh, but for the purpose of this illustration we have taken a conservative approach and have used the URM damage probabilities. A less conservative alternative, perhaps assuming probabilities intermediate between the URM and reinforced concrete building (RFC) probabilities, is probably more realistic and would reduce the benefits of strengthening. But as will be seen from the cost-benefit analysis results, any difference would not affect the basic conclusions.

No account has been taken of MM7 quakes because the probability of serious damage or collapse in these events is very remote.

Table 1 shows the probability of serious damage/collapse probabilities that were used. Table 2 shows the lower probabilities of building collapses.

Table 1: Probability of damage/collapse (%) by earthquake and building type

Quake	**URM defective**	**URM sound**	**RFC medium height**
MM 8.5	1.05	0.51	0.32
MM 9.5	10.4	4.96	2.37
MM10.5	52.62	24.87	9.59

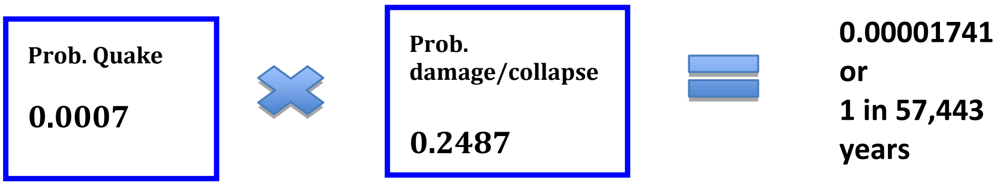
Table 2: Probability of collapse (%)

Quake	**URM defective**	**URM sound**	**RFC medium height**
MM 8.5	0.177	0.074	0.064
MM 9.5	3.10	1.20	0.655
MM10.5	24.42	9.93	3.57

Multiplying the probabilities of an event occurring and the probability of serious damage/collapse generates an annual probability of serious damage/collapse for each earthquake type.

For example, if we take the MM 10.5 quake, the probability that a MM10 or larger quake will occur in a year is 1 in 14,286 or 0.0007. If we multiply this probability by the probability of serious damage/collapse (which is 0.2487 from table 1) this gives an annual probability of severe damage/collapse from this very large earthquake of 0.00001741, or once every 57,443 years.

Figure 1: Calculating the annual probability that a building will collapse in a severe earthquake



Adding the results for the three earthquake types gives the overall serious damage/collapse probability. It is 0.0001055, or once every 9476 years.

The reason that this probability is so low is that the probability of very serious quakes (MM10.5) where there is a high probability (nearly 25 percent) of serious damage or collapse is quite low. It is about one tenth as likely as a quake of the same magnitude in Wellington.

The probability of collapse is smaller again. A complete collapse can be expected once every 40,600 years.

3. Earthquake related costs without strengthening

The key seismic event related costs are:

- *The value of the lives lost in an earthquake.*
  The standard valuation of a life saved in New Zealand is the $3.65-million figure used to evaluate life safety benefits of roading improvement projects.

- *Serious injuries.*
  These are about as common as fatalities but are much less expensive, typically in the low hundreds of thousands of dollars.

- *Savings on future repair costs.*
  It is difficult to put a value on this item. Seismic strengthening cost-benefit studies we have seen show it does not figure highly as a benefit. One reason is that strengthening is designed to save lives not to mitigate property damage. Even if strengthening saves lives there may be a substantial repair bill, or, as the Christchurch experience illustrates, demolition maybe the most economic option. There will be a window where strengthening will make a difference, but it is almost impossible to put a monetary value on it. Almost certainly the expected value of the savings will be small. To illustrate, strengthening that reduces the repair bill by $1-million in a 875-year quake has a value of just over $1000 a year.

Some commentators argue that there would be wider economic and social benefits from strengthening, and that strengthening could also assist in post-quake recovery. These arguments are not credible. It is the robustness of key infrastructure that is most important, in both respects. Whether the Opera

House is functioning post-quake or not will be irrelevant. We have not put any value on these wider “benefits”.

To simplify the analysis we have assumed that all benefits will be a function of life safety benefits and to capture them all we have used a higher figure of $5-million per life saved.

Additional assumptions

To calculate the “unstrengthening” base cost of seismic events we have made the following assumptions:

- *Probability of death given damage/collapse*
  The probability that an individual would be killed if the building is severely damaged or collapses is assumed to be 25 percent. The GNS Science estimate for URM buildings is just 5 percent, but the Opera House is not an ordinary building and we have assumed a probability of death rate that is more in keeping with death rates in reinforced concrete buildings.

- *Building occupancy rates*
  This is a critical assumption because the life-safety benefits of strengthening will depend on how many people attend performances and for how long. We have assumed that there are 52 performances a year attended by an average of 500 people. They are in the theatre for an average of three hours. There will also be performers and others who are there for longer periods. This factor is captured by assuming that there are 10 workers who occupy the building for an average of 40 hours a week and for 48 weeks a year. These assumptions, along with the others can be readily adjusted.

- *Discount rate*
  The discount rate allows us to present the annual savings as a single present value number. We have assumed a rate of 4 percent. This is lower than the 6.5 percent used in the MBIE national cost-benefit analysis and will generate higher present value figures.

The expected annual costs from seismic events is $1579. The present value of the costs takes the annual costs which are assumed to occur year after year infinitely into the future and discounts them using the 4 percent rate. This generates a present value of **$39,467.**

The benefit of strengthening

The monetary value of the benefits from strengthening is derived by calculating the costs of seismic events after strengthening and deducting this figure from the pre-strengthening cost estimate.

The key variable here is the impact of the strengthening on the probability of collapse. There is no definitive source data here. The NZSEE suggests that a 33 percent NBS building is 10 to 20 times riskier than a 100%NBS building and a 67%

NBS building is three times as risky. A building around 15-20% NBS might be perhaps two times riskier than a 34%NBS building. As discussed above we don't have a precise fix on the %NBS status of the building, nor are the NZSEE numbers authoritative, so it it is hard to say just how much a difference strengthening to say the 70-75 % NBS, mentioned in the costing report, would make.

However the exact numbers don't matter too much so we will assume that risk is reduced by a factor of nearly 6. That is, the cost of seismic events is reduced to just 15% of the pre-strengthening cost.

The benefits of strengthening are then 85% of the pre-strengthening costs. This is **$33,547.**

For the 34% option it is assumed that the risk of deaths and injury is reduced by half. The benefits for this option are **$19,733.**

Costs of strengthening
The costs of strengthening are taken from the Holmes Group report.

Table 3: Main results

PV Seismic Costs without strengthening	**$18,911**		
Strengthening option	**PV Benefits $000**	**Costs $000**	**Benefits to mid-range costs %**
35-45%NBS	$19.7	$6200-$6800	0.3
70-75% NBS	$33.5	$10,000-$11,000	0.3

It is obvious that the benefits are tiny compared to the costs under both strengthening options. – just 0.30 percent of costs in both cases.

If the Council goes ahead with the strengthening then it will be making an investment. For every $ it invests it will get back for the people of Hastings just 0.3 cents.

The factors that contribute to these outcomes are:

- Large earthquakes, where there is a material chance of death, are extremely rare.
- It is unlikely that the Opera House will be occupied when a major earthquake strikes. The assumption is that an audience would occupy the building just 1.8 percent of the time. This low audience occupancy rate means that 74

percent of the benefits from a reduction in life risk accrue to the audience and 26 percent to the workers.

- Even when a large earthquake strikes when a show is in progress the chance of an individual being killed is not high. In a MM10.5 quake it is 6 percent.
- In more frequent quakes the odds of being killed are much lower. The odds are just 0.1 percent in a MM8.5 quake.

The risk of death for a member of the audience in a single three-hour performance is extremely low. The odds are 110 million to one. The odds of being killed in a three hour car journey are in the order of 1.5 million to one.

Different assumptions
The model inputs can readily be adjusted for different assumptions about occupancy. For example, if the number of performances were doubled, strengthening benefits would increase by just under 75 percent (assuming there was no related increase in the number of permanent workers).

The model could also be refined in a number of ways. For example:

- By taking account of the Opera House ground conditions (these are not as favorable as assumed in the GNS data, which assume average ground conditions). This would increase the benefits.
- Adjustments could be made to the assumptions about earthquake return periods, and the probability of serious damage/collapse to take some account of uncertainties around the these numbers, particularly for the return times of the largest earthquakes. There is no right way to do this but a reasonable approach could be to double or treble the respective probabilities. However, even if we were to make some more conservative adjustments, and increased the benefits by a factor of 5, to 1.5 percent of the cost, the fundamental message from the analysis remains the same. The costs far outweigh the benefits.

What about Christchurch?
One objection to the probabilistic analytical approach to decision making presented above is that the Christchurch "proves" that you can't rely on estimates about the frequency of earthquakes. The argument goes "Christchurch was meant to be low risk but was hit by an unknown quake so it is likely that a big quake could anywhere". The facts here are as follows:

- Christchurch was regarded as having medium seismic risk and part of that assessment was based on an allowance for unknown fault lines.
- The size of the quake, 6.3 on the Richter scale, was consistent with the model used to assess Christchurch seismic risk.
- What was unusual were the forces generated by the quake on a relatively small part of Christchurch. These were some of the strongest forces recorded in an urban area and can be explained by the shallowness and direction of the quake, and the particular geology of the area, which amplified the forces from what was not an especially large earthquake.

- Seismic hazard assessments for New Zealand were re-evaluated after the quake and, we understand, that no material changes have been made outside the Canterbury area.
- Given the magnitude of the forces experienced the building stock performed well, perhaps better than expected, and would not call into question the GNS model of the likelihood of severe damage or collapse in severe earthquakes.

A single event doesn't invalidate seismic seismic hazard models any more than a single plane crash proves that flying is unsafe.

In our view the probabilistic cost-benefit approach to decision making, that captures the best scientific evidence, is to be strongly preferred to the NZSEE approach, which is echoed in the Review, that amounts to little more than an unsupported assertion that buildings rated at less than 34%NBS present an "unacceptable" risk.

A rational policy approach would be to not proceed with strengthening the Opera House if the costs outweighed the benefits. It is very clear under any reasonable set of assumptions that the costs of strengthening far outweigh the costs.

Conclusions

Some firm conclusions can be drawn from the analysis:

- The suggestion in the Review that life-safety concerns could be mitigated by placing a limit on the number of shows over a given period of time should not be considered. The analysis clearly shows that life-safety risk for a single performance is extremely small and that there is no rational basis for limiting the use of the Opera House.

- The conclusions drawn from the detailed seismic assessment are misleading. The Review states "*The assessments are indicating* ***serious shortcomings*** (our emphasis) *in terms of structural adequacy of these buildings to the point where elements are believed to pose a threat to life."*(p. 7) All buildings pose a threat to life if the earthquake is big enough. The issue is how big is that threat. The tone of the statement is that the threat is a significant one, but that is simply not consistent with the evidence.

- The original LHT advice (back in 1998) that substantial strengthening of the buildings would not justified was sound and is still sound. In 2004 LHT reaffirmed their view that the buildings are the buildings could be expected to resists very large seismic events although they would not be as resistance as modern buildings and added "*It is not normally seen as feasible or economically justifiable to adjust their behavior to a more ductile form by the addition of more structural members."* p.30. The LHT view is justified by the cost-benefit analysis.

A theme running through the Review is that while the LHT judgment might have been all right for its time, it has been overtaken by progress in the assessment of risk. While there has been progress in a technical sense of assessing a buildings' seismic resistance, there has not been progress in the methodologies used to judge whether strengthening is warranted. Indeed our analysis strongly suggests that the strengthening advice based purely on the %NBS rating of a building is a major backward step.

Section four: Council processes

We do not have anything to add to the discussion of the Council's historical processes. What is most relevant is what it does now. We suggest the following:

- The Council should obtain independent advice on its legal obligations with respect to the strengthening of the buildings and on the earthquake-prone-building test it is applying to buildings in its jurisdiction.
- The Council should not rely exclusively on advice from engineers to decide whether the buildings need strengthening and to what level.
- If the Council still wishes to pursue a %NBS target then it should consider whether the buildings need to be stronger than equivalent private buildings as suggested by its consultants.
- The Council should obtain independent advice on the life safety risk posed by the buildings.