The flaw in the score

Risk sensitivity in the NZSEE %NBS methodology

December 2014

tailrisk economics

te maha hoki o nga pihikete

About Tailrisk economics

Tailrisk economics is a Wellington economics consultancy. It specialises in the economics of low probability, high impact events including financial crises and natural disasters. Tailrisk economics also provides consulting services on:

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

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Executive summary

It has been argued that the Tailrisk Economics critique of the New Zealand Society of Earthquake Engineering (NZSEE) building seismic risk framework is flawed because the report failed to understand that the framework was sensitive to the different levels of seismic risk in different regions. The argument is that the impact of differences in seismicity on risk is picked-up though different hazard, or Z-scores, factors.

This paper presents an assessment of the NZSEE framework risk sensitivity methodology that demonstrates that it is fundamentally flawed. It adjusts for just a small part of geographical differences in seismic risk.

We conducted a test of the life safety standards at the earthquake prone trigger point (33% of the new building standard) in Auckland and Wellington. We found that the risk of life threatening earthquakes in Auckland was 750 times less than in Wellington. The Z-score methodology attempts to compensate for this difference by setting a lower standard for building strength in Auckland than Wellington, but the effect is to offset the difference in earthquake risk, by a factor of just 3. It fails to compensate for the difference in seismic risk by a factor of at least 250.

As a consequence:

- The life safety standard for earthquake prone buildings in Auckland compared to those in Wellington is at least 250 times higher
- 33%NBS buildings in Auckland are much less risky than 100% NBS buildings in Wellington
- Buildings with the same percentage of new building standard (%NBS) assessments in different parts of the country will have very different risks
- NZSEE assessments that buildings in much of New Zealand are 'high risk' are objectively and demonstrably false.

The NZSEE risk assessment framework does not deliver logical and consistent results.

This framework has been supported by the Ministry of Business Innovation and Employment. The Ministry needs to either demonstrate that the NZSEE framework does work and delivers consistent risk assessments, or change its advice and withdraw their letter of support for the NZSEE framework. Similarly with the NZSEE. They should either demonstrate that their framework delivers consistent life safety assessments, or withdraw their earthquake risk grading system.

Part one: Critiques of 'Error Prone Bureaucracy'

Since releasing our report 'Error Prone Bureaucracy' in April 2014, we have had many positive responses to the analysis in the document. The one criticism,[1] which was conveyed to us when we appeared before the Local Government and Environment Select Committee, which was considering the amendment to the earthquake prone buildings sections of the Building Act, was that we had not understood, or properly taken into account, that the NZSEE framework was in fact risk sensitive.

We have heard from other sources that this criticism has been used as an excuse to ignore our overall critique of the NZSEE framework for identifying earthquake prone buildings.

One of our key criticisms of the NZSEE framework was that it did not consistently and logically account for the risk of buildings in regions that have different seismicity. Notably, buildings that were identified as being 'earthquake prone' in Auckland were safer, by a very wide margin, than buildings with the same %NBS rating in seismically active Wellington.

In a logical and coherent regime, the risk of buildings in different regions with the same %NBS should be similar. Our argument was that the cost benefit report produced for the Ministry showed that this could not be true.

In our report we attempted to understand the why there was such a big difference between the relative risks captured in the cost benefit analysis, and those implicit in the NZSEE framework. One explanation that we identified, was that a lower limit on the size of a moderate earthquake was introduced into the NZSEE framework to artificially increase the risk for Auckland.

However, we suspected that there was much more to it that, but had not identified the precise source of the problem at the time the Error Prone Bureaucracy report was finalised. It turns out that the flaw in the NZSEE framework is obvious, very significant, and we hope, not too difficult to explain.

Our explanation is set out in the next section.

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[1] The paper has been critically reviewed by MBIE. A review of documents obtained under the Official Information Act showed that MBIE did not find any errors in the paper. A copy of the MBIE review and our comments on errors that MBIE claimed to have found are set out in Appendix A.

Part two: The flaw in the score

Three uncontroversial propositions

We start with three uncontroversial propositions about the seismic risk of a building.

1. **The relevant risk is the risk to life**
   This risk can be expressed in terms of the probability that a building occupant will be killed over the course of a year. An equivalent expression, which is easier to read for low risk buildings, is the number of years it would take, on average, before the occupant will be killed in an earthquake.

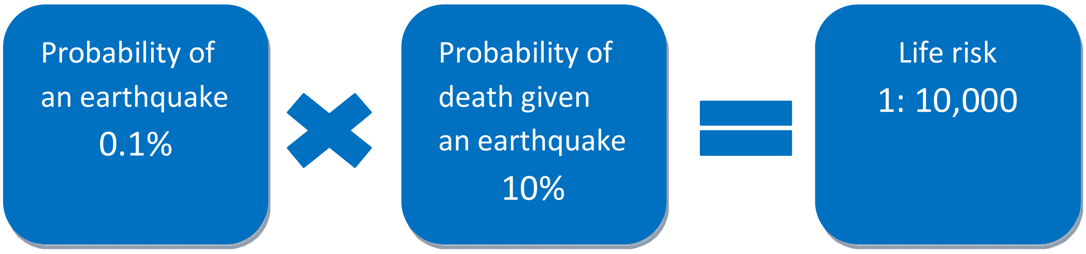
2. **The risk to life is the product of the probability that there will be an earthquake that can cause deaths, and the probability that an occupant will be killed if there is a life threatening earthquake**
   In most locations deaths can occur over a range of earthquake magnitudes, but to illustrate the concept it is easier to think about one type of 'killer' earthquake. We assume that this earthquake has an average return time, in location A, which has high seismicity, of 1,000 years. Equivalently, the probability that a killer earthquake will occur over a year is 0.1 percent.

   The probability that the occupant will die, if there is a killer earthquake, will be a function of the strength of the building. The stronger the building is less likely it is to collapse.

   The likelihood of death, given a killer earthquake, will also be a function of the type of building. The probability of death, if a building collapses or is badly damaged is significantly higher, for example, in a modern high-rise building than in an unreinforced masonry building. However, to explain how geographical risk sensitivity works in the NZSEE model, it simplifies matters to abstract from this complexity and assume that casualty rates, given a collapse, are common across all buildings.

   To illustrate the life safety calculation, if the probability of a killer earthquake is 0.1 percent (a return period of 1,000 years) and the probability of death in the event of a killer earthquake is, say, 10 percent, then the life risk posed by the building is 0.001 times 0.10 = 0.0001 or 0.01 percent. That is, the life risk is 1:10,000 years.

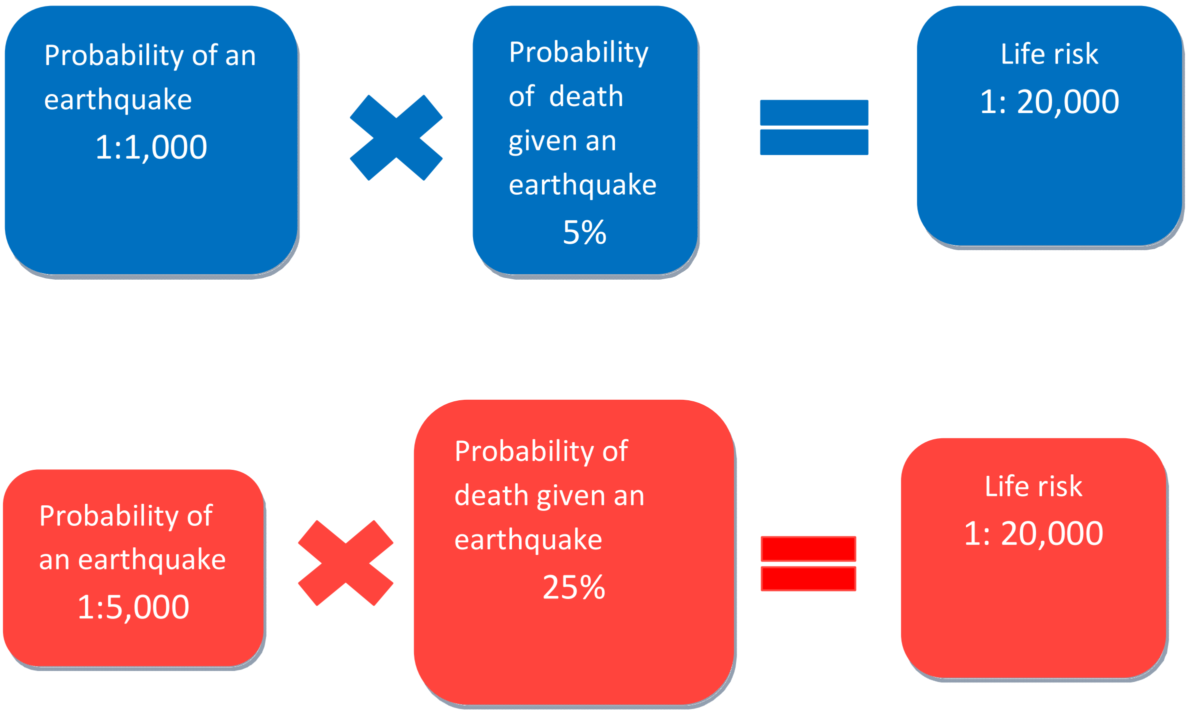
Figure 1 — Calculating life risk



3. **The probability of an earthquake and the likelihood of death given an earthquake can be combined in different ways to generate the same risk outcome**

   For example, a building in a city that has a 1,000:1 chance of a killer earthquake, which is relatively robust with a 5 percent chance that an occupant will be killed if there is an earthquake, has the same risk (1:20,000) as a weaker building (with a 25 percent chance of death) in a city with a 5,000:1 chance of the same quake.

Figure 2 — Equivalent risks



How does the NZSEE framework account for geographical differences in seismic risk?

In the NZSEE (2006) framework geographical differences in seismic risk are captured by applying a hazard factor, the Z score, to the raw assessment of building strength.

The Z factor is described by McVerry (2002) in the following terms. "The mapped hazard factor for scaling normalized code spectra is defined as 0.5 times the 500-year magnitude-weighted SA (0.5s) value for the shallow-soil class except where the minimum and maximum Z-values govern".

Essentially what is happening here, is that the metric for thinking about relative risk is switched from the more intuitive relatively probability of earthquake occurrence, to a statement about the relative force of an earthquake with the same probability of occurrence.

We were unable to locate a document that clearly explains the conceptual reasoning behind this approach and in particular, how the Seismic Risk Committee of the New Zealand Standards Association calibrated the current Z factors from the available evidence. We have been reliably informed that there is no public documentation of this process.

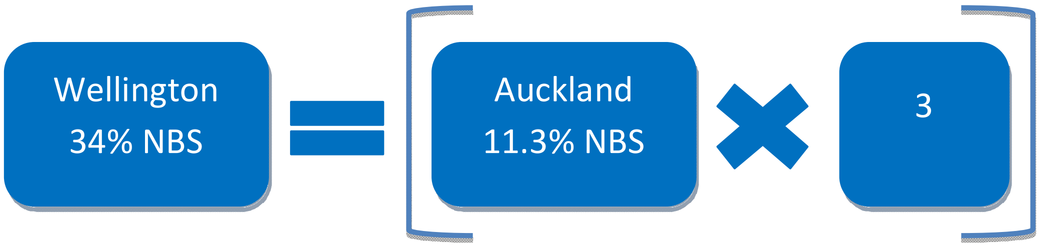
Fortunately, to understand the impact of the Z score on the assessment of the Auckland's relative seismic risk in NZSEE (2006), it is not necessary to have access to the detail behind the calculations. It is just necessary to know the impact on the %NBS calculation in the framework. In the Initial Evaluation Procedure methodology the Z score has the effect of multiplying the %NBS by a factor of three. In the full model, the impact will vary with building characteristics and ground conditions. A set of NBS calculations for identical Auckland and Wellington buildings which shows the impact of the hazard factor is set out in Appendix 3A of NZSEE (2006). Some of the tables are reproduced in Appendix C below. The tables show shows the ratios of Auckland to Wellington %NBS for 1935-65 buildings, which are of most interest from a strengthening perspective, range from about 2.5 to 3.

In this analysis we have taken the upper end of the range and have assumed that the impact of the hazard factor on Auckland buildings %NBS is three.

That means that if an Auckland building receives a 'raw' rating of 11.3 percent of NBS this rating is multiplied by 3 to generate a final rating of 34 percent. The building passes the Earthquake Prone Building trigger point and is not earthquake prone.

This does not mean that the Auckland building is as strong as a Wellington building that is also rated at 34 percent. It will not perform as well in a strong earthquake. It just means that some account has been taken of the different seismicity of the two cities, and that the Auckland percentage assessment has been made against the lower Auckland new building standard.

Figure 3 — Auckland and Wellington 34% NBS



Evaluation of the NZSEE (2006) methodology

If the NZSEE (2006) methodology works then the Auckland building rated at 34%NBS should have the same life safety risk as a Wellington building that is also rated at 34%NBS. We test that proposition by estimating the relative life safety risk of the Auckland and Wellington buildings.

The ratio three does not directly tell us anything about the two components, explained above, in the life risk calculations for Wellington and Auckland buildings. To understand the meaning of the ratio we have to translate what is a relative strength figure into risk terms.

There are two steps here:

One: Translate relative building strength to a relative collapse likelihood

We need to know how much more likely an Auckland building with a strength of 11.3 % NBS is to collapse than a Wellington building with a strength of 34% NBS.

There are two possible sources of information on this relationship.

The first is the NZSEE's assessment of the relationship between risk of building collapse, or substantial damage, and building strength. According to table 2.1 in NZSEE (2006), a building with a strength of less than 20% NBS has more than 25 times the risk of a 100% NBS building compared to 10 times the risk of a 33 % building. This suggests a ratio of 2.5. A more precise graphical depiction of the relationship is shown in Appendix B. (Source MBIE). This shows a building with an 11.3% NBS has about three times the likelihood of collapse, if there is a severe earthquake, than a building rated at NBS 34%.

Table 1 — NZSEE (2006) % NBS and risk

Percentage of NBS	Relative risk (approx.)
>100	<1
80-100	1-2 times
67-80	2-5 times
33-67	5-10 times
20-33	10-25 times
<20	>25 times

The second set of information is a graph that shows the relationship between building types and the probability of collapse for different building types in earthquakes of different magnitudes. The graph was presented in the Ministry's expert report 2012 (Taig) that was commissioned for the Seismic Strengthening consultation. The figure shows a span of about 1:10 from the weakest to strongest building types, but does not specifically depict the relationship by % NBS. However, the information is consistent with the 1:3 ratio in the NZSEE's assessment.

Two: Assess the probability of large earthquakes

To assess the relative risk of large earthquakes that could cause fatalities in Auckland and Wellington, we have taken the figures presented in the 2012 Martin Jenkins report. These were provided by GNS Science for the MBIE's 2012 cost benefit study.

Note that no figures were provided for MM10 or MM11 quakes for Auckland. This was probably because GNS Science either thought that earthquakes of these magnitudes were not possible and that the theoretical, continuous, earthquake likelihood distribution was truncated at the top end, or that the likelihoods were so small as not to be worth considering for a cost benefit analysis.

We have assumed that there is a continuous distribution, and that MMI0 and MMII quakes have return times that are respectively 10 and 100 higher than the MM9 return time. A theoretical curve would generate even higher numbers.

Note that our continuous distribution assumption increases the expected fatality rate for Auckland presented in the Martin Jenkins report by a factor of nearly three. The expected annual number of earthquake fatalities in Central Auckland is just 0.00067 if only MM9 earthquakes are taken into account. This increases to 0.0019 once some positive probability is placed on the occurrence of MM10 and MM11 events. The average death rate is still extremely low.

Table 3 — Return times calculations

Wellington			Auckland			
Earthquake	Return times yrs.	Total Expected deaths Annual	Earthquake	Return time years	Total Expected deaths Annual	Ratio of return times Auck./Wgtn.
MM8	120	0	MM8	7400	0	62
MM9	400	0.073	MM9	120,000	0.00067	300
MM10	1500	0.253	MM10	1,200,000	0.00089	800
MM11	8500	0.179	MM11	12,000,000	0.00019	1412
Total		**0.505**			**0.0019**	**745**

The next step is to calculate the ratio of return times for Auckland and Wellington for each event type. Table 3 above shows that these ratios range from 300 for MM9 to 1,412 for MM11 earthquakes. These ratios are then weighted by the contribution of each earthquake type to the Auckland expected fatality rate to generate an overall ratio. This ratio is 745.

Three: Calculate relative risk

We can now calculate the relative risk of the Auckland and Wellington buildings that have a NBS 34% rating using the NZSEE framework.

Setting Wellington risk at 1, the Auckland risk is calculated as:

> 1/745 - the difference in the probability of a fatal earthquake
>
> *times*
>
> 3 - the relative difference in the probability that a building will collapse if there is an earthquake
>
> **Equals .004 times the Wellington figure**

Figure 4 — Auckland 34% Building Relative life risk

If the NZSEE is right and the hazard factor, or Z-score, compensates for differences in seismicity in different regions, and ensures that 34% NBS assessments define a common standard of risk, then the Auckland relative risk figure should be one. It is clearly not. The Auckland 'earthquake prone building' standard is 248 times safer than the Wellington 'earth quake prone building' standard. The relative Z score of three adjusts for just a small part of the difference in seismic risk.

Simply put, the logic behind the relative Z-score approach for compensating for differences in seismic hazard for existing buildings is fundamentally flawed.

Why is the Z-score so wrong?

Three factors contribute to the huge mis-statement of relative risk.

A floor on seismicity was applied to Auckland

The actual seismic risk in Auckland is not used. Rather, as demonstrated in our Error Prone Bureaucracy paper, a higher level of risk is artificially applied.

Calibration was conservative

More generally, we are informed, the Seismic Risk Committee has taken a conservative approach to calibrated the Z-scores. They are set at a lower level than would be justified by the seismic risk evidence the Committee considered. The rationale was that in a new building standard this conservatism does not matter too much, because it would have only a minor impact on new Auckland building costs. The same logic, obviously, does not translate across to the existing building strengthening framework, where even apparently small tweaks in a calibration can have very serious economic consequences.

The focus was on the wrong earthquake magnitudes

Most importantly, assessments of relative seismicity that might be relevant to the new building standard, are not appropriate for the existing building standard. With the new building standard, the concern is with building damage as well as life safety, and relative seismicity has largely been evaluated with respect to the relative frequency of shocks (over the MM5-MM8 range- for example see Dowrick (1991)) that will present a risk of damaging buildings.

With the existing building standard, the concern should be just with life safety. The assessment of relative seismicity, therefore, should be based on the relative frequency of those earthquake events that present a material risk to life. That is, the standard should, as we have done, focus on MM 9 to 11 earthquakes. The difference in the focus is extremely important, as the measure of relative seismicity will depend on the size of the earthquakes.

To illustrate from table 2, MM8 events are 61 times more frequent (7400/120 years) in Wellington than in Auckland. MM9 events on the other hand are 300 times more frequent. Thus the relative risk of a quake in Wellington is five times higher for a MM9 event than a MM8 one. We do not have the data to hand, but it should be readily apparent that an assessment of relative seismicity using data centered on MM7 events will be much lower than one centered on MM10 events.

Part three: Implications

The ‘flaw in the score’ that we have identified strikes at the core of the NZSEE risk measurement framework. It means that:

- The % NBS calculations in all of the regions whose seismicity falls between the Auckland and Wellington levels will also reflect quite different levels of risk from the Wellington base figure.
- The NZSEE risk grading system, which is based on % NBS scores, is fundamentally flawed. All New Zealand buildings with a %NBS score of 33 or less are described as risky. This is obviously not the case. If we were to assume, conservatively, that the life safety risk of a Wellington 33% NBS building was 1:100,000, then an Auckland 33% NBS life safety risk would be 1:25,000,000. While some allowance could be made for uncertainties in this calculation, under any set of reasonable assumptions the Auckland life safety risk would still be well below the 1:1,000,000 level which is a benchmark figure for ‘riskless’.
- The NZSEE designation of 33% NBS buildings in Auckland, and in many other New Zealand cities, as ‘risky’ is demonstrably and objectively false.

A frequent criticism of the NZSEE framework is that it is a ‘one size fits all’ system that does not take account of geographical differences in seismicity. MBIE clearly thinks that it is appropriately risk sensitive and has advised their Minister accordingly. When the Bill was introduced, the then Housing Minister went to some lengths to make this point.

We think this paper settles the issue. The critics are right. MBIE needs to either demonstrate that the NZSEE framework does deliver consistent risk assessments, or change their advice and withdraw the letter that supports the NZSEE framework.

Similarly with the NZSEE. They should either demonstrate that their framework delivers consistent life safety assessments or withdraw their earthquake risk grading system.

References

Dowrick (1992) 'Seismic hazard estimates for the Auckland area, and their design and construction implications', Bulletin of the New Zealand Society for Earthquake Engineering, vol. 25 No. 3

Matuschka T., Berryman K.R., O'Leary A.J., Mulholland W.M. and Skinner R.J. (1985) 'New Zealand seismic hazard analysis', Bulletin of the New Zealand Society for Earthquake Engineering, vol. 18 No. 4

NZSEE (2006) 'Assessment and Improvement of the Structural Performance of Buildings in Earthquakes'

Tailrisk Economics (2014) 'Error Prone Bureaucracy'

Appendix A: MBIE Critique of ‘Error Prone Bureaucracy’

The document “Error Prone Bureaucracy’ was released on 2 April 2014. MBIE’s comments were on an earlier draft that they obtained on 25 March without our knowledge or consent. The earlier draft was not substantively different from the final.

The following is the full MBIE report on the document, our comments, together with a report to the Chief Executive in response to his request to be told what his staff thought of the points made.

There are no other documents that analyse the report.

(12)

Tailrisk Economics Report March 2014

Main themes raised by Mr Harrison

Issues Mr Harrison has with the definition of 'moderate earthquake' and defining an 'earthquake-prone building' include:

- in his opinion, the definition should focus on the likelihood of a building collapsing
- he believes the current definition and the way it is applied captures too many buildings
- he recommends the way buildings are defined and assessed as earthquake-prone should be changed
- he asserts the New Zealand Society for Earthquake Engineering guidelines on how to assess whether a building is earthquake-prone operationalise the legal threshold and could be interpreted as setting the earthquake-prone building threshold, in practice
- he believes the way building are assessed as earthquake-prone does not reflect the legislation
- he considers the original legislation and policy settings flawed.

Mr Harrison contends that risks are incorrectly interpreted:

- he notes the risk to life from earthquakes is less than the risk to life from other risks
- different areas have different risk of earthquakes – he believes this has not been adequately accounted for.

Mr Harrison's criticisms of the Ministry's analysis include:

- his view that cost-benefit analysis is the most appropriate tool for informing the policy for earthquake strengthening requirements
- his contention that the problem is poorly defined
- his opinion that the Ministry's cost-benefit analysis is inadequate and/or inadequately considered by policy makers
- his belief that the impact of the proposals on the parties affected by them, especially building owners, was not sufficiently considered
- in his opinion, the analysis is not evidence based and did not consider alternative options (he has specifically identified a lack of options for changing the definition used to identify earthquake-prone buildings)
- his view is that the Regulatory Impact Statement was therefore inadequate
- his belief that Treasury's review of the Regulatory Impact Statement was inadequate.

Mr Harrison has issues with the interface between the Health and Safety legislation and the earthquake-prone building provisions in the Building Act, including:

- in his opinion, building owners could be prosecuted if they do not strengthen their earthquake-prone buildings.

Mr Harrison has issues with the consultation undertaken, including:

- his assertion that the 2012-13 review did not discuss the impacts of the proposals with affected parties
- his belief that the review did not intend to review the threshold for defining an earthquake-prone building
- in his opinion, the review was not comprehensive or genuine (a 'sham')
- his belief that the consultation in 2004 on the regulations defining 'moderate earthquake' was not wide enough.

Mr Harrison's key recommendations are:

- define 'earthquake-prone' more precisely in legislation
- the Government should redevelop its earthquake-strengthening standards and policies
- an independent authority should do this analysis
- the Health and Safety Act should be amended so death or injury in an earthquake are not grounds for prosecution under this Act
- grading the earthquake risk of a building according to their estimated strength relative to the new building code should be replaced by a measurement system that directly informs occupants of their life safety risk and compares this to other risks
- the New Zealand Society for Earthquake Engineering should withdraw its earthquake strengthening recommendations
- territorial authorities should withdraw earthquake-prone classifications that are not based on the legal definition of earthquake-prone
- the Government should fund most of the strengthening work if it progresses its proposals
- the Government should strengthen buildings in a much shorter timeframe than that proposed, in the very few localised areas where this would be a net benefit.

Examples of factual omissions and inaccuracies

Consultation on the 2004 regulations

- Mr Harrison asserts that there was targeted consultation only on the discussion document for the regulations
- response: there was targeted consultation and the document was released for public comment on the interim website (established while the 2004 Building Act was being developed but before the Department of Building and Housing was formed)

Changing the definition of 'moderate earthquake'

- Mr Harrison discusses how a change in the technical standards changes the definition of 'moderate earthquake' and therefore increases the strengthening threshold – in his opinion, this should be an explicit policy decision
- response: the Bill sets the definition of 'moderate earthquake' to a fixed point in time in order to ensure that any changes are made in a transparent manner that includes public consultation

International comparison

- Mr Harrison contends that no other country has across the board national earthquake strengthening standards
- response: in order to compare policies across different jurisdictions, analysts must consider whether the building regulatory systems are set and delivered at state and/or municipal level – there will be few national requirements where this is the case. In the United States, building regulation is a state and/or municipal matter, and states with higher seismicity generally have mandatory strengthening requirements.

(18)

Out of Scope [redacted]

From: [redacted]
Sent: Thursday, 3 April 2014 9:42 a.m.
To: [redacted]
Subject: FW: Earthquake prone buildings

From: [redacted]
Sent: Thursday, 3 April 2014 8:42 a.m.
To: David Smol
Cc: [redacted]
Subject: RE: Earthquake prone buildings

Good morning David,
My team have analysed the report and provided the attached advice to Minister Williamson's office, who in turn provided comment to the Herald in response to the Tailrisk report.

Our advice was that it appears to be a personal view that the current system is already excessive and the proposed changes are unwarranted. Mr Harrison also criticised the consultation process for the review and the analysis underpinning the proposals.

In some cases, his assertions are misleading or incorrect. For example, he discusses the way in which the definition of 'moderate earthquake' changes when the relevant engineering standards are revised. However, he does not acknowledge that the Bill sets the definition of moderate earthquake to a specific point in time in order to make the process of changing this definition more open and transparent. Another example is his assertion that the consultation for the 2004 regulations setting out the definition of 'moderate earthquake' was targeted to specific groups only – we have no reason to believe that they were not publically released for comment in addition to this targeted consultation.

We advised that the Minister took the approach of reaffirming his key messages rather than rebutting every point Mr Harrison made. We also recommended the Minister comment that people have another opportunity to submit their views on the Bill through the select committee process.

Regards,

[redacted]

[redacted]

Comments on ' factual omissions and inaccuracies'

1.Consultation on the '2004' regulations

"Mr. Harrison asserts that there was targeted consultation only on the discussion document for the regulations".

Comment

- The regulations were passed in 2005 not 2004. This is the Ministry's error.
- The reviewer agreed that there were targeted consultations but said that the document was released for consultation on the website. We do not agree with the implication that putting a document on a website is a serious way of consulting with a large number of potentially affected building owners who would not be regularly monitoring the website. We were unable to verify that the document did appear on any website and we note that the claim that there was broader consultation was amended in responses to the Minister and the Chief Executive of MBIE to 'we have no reason to believe that they were not publically released for comment in addition to this targeted consultation.'

2. Definition of moderate earthquake
"He does not acknowledge that the bill sets the definition of moderate earthquake…"

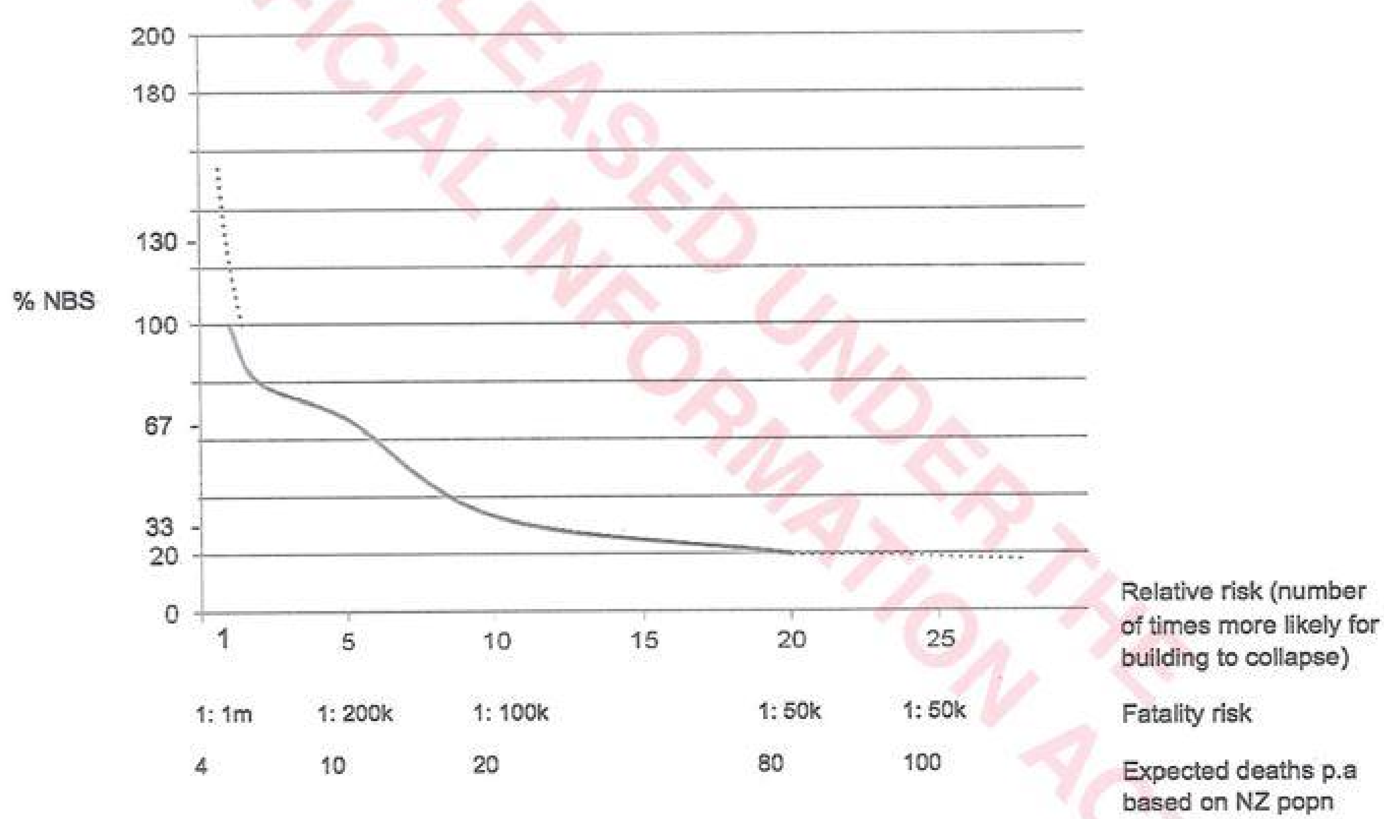
This is incorrect. We were aware that the calibration of moderate earthquake is in the bill. See page 49 of the report.

3.International comparison

Our statement that no other country has an across-the-board earthquake strengthening standards was not disputed.

Appendix B: %NBS and building collapse risk

Figure 1. New Building Standard (NBS) relative to risk of building collapse (and fatality risk)



Appendix C: NZSEE(2006) %NBS calcs.

WELLINGTON

μ	1.25	T = 0.4s	T = 1.0s	T = 2.0s
IL	2	Short	Interm	Long
Code Era	Soil Type	(%NBS)b	(%NBS)b	(%NBS)b
WGTN 1931-1935	A or B Rock	17	38	62
	C Shallow Soil	14	30	49
	D Soft Soil	11	19	30
	E Very Soft Soil	12	12	19
1935-1965	A or B Rock	14	30	49
	C Shallow Soil	11	24	39
	D Soft Soil	9	15	24
	E Very Soft Soil	10	10	16
1965-1976	A or B Rock	29	40	52
	C Shallow Soil	23	32	41
	D Soft Soil	18	20	25
	E Very Soft Soil	20	13	16
1976-1992	A or B Rock	86	108	138
	C Shallow Soil	69	86	110
	D Soft Soil	54	59	74
	E Very Soft Soil	54	38	48
1976-1984 Reinforced Concrete	A or B Rock	103	129	165
	C Shallow Soil	82	104	132
	D Soft Soil	65	70	89
	E Very Soft Soil	65	45	58
1992-2004	A or B Rock	78	75	63
	C Shallow Soil	73	91	73
	D Soft Soil	72	84	69
	E Very Soft Soil	72	54	44

WELLINGTON

μ	1.25	T = 0.4s	T = 1.0s	T = 2.0s
IL	3	Short	Interm	Long
Code Era	Soil Type	(%NBS)b	(%NBS)b	(%NBS)b
WGTN 1931-1935	A or B Rock	14	30	49
	C Shallow Soil	11	24	39
	D Soft Soil	9	15	24
	E Very Soft Soil	10	10	16
1935-1965	A or B Rock	14	30	49
	C Shallow Soil	11	24	39
	D Soft Soil	9	15	24
	E Very Soft Soil	10	10	16
1965-1976	A or B Rock	30	41	53
	C Shallow Soil	24	33	42
	D Soft Soil	19	20	26
	E Very Soft Soil	21	13	17
1976-1992	A or B Rock	94	119	152
	C Shallow Soil	75	95	121
	D Soft Soil	59	64	82
	E Very Soft Soil	59	42	53
1976-1984 Reinforced Concrete	A or B Rock	113	142	182
	C Shallow Soil	90	114	145
	D Soft Soil	71	77	98
	E Very Soft Soil	71	50	63
1992-2004	A or B Rock	70	68	56
	C Shallow Soil	66	82	66
	D Soft Soil	65	76	62
	E Very Soft Soil	65	49	40

WELLINGTON

μ	1.25	T = 0.4s	T = 1.0s	T = 2.0s
IL	4	Short	Interm	Long
Code Era	Soil Type	(%NBS)b	(%NBS)b	(%NBS)b
WGTN 1931-1935	A or B Rock	10	21	34
	C Shallow Soil	8	17	27
	D Soft Soil	6	10	17
	E Very Soft Soil	7	7	11
1935-1965	A or B Rock	10	21	34
	C Shallow Soil	8	17	27
	D Soft Soil	6	10	17
	E Very Soft Soil	7	7	11
1965-1976	A or B Rock	22	30	38
	C Shallow Soil	17	24	30
	D Soft Soil	14	15	19
	E Very Soft Soil	15	9	12
1976-1992	A or B Rock	86	108	138
	C Shallow Soil	69	86	110
	D Soft Soil	54	59	74
	E Very Soft Soil	54	38	48
1976-1984 Reinforced Concrete	A or B Rock	103	129	165
	C Shallow Soil	82	104	132
	D Soft Soil	65	70	89
	E Very Soft Soil	65	45	58
1992-2004	A or B Rock	55	53	44
	C Shallow Soil	51	64	51
	D Soft Soil	51	59	48
	E Very Soft Soil	51	38	31

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μ	1.25	T = 0.4s	T = 1.0s	T = 2.0s
IL	2	Short	Interm	Long
Code Era	Soil Type	(%NBS)b	(%NBS)b	(%NBS)b
1935-1965	A or B Rock	43	94	151
	C Shallow Soil	34	75	120
	D Soft Soil	27	46	74
	E Very Soft Soil	30	30	48
1965-1976	A or B Rock	60	83	106
	C Shallow Soil	48	66	84
	D Soft Soil	38	41	52
	E Very Soft Soil	42	26	33
1976-1992	A or B Rock	133	167	213
	C Shallow Soil	106	134	170
	D Soft Soil	84	91	115
	E Very Soft Soil	84	59	74
1976-1984 Reinforced Concrete	A or B Rock	159	200	256
	C Shallow Soil	127	160	204
	D Soft Soil	100	109	138
	E Very Soft Soil	100	70	89
1992-2004	A or B Rock	120	116	97
	C Shallow Soil	113	141	113
	D Soft Soil	111	130	106
	E Very Soft Soil	111	84	68

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μ	1.25	T = 0.4s	T = 1.0s	T = 2.0s
IL	3	Short	Interm	Long
Code Era	Soil Type	(%NBS)b	(%NBS)b	(%NBS)b
1935-1965	A or B Rock	43	94	151
	C Shallow Soil	34	75	120
	D Soft Soil	27	46	74
	E Very Soft Soil	30	30	48
1965-1976	A or B Rock	61	84	108
	C Shallow Soil	49	67	86
	D Soft Soil	39	41	53
	E Very Soft Soil	42	27	34
1976-1992	A or B Rock	146	184	235
	C Shallow Soil	117	147	187
	D Soft Soil	92	100	127
	E Very Soft Soil	92	64	82
1976-1984 Reinforced Concrete	A or B Rock	175	220	282
	C Shallow Soil	140	176	224
	D Soft Soil	110	120	152
	E Very Soft Soil	110	77	98
1992-2004	A or B Rock	108	104	87
	C Shallow Soil	102	127	102
	D Soft Soil	100	117	95
	E Very Soft Soil	100	75	62

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μ	1.25	T = 0.4s	T = 1.0s	T = 2.0s
IL	4	Short	Interm	Long
Code Era	Soil Type	(%NBS)b	(%NBS)b	(%NBS)b
1935-1965	A or B Rock	30	65	106
	C Shallow Soil	24	52	84
	D Soft Soil	19	32	52
	E Very Soft Soil	21	21	34
1965-1976	A or B Rock	44	61	78
	C Shallow Soil	36	49	62
	D Soft Soil	28	30	38
	E Very Soft Soil	31	19	25
1976-1992	A or B Rock	133	167	213
	C Shallow Soil	106	134	170
	D Soft Soil	84	91	115
	E Very Soft Soil	84	59	74
1976-1984 Reinforced Concrete	A or B Rock	159	200	256
	C Shallow Soil	127	160	204
	D Soft Soil	100	109	138
	E Very Soft Soil	100	70	89
1992-2004	A or B Rock	84	81	68
	C Shallow Soil	79	98	79
	D Soft Soil	78	91	74
	E Very Soft Soil	78	59	48