Proceedings of the Tenth Pacific Conference on Earthquake Engineering
Building an Earthquake-Resilient Pacific
6-8 November 2015, Sydney, Australia

Relative Risk of Non-code-compliant Buildings

M. Nayyerloo, W.J. Cousins & S.R. Uma

GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand

ABSTRACT: Percentage New Building Standard (%NBS) is used as a screening measure in New Zealand to identify weak structures which are deemed not to have adequate earthquake strength to survive moderate seismic events. This measure is increasingly being used in the property market as indicative of the level of safety of a building and consequently its suitability for long term lease by large commercial tenants actively seeking safer premises to accommodate their staff and customers. The %NBS seismic rating is also now commonly used in the insurance industry as indicative of construction quality for casualty and material loss modelling purposes. However, there is no quantitative method of comparing the risk of none-code-compliant buildings with their equivalent code-compliants or with other similar none-code-compliant buildings at different %NBS levels to enable utilising the already available seismic assessment information for better informed insurance casualty and material loss modelling. This paper proposes a simple method for quantifying and comparing the relative risk of a non-code-compliant building to a 100% code-compliant building of similar vulnerability class (structural form, material, height and design era). The resulting relative risk curves, which are functions of %NBS, are particularly useful for regional loss modelling where a large portfolio of buildings is involved and reviewing individual seismic assessment reports to assign suitable vulnerability classes is not possible.

1 INTRODUCTION

Changes to the New Zealand Building Act in 2004 have resulted in all local authorities being required to adopt a policy to identify earthquake-prone buildings. The evaluation methodology involves an initial screening process which uses the Initial Evaluation Procedure (IEP) prescribed within the earthquake risk buildings recommendations (commonly known as the red book) published by the New Zealand Society for Earthquake Engineering (NZSEE) and endorsed by the former Department of Building and Housing (NZSEE 2006). The NZSEE introduced a system for grading buildings according to their assessed seismic performance compared to the current code requirements and expressed as the Percentage of New Building Standard (%NBS). According to this grading, a building is considered to be low risk if it scores at least 67% or 2/3 of the current code (Grades A or B), moderate risk if scores below 2/3 but above 1/3 (Grade C), and high risk if it meets less than 1/3 of the current code requirements (Grades D or E). A Grade A or B building is assumed to have less than 5 times the relative risk of a current code compliant building, a Grade C building has 5 to 10 times the relative risk, and Grades D or E have more than 10 times the relative risk. High risk buildings are required to either be strengthened or abandoned under the Building Act and moderate or low risk buildings are considered to be acceptable legally although improvement is encouraged.

The %NBS measure is increasingly being used in the property market as indicative of the level of safety of a building and consequently its suitability for long term lease by large commercial tenants actively seeking safer premises to accommodate their staff and customers. Many large tenants have put internal health and safety regulations in place that prohibit them from occupying less than 67% NBS premises. The %NBS seismic rating is also now commonly used in the insurance industry as an indication of construction quality for casualty and material loss modelling purposes (e.g. %NBS>67 sound, otherwise deficient). However, there is no quantitative method of comparing the risk of none-code-compliant buildings with their equivalent code-compliants or with other similar none-code-compliant buildings at different %NBS levels to help better inform such decisions and to enable utilising available seismic assessment rating information for better informed insurance casualty and material loss modelling. The relative risk curve provided in the NZSEE red book is a) only a qualitative assessment of the relative risk, predominantly based on expert judgment and b) is meant to provide an indication of the relative risk to life as opposed to physical damage.

This paper proposes a simple method for quantifying and comparing the relative risk of non-code-compliant building with a 100% code-compliant building of similar vulnerability class (structural form, material, height and design era). Two aspects of risk are considered: risk to life and risk to building. Risk due to downtime or interruption to business was not part of this study.

The resulting relative risk curves, which are functions of %NBS, are particularly useful for regional loss modelling where a large portfolio of buildings is involved and reviewing individual seismic assessment reports to assign suitable vulnerability classes is not possible. In such cases, suitable vulnerability classes could be assigned to the modern code-compliant classes of buildings present in the portfolio, seismic performance of which is usually better understood compared to older non-code-compliant buildings, and then the vulnerabilities of remaining buildings could be assesed relative to the modern code-compliant buildings of same class using their %NBS and the relative risk curves derived.

2 RELATIVE RISK

2.1 Annual exceedance probability (AEP) approach

One way of looking at relative risk is to compare the hazard levels that buildings at different %NBS have been designed to and compare the respective annual exceedance probabilities of the hazard levels. Table 1 lists the relative risk factors calculated as ratios of AEPs for different %NBS levels over the AEP of a code-compliant building at 100% NBS. This approach is similar to the approach taken by the NZSEE.

Table 1. Relative risk factors from the AEP approach

Return Period (years)	NZS1170.5 Return Period Factor (R)	%NBS	AEP	Relative Risk
2500	1.8	180	0.0004	0.19
2000	1.7	170	0.0005	0.24
1000	1.3	130	0.0010	0.48
500	**1.0**	**100**	**0.0021**	**1.00**
250	0.8	75	0.0040	1.90
200	**0.7**	**67**	**0.0050**	**2.38**
100	0.5	50	0.0100	4.75
50	0.4	35	0.0200	9.50
47	**0.3**	**33**	**0.0213**	**10.11**
25	0.3	25	0.0400	19.00
20	0.2	20	0.0500	23.75
10	0.1	10	0.1000	47.51

2.2 Damage ratio based approach

Another way of looking at relative risk of buildings at different %NBS is to compare the likely damage and consequent repair costs using empirical fragility models developed for different building classes defined by a combination of the building structural system, material, age, height and quality of construction (Cousins 2004; King and Bell 2009). Fragility models relate shaking intensities to expected levels of damage and loss for different classes of building (Figure 1). Calculating and comparing damage ratios for shaking intensities derived from the National Seismic Hazard Model

(Stirling, McVerry et al. 2012) for corresponding return periods to each %NBS level yields an understanding of the relative risk of buildings at different %NBS.

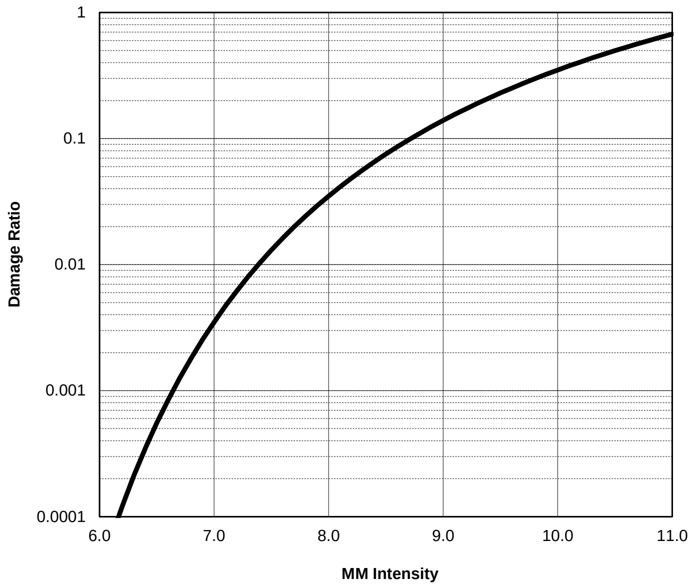

Figure 1. Example of empirical fragility models for sound low-rise brick masonry shear wall structures ('MM Intensity' is the Modified Mercalli Intensity and 'Damage Ratio' is defined as the ratio of repair cost over replacement cost).

Table 2 lists the shaking intensities in New Zealand Modified Mercalli (MM) scale (NZSEE 1992; Dowrick 1996; Hancox, Perrin et al. 2002) for return periods corresponding to each %NBS level for Auckland, Christchurch and Wellington as representatives of low, medium and high seismicity areas in New Zealand. Shown in the table are also the average damage ratio based relative risk (DR-RR) factors calculated for the 35 different building fragility classes defined in King and Bell 2009. The underpinning building fragility models used are mainly based on data from above MM7 shaking intensity zones in the past earthquakes, therefore the average factors were calculated for only the above MM7 range to avoid uncertainties associated with extrapolation in the fragility models for the lower shaking intensity range. Also in the table are the averages of the DR-RR factors for the three seismicity zones

2.3 **Fatality ratio based approach**

Risk can also be perceived as the relative probability of death in past earthquakes in buildings at different %NBS levels. Empirical casualty models developed based on the actual performance of different classes of building in earthquakes in New Zealand and overseas and fatality rates in them provide fatality rates for different levels of shaking (Spence, Pomonis et al. 1998; Cousins 2004; Cousins, Spence et al. 2008; King and Bell 2009), which then could be compared to arrive at a relative risk factor.

Similar to the procedure adopted to calculate damage ratio based relative risk factors, fatality rates for the 35 building casualty classes defined by King and Bell 2009 were calculated for the MM intensities corresponding to each %NBS level as in Table 2 and averaged to arrive at fatality ratio based relative risk (FR-RR) factors for Auckland, Christchurch and Wellington. The results are shown in Table 2. In the table there are also the overall average factors for the three seismicity zones. Similar to before, the results were limited to only above MM7.5 to avoid huge uncertainties in the lower shaking intensity part of the casualty models used.

Table 2. Relative risk factors from the damage ratio and fatality ratio approaches (Christchurch MMIs do not include the enhanced seismicity due to the Canterbury Earthquake Sequence).

Return Period (years)	%NBS	MMI (WLG)	MMI (CHC)	MMI (AKL)	DRRR (WLG)	DRRR (CHC)	DRRR (AKL)	DRRR (Avg)	FRRR (WLG)	FRRR (CHC)	FRRR (AKL)	FRRR (Avg)
2500	180	10.3	8.5	7.5	0.39	0.36	0.30	0.35	0.12	0.13	0.12	0.12
2000	170	10.2	8.4	7.4	0.42	0.40	0.39	0.40	0.14	0.16	--	0.15
1000	130	9.7	8.1	7.0	0.60	0.61	--	0.61	0.32	0.38	--	0.35
500	**100**	**9.2**	**7.8**	**6.6**	**1.00**	**1.00**	**--**	**1.00**	**1.00**	**1.00**	**--**	**1.00**
250	75	8.6	7.5	6.2	1.92	1.84	--	1.88	3.99	3.12	--	3.56
200	**67**	**8.4**	**7.4**	**6.1**	**2.43**	**2.31**	**--**	**2.37**	**6.48**	**--**	**--**	**6.48**
100	50	7.9	7.1	5.6	5.53	5.47	--	5.50	32.94	--	--	32.94
50	35	7.4	6.7	5.2	15.18	--	--	15.18	--	--	--	--
47	**33**	**7.3**	**6.7**	**5.2**	**17.08**	**--**	**--**	**17.08**	**--**	**--**	**--**	**--**
25	25	6.9	6.3	4.8	--	--	--	--	--	--	--	--
20	20	6.7	6.1	4.6	--	--	--	--	--	--	--	--
10	10	6.2	5.6	4.2	--	--	--	--	--	--	--	--

3 RESULTS AND DISCUSSION

Figure 2 compares the approximate relative risk factors for non-code-compliant buildings recommended by the NZSEE, which presumably have been derived following the AEP approach explained in Section 2.1, with the results from the damage and fatality ratio approaches. The results from the damage ratio approach broadly match with the relative risk factors from the AEP approach for the %NBS range between 100% and 50% but yield somewhat higher relative risk factors for buildings at lower than 50% NBS. Conversely, the fatality ratio approach yields relative risk factors which are considerably higher for the %NBS range below about 75%.

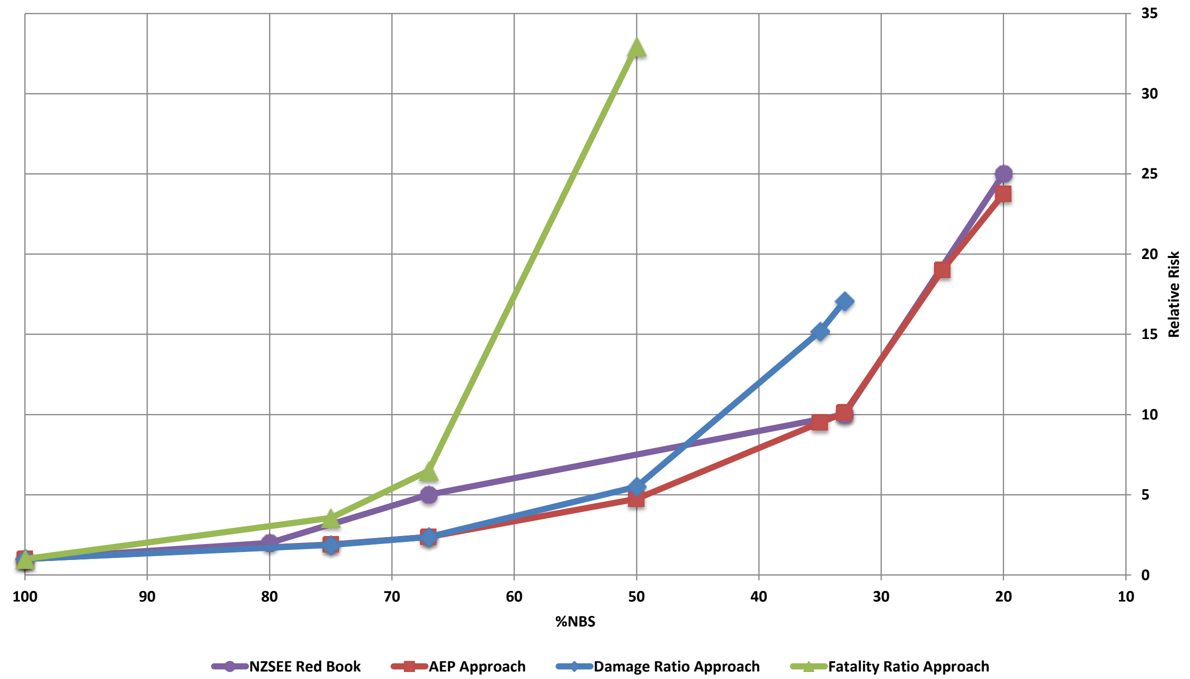

Figure 2. Comparison of the relative risk curves

4 CONCLUSION

The paper presented three different approaches to quantifying and comparing the relative risk of non-code-compliant building to a 100% code-compliant building of similar vulnerability class. The relative risk was evaluated from a) hazard level, b) life-safety and c) damage/loss points of view. The resulting relative risk curves, which are functions of %NBS, can help people make better informed decisions on the level of safety of non-code-compliant buildings and their likely level of damage/loss as a result of an earthquake for casualty and material loss modelling purposes. The results are particularly useful for regional loss modelling where a large portfolio of buildings is involved and reviewing individual seismic assessment reports to assign suitable vulnerability classes is not possible. The relative-risk factors derived showed that the NZSEE recommended relative risk factors almost matched the results of the hazard annual exceedance probability approach. However, compared to the damage ratio approach, the NZSEE factors are lower for the range below 50% NBS. The fatality ratio approach also resulted in higher factors than the NZSEE recommendations, particularly in the sub-75% NBS range.

5 ACKNOWLEDGEMENT

The funding provided by the New Zealand Ministry for Business, Innovation and Employment (MBIE) through the 'RiskScape' programme (www.riskscape.org.nz), which enabled this research is gratefully acknowledged. The authors are also thankful to GNS Science for providing travel grant through the 'Post-Earthquake Functioning of Cities' research programme. Helpful comments and suggestions provided by colleagues from GNS Science are also acknowledged. A summary of the results presented in this paper has already been presented as a poster at the 2015 New Zealand Society for Earthquake Engineering Conference, 10-12 April, Rotorua, New Zealand.

REFERENCES:

Cousins, W. J. (2004). Towards a first-order earthquake loss model for New Zealand. New Zealand Society for Earthquake Engineering Conference. Rotorua**:** Paper No. 29.

Cousins, W. J., R. Spence, et al. (2008). Estimated Casualties in New Zealand Earthquakes. Australian Earthquake Engineering Conference (AEES). Ballarat, Victoria, Australia.

Dowrick, D. J. (1996). "The Modified Mercalli Earthquake Intensity scale – Revisions arising from recent studies of New Zealand earthquakes." Bulletin of the New Zealand Society for Earthquake Engineering **29**(2): 92-106.

Dowrick, D. J. and D. A. Rhoades (2005). "Revised models for attenuation of Modified Mercalli Intensity in New Zealand earthquakes." Bulletin of the New Zealand Society for Earthquake Engineering **38**(4): 185-214.

Hancox, G. T., N. D. Perrin, et al. (2002). "Recent studies of historical earthquake-induced landsliding, ground damage, and MM intensity in New Zealand." Bulletin of the New Zealand Society for Earthquake Engineering **35**(2): 59-95.

King, A. and R. Bell (2009). RiskScape Project: 2004 - 2008, GNS Science Consultancy Report 2009/247**:** 162p.

NZSEE (1992). "Report of a Study Group of the NZSEE: A revision of the Modified Mercalli Seismic Intensity scale." Bulletin of the New Zealand Society for Earthquake Engineering **25**(4): 345-357.

NZSEE (2006). Assessment and Improvement of the Structural Performance of Buildings in Earthquakes. New Zealand Society for Earthquake Engineering. 336p.

Smith, W. D. (2002). "A model for MM intensities near large earthquakes." Bulletin of the New Zealand Society for Earthquake Engineering **35**(2): 96-107.

Spence, R. J. S., A. Pomonis, et al. (1998). Estimating human casualties in earthquakes: the case of Wellington. Sixth SECED (Society for Earthquake and Civil Engineering Dynamics) conference: Seismic Design Practice into the Next Century. Oxford, UK**:** 277-286.

Stirling, M., G. McVerry, et al. (2012). "National Seismic Hazard Model for New Zealand: 2010 Update." Bulletin of the Seismological Society of America **102**(4): 1514-1542.