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NEW ZEALAND SPECIFIC CONSEQUENCE FUNCTIONS FOR SEISMIC LOSS ASSESSMENT

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ABSTRACT

Quantitative seismic loss assessment has become an increasingly popular tool for evaluating the seismic performance of structures. The growth in popularity is largely in response to a desire to look beyond the traditional life safety performance objective and instead consider also economic losses and downtime due to earthquakes. A key step in the loss assessment calculation process is relating damage in both structural and nonstructural components to appropriate repair strategies and subsequently repair costs and repair times. This is achieved through the use of so-called consequence functions, which in this paper are derived specifically for the New Zealand context. Furthermore, a framework is established for other researchers and professional engineers to continue to build on and improve the initial dataset. It is shown that using New Zealand specific consequence functions can have a noticeable effect on estimates of expected annual loss when compared to a benchmark case using consequence functions from FEMA P-58. The opportunity is also taken to evaluate the impact of recent updates to the New Zealand National Seismic Hazard Model, with the results for a case-study building in Wellington indicating that the change in hazard has a far more significant effect on estimates of loss when compared to the choice of different consequence functions.

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INTRODUCTION

Historically, the focus of seismic design has been to prevent structural collapse and loss of life during earthquake ground shaking. The provisions of modern seismic design codes arguably achieve this objective, to a reasonable level of reliability, as observed, for example, during the 1989 Loma Prieta and 1994 Northridge Earthquakes. Both of these events had large magnitudes and struck close to populated areas but resulted in fewer than 100 fatalities [1]. Despite the limited loss of life, many deemed the performance of buildings during these earthquakes as unacceptable due to the substantial economic losses, with Northridge registering as the most expensive natural disaster in history at the time of its occurrence. This led to the rise of Performance-Based Earthquake Engineering (PBEE), which places greater emphasis on quantifying seismic performance through consideration of not just life safety but also repair costs and post-earthquake loss of function [2], the so-called three D's of "Deaths, Dollars and Downtime".

A similar scenario has been experienced in New Zealand over recent years, most notably with the 2011 Christchurch and 2016 Kaikōura earthquakes, which resulted in limited loss of life but significant disruption and economic losses. In response to an increased desire for improved building performance in future earthquakes, the Ministry of Building, Innovation and Employment (MBIE) has funded the development of Low-Damage Seismic Design Guidance, which is currently in preparation. This guidance is considering the use of repair cost and expected annual loss targets as performance objectives. The guidance also sets out design criteria and checks that can be undertaken to achieve the intended performance outcomes.

To enable evaluation of seismic losses, it is necessary to be able to relate building component damage to losses in terms of repair costs and repair time. This is achieved through so-called consequence functions. This work aims to address the paucity of New Zealand specific consequence functions by evaluating repair costs and repair time for earthquake induced damage in buildings. Furthermore, a framework is established for continuing to build a more extensive "library" of consequence functions in a consistent manner as more data become available.

The subsequent sections of this paper provide a background on seismic loss assessment before proceeding to a detailed description of the development of New Zealand specific consequence functions. Data access and future improvements are then discussed before providing an application example.

BACKGROUND ON SEISMIC LOSS ASSESSMENT

Whilst many approaches to PBEE and seismic loss assessment have been proposed, the most well established is the methodology developed by the Pacific Earthquake Engineering Research (PEER) Centre. An overview of the PEER PBEE methodology is provided in Porter [2] and herein the key steps are reported with reference to Figure 1.

- *Hazard Analysis* - Following the definition of the structure and its location, probabilistic seismic hazard analysis is undertaken to obtain a hazard curve in terms of a relevant intensity measure (IM), such as $Sa(T_1)$ (the spectral acceleration at the period corresponding to the first mode of vibration of the structure).
- *Structural Analysis* - A structural analysis method, such as nonlinear time-history analysis (NLTHA), is used to analyse the structural response of the building at a number of intensities. The structural response is measured in terms of a vector of engineering demand parameters (EDPs) conditioned on the seismic intensity being considered. Common EDPs include interstorey drift ratio and peak floor acceleration. It is important to note that at this step it is crucial to obtain the conditional probability distribution of

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EDPs, e.g. through the use of multiple ground motions in the NLTHA, rather than just a single response estimate.

- *Damage Analysis* - This step relates the structural response of the building to the expected damage in structural and nonstructural building components. Each building component is assigned a fragility curve, typically assumed to be a lognormal distribution that defines the probability of that component being in a specific damage state (DS) conditional on EDP. Fragility functions that may be relevant in the New Zealand context have been evaluated by Yeow et al. [3].
- *Loss Analysis* - Once the expected damage in the building is estimated, the loss in terms of relevant performance parameters can be calculated on a component-by-component basis. As mentioned previously, the most common performance parameters for consideration are injuries or fatalities, repair cost and post-earthquake loss of function. The relationship between damage state and component loss is defined through consequence functions, the main subject of this article, which are described in detail in the following section.

The above methodology can be used to calculate losses at a given earthquake intensity, under a specific earthquake scenario, or over time (in this case the performance metric is the expected annual loss, EAL). The calculation process is described mathematically in Equation 1 [2]; however, in practice, this integral must be solved numerically using appropriate loss assessment software, such as PACT [4]. For more extensive guidance on seismic loss assessment, the reader is referred to FEMA P-58 [5].

$$g[DV|D] = \iiint p[DV|DM]p[DM|EDP]p[EDP|IM]p[IM|D]\, dIMdEDPdDM \quad (1)$$

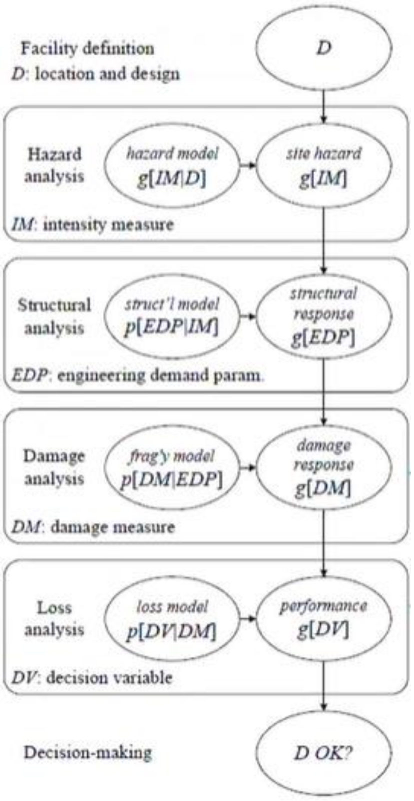


Figure 1: Overview of PEER PBEE methodology (reprinted from Porter [2] with permission from IOS Press).

Given that the PEER PBEE process is well established, as reported in FEMA P-58, the process and documentation developed in this work has sought to match as closely as possible that of FEMA P-58. This is intended to provide a sense of familiarity to end users and a reasonable level of compatibility with existing calculation tools and supporting documentation.

DEVELOPMENT OF CONSEQUENCE FUNCTIONS

As illustrated in the previous section, consequence functions are a critical tool in seismic loss assessment. However, the lack of New Zealand specific consequence functions means that previous loss assessment studies have had to rely largely on adapting overseas data. Although overseas data can be adapted for use in New Zealand, this introduces the challenge of using suitable exchange rates, adjusting for different costs of materials and labour, etc. Furthermore, some structural systems, building components and repair methodologies used overseas may not be applicable to New Zealand construction practices. It is also worth noting that the construction industry has learnt a lot about what is involved in the post-earthquake repair of buildings as a result of recent earthquakes, and therefore it is an ideal time to document some of these learnings. One such lesson of particular note is the high cost of removing and reinstalling nonstructural components to access structural components for inspection and potential repair [6,7].

The steps used to develop New Zealand specific consequence functions are illustrated in Figure 2 and described in the following sub-sections.

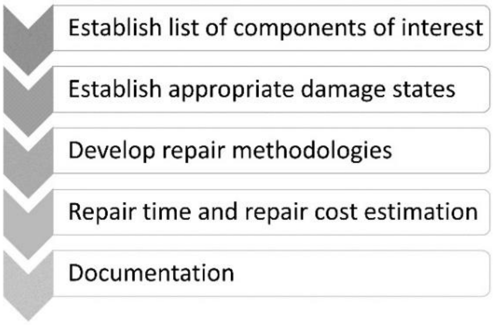


Figure 2: Steps in developing New Zealand specific consequence functions.

Establishing List of Components

To establish a list of components, FEMA P-58 was used as a starting point. The list of components was then simplified and reduced by removing components that were deemed to be of little relevance in the New Zealand context, a process undertaken in conjunction with an architect and building services engineers. A reduction in the list of components was also necessary to stay within budgetary constraints of the research project, noting that future research could look to expand the database.

The taxonomy used to group the various building components was adapted from FEMA P-58. This starts with a *Component Category* of either B – Shell, C – Interiors, or D – Services (the other FEMA P-58 categories of A – Substructure, E -Equipment and Furnishings, and F – Special Construction and Demolition were not considered as part of the current work). Each component is then assigned a *Component Type*, which is used to group together similar components, e.g. “Partition walls”. Finally, each component is given a unique *Component Name*. The component name is intended to be brief yet descriptive in nature, for example, “Fire-rated timber stud partition wall”. A more detailed description can then be provided in the optional *Component Description*.

In total, 39 building components were included in the list, with the component category breakdown being B – Shell (7), C – Interior (7), and D – Services (24). Whilst the selected components are applicable to any building type, they were generally selected with a focus on use in loss assessment for typical New Zealand multi-storey residential and commercial buildings.

Establishing Appropriate Damage States

As shown in Figure 1, damage measures (or damage states) provide the link between the damage analysis and loss analysis stages. The extent of damage that could be incurred by a building component during an earthquake is probably best considered as a continuum from no damage to complete destruction requiring replacement. However, for practical loss assessment purposes, this continuum must be divided into a number of discrete damage states that roughly align with step changes in the severity of damage. FEMA P-58 considers up to five damage states, whereas it was found in the current work that no more than four were required for the components considered. Furthermore, FEMA P-58 allows for mutually exclusive damage states, i.e. two alternative forms of damage of similar severity, whereas only sequential damage states were considered in the current work (i.e. each progressive damage state represents increasingly severe damage). The advantage of allowing for mutually exclusive damage states is that different forms of damage can be considered along with corresponding probabilities that one or another occurs; however, this was not required for any of the components included at present.

For the damage states to be of practical use, they needed to be consistent with existing component fragility functions. The damage states were therefore based on New Zealand specific research [8-13] (the preferred choice), international research [14-19], FEMA P-58 or engineering judgement. Figure 3 provides an example of the damage state descriptions for the steel frame reduced beam section (RBS) connection.

Developing Repair Methodologies

For each component, repair methodologies were established for the various damage states through a collaborative effort involving an architect, structural engineers, and building services engineers. The repair methodologies were primarily based on experience and professional judgement, leveraging where possible common practice from building repairs following the Canterbury Earthquake Sequence. Alternatively, repair methodologies were adopted from existing research or post-earthquake repair guidelines.

All repair methodologies were developed for the following basis of repair: *'Repair actions assume repair or replacement "in-kind" and do not include work associated with bringing a non-conforming installation or structure into compliance with newer criteria. Furthermore, repairs are not assumed to fully restore the building to its as new condition but to a level that is as close as reasonably practicable to its pre-earthquake condition'*. This was an important point to establish prior to developing repair methodologies, as the requirements for building repairs may vary under different circumstances. For example, it is not uncommon for insurance policies to use the term *"as new"* when describing the level of reinstatement that is covered. Similarly, repairs may go beyond simply returning the building to its original condition, either by owner choice or legislative requirements [20].

Figure 3 shows the repair methodologies for the RBS connection example. It can be seen that the description is relatively brief and there is a reasonable amount of room for interpretation by whomever would have to implement such a solution, e.g. in the choice of specific repair product brand.

Repair Time and Repair Cost Estimation

To establish repair costs, a New Zealand construction company (herein also referred to as "the contractor") was engaged to undertake cost estimation for the proposed repair solutions. This was not an independent process and did involve some level of collaboration between the authors and the construction company's quantity surveyors (cost estimators). One challenge that was identified during this process was that quantity surveyors generally base cost estimates on quite precise definitions of the work to be undertaken in relation to a specific project, and it took some effort to establish repair cost that were broadly representative of the works required to address more generic damage. It is worth noting that repair cost estimates were made for each component individually and did not account for potential interdependencies between different components.

To account for the uncertainty in repair costs, estimates were made of the 10th, 50th and 90th percentile values of the repair cost distribution. These were referred to as the P10, P50 and P90 repair costs, using the same definitions as FEMA P-58. The specific way that these definitions were communicated to the quantity surveyors was that *"Nine out of 10 times the repair cost for the component should exceed the P10 value"*, and similarly for P50 and P90. It should be noted that this simplified approach does not capture all sources of uncertainty, such as the variation in estimates between different contractors. Repair costs are intended to correspond to construction undertaken in Christchurch in 2021 and are reported in New Zealand Dollars (NZ$). No specific consideration has been given to the possibility of increased costs immediately following an earthquake due to an increase in demand.

Following the approach of FEMA P-58, component repair time has been calculated based on an assumed percentage labour multiplier and a labour rate, as per Equation 1:

$$Repair\ time = \frac{Repair\ cost\ \times \%Labour}{Labour\ rate} \tag{1}$$

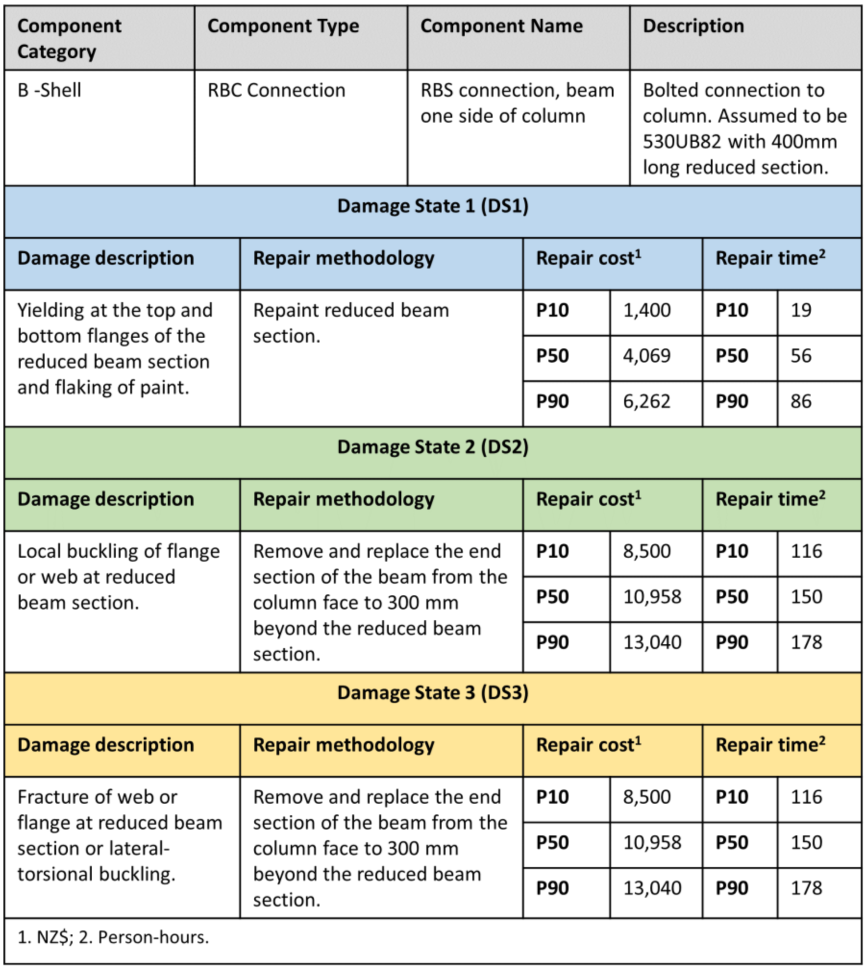
where *%Labour* (estimated by the contractor) is the percentage of the repair cost attributed to the cost of labour.

On the advice of the contractor, a labour rate of NZ$60 per hour has been assumed. As illustrated in Figure 3, for the RBS example the percentage of the DS1 repair cost attributed to labour was 82% and the corresponding P50 repair time was therefore 56 person-hours. Repairs times should be considered as a lower bound, given that they do not include post-earthquake factors that may extended normal construction timeframes, e.g. labour and material shortages, damaged transport infrastructure. Furthermore, the time from event to starting repair work is not considered and may in cases be significant, for example, if a complex insurance claim needs to be settled.

Documentation

The consequence functions have been recorded in a "Master" Microsoft Excel spreadsheet. This spreadsheet contains all the information discussed in the previous sections for each component and each damage state, including relevant sources of information. Additionally, the spreadsheet comments on the possibility of "consequential damage" that may be caused by the failure of a component (e.g. unbraced pipework may sway and damage adjacent components) and notes whether damage is dependent on the direction a component is oriented.

The cost breakdown for each component is provided in a separate "Cost breakdown" spreadsheet. This shows the individual line items used to build up component repair costs. Inclusion of the cost breakdown was considered to be of fundamental importance to the project as it provides a high level



Component Category	Component Type	Component Name	Description
B -Shell	RBC Connection	RBS connection, beam one side of column	Bolted connection to column. Assumed to be 530UB82 with 400mm long reduced section.

Damage State 1 (DS1)

Damage description	Repair methodology	Repair cost[1]		Repair time[2]	
Yielding at the top and bottom flanges of the reduced beam section and flaking of paint.	Repaint reduced beam section.	**P10**	1,400	**P10**	19
		P50	4,069	**P50**	56
		P90	6,262	**P90**	86

Damage State 2 (DS2)

Damage description	Repair methodology	Repair cost[1]		Repair time[2]	
Local buckling of flange or web at reduced beam section.	Remove and replace the end section of the beam from the column face to 300 mm beyond the reduced beam section.	**P10**	8,500	**P10**	116
		P50	10,958	**P50**	150
		P90	13,040	**P90**	178

Damage State 3 (DS3)

Damage description	Repair methodology	Repair cost[1]		Repair time[2]	
Fracture of web or flange at reduced beam section or lateral-torsional buckling.	Remove and replace the end section of the beam from the column face to 300 mm beyond the reduced beam section.	**P10**	8,500	**P10**	116
		P50	10,958	**P50**	150
		P90	13,040	**P90**	178

1. NZ$; 2. Person-hours.

Figure 3: Example consequence function for a steel frame reduced beam section (RBS) connection with three damage states.

of transparency for users and allows for correction of potential errors or inconsistencies in cost build ups.

DATA ACCESS AND FUTURE IMPROVEMENTS

All data are freely available on the NEHRI Design Safe website (https://www.designsafe-ci.org/data/browser/public/designsafe.storage.published/PRJ-3126, last accessed 24/3/23). As mentioned previously, the work undertaken as part of the current project only considered a limited number of building components. It is therefore important that other researchers are able to contribute and provide consequence functions for additional components and propose amendments to the existing consequence functions as required. At present, to make changes, users should contact the corresponding author of the current paper. However, a key future improvement is to develop a more robust system where users can readily make changes and additions while the overall quality of the data is maintained.

During the project there were two key building components for which consequence functions could not be derived due to a lack of data at the time: exterior cladding and lifts. The lack of available data for the latter was particularly curious given that interest in the seismic performance of lifts in New Zealand goes back as far as at least 1968 [21]. The addition of consequence functions for these components, which are present in nearly every multistorey building, is a high priority future improvement, and significant progress has already been made in the case of cladding [22].

Although the current work has aimed to closely follow the FEMA P-58 template, one area of difference is the consideration of reduction of repair costs with increasing quantities due to efficiencies of scale. This was unable to be considered due to time and budget limitations; however, scope should be allowed for this in future improvements. Similarly, the available budget only allowed for engagement of a single contractor, but future work could include cost estimates from additional contractors to obtain more robust estimates of repair costs and the associated uncertainty.

APPLICATION EXAMPLE

To investigate the impact that the newly derived consequence functions might have on a loss-assessment project, a case-study of a 12-storey steel frame building by Yeow et al. [23] is re-examined.

The building is hypothetically located in Wellington on subsoil class C and has a floor area of 1536 m^2. Whilst the structure is identical to that studied in Yeow et al. [23], the nonstructural components have been slightly modified to better align with those available in the new NZ-specific database. Table 1 shows the quantities of all damageable structural and nonstructural components, and a full summary of fragility and consequence functions is provided in Table A1.

Two loss assessments were carried out for the building. In the first assessment, referred to as the "benchmark" case, the consequence functions from FEMA P-58 are used. In the second assessment, referred to as the "NZ-specific" case, the New Zealand specific consequence functions are used. It is important to note that a number of the mechanical components listed in Table 1 did not have suitable equivalent New Zealand specific consequences, and in these instances (indicated by an asterisk) the FEMA P-58 consequence functions are used for both the benchmark and NZ-specific loss assessments.

Table 1: Quantities of damageable structural and nonstructural building components considered in the loss assessment calculations.

Component	Quantity	Unit
RBS connection 1-sided	8	per floor
RBS connection 2-sided	12	per floor
Column base*	10	each
Full height partitions	214	m per floor
Exterior glazing	543	m^2 per floor
Stairs	2	per floor
Suspended ceilings (A<23 m^2)	10	per floor
Suspended ceilings (A>23 m^2)	3	per floor
Braced ceilings	51	braces per floor
Sprinkler droppers	15	per floor
Sprinkler pipes	3	305 m length
Water pipes*	3	305 m length
Sanitary pipes*	1	305 m length
Chiller*	1	each
Cooling tower*	1	each
Air handling units*	4	each
Ducts*	2	305 m length
Drops and diffusers*	15	per floor
Coils*	8	per floor
VAV boxes*	10	per floor
Traction elevator*	3	each
Transformers*	1	each

Losses were calculated in terms of 2022 NZ$ and therefore adjustment of repair costs was required to account for currency conversion and inflation. FEMA P-58 repair costs estimated in 2009, 2010 and 2011 were converted to 2022 US$ by multiplying by factors of 1.39, 1.37 and 1.32, respectively, to account for inflation. US$ were then converted to NZ$ at an exchange rate of 1 US$ to 1.6 NZ$. The New Zealand specific consequence functions, which were estimated in 2019, were multiplied by a factor of 1.08 to account for inflation. For the purposes of the example, it was not deemed necessary to adjust the costs for the fact that the building is located in Wellington (whereas the consequence functions are based on Christchurch repair costs).

The losses were estimated using the Seismic Loss Assessment Tool, SLAT [24], with the building response from Yeow et al. [23] reused as the engineering demand parameter (EDP) inputs, along with the fragility and consequence functions described in Table A1. The hazard model adopted was identical to that used in Yeow et al. [23] based on a New Zealand-specific rupture forecast model from Stirling et al. [25] and ground motion models by Bradley [26] for spectral acceleration at 2.0 s.

Component-by-Component Comparison

Before examining the loss assessment results, it is worth considering a direct comparison of repair costs. Figure 4 shows the repair costs for components where a direct comparison was possible, i.e. repairs for both the benchmark and NZ-specific cases are based on the same or similar damage descriptions. It can be seen that the ratio of benchmark to NZ-specific repair cost varies between 0.25 and 2.5. Although this is a large range, it is not unexpected given the potential differences in repair methodologies, local material and labour costs, and inherent uncertainties in cost estimation. Note that for both RBS connections and stairs, the NZ-specific consequence functions include one more damage state and therefore comparisons are in terms of benchmark DS_i and NZ-specific DS_{i+1}.

For further details on individual component repair costs, the reader is referred to Table A1 and the available cost breakdown spreadsheet. However, it is worth considering one example, the RBS connection, to highlight some of the potential sources of cost difference. It can be seen that for the RBS connection there is no change in repair cost from DS2 to DS3 in the New Zealand specific case. This is because the DS2 damage description was based on FEMA P-58 and the corresponding repair method of heat straightening was judged to be an unlikely repair option in New Zealand (those involved in the project could not find any examples of this having been undertaken). Therefore, at DS2 it is assumed that the joint will already be completely replaced (equal to the DS3 repair method). The benchmark repair costs for DS3 are substantially higher than the NZ-specific repair, which is due to a difference in the actual replacement costs (rather than temporary works, propping etc). Conversely, the NZ-specific costs tend to be higher for the case of partition walls.

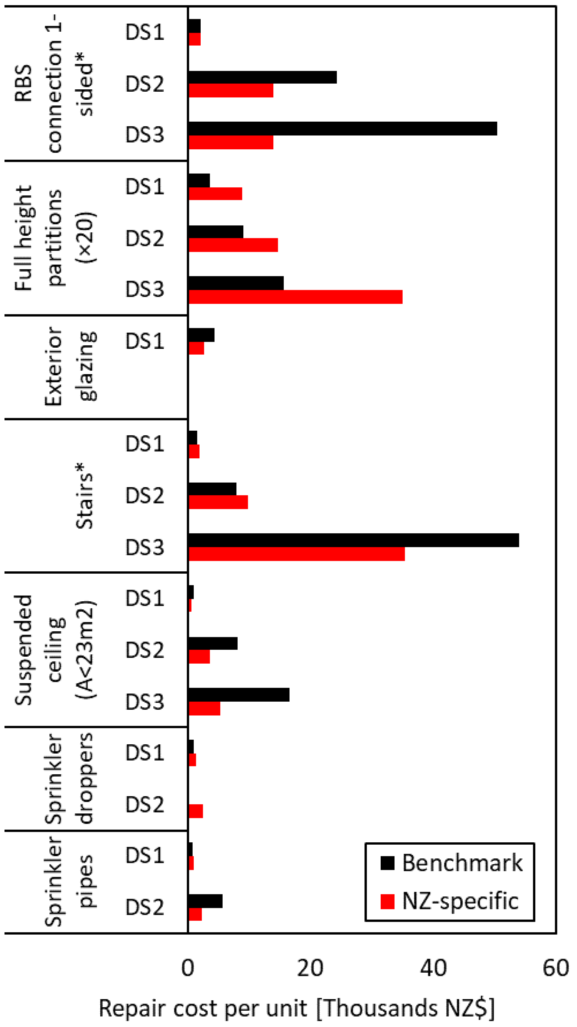


Figure 4: Direct comparison of component repair costs. (*) Damage states numbers refer to the benchmark consequence functions.

Impact on Losses

The expected annual losses for the benchmark and NZ-specific assessments were NZ$63,000 and NZ$76,600, respectively. To examine this in more detail, Figure 5 shows the expected loss conditional on intensity. At lower intensities the losses tend to be larger when the NZ-specific consequence functions are used and at higher intensities the benchmark consequence functions result in larger losses. As shown in Figure 6, this is driven by the repair costs associated with partition wall damage, which makes up the largest portion of losses at lower intensities. At higher intensities structural damage starts to control the losses (Figure 7), in which case the benchmark consequence functions for the RBS connections are more severe.

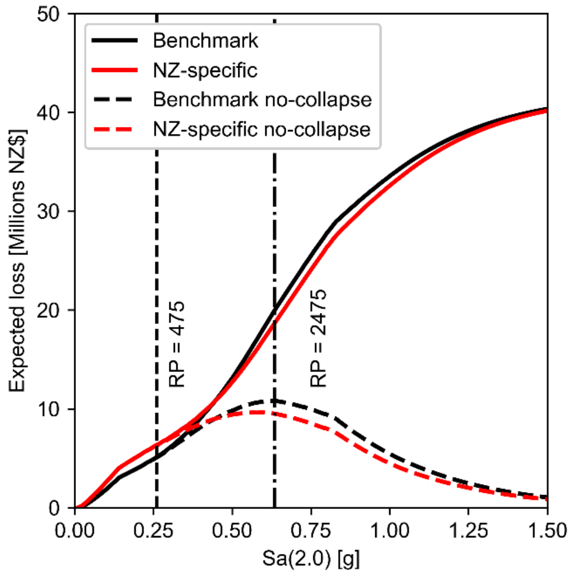


Figure 5: Expected loss conditional on intensity (with collapse cases both included and excluded).

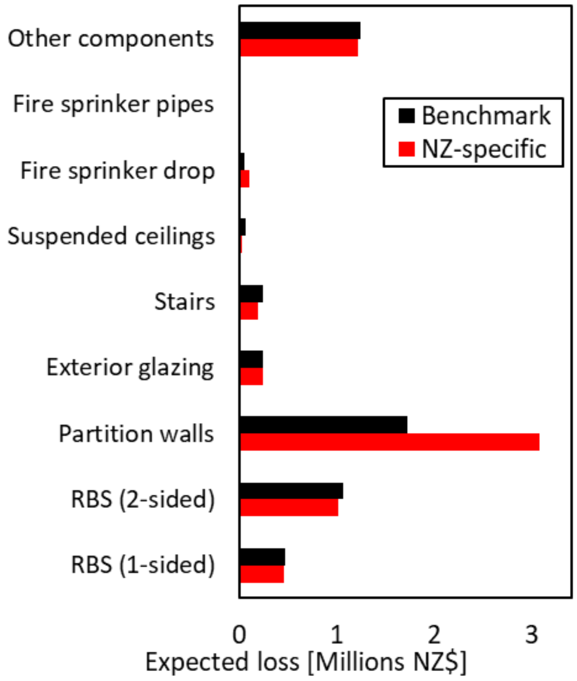


Figure 6: Disaggregation of expected loss at an intensity corresponding to a return period of 475 years.

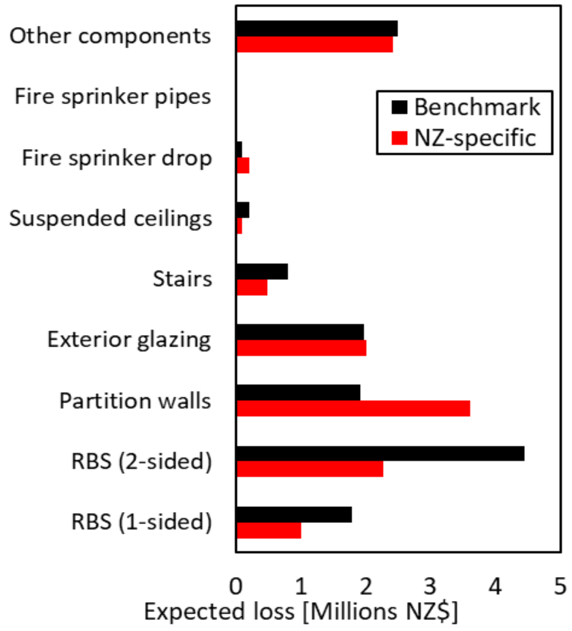


Figure 7: Disaggregation of expected loss at an intensity corresponding to a return period of 2475 years.

Impact of Recent Changes in Seismic Hazard Estimates

Given the recent release of an updated New Zealand National Seismic Hazard Model [27], the current loss assessment results have been utilised to understand the potential impacts that the updated hazard model may have on direct economic losses. A comparison is therefore made of the expected annual losses using the "2018 hazard", utilised in the preceding loss assessment, and the updated "2022 hazard" [28].

Figure 8 shows the hazard curves for the two models in terms of spectral acceleration at a period of vibration of 2 s, *Sa*(2.0). In both cases, the hazard curves are for the mean hazard and epistemic uncertainty has not been considered. To adjust the loss assessment results for the updated hazard, it has been assumed that there is no change in the distribution of engineering demand parameters conditional on intensity, i.e. *p*[EDP|IM]. This was deemed to be a reasonable simplifying assumption given that differences in *p*[EDP|IM] are not expected to have a major effect on losses when compared to the difference in hazard, i.e. *g*[IM|D].

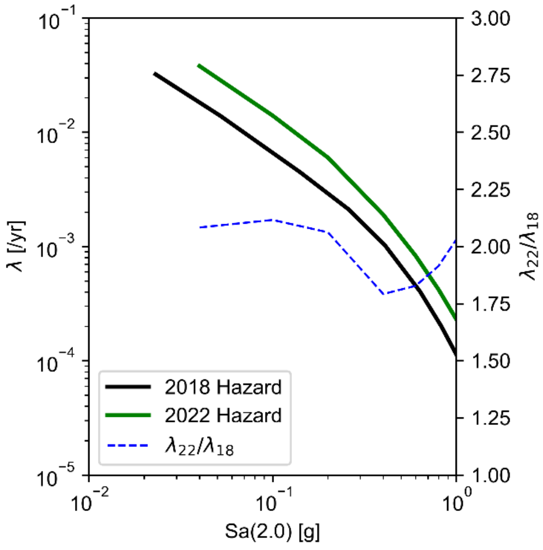


Figure 8: Hazard curves in terms of Sa(2.0) for the hazard model used by Yeow et al. [19] and the updated New Zealand National Seismic Hazard Model.

The results in Table 2 show that the updated hazard model leads to substantially larger expected annual losses. When the benchmark consequence functions are used the losses increase by a factor of 1.82 and in the NZ-specific case by a factor of 1.79. In both cases, the increase is of the same order of magnitude as the increase in seismic hazard across the intensities of interest (see Figure 8).

Table 2: Expected annual loss considering the 2018 and 2022 seismic hazard models.

Hazard model	Consequence functions	
	Benchmark	**NZ-Specific**
2018	NZ$63,8000	NZ$76,600
2022	NZ$116,000	NZ$137,000

CONCLUDING REMARKS

Seismic loss assessment is an important tool for understanding the likely impact of earthquakes, in particular when it comes to direct economic losses. To obtain reliable loss assessment results, it is important to have consequence functions that can faithfully represent repairs costs and repair time for building components in a local context.

This work has presented a set of New Zealand specific consequence functions for use in loss assessment projects, which have been developed in a collaborative effort between academics, design professionals and a construction company. More importantly, a framework has been established to continually expand the set of available consequence functions, with a focus on transparency and continued improvement.

Through an application example, the potential impact of using non-local consequence functions has been demonstrated, with a difference in expected annual loss of 22% between the so-called benchmark and New Zealand specific cases. Noting that it will take some time to develop a more comprehensive database of New Zealand specific consequence functions, it appears likely that New Zealand practitioners and researchers undertaking loss assessment projects will still have some reliance on overseas data for the foreseeable future. Caution should be exercised in checking that any adopted international consequence functions adequately represent local New Zealand practices.

The loss assessment example has been extended to also consider the impact of recent updates to the New Zealand National Seismic Hazard model. For the particular case-study example, the differences in expected annual loss due the change in hazard far outweigh the difference due to the choice of consequence functions. However, the use of these consequence functions is expected to prove a useful tool for those seeking to understand New Zealand's exposure to seismic risk as our knowledge of seismic hazards continue to evolve.

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Table A1: Fragility function means (θ) and dispersion (β) and corresponding repair costs ('000 NZ$) used in the benchmark and NZ-specific loss assessment calculations.

Component	**Unit**	**DS1**			**DS2**			**DS3**			**DS4**		
		θ	β	$	θ	β	$	θ	β	$	θ	β	$
Benchmark (FEMA P-58)													
RBS 1-sided (<=W27)	Each	0.0064	0.29	2119	0.022	0.3	24.3	0.05	0.31	50.4			
RBS 2-sided (<=W27)	Each	0.0064	0.29	3.14	0.022	0.3	38.1	0.05	0.31	87.0			
RBS 1-sided (>=W30)	Each	0.0064	0.29	2.19	0.022	0.3	26.5	0.05	0.31	57.2			
RBS 2-sided (>=W30)	Each	0.0064	0.29	3.14	0.022	0.3	42.5	0.05	0.31	101			
Column base	Each	0.03	0.3	31.7	0.04	0.3	35.7	0.05	0.3	38.3			
Full height partitions	1.2m	0.0027	0.44	0.180	0.006	0.38	0.459	0.01	0.55	0.786			
Exterior glazing	2.8m^2	0.0338	0.4	3.45									
Stairs	Each	0.005	0.6	1.55	0.017	0.6	8.01	0.028	0.45	54.0			
Suspended ceil. (A<23m2)	23m^2	1.6	0.3	1.03	1.95	0.3	8.09	2.07	0.3	16.6			
Suspended ceil. (23m2<A)	56m^2	1.47	0.3	2.48	1.88	0.3	19.4	2.03	0.3	39.9			
Braced ceiling	67m^2	1.6	0.3	1.03	1.95	0.3	8.09	2.07	0.3	16.6			
Sprinkler drops	Each	0.95	0.4	1.10									
Sprinkler pipes	305m	1.5	0.4	0.767	2.6	0.4	5.81						
Water pipe	305m	1.5	0.4	0.833									
Sanitary pipe	305m	3	0.5	9.55									
Chiller capacity 350-700	Each	0.72	0.2	559.4									
Cooling tower	Each	1.52	0.4	285.4									
Packed air handling units	Each	1.54	0.6	137.5									
Ducts < 6 ft^2 cross section	305m	1.5	0.4	1.43	2.25	0.4	13.9						
Drops and diffusers	10 unit	1.5	0.4	6.58									
Coils	10 unit	2.25	0.4	15.3	2.6	0.4	59.2						
VAV boxes	10 unit	1.9	0.4	32.9									
Traction elevator	Each	0.35	0.4	52.4									
Transformers 350-750 kVa	Each	3.05	0.5	93.6									
NZ-specific													
RBS 1-sided (<=W27)	Each	0.0064	0.29	2.19	0.01	0.17	44.0	0.022	0.3	14.0	0.05	0.31	14.0
RBS 2-sided (<=W27)	Each	0.0064	0.29	3.14	0.01	0.17	6.59	0.022	0.3	21.0	0.05	0.31	24.8
Full height partitions	1.2m	0.0027	0.44	0.443	0.006	0.38	0.734	0.01	0.55	1.75			
Exterior glazing	2.8m^2	0.0338	0.4	2.74									
Stairs	Each	0.003	0.6	0.686	0.005	0.6	2.00	0.017	0.6	9.84	0.028	0.45	35.5
Suspended ceil. (A<23m2)	23m^2	1.6	0.3	0.566	1.95	0.3	3.62	2.07	0.3	5.30			
Suspended ceil. (23m2<A)	56m^2	1.47	0.3	1.36	1.88	0.3	8.68	2.03	0.3	12.7			
Sprinkler drops	100 unit	0.95	0.4	1.33	1.2	0.4	2.55						
Sprinkler pipes	305m	1.5	0.4	0.948	2.6	0.4	2.30						