Seismic risk management of a large public facilities portfolio: a New Zealand case study

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Abstract

Purpose – The purpose of this article is to assist facilities asset managers who are dealing with regulatory environments pertaining to earthquakes and buildings. These professionals can learn a great deal from the successes and short-comings of a case study programme from the Auckland Council Property Department (ACPD), which manages the public facilities portfolio for the largest local administrative region in New Zealand in both population and landmass.

Design/methodology/approach – ACPD has initiated its response to New Zealand's earthquake mitigation mandates by identifying buildings most at risk to an earthquake in its large and varied portfolio through the use of a rapid building evaluation programme strategically targeted to vulnerable building types with consequential attributes, including service type, number of occupants, floor area and geographic location.

Findings – ACPD was able to rapidly cull down its portfolio of approximately 3,500 buildings to just over 100 "high-exposure" buildings in urgent need of evaluation, set priorities for future evaluations, estimate needed operational and capital expenditures for long-term planning and provide useful information to more general facilities management decision-making processes.

Originality/value – A number of major cities around the world in areas of high seismicity have enacted ordinances mandating seismic retrofitting. However, much of the existing guiding literature

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regarding earthquake-related portfolio evaluations and costs pertains to specific scenarios involving real or hypothetical earthquakes. This case study, in contrast, details the approach taken by a public portfolio owner responding to legal mandates and attempting to quantify and reduce its life-safety risk exposure across a large portfolio as efficiently as possible using readily available information, a rapid building evaluation programme and best-practice predictive models for consulting and construction work.

Keywords Public sector, Risk management, Earthquakes, Building evaluation, Costing, Property portfolio management

Paper type Case study

Introduction

Facilities asset managers in New Zealand and elsewhere are responding to regulatory and market forces in the wake of recent earthquakes to assess and retrofit buildings determined to be particularly vulnerable to earthquakes. The Auckland Council Property Department (ACPD) is engaging in a proactive effort to assess its portfolio of approximately 3,500 buildings, prioritise its building assets for seismic retrofit and forecast construction costs for long-term planning. Within the programme structure, the following varied and often competing factors must be accommodated:

- ACPD's legal, fiscal and ethical obligations to the people of Auckland per building regulations, health and safety protocols and functional priorities for service delivery;
- Heritage preservation and community and cultural values;
- Varied and numerous stakeholders across the largest local administrative region in New Zealand in both population and landmass (the estimated population of 1.5 million people within the Auckland local authority area accounts for about one-third of the nation's population) (Statistics New Zealand, 2013); and
- Auckland's prominent role in New Zealand's economy which requires Auckland's building stock to be resilient to natural disasters (as of 2012, Auckland's economy accounted for an estimated 37 per cent of New Zealand's GDP, and the region's economic growth had outpaced New Zealand's national economic growth in 7 of the preceding 11 years) (Monitor Auckland, 2012).

The purpose of the programme described herein for ACPD was to identify the buildings most at risk to an earthquake in its large and varied portfolio, which warranted the use of a rapid building evaluation programme supplemented by strategically chosen detailed assessments and cost estimate assumptions. The purpose of reporting upon the ACPD programme herein was to help advance the practice of facilities managers and asset planners around the world dealing with similar regulatory environments pertaining to earthquakes and buildings and who could learn a great deal from the successes and short-comings of a case study programme with such an expansive scope. From a technical research perspective, the typological classification and rapid vulnerability evaluation of buildings within the ACPD portfolio can provide valuable comparative data for risk modellers in New Zealand and in other countries with British-style historical construction.

Building regulations pertaining to seismic risk mitigation

Cities in areas of high seismicity that have enacted ordinances regarding seismic retrofitting include Los Angeles (City of Los Angeles, 1949, 1985), San Francisco (Newman, 1976; City of San Francisco, 1993) and Tokyo (Tokyo Metropolitan Government, 2011). Such ordinances have generally been aimed at specific types of vulnerable buildings (e.g. unreinforced load-bearing masonry), specific building components (e.g. chimneys or parapets) or buildings in critical locations (alongside roads intended for emergency transportation access and egress after a major disaster). Other cities, including Portland (City of Portland, 2004), Seattle (City of Seattle, 2009) and Vancouver (City of Vancouver, 2012), have enacted ordinances mandating seismic retrofits to buildings or building components, but only if those buildings are being altered or rehabilitated ("triggering" a required seismic retrofit). Further details pertaining to such historic ordinances and their effects are summarised in other studies (FEMA, 2009; Paxton *et al.*, 2015).

More recently, officials in San Francisco (City & County of San Francisco, 2013), Los Angeles (Lin and Xia, 2014; City of Los Angeles, 2014) and Seattle (City of Seattle, 2014) have lobbied for additional seismic retrofit mandates targeting specific building material types and/or geometric configurations such as "soft storeys". Even still, few seismic retrofit mandates in the world are as comprehensive as that encapsulated in the New Zealand Building Act (New Zealand Parliament, 2004). The Building Act requires that local authorities to identify and enforce changes to buildings that are considered "earthquake-prone", which is defined in the Building Act and the corresponding regulations (New Zealand Parliament, 2005) as a building that is likely to have its capacity exceeded in a "moderate" earthquake with an intensity equal to one-third of the intensity of the current design basis earthquake (DBE) and is likely to collapse, causing injury or death or property damage to others. The corresponding Auckland Council regulatory policy (Auckland Council, 2011) mandates that most normal buildings deemed to be earthquake-prone should be retrofitted or demolished within 20 years of receiving notification from the regulator. Additional allowances are provided for buildings with registered heritage value. Note that the seismic risk mitigation mandates in New Zealand, in contrast to other places, are not particular to certain types of building materials, components or structural systems, notwithstanding that certain types are more likely to be considered earthquake-prone.

The Canterbury Earthquakes Royal Commission of Inquiry (Cooper *et al.*, 2012) reported on the causes of building failure as a result of the 2010-2011 Canterbury, New Zealand earthquakes and the legal and best-practice requirements for buildings in New Zealand city centres. Recommendations from the Royal Commission have been implemented into building regulations proposed by the Ministry of Business, Innovation and Employment (MBIE) for an amendment to the Building Act (New Zealand Parliament, 2013), potentially accelerating mandated timeframes for assessment and retrofit or demolition. Furthermore, a publicly accessible national register of earthquake-prone buildings is likely to be operated by MBIE.

Seismic assessment procedures formally utilised in New Zealand entail a scoring system of per cent New Building Standard (%NBS) as proposed by the New Zealand Society for Earthquake Engineering (NZSEE, 2014), which indicates the expected capacity of the building as a percentage of the DBE demands prescribed by current standards (NZS, 2004). The phrase "new building standard" is indicative of the intent of the scoring system, where a building that is assessed as having a resistance exceeding

100%NBS is expected to withstand the current DBE demands (i.e. ratio of capacity to demand is higher than 1.00), whereas a building assessed at 33%NBS is expected to withstand only one-third of the DBE. Hence, a building with a score of less than 34%NBS is deemed potentially "earthquake prone" and may be subject to regulatory measures in accordance with the Building Act (New Zealand Parliament, 2004) and current Auckland Council (2011) policy, warranting further assessment and possibly structural retrofits, change of use or demolition.

Furthermore, building owners such as ACPD have responsibilities under the Health and Safety in Employment Act (New Zealand Parliament, 1992) to take all practicable steps to reduce risk in all workplaces (through structural enhancement and/or safety training) for which it is the employer, the entity in control of the workplace, or the principal (in regard to contractors and subcontractors) (Turner, 2011). If someone is seriously harmed during an earthquake in New Zealand, and non-compliance with the Building Act is considered a factor in the incident, then enforcement under the Health and Safety in Employment Act is also possible (WorkSafe New Zealand, 2013). The %NBS thresholds and various potential legal implications are summarised in Table I.

Note that calculated risk levels listed in Table I are not proportional to the %NBS scoring range, as a building determined to have a score of 33%NBS is assumed to have a collapse or partial collapse risk that is approximately 10-20 times higher than a building rated at 100%NBS, because of the lower average return period of relatively moderate earthquakes as compared to more intense earthquakes (NZSEE, 2014). The earthquake defined by the loadings standard (NZS, 2004) as the DBE for any particular building is influenced by a number of factors, including the location, site conditions and functional purpose of the building being considered. Note that the correlation between %NBS ratios determined for existing, older buildings and those determined for newly designed buildings can be skewed by, amongst other factors, differences in characteristic strengths presumed and factors of safety utilised (Au *et al.*, 2013).

Rapid seismic building evaluation techniques

ACPD's experience with access to building plans for its historic buildings is likely consistent with that of other large portfolio owners in that as-built structural plans are rarely maintained because of a lack of periodic use (in contrast to architectural, fit-out,

Table I. Associated values and implications of seismic assessment %NBS scores

%NBS	EQ risk category	Approximate relative risk (NZSEE, 2014)	Potentially affected by the Building Act (2004) and Health and Safety Act (1992)	Non-compliant with current loading standard (NZS, 2004)
<20	Prone/high risk	>25 times	X	X
20-33		10-25 times	X	X
34-66	Moderate risk	5-10 times		X
67-79	Low risk	2-5 times		X
80-100		1-2 times		X
>100	Complies with current loading standard	<1 time		

Source: NZSEE (2014)

cladding, HVAC and utility plans, which are more regularly referenced for ongoing maintenance efforts). Furthermore, even in cases where as-built structural building plans are available, non-recorded building additions and alterations, non-structural elements and deteriorations in the condition of structural elements are not necessarily indicated in such plans. Hence, an on-site building structural evaluation programme is necessary, and a preferred evaluation method is able to be used rapidly and cost-effectively to cull a large portfolio of buildings down to the buildings most likely to be seismically vulnerable. Most of the historically prominent guidelines regarding rapid seismic assessments of buildings pertain to buildings that have already been damaged by earthquakes (ATC, 1985, 1989, 2000). However, in recent years, the importance of rapid visual screening for potential future seismic hazards has been acknowledged by the publication of standards in, for example, the USA (FEMA, 2002), Canada (CSA, 2014) and New Zealand (NZSEE, 2014). These rapid evaluation techniques have also been leveraged with modern tools, such as spatial mapping (e.g. ArcGIS) and virtual environments (e.g. Google Street View), as used in the ACPD programme to a limited extent and used elsewhere to a greater extent (Anagnos *et al.*, 2012; Ploeger *et al.*, 2015).

Seismic building evaluations in New Zealand are generally performed in three general stages, as prescribed in the NZSEE (2014) assessment guidelines – preliminary assessment, initial seismic assessment (ISA) and detailed seismic assessment (DSA). Preliminary assessments and ISAs are both considered "rapid" in that they can be performed completely within a day, and generally within a few hours, for most individual buildings. The initial evaluation procedure (IEP) is the method for ISAs preferred by most local authorities in New Zealand and is a provisional, qualitative screening procedure that provides an approximate assessment of seismic risk in terms of %NBS following a cursory site visit. In comparison, a DSA typically provides more detail and involves comprehensive calculations and/or computer models. A preliminary assessment for purposes of ACPD's rapid building evaluation programme comprises the IEP but without an assessment of geometric irregularities (i.e. building configurations that may result in undesirable behaviour under earthquake loading) such that the procedure can be applied off-site knowing only the building height, structural system, year of design and importance level (NZS, 2002). Regarding the design year, knowledge of the materials and loadings standards to which a building was designed heavily influence assumptions about its seismic capacity (Uma *et al.*, 2008; MacRae *et al.*, 2011). The importance level is largely dictated by the size of the building (in square metres of total floor space), the number of regular and maximum occupants and the building's intended post-disaster functions (e.g. buildings housing Auckland Council's Civil Defence and Emergency Management response teams are assessed to a higher importance level and, hence, a more intense DBE).

Comparable seismic risk management policies in New Zealand

To ensure correlation with state-of-the-art engineering and property management practices elsewhere, a survey of owner policies for peer facilities in New Zealand was warranted. For example, Wellington City Council (WCC) is a peer local authority that as of April 2013 owned 683 buildings (Brown, 2013). Any building deemed potentially earthquake-prone by an ISA has been tagged with publicly viewable notices, and some buildings (e.g. those containing large numbers of children) have been closed until further assessments or retrofits are commissioned. A DSA will be commissioned for every building owned by WCC with an ISA score of below 33%NBS. Regardless of the ISA score, however, WCC's health and safety policy is to commission a DSA for every building within their portfolio that could subject them to action under the Health and Safety in Employment Act (New Zealand Parliament, 1992), primarily those buildings that house Council staff or are accessible to the public. As of April 2013, WCC considered 128 of its 683 buildings to be subject to this health and safety policy. WCC has commissioned soil borings at several of its building sites to better understand amplification and liquefaction potential. As of March 2014, WCC had demolished one minor building and applied for consent to demolish another, largely because of earthquake-related concerns (Brown, 2014). Note that on an international scale, Wellington has a high seismic hazard compared to Auckland's moderate seismic hazard (NZS, 2002; ASCE, 2014).

The New Zealand Department of Corrections (Corrections) owns over 870 buildings across the country and commissioned an engineering consultant to assess these buildings using the IEP. Thereafter, Corrections' seismic risk committee developed a risk-framework which was largely quantitative in nature and took into account IEP scores, health and safety issues related to seismic hazards that may not normally be captured by the IEP and functional utilisation of the buildings (based on hours of use). These three categories were assigned weighted scores (30, 50 and 20 per cent) to compute an overall risk value. The risk value spectrum was divided into four action categories for the buildings to be assigned response plans within 12, 24, or 36 months or to consider the building for future disposal (Linstrom and Sharpe, 2013).

The New Zealand Ministry of Education (MoE) owns and manages approximately 16,000 buildings across the country, excluding ancillary structures (such as utility sheds and boiler houses). The MoE formed an Engineering Strategy Group (ESG) to provide technical leadership on structural assessments and strengthening of school buildings. That group has advised that the MoE's buildings should be prioritised based largely on structural configuration, with particular emphasis assigned to buildings constructed of unreinforced masonry (URM), buildings of two or more storeys with heavy construction, especially reinforced concrete (RC), and single-storey buildings with large open areas (Armstrong, 2013). Given that 80 per cent of the buildings in the MoE's portfolio are constructed primarily of timber, and that many of the geometric and detailing configurations of its buildings are consistent across the portfolio, the ESG pursued physical testing of exemplar buildings and used the results from the testing in published guidelines for the seismic evaluation of timber-framed buildings (Sheppard and Brunsdon, 2013).

Risk management priorities in the Auckland Council Property Department facilities portfolio

ACPD's acceptable risk thresholds and strategies for prioritising building evaluations can be considered in comparison to the peer owner policies summarised previously. In comparison to WCC, the buildings in the ACPD portfolio are far more numerous (over 3,500 compared to WCC's 683) and are located in a region with a relatively lower seismic hazard, so defaulting to commissioning DSAs for all occupied buildings and all buildings with ISA scores lower than 33%NBS would likely result in an inefficient use of resources. In comparison to Corrections and the MoE, ACPD's buildings are used in a wider range of service and commercial functions (Table II) and have a greater variety of structure types, so a more qualitative strategic review is preferable. However, the importance of protecting building occupants, considering building utilisation rates, and

Primary function type	No. of buildings	Average documented floor area per building (m^2)	Estimated total floor area for all buildings (m^2)
Animal welfare centre/pound	*21*	*380*	*7,985*
Arts/museum/cultural centre	*30*	*922*	*27,648*
Cafe/restaurant	21	451	9,470
Camp/hut/lodge Building	67	249	16,710
Car parking building	18	4,819	86,743
Chapel/crematorium	12	574	6,885
Childcare facility	6	333	2,000
Commercial/investment building	282	1,870	527,433
Community centre	*30*	*813*	*24,391*
Community facility	*226*	*1,270*	*286,960*
Community hall	*96*	*390*	*37,444*
Community house	21	301	6,319
Council office/service centre	*70*	*6,594*	*461,605*
Event/entertainment centre	2	86	172
Farm building	44	214	9,403
Fire station	13	304	3,952
Horticulture/glasshouse	22	126	2,782
Housing for the elderly	460	146	67,223
Kitchen	9	244	2,194
Laundry	33	134	4,408
Library	*38*	*1,596*	*60,641*
Local board accommodation	*1*	*690*	*690*
Resident-owned subsidised housing	38	287	10,908
Public display/education building	10	245	2,449
Public toilet/changing shed	911	120	109,225
Pump house	13	163	2,115
Recreation/leisure centre	*14*	*4,202*	*58,828*
Residential	590	337	198,953
Residential garage	41	211	8,638
Shade/shelter	24	1592	38,213
Sports facility	74	764	56,506
Stadium/grandstand/arena	*21*	*1,068*	*22,425*
Swimming complex/aquatic centre	*38*	*2,049*	*77,856*
Transfer station/refuse facility	*16*	*512*	*8,192*
Velodrome	2	?	?
Visitor/information centre	*11*	*272*	*2,995*
Works depot/utility building	197	772	152,146
Mixed use	*51*	*1,414*	*72,129*
Not recorded	3	1,567	4,702
Total	*3,576*	–	*2,479,337*

Note: ? = unknown/not recorded

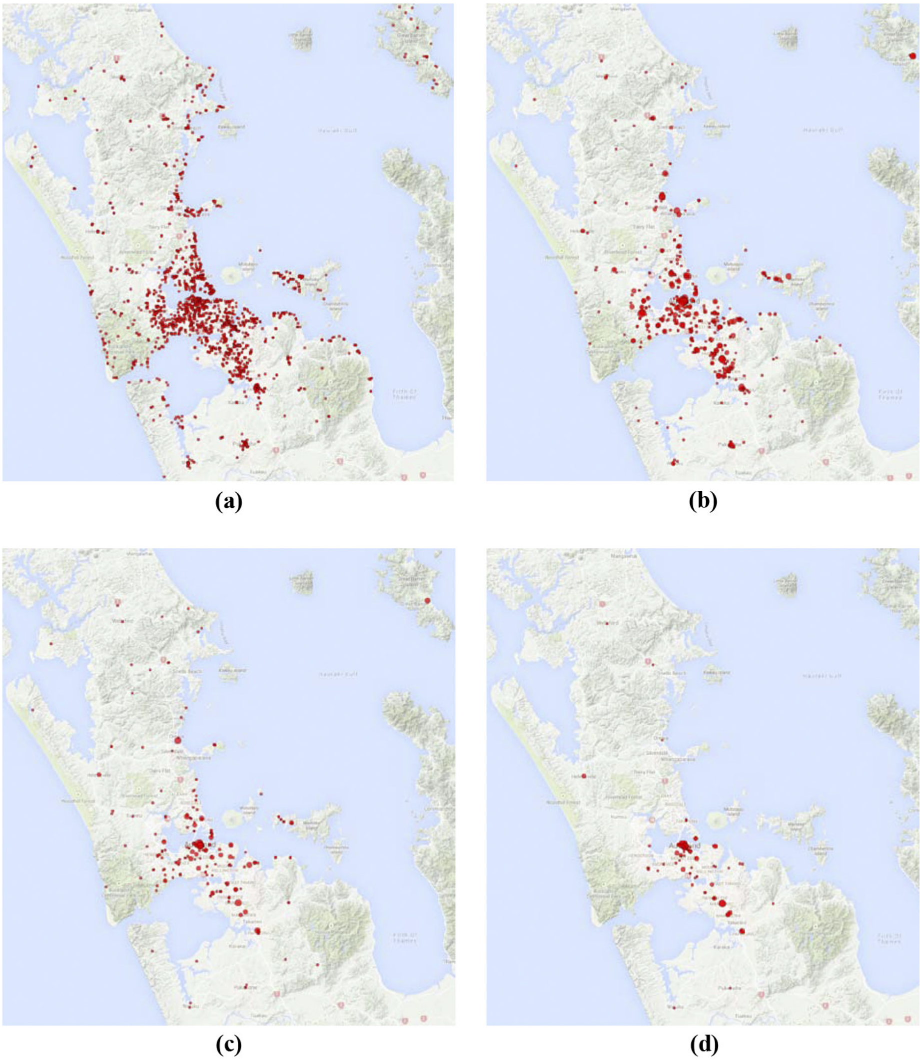
Table II. ACPD's portfolio by function type as of March 2015 attempting to leverage the evaluation of representative buildings within the portfolio to steer work on similar buildings are all considerations from peer owners that ACPD has incorporated into its seismic risk mitigation programme. ACPD has also implemented the recommendations from the New Zealand Property Management Centre of Expertise (2013) which include the following:

- [Set] *an expectation that where hazards are identified, all practical steps are taken to remove or minimise the risk posed […] Employers need to exercise judgement in this respect.*
- *Being "earthquake prone"* [per an ISA] *doesn't necessarily mean that your building should not be occupied but it does mean that an expert engineering assessment* [DSA] *should be obtained as soon as possible.*
- *To ensure that no unnecessary cost is incurred, agencies need to form a view of where the tolerable risk point is in relation to a particular building and balance this against the requirement to keep staff and the public safe.*

ACPD considers its "risk point" as the product of three components, vulnerability, hazard and consequence. Any appropriate seismic evaluation programme must account for all three of these factors. Initially, the only data available for the buildings in the ACPD's portfolio (held in a *SAP* database platform) were street address, number of assigned occupants (available numbers included staff and elected representatives but not visitors or patrons) and functional type of each building (Table II). Hence, the rapid evaluation programme was prioritised based on perceived risk as derived from these attributes, in which location (Figure 1(a)) was used as a preliminary proxy for vulnerability based on the age of design (with field assessments targeted initially to geographic areas of the region known to have been settled and built up earlier) and as a proxy for hazard (with South Auckland being closest to known active faults) (Kenny *et al.*, 2011). The consequence component of risk was considered in relation to the number of assigned occupants and functional type wherein core service buildings that are used to provide public services directly to the community and are often occupied by Auckland Council associates, as well as members of the public, were prioritised for evaluation (Figure 1(b)). The core service function types are italicised in Table II.

The buildings prioritised based on the initial round of portfolio filtering were identified to the facilities maintenance managers, who were asked to provide the best available information on design age (or, alternatively, construction age), structure type and number of storeys above grade for each building. Information provided by the maintenance managers was supplemented by data contained within ArcGIS spatial map files from Quotable Value (QV) Limited, a state-owned valuation information services provider. Attained QV information included approximate design ages and heights for some buildings but did not include structure type. Floor areas were documented for as many buildings as possible (Table II), and if not available from the maintenance manager or QV, they were generally approximated as the footprint area measured from an Auckland Council GIS map multiplied by the number of visible storeys (from photographs, site visits or Google Street View).

As noted previously, knowledge of the relevant design standards to which a building was constructed heavily influences assumptions about its seismic capacity (Uma *et al.*, 2008; MacRae *et al.*, 2011) and is especially influential in regards to the %NBS score



Notes: (a) All ACPD buildings (3576); (b) ACPD core service buildings sized by number of assigned occupants (663); (c) ACPD core service buildings designed prior to 1976 sized by number of assigned occupants (226); (d) ACPD buildings designed prior to 1976 and constructed primarily of URM or RC frames sized by number of assigned occupants (108)
Source: Google Maps

Figure 1.
Maps of priority buildings in the ACPD portfolio as of March 2015 (# buildings shown)

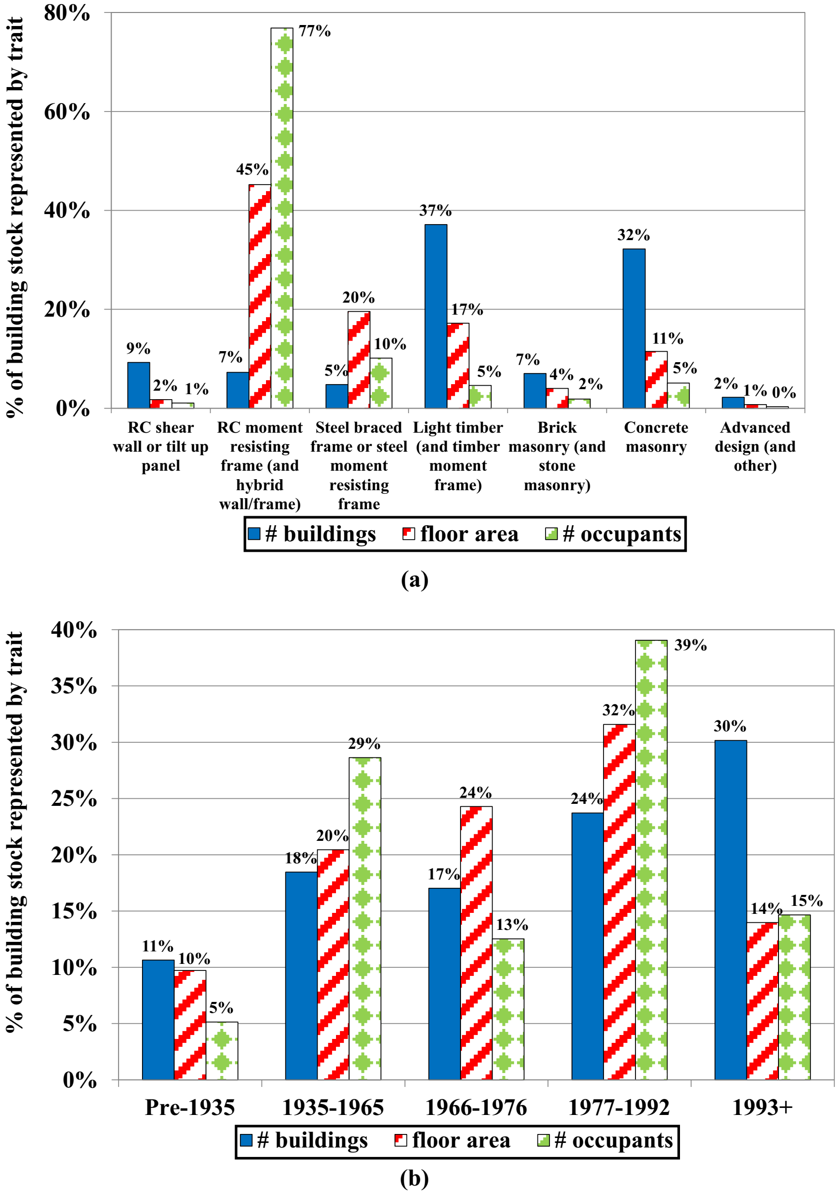
derived from the IEP (NZSEE, 2014). Hence, where such information was available, buildings were assigned to one of the following age groups: pre-1935, 1935-1965, 1966-1976, 1977-1992 and 1993+. Generally speaking, older buildings are perceived to be more vulnerable to earthquakes (Figure 1(c)), particularly buildings of most structure types designed prior to 1976, when a modern understanding of building ductility was implemented into the loadings standard. Ductility, as considered here, is the ability of a building to reach its peak strength and continue deforming under earthquake demands without weakening.

Consistent with the MoE priorities and those buildings recognised by the Canterbury Earthquakes Royal Commission (Cooper *et al.*, 2012) as being particularly vulnerable to earthquakes, two structure types were prioritised for identification and rapid evaluation in the ACPD programme:

- Load-bearing URM buildings, which were typically constructed in Auckland between 1880 and 1940, being a structure type that was responsible for 39 fatalities during the 2011 Christchurch earthquake at 20 different sites; and
- RC-frame buildings, which were typically built in New Zealand anytime from the early 1900s, being a structure type that was responsible for 133 fatalities during the 2011 Christchurch earthquake because of the collapses of the Pyne Gould Corporation (PGC) building and the Canterbury Television (CTV) building.

Hence, the next iteration of prioritisation for initial evaluations was correlated with those ACPD buildings constructed with potentially vulnerable structure types (Figure 1(d)). Note that the buildings mapped in Figure 1(d) include buildings outside the core services portfolio, as URM walls may be more dangerous to passers-by in close proximity to buildings than to building occupants during earthquakes (Moon *et al.*, 2014). Note also the progressive culling of the ACPD building stock from its entirety down to the most potentially at-risk buildings (at least those that were documented with relevant attributes of vulnerability and consequence) in sequence from Figures 1(a)-(d). Hazard was considered insofar as the buildings are spatially distributed with some being located nearer to known active faults (Kenny *et al.*, 2011) and known soft soils sites (Edbrooke, 2001).

One notable exception exists to the previously described prioritisation by structural vulnerability. Contrary to most structure types, RC-frame buildings constructed in New Zealand prior to the 1960s are not necessarily more vulnerable than their more modern 1960s-80s counterparts, as they are typically low-rise and have more redundant structural elements. In contrast, more modern RC-frame buildings are generally taller with fewer redundant elements and greater geometric irregularities (NZSEE, 2014). The fatal collapses of the two relatively modern RC-frame buildings during the 2011 Christchurch earthquake, constructed in 1966 (PGC) and 1986 (CTV), brought greater attention to deficiencies in newer-type RC construction, particularly where some columns in these buildings were not designed with ductile reinforcement detailing. Although the vulnerability of URM walls to out-of-plane collapse from earthquake demands and the extent of retrofit intervention necessary is relatively easily determined with knowledge of the wall and floor geometry (Walsh *et al.*, 2014a), the vulnerability and extent of retrofit intervention necessary for RC-frame buildings depends largely on reinforcement detailing and displacement demands, which are not as easily determined without a complete DSA (Walsh *et al.*, 2014b). Furthermore, despite the relatively small number of buildings in the ACPD portfolio constructed of RC frames (Figure 2(a)), this type of building constitutes the most significant portions of the ACPD portfolio in terms of both floor area and number of assigned occupants. Hence, multi-storey RC-frame buildings in the ACPD core services portfolio with assigned occupants were prioritised



Notes: (a) Structure type [per GNS (2010) category]; (b) Design age

Figure 2.
ACPD building portfolio distributions by documented vulnerability characteristics as of March 2015

first to be evaluated through DSAs over all other buildings, and those RC-frame buildings included buildings constructed as recently as the late 1980s (an era of design which is also prominent across the ACPD portfolio, Figure 2(b)). Figures 2(a) and (b) were created based on available data for 894 and 1,598 buildings, respectively.

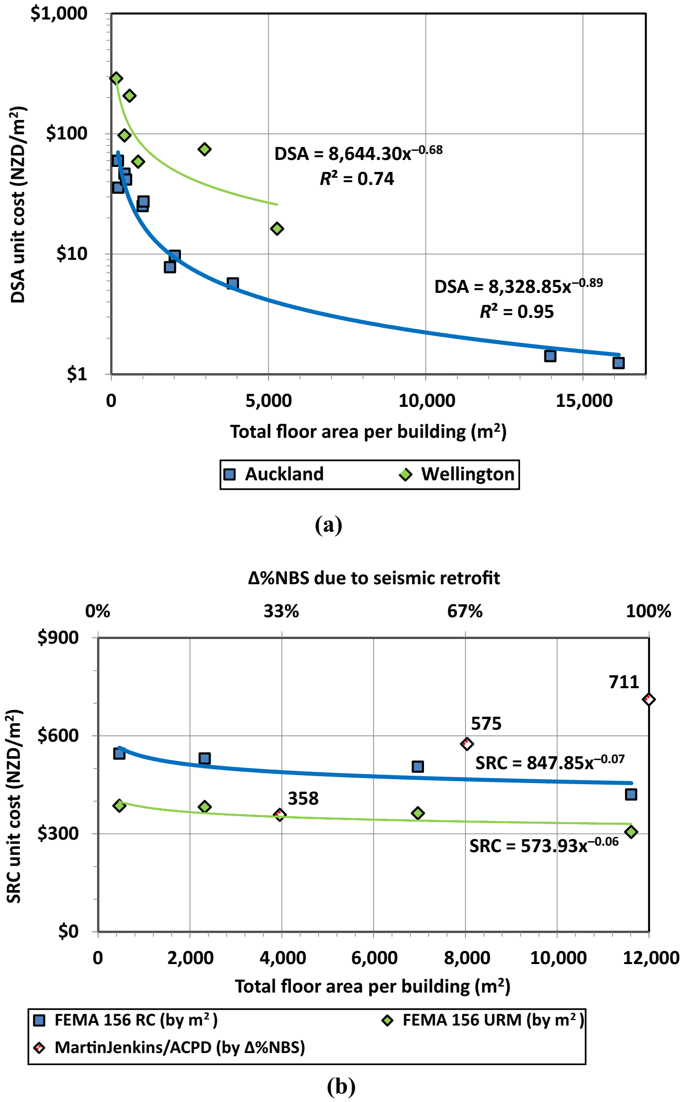
Seismic mitigation mandates, such as the one currently enforced in New Zealand, are often perceived as being in conflict with other social objectives and legislation, such as that pertaining to heritage preservation (New Zealand Parliament, 1993). ACPD has identified 217 buildings within its portfolio that are listed with either Heritage New Zealand or the Auckland Council heritage register. Such heritage registration will impose strict limitations on both seismic retrofit and disposal options. Auckland Council's consideration of heritage buildings specifically is addressed in other literature (Brown *et al.*, 2014).

Risk profiles and estimated cost liabilities

As of March 2015, ACPD had commissioned 7 building retrofits, 10 DSAs, 319 IEPs and 434 preliminary evaluations on the buildings in its portfolio. For predictions of the entire portfolio's risk profile, the results of the completed evaluations have been marginally weighted in accordance with the structure type and age distributions, shown in Figure 2, to account for the bias of the current assessments towards buildings most likely to be at risk. ACPD estimates that approximately 6 per cent of its portfolio by number of buildings is potentially at high risk (earthquake-prone), approximately 17 per cent is potentially at moderate risk, approximately 25 per cent is at low risk and the remainder (approximately 52 per cent) is very low risk and theoretically compliant with the current loadings standard (NZS, 2004). One of the reasons for predicting a relatively low percentage of high-risk buildings is that approximately 90 per cent of the buildings in the ACPD portfolio where the number of storeys above grade is known are single-storey buildings, which suggests a relatively low-risk exposure across the complete ACPD portfolio.

Preliminary, empirical models for estimating the cost of commissioning a DSA for an individual building are shown in Figure 3(a) for Auckland (eleven data points) and Wellington (six data points). Note that these preliminary models for DSA costs do not account for differences in structure type, importance level, existing %NBS, target %NBS (desired for assessment or intended for retrofit) or specific DSA methodology. Furthermore, ACPD expects that by grouping buildings into packaged DSA projects, they may keep the cost of DSA per building lower than is indicated by the models in Figure 3(a). Note that DSAs are generally expected to be less expensive in Auckland than they are in Wellington, most likely because of the higher seismicity in Wellington and associated increased complexity of analysis and liability for the engineering consultants performing the DSAs.

Much of the research focus on earthquake-related construction costs pertains to benefit-cost assessments regarding the extent of seismic retrofits and serviceability repairs following actual earthquakes or hypothetical earthquakes expected during the service life of individual buildings, as summarised in other studies (Alani and Khosrowshahi, 2007). In contrast, ACPD is responding to legal mandates and attempting to quantify and reduce its life-safety risk exposure across a large portfolio as efficiently as possible. The near-term, effectively binary decision to retrofit or dispose/change-use of a relatively large number of buildings considering service, community and heritage values takes precedent, at least initially, over decisions related to the extent of retrofit to be considered for individual buildings (except in the case of those few buildings needed for civil defence activities). Hence, the use of basic predictive models for seismic retrofit construction (SRC) costs is appropriate for quantifying ACPD's risk exposure in fiscal terms and for informing the future strategic actions taken once initial assessments are completed. Note that SRC costs, for purposes of this programme, are



Notes: 1.00 NZD ≈ 0.75; USD ≈ 0.50 GBP; (a) DSA; (b) SRC

Figure 3. Unit cost estimate models used for initial cost estimating

generally assumed to account for all physical works related explicitly to seismic strengthening. Some buildings in the ACPD portfolio, especially older buildings with heritage registrations, are also likely to require extensive non-structural rehabilitation works that are not accounted for by the models proposed herein (e.g. new or rehabilitated roofing, cladding, windows, HVAC systems, carpeting, electrical wiring, ornamentation, etc.).

New Zealand consulting firm MartinJenkins (2012) developed SRC models which accounted inexactly for design age, structure type and discrete %NBS thresholds desired after retrofit (specifically 34%NBS, 67%NBS and 100%NBS). The MartinJenkins' SRC models were based on the results from a survey of a small group of New Zealand structural engineers. ACPD validated the accuracy and applicability of the MartinJenkins models with local structural engineers in Auckland and with relevant international literature (FEMA, 1994) and then simplified the MartinJenkins models so as to represent generic buildings and account for discrete target improvement levels (Δ%NBS, Figure 3(b)) for application to individual buildings. The FEMA (1994) approximate SRC unit costs were initially published for the USA and accounted for structure type, approximate floor area and regional seismicity. ACPD considered the FEMA SRC unit costs for a region of moderate seismicity and adjusted them to account for foreign exchange rates (1.00 NZD = 0.75 USD) and construction industry inflation (average of 4.66 per cent per year per ENR, 2014). The adjusted FEMA SRC models for RC and URM buildings are also shown in Figure 3(b). Typical SRC unit costs for most scenarios are assumed to be between 300 and 600 NZD/m^2, as indicated in Figure 3(b).

To consider the fiscal liabilities associated with ACPD setting uniform acceptable risk thresholds across the entire portfolio, generic unit costs were considered in regards to the aforementioned predicted risk profiles (Table III). Any SRC work would be assumed to interfere with building occupants to the extent that they would need to be moved temporarily, so a unit cost of 5,000 NZD per occupant was assumed from previous experience within ACPD. As noted previously, singular buildings or particular types of buildings often accommodate a great portion of building occupants. In the case of the scenario presented in Table III in which 630 assigned occupants are potentially affected by ACPD setting a portfolio-wide acceptable risk threshold of "moderate" or better (≥34%NBS), 301 of those occupants reside in a single building where the only documented components that are potentially "earthquake-prone" are isolated stairwell connections that are relatively inexpensive to retrofit. Other common vulnerable building components that by themselves are relatively inexpensive to repair include chimneys, parapets and gable end walls, especially in URM buildings. Hence, the unit costs charted in Figure 3 and listed in Table III represent expected averages subject to very high variances for individual buildings.

Strategies for ongoing seismic risk evaluation and mitigation efforts

For purposes of budgeting for long-term expenses, ACPD has requested from Auckland Council executives and elected representatives the funding needed to commission DSAs and SRC for all buildings determined through the ISA process to be potentially high risk, resulting in the total value presented in Table III of approximately 50m NZD. A portion

Acceptable risk threshold	No. of buildings below threshold	Average floor area per building affected (m^2)	No. of occupants affected	DSA unit cost (NZD/m^2)	SRC unit cost (NZD/m^2 by Δ%NBS)	Occupant move unit cost (NZD/occ.)	Total cost (mil NZD)
Moderate, ≥34%NBS	211	617	630	27.35	358	5,000	53
Low, ≥67 %NBS	821	953	1,094	18.59	575	5,000	470
Compliant, >100 %NBS	1,720	1,250	2,972	14.60	711	5,000	1,574

Note: 1.00 NZD ≈ 0.75 USD ≈ 0.50 GBP

Table III. Estimated generic seismic mitigation costs across the ACPD portfolio of this total amount has been resourced and will be spent over the next 20 years with formal review every 3 years. Note that the total costs in Table III were tabulated assuming work was contracted for individual buildings, whereas savings are expected from packaging groups of similar buildings together. These savings can then be used to commission DSAs for important buildings determined through the ISA process to be potentially moderate risk.

Although a great deal will be learned about individual buildings through DSAs, ACPD will continue to seek improvement in its processes and knowledge database through investigation of soil types and by performing spatially based hazard models to account for spatial variances in hazard within the Auckland region considering the most likely earthquake scenarios. Furthermore, advanced awareness regarding the vulnerabilities of non-structural components and potential remedies (Cormier, 2010) will be incorporated through Auckland Council's health and safety processes. Ongoing efforts to derive DSA and SRC costs from ACPD and peer projects will lead to the development of more sophisticated cost estimation models with greater predictive capabilities of variances due to specific building conditions. In the near-term, ACPD intends to control such variances by packaging buildings of similar structural configurations (e.g. URM buildings) and geographic locations together in requests for proposal to engineers, architects and contractors so that exemplar assessments and retrofits can be utilised at lower unit costs and to ensure greater consistency of engineering evaluations and strengthening works.

Summary and conclusions

The New Zealand Government has enacted sweeping seismic risk mitigation mandates similar to but more comprehensive than those previously enacted or currently being considered by other governments around the world. ACPD has initiated its response to the mandate by identifying buildings most at risk to an earthquake in its large and varied portfolio through the use of a rapid building evaluation programme strategically targeted to vulnerable building types with consequential attributes, including service type, number of occupants, floor area and geographic location. Specifically, buildings primarily constructed of URM and pre-1995 RC with assigned occupants and that provide regular functional services to the community were prioritised for evaluation and future potential retrofit work.

ACPD has reviewed the policies and strategies of a number of peer portfolio owners in New Zealand to ensure that best-practice approaches are utilised in its seismic evaluation and retrofit prioritisation programme and has adopted a number of such strategies. In contrast to what some peer owners have incorporated into their strategies and policies, however, decisions to commission further seismic assessment of and eventually retrofit or dispose/change-use of any individual building will not rest entirely or even largely on the assessed earthquake risk of that building. ACPD has and will likely continue to utilise a qualitative approach towards its strategic property portfolio review to account for numerous stakeholders and criteria such as service, community and heritage values associated with its buildings, wherein major decisions pertaining to the future use of such buildings will lie with the occupying service providers, relevant local boards and regional heritage advisors.

Were Auckland Council to eventually adopt a more quantitative high-level approach towards facilities management decisions (Langston, 2013), the technical information being accrued by ACPD as part of its seismic evaluation programme could readily be incorporated into weighted criteria pertaining to design standard, regulatory compliance and structural condition. ACPD does currently quantify historic and predicted future life-cycle maintenance and capital expense costs for its buildings, and the cost estimate models proposed herein for SRC work are provisionally being implemented into its capital renewals planning.

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