A Case for Resilience in New Zealand

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ABSTRACT

The concepts of resilience and holistic building performance drive the seismic design approach for structures of high importance or special post-disaster function. Considerable advancements have been made in the development of resilient and low damage building systems. However, seismic design to the New Zealand Building Code focuses on life safety and collapse prevention. Minimisation of damage, repair costs or recovery times are not specifically addressed. The absence of New Zealand based guidance to measure seismic performance is a challenge for quantifying resilience in a meaningful and consistent manner.

The New Zealand National Archives Building is a high importance, nationally significant building, comprising a purpose-built specialist facility to house our national treasures. Client-driven performance objectives demanded state-of-the-art solutions to achieve the required functional continuity, recovery, and damage mitigation targets. A multi-disciplinary approach was adopted by the design team, including quantifying site-specific seismic hazard, implementing a Triple Friction Pendulum Bearing isolation system, and specific design for non-structural systems such as partitions, facades, storage shelving and services.

The United States Resiliency Council (USRC) seismic rating system was used in conjunction with the FEMA P-58 framework to quantify holistic building performance with respect to safety, damage, and recovery metrics. Additionally, the recently released ATC-138 methodology was adopted in computation of the recovery dimension to identify critical path systems affecting total building downtime. This paper presents an overview of key aspects of resilience in design, before detailing a case-study application of the USRC seismic rating system and discussing its applicability to quantify seismic resilience within a New Zealand context.

1 INTRODUCTION

The New Zealand Building Code (NZBC) focuses on minimising loss of life and preventing structural collapse during seismic events. NZBC minimum designs typically dissipate seismic energy through mechanisms of ductility and damage and have demonstrated good performance with respect to life safety when ‘tested’ through real life earthquake events (Kam et al., 2011). The NZBC does not endeavour to define objectives beyond life safety with respect to minimising damage or downtime which are associated with economic and social losses.

Within the New Zealand buildings and construction industry, many practitioners are working with their clients to construct buildings that provide ‘beyond code’ levels of seismic resilience. These systems are particularly prevalent for important public buildings with post-disaster function, but in recent years have been increasingly adopted for ‘normal’ structures such as offices and apartments (Ballagh et al., 2020 and Broglio et al., 2017). The adopted structural systems are numerous with ‘low damage structural systems’ such as buckling restrained braces, eccentrically braced frames with replaceable links and sliding hinge joints utilised (Hogg, 2015). The use of sophisticated systems such as base isolation and supplemental damping is becoming more common for both new build and retrofit solutions (Skidmore et al., 2022).

Within the New Zealand industry, there are no published standards or guidelines for quantifying seismic performance and resilience. Practitioners adopt broad qualitative descriptions for communicating the expected seismic performance of structures with clients, stakeholders, and the public. This leads to a broad range of interpretations and descriptions of anticipated seismic performance outcomes.

There is a critical industry need for standardisation of the quantification and communication of seismic performance and resilience. When purchasing a home appliance, consumers can readily ascertain the relative energy performance of the options through the energy star rating system. It is imperative that seismic performance is communicated with building owners and the public in a manner that is clear, simple to understand, and highlights relative performance. The adopted performance metric should address holistic building behaviour and should not be limited to the structural damage and response. The expected performance of the building envelope, fitout, and contents should all be considered as these make up a significant portion of building value and are critical to functionality.

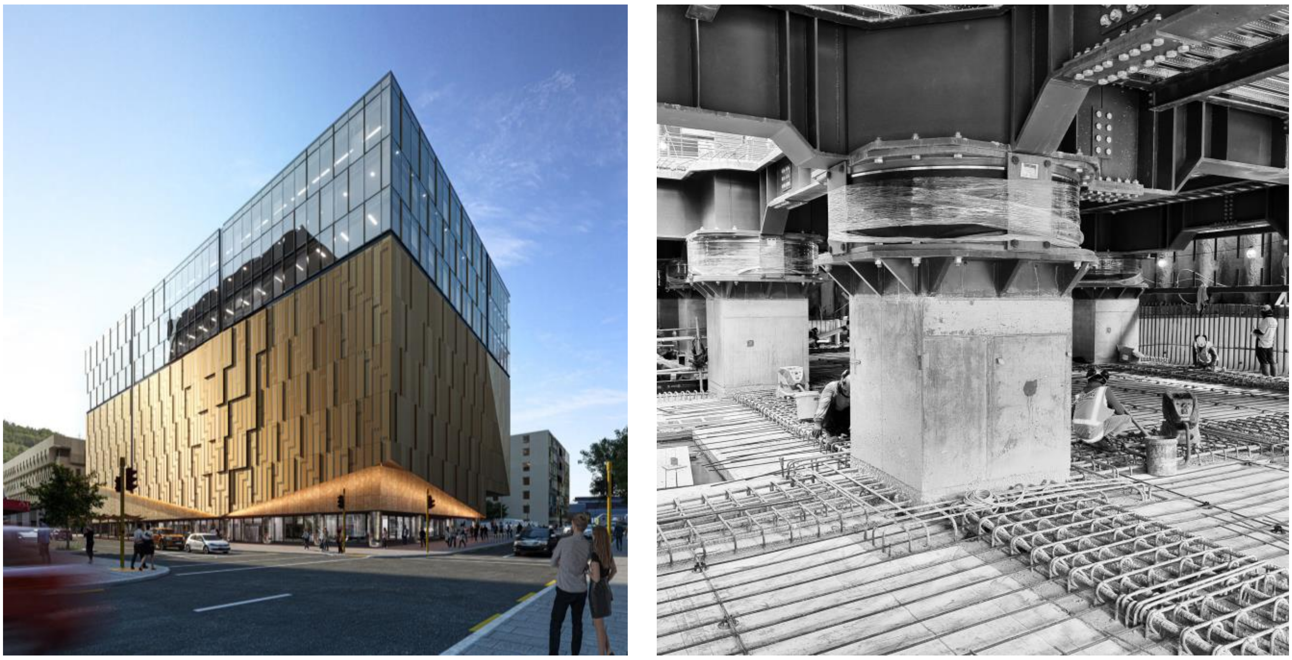
The Archives facility represents an example of a building within the New Zealand context where an internationally recognised seismic rating system has been adopted. The facility has a high level of societal benefit and importance; therefore, the seismic design criteria were required to be more stringent than code. In the absence of New Zealand based industry guidance the United States Resiliency Council rating system (USRC, 2015) was adopted to quantify the seismic performance. The USRC seismic rating system is holistic, rating the building with respect to safety, damage, and recovery. At project inception, a four-star USRC rating was considered appropriate for the protection of the holdings and collections.

The application of the USRC seismic rating system to the Archives project has resulted in several ‘lessons learned’. Within the small and physically remote New Zealand market there are commercial/procurement challenges when rapid post-disaster recovery, functionality and occupancy are required. Carefully considered design criteria are necessary for facades and building services for facilities which require post-disaster functionality. This paper summarises key design aspects required to achieve highly resilient design outcomes across the USRC safety, damage and recovery metrics.

2 THE ARCHIVES BUILDING

2.1 Building Overview

A purpose-built specialist facility for Archives New Zealand is currently under construction and due for completion in early 2025. The building is located at the intersection of Aitken and Mulgrave Streets within the parliamentary precinct in Wellington. The new Archives building has been designed to house the nation’s Taonga (national treasures) and has been designed accordingly to protect the contents from earthquakes through the adoption of stringent seismic performance objectives. The facility is an eight-storey rectangular shaped building with a single basement level (Figure 1). To meet the high level of seismic performance within the context of central Wellington seismicity, a base isolated structure was adopted. Further description of the design features is provided in Beetham et al. (2022).



(a) (b)

Figure 1: (a) Architectural render of Archives building and (b) base isolation system.

The broad range of building contents and fit-out in this mixed-use development required careful consideration throughout design. The lower five floors support a combination of static and mobile archival storage shelving systems that required rigorous peer review and physical testing at both the component and system level to ensure compliance with performance requirements. The basement space within the building is to be occupied and incorporates internal walls with sophisticated proprietary movement joints to accommodate expected damage limit state (DLS) movements of up to 600 mm at the isolation plane. Interior fit-out walls within the superstructure utilise deflection heads that are designed to avoid damage at DLS building drifts, whilst still satisfying fire and acoustic provisions. Although the base isolation system provides an inherent level of protection to building services throughout the structure by minimising floor accelerations and inter-storey drift demands, additional bespoke seismic restraint and equipment specification considerations were included to enhance post-earthquake recovery performance.

2.2 Seismic Performance Objectives

To meet the ambitious seismic performance criteria for the development, it was critical that the design team considered components beyond the primary structure. Addressing the performance of the holistic building system in this manner required a massive collaborative effort from the design team. Full system building performance is not commonly considered within the New Zealand context and performance considerations are often limited to structure only. Table 1 provides a high-level outline of the performance objectives for the development.

In addition to the performance-based objectives described in Table 1, the building owner specified resilience-based objectives for seismic hazards in the form of a minimum requirement for a USRC rating of four stars. This is discussed further in Section 4.

Table 1: Performance objectives and business continuity.

Limit State	Return Period	Performance Description
SLS1 (Operational)	1/25 years	Continued occupancy and use highly likely. Negligible damage occurs.
DLS (Immediate Occupancy)	1/500 years	Continued occupancy likely. Minor readily repairable damage. Drift limited to 0.90%.
ULS	1/1000 years	No permanent drift in superstructure, which remains nominally elastic. Isolation system may have some residual displacement.
CALS (Collapse Prevention)	1.5 × ULS (circa <2% chance of exceedance over life)	Life safety limit state. Superstructure ductility/damage expected. Substructure remains elastic. Continued occupancy unlikely without repair.

3 PERFORMANCE MEASUREMENT FRAMEWORKS

3.1 International Performance Measurement Systems

The assessment of seismic resilience in the building sector has gained significant international interest over the past decade, leading to the development and implementation of a range of performance measurement systems (Boston and Mitrani-Reiser, 2018). These systems capture holistic building performance by considering the safety of the occupants during a seismic event, the magnitude of damage that may occur and the recovery time required to return the building to its intended functionality. Arguably the most comprehensive is the USRC seismic rating system, which was developed with the intention of communicating loss assessment in a manner that is meaningful to stakeholders and the public. Other international rating systems include the Resilience-based Earthquake Design Initiative (REDi) produced by the engineering firm Arup, the New Zealand QuakeStar Rating System which was modelled after the USRC seismic rating system, and the US Office of State-wide Health Planning and Development (OSHPD) Seismic Performance Categories for hospitals with special post-disaster functions.

3.2 US Resiliency Council (USRC) Rating System

The USRC is a non-profit organization established in the United States with the intent to implement meaningful rating systems that describe the performance of buildings during earthquakes and other natural hazard events. It also has a mission to educate the general public in understanding earthquake and other natural hazard risks with the ultimate goal of improving societal resilience. The USRC's first rating system is for earthquakes and was the rating system applied to the Archives building. The USRC has since expanded to also include a rating system for wind hazards.

The USRC seismic rating system measures resilience along three dimensions: (1) safety, (2) damage, and (3) recovery as shown in Figure 2. Each of the dimensions are briefly described below:

- The safety dimension "addresses thresholds for the building in terms of the potential for people in the building to get out after an earthquake event and avoid bodily injuries or loss of life during the event" (USRC, 2015).
- The damage dimension "reflects an estimate of the cost to repair the building after an event" sufficiently to allow the building to be used as it was before the event.
- The recovery dimension is an "estimate of the time until a property owner or tenant is able to enter and use the building for its basic intended function".

Once a quantitative assessment of each of the three dimensions has been performed, the performance in each dimension is mapped to a star rating. A building assessed to the USRC seismic rating system can achieve between one and five stars in each dimension. Further, a building which achieves sufficient stars in all three dimensions can be assigned a USRC certification ranging, in order of increasing performance, from Certified to Silver, Gold and Platinum (Figure 2).

	SAFETY	DAMAGE	RECOVERY
★★★★★	Blocking exit paths unlikely	Minimal Damage (<5%)	Immediate to Days
★★★★	Serious injuries unlikely	Moderate Damage (<10%)	Within days to weeks
★★★	Loss of life unlikely	Significant Damage (<20%)	Within weeks to months
★★	Isolated loss of life	Substantial Damage (<40%)	Within months to a year
★	Loss of life likely	Severe Damage (40%+)	More than a year

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Figure 2: USRC seismic rating dimensions.

The quantitative assessment to obtain a USRC rating can be performed using one of two methods. The first is a translation of a simple ASCE 41 Tier 1 checklist into a USRC rating. As the ASCE 41 Tier 1 checklists are a less detailed evaluation of a building, the USRC limits the number of stars that can be achieved in each dimension when using this method. The more detailed method to obtain a USRC rating is using FEMA P-58 *Seismic Performance Assessment of Buildings* (FEMA, 2018) as described in the following section.

A USRC Verified Earthquake Rating must be performed under the direction of a USRC Certified Rating Professional who is an individual that has completed and passed the USRC training program. USRC Verified Earthquake Ratings are also reviewed by an independent USRC Certified Rating Reviewer.

3.3 FEMA P-58 Framework

FEMA P-58 is a next-generation performance-based seismic design document published by the Federal Emergency Management Agency (FEMA). It utilizes the seismic hazard at a site, structural demand parameters, building collapse resistance, structural and non-structural component fragilities, and Monte Carlo simulation to determine a building's expected seismic performance with respect to injuries/fatalities (i.e., safety dimension of USRC), cost to repair (i.e., damage dimension of USRC), and time to repair (i.e., recovery dimension of USRC). Most importantly, FEMA P-58 explicitly accounts for uncertainty in each step of the process through a probabilistic, rather than deterministic, calculation methodology.

While the probability and consequence of building collapse is explicitly considered within the FEMA P-58 framework, for projects pursuing enhanced seismic performance, building collapse typically has a negligible contribution to the expected building performance. More significant to the calculation of the measures of safety, damage and repair within the FEMA P-58 framework are consequence functions associated with each structural and non-structural fragility. These consequence functions define the expected distribution of injury/fatality, repair cost, and repair time for a given damage level of a component. For example, the cost to repair the anchorage of an air handling unit when the anchorage has pulled out of a concrete house-keeping pad is expressed as a best-estimate cost and an associated uncertainty (i.e., distribution of expected cost to repair). By integrating/summing the injury/fatality, repair cost, and repair time resulting from the consequence functions across all components, the building-level injury/fatality rate, repair cost and repair time are calculated within the FEMA P-58 framework.

The application of FEMA P-58, particularly the Monte Carlo simulation and interaction with the structural and non-structural fragility curves, is computationally intensive. It is therefore regularly implemented in software such as the Seismic Performance Prediction Program (SP3) developed by Haselton Baker Risk Group (HBR).

3.4 ATC-138 Methodology for Recovery Dimension

Although the FEMA P-58 framework can compute recovery time, it was identified after its release that many of the neglections and simplifying assumptions led to unsuitable estimates of recovery time. Recovery time is defined as the time to regain function, which is generally longer than direct repair time.

To address the concerns over the FEMA P-58 repair estimates, the Applied Technology Council (ATC) pursued the ATC-138 project which resulted in a new volume in the FEMA P-58 series of reports entitled "Methodology for Assessment of Functional Recovery Time" (ATC, 2021). While the ATC-138 method is built on the FEMA P-58 framework (e.g., uses Monte Carlo simulation and repair consequence functions), it introduced concepts not previously considered by FEMA P-58 including impeding factors, fault trees for identifying building system function, repair schedule dependencies, and explicit consideration of temporary repair measures. Impeding factors in the ATC-138 method include inspection, financing, engineering mobilization, design, permitting, and contractor mobilization. An example fault tree showing the potential "faults" which would prevent building HVAC function are shown in Figure 3.

In the original FEMA P-58 framework, these concepts were either neglected or were treated in a simplified manner. For example, in the original FEMA P-58 framework, repair time did not consider impeding factors and could be calculated as either a parallel or series schedule (i.e., all systems could either be worked on at the same time or only one after the other, respectively). In the ATC-138 method, the interdependencies between repair of different systems is considered directly.

Another essential product of the ATC-138 method is the concept of a building's basic intended functions. Basic intended functions are the systems and operations within a building that need to be functioning after an earthquake for the building to serve its intended purpose. The ATC-138 method recognizes that basic intended functions are less than are required for pre-earthquake functionality. For example, it is likely acceptable for an office building to continue to function after an earthquake even with minor cracking to drywall or a broken window that can be temporarily boarded up. However, it would not be acceptable for an office building to continue to function after an earthquake if its primary transformer was not operational (i.e., no electrical power). As will be discussed in Section 4.1, a building's basic intended functions can be subjective and often requires a nuanced discussion between the owner and the design team.

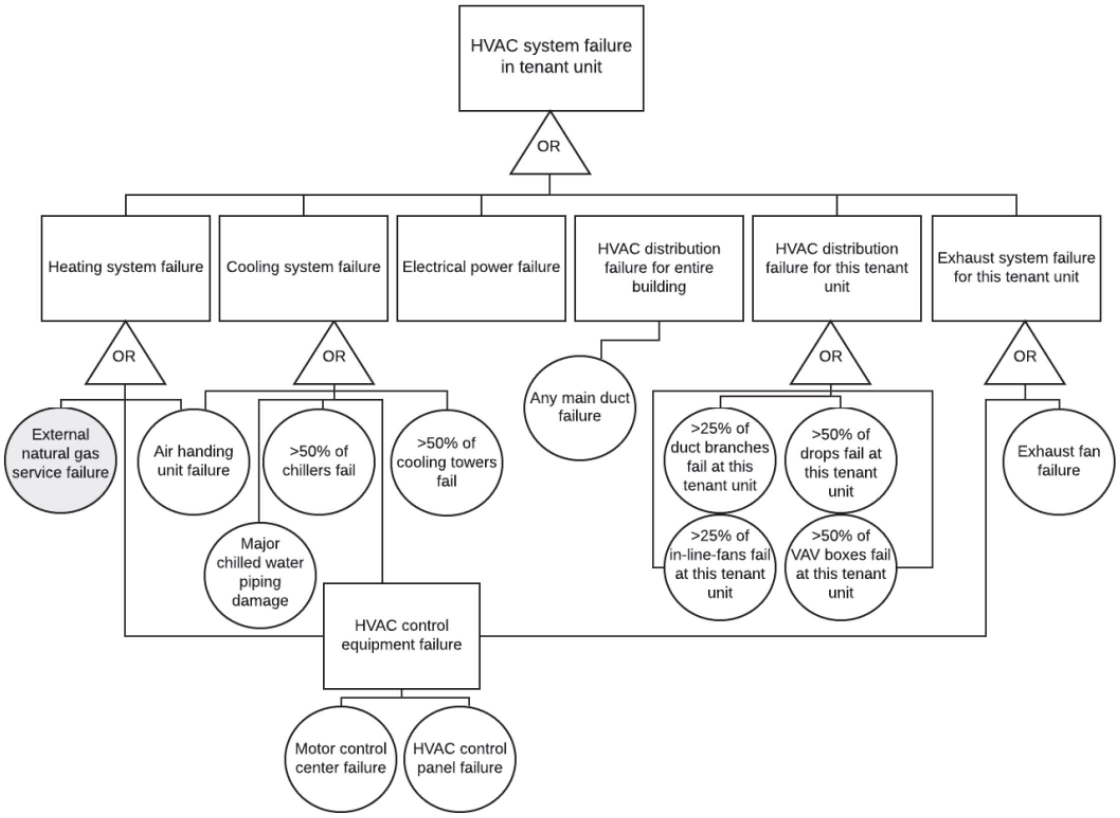


Figure 3: Fault tree for HVAC system function (reproduced from ATC-138).

4 APPLICATION OF USRC RATING SYSTEM TO THE ARCHIVES BUILDING

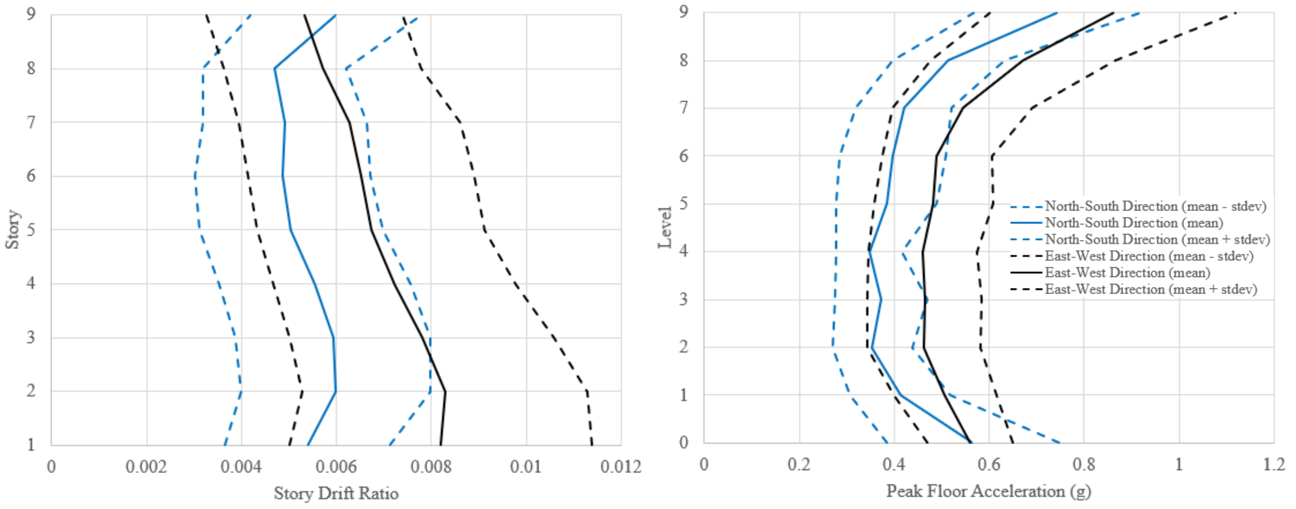
4.1 Defining Basic Intended Function

As discussed in Section 3.4, a critical aspect of a resilience assessment like that performed for the Archives building, particularly when assessing recovery time, is the description of basic intended function. The Archives building is first-and-foremost intended to protect holdings and collections of national significance. Storage of these materials generally occurs on Levels 1 through 5 with Levels 6 through 8 housing supporting office and lab spaces. In discussions with the building tenant, it was clear that archival storage is of immense importance through and following the earthquake but that the office and laboratory spaces were not expected to be needed for some time after a major event. Therefore, while the building generally contains two, distinct occupancies, the basic intended function of the Archives building was predominantly safe storage of archival materials. Furthermore, safe storage of archival materials meant, at a minimum, temperature and humidity control (including prevention of envelope damage), enhanced storage rack performance, no fluid-filled pipe leaks, and fire protection functioning. It did not necessarily require that the elevators worked since archival materials were not planned to be moved following an event nor did it require that the office or laboratory spaces be functioning. The latter was an especially important characterization of basic intended function for this building since it permitted greater damage and loss of function in these spaces which are enclosed by a different façade type and served by a separate HVAC system without compromising the function of the primary archival spaces.

4.2 FEMA P-58 and ATC-138 Resilience Assessment

The FEMA P-58 and ATC-138 resilience assessments for the Archives building were performed for 1/1000-year seismic hazard. Engineering demand parameters consisting of peak story drift ratio, residual story drift ratio, and peak floor acceleration were taken from nonlinear response history analysis results. See Figure 4 where the mean, mean plus one standard deviation, and mean minus one standard deviation estimates of story drift ratio and peak floor acceleration are reported. Mean and standard deviation are computed over the suite of seven records. Since the FEMA P-58 and ATC-138 methods are probabilistic, it is necessary to characterize engineering demand parameters in terms of a best estimate (e.g., mean) and a variability (e.g., standard deviation). This distribution of engineering demand parameters feeds into the Monte Carlo simulation embodied within the FEMA P-58 and ATC-138 methods. Residual drift ratios were also extracted from the nonlinear response history analysis. Although residual drifts were essentially negligible for the Archives building, they were used in the FEMA P-58 and ATC-138 calculations for completeness.

It is clear from Figure 4 that the seismic isolation system is achieving significant reductions in peak story drift ratio and floor acceleration compared to a fixed-base building. However, it should be noted that peak story drift ratio and floor acceleration are not negligible, with peak floor accelerations at the roof reaching 0.8g. These results identify that demands on non-structural elements can be significant even for a seismically isolated building when that building is subjected to very large ground motions. The engineering demand parameters, notably peak story drift ratio and peak floor acceleration, are then integrated with the structural and non-structural fragility curves.

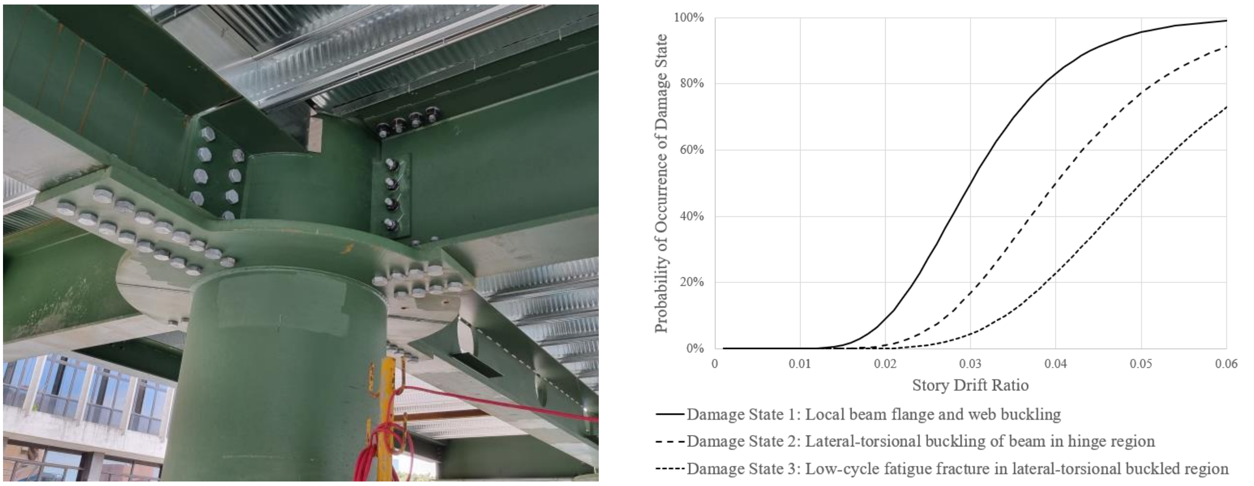


(a) (b)

Figure 4: (a) Peak story drift ratios and (b) peak floor accelerations for 1/1000-year event. Story 1 corresponds to the story between ground level (i.e., level immediately above isolation plane) and Level 1.

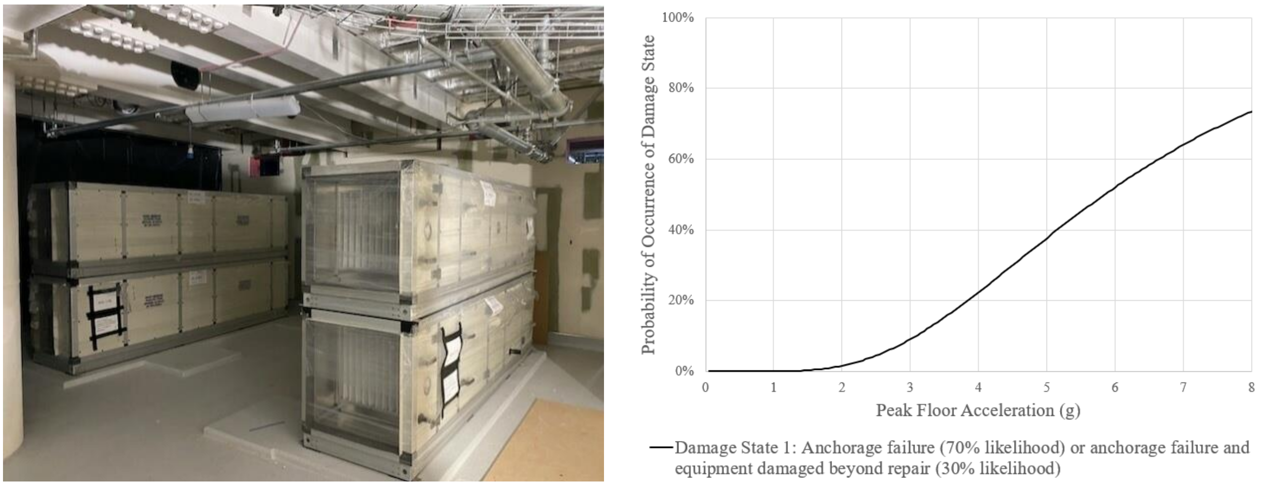
A complete take-off of all structural and non-structural components was completed for the Archives building to populate the structural and non-structural quantities, location in building height, fragility curves, and consequence functions in the FEMA P-58 and ATC-138 assessment. In particular, the services engineer was particularly helpful in identifying quantities, types and locations of mechanical, electrical, plumbing and fire protection equipment (e.g., chillers, transformers, etc.) and distribution systems (e.g., ducts, piping, etc.) which, while essential to building function, are not the expertise of structural engineers.

Example fragility curves and associated construction photos are shown for a steel beam-column moment connection and the anchorage of an air-handling unit in Figure 5 and Figure 6, respectively. The resilience assessment model for the Archives building adopted more than 60 unique fragility types, with many components associated with a given fragility type. For the steel beam-column moment connection in Figure 5, the fragility exhibits three potential damage states ranging from less severe (Damage State 1: Local beam flange and web buckling) to more severe (Damage State 3: Low-cycle fatigue fracture in lateral-torsional buckled region). For a given demand story drift ratio, the fragility curve describes the probability that a steel beam-column moment connection will be in each damage state. For the example of a 3% demand story drift ratio, the connection would have a probability of being either undamaged, in Damage State 1, in Damage State 2, or in Damage State 3 of approximately 50%, 33% (50% - 17%), 12% (17% - 5%), and 5%, respectively. For the anchorage of an air-handling unit in Figure 6, only one damage state is present. However, for that damage state, there is a 70% likelihood that only the anchorage will fail with the remaining 30% being the likelihood that the anchorage failure also results in equipment failure. Note that a separate fragility is also defined for non-anchorage failures (i.e., within-equipment failures).



(a) (b)

Figure 5: Archives building beam-column connection: (a) construction photo, and (b) assumed fragility curve from FEMA P-58.



(a) (b)

Figure 6: Archives building air handling unit: (a) construction photo, and (b) assumed fragility curve for equipment anchorage from FEMA P-58 adjusted for project-specific anchorage forces.

4.3 Mapping FEMA P-58 and ATC-138 Results to USRC Criteria

The FEMA P-58 and ATC-138 resilience assessment produce quantitative values of injury/fatality rates, repair costs, and recovery times. These values include a best estimate (e.g., mean or median) as well as a variability (e.g., dispersion or standard deviation). The criteria defined by the USRC for translating the assessment results to a resilience rating are then applied. Table 2 summarizes the FEMA P-58/ATC-138 resilience assessment results alongside the USRC criteria. For the Archives building, 4-stars were targeted for safety, damage and recovery which are associated with quantitative criteria established by the USRC. USRC criteria for safety and damage are for the median estimate from the FEMA P-58 results. The USRC criterion for recovery is for the median recovery time from the ATC-138 results.

Table 2: Quantitative measurements of safety, damage, and recovery for Archives building.

		Safety	**Damage**	**Recovery***
Project Requirement	Required Rating	4 stars	4 stars	4 stars
	Required Criteria	Fatality rate < 0.0001 Injury rate < 0.02	Repair cost <10% of replacement cost	Recovery time < 4 weeks
Project Achieved	Rating Achieved	5 stars	5 stars	4 stars
	Criteria Achieved	Fatality rate negligible Injury rate = 0.001 Egress routes intact	Repair cost = 0.5% of replacement cost	Recovery time = 10 days
	Criteria for Rating Achieved	Fatality rate < 0.00003 Injury rate < 0.02 Egress routes intact	Repair cost <5% of replacement cost	Recovery time < 4 weeks

* Recovery calculations performed assuming the availability of seismically certified equipment. Due to limitations of sourcing seismically certified equipment, the recovery requirement was later removed for the project. See Section 5.1.1.

The Archives building achieved five stars in safety and damage without additional design requirements beyond those summarized in Section 2.2. However, additional design interventions for non-structural systems and components were required to increase the recovery dimension from three stars to four as required by the building tenant's initial requirements. The enhanced design considerations to achieve the project's USRC rating requirements are summarized in Beetham et al. (2022). As discussed in Section 5.1.1, certain construction realities made some of these enhanced design requirements cost-prohibitive such that the requirement for a recovery rating of 4-stars was eventually removed from project requirements.

5 QUANTIFYING RESILIENCE IN A NEW ZEALAND CONTEXT

5.1 Unique Challenges in Applying and Achieving a USRC Rating in New Zealand

While the USRC was founded in the United States, its rating system is, to a degree, agnostic to country and building code. However, application outside of the United States does involve considerations ranging in complexity from minor hassles (e.g., converting metric quantities to imperial, relating New Zealand building code design forces on non-structural components back to U.S. building code formats, etc.) to construction cost-prohibitive measures stemming from a difference in product availability. Some of the challenges faced on the Archives building are outlined in the following sections.

5.1.1 Sourcing seismically certified equipment in New Zealand

When the peak floor acceleration at the attachment point of a piece of mechanical, electrical, plumbing or fire protection equipment is high enough, the within-equipment accelerations (which are often amplified by the dynamics of the equipment itself) can cause failure of individual components making up the equipment. While the level of peak floor acceleration that causes loss of operation is uncertain, it has been quantified for "standard" equipment supplied in the U.S. Assuming the acceleration capacity of equipment supplied in New Zealand is similar to that in the U.S., peak floor accelerations in New Zealand buildings, particularly those in locations like Wellington, can be significant enough to cause a high probability of loss of equipment function. In these situations, more robust and seismically certified equipment must be sourced.

In the United States, equipment within systems needed for continued operation of essential services buildings are required to demonstrate seismic certification. Seismic certification is commonly demonstrated through shake-table testing following ICC-ES AC 156 *Seismic Certification by Shake-table Testing of Non-structural Components*. The "product line" for this piece of equipment is then considered seismically certified. For hospitals in California, the Department of Health Care Access and Information (HCAI), serves as the regulatory authority. HCAI maintains a list of seismically certified equipment suppliers via a Special Seismic Certification Preapproval program. As a result, there is a demand for seismically certified equipment in the U.S. and a structure of regulatory pre-approval to support that demand. Therefore, while seismically certified equipment is not pervasive in the U.S., it is available "off-the-shelf" from multiple manufacturers.

Due to several factors such as the smaller market, lack of code requirements for seismic certification, and therefore absence of regulatory pre-approval, seismically certified equipment is essentially not available or difficult to source in New Zealand. While project-specific seismic certification of equipment is possible, it is significantly cost prohibitive since it only amortizes the cost of such testing over a handful of units rather than a complete product line. These realities make sourcing of seismically certified equipment in New Zealand problematic and ultimately infeasible for the Archives building.

5.1.2 Correlating differing design, review and inspection practices in NZ to the US

The FEMA P-58 fragility database includes an extensive list of structural and non-structural components. However, the fragilities and their consequence functions are implicitly associated with detailing, design, inspection, and installation practice in the U.S. For example, as described in Section 4.2, the beam-column joint fragility from FEMA P-58 is representative of a steel beam-column joint designed and detailed as a prequalified steel special moment frame in accordance with the American Institute of Steel Construction (AISC) 358 *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*. Therefore, while similar performance is expected of a well-designed and detailed beam-column joint connection in New Zealand, the underlying data does not directly address the difference in steel design/detailing, inspection, repair methods, or repair times.

Selection of appropriate fragilities from the FEMA P-58 database to represent non-structural components detailed, designed, inspected and installed following New Zealand practice also represents a challenge. This process is especially exacerbated by the strong dependence of performance of non-structural components to the level of regulatory review, inspection and installation. These aspects differ between New Zealand and the U.S. For example, the FEMA P-58 fragility database distinguishes between non-structural components designed, inspected and installed for an essential facility versus an essential facility subject to California's Department of Health Care Access and Information (HCAI) jurisdiction. While a project seeking enhanced resilience like the Archives building may electively impose heightened inspection requirements beyond that exercised for code-conforming essential facilities in the United States, those requirements may not encompass the degree of oversight and inspection associated with HCAI projects. Choosing the appropriate fragility in the FEMA P-58 database therefore either becomes a matter of engineering judgment or necessitates sensitivity analyses to the assumed fragilities.

5.1.3 Hazard level in NZ commensurate with design-basis earthquake in the US

As described in Section 2.2, the Archives building has been assessed for multiple levels of seismic hazard ranging from the 1/25-year event to beyond the 1/1000-year event. For a USRC rating, the design-basis earthquake as defined in U.S. building codes is required to perform the resilience rating at the same hazard level as that used for life-safety design. The design-basis earthquake in the U.S. is taken as two-thirds of the Risk-Targeted Maximum Considered Earthquake (MCE_R), where the MCE_R approximately corresponds to a 1/2500-year event. As a result of this definition, the design-basis earthquake does not have a unique return period, nor does it necessarily correspond to "design-basis" in the New Zealand building code. For the Archives building, two-thirds of the 1/2500-year event approximately corresponds to the 1/000-year event which was then used for the resilience assessment. This therefore meets the letter of the USRC rating requirements. It likely also meets the intent of the USRC rating requirements (i.e., the USRC rating is performed at approximately the "design-basis" event of the New Zealand building code).

5.2 Suggested USRC Modifications for New Zealand Context

Based on the challenges in applying and achieving a USRC rating for the Archives building identified in Section 5.1, the following modifications to USRC resilience ratings are suggested for New Zealand application:

- *Increase demand for seismically certified equipment* – If New Zealand buildings are to demonstrate functionality following significant earthquake shaking with high certainty, seismically certified equipment will likely be required. Voluntary requirements on a project-specific basis are unlikely to be practical in changing the state-of-the-practice of equipment supply given the cost-prohibitive nature of project-specific testing. Therefore, a mandate for seismically certified mechanical, electrical, plumbing, and/or fire suppression equipment may be necessary via the New Zealand building code or jurisdictional requirements.
- *Develop a fragility database for components matching New Zealand design, detailing, inspection and installation practice* – A fragility database similar to FEMA P-58 except developed for New Zealand practice would be useful in anchoring the fragility and consequence functions used in New Zealand resilience assessments/ratings. This would require compilation of existing structural and non-structural physical tests in New Zealand research, converting that research into standardized fragility curves, and assembling a group of experts to establish the injury/fatality, repair cost, and repair time consequence functions. Significant work could be carried forward from the FEMA P-58 database from the U.S., just modified to address the differences expected for New Zealand practice.
- *Define the appropriate hazard level* – Seismic ratings following the USRC requirements in the U.S. use the hazard level matching that for which new buildings are designed. In New Zealand, it may be appropriate to consider a different level of seismic hazard corresponding to community-level needs (i.e., to avoid population migration following a significant event) or the general public's expectation of performance (i.e., low loss of building function following a moderate event). While many of these considerations may be similar between the U.S. and New Zealand, it is recognized that community-level dynamics and public expectation may differ.

5.3 Implications for Future Design Guidelines

In the U.S., the building code is considering requirements for seismic design for functional recovery. Functional recovery is defined as the post-earthquake recovery state in which a building is maintained or restored to safely and adequately support its basic intended function. Currently being developed for the 2026 National Earthquake Hazards Reduction Program (NEHRP) provisions - the predecessor of the 2028 American Society of Civil Engineers (ASCE) 7 standard - seismic design for functional recovery purposely extends beyond current U.S. code intent of life safety. In the framework of the USRC rating method, current U.S. building codes operate explicitly and almost exclusively on the safety dimension. Damage and recovery are not explicitly targeted. The shift to also explicitly design for functional recovery in the U.S. would target the recovery dimension directly.

Like the U.S., New Zealand building codes also only explicitly target a life safety-based objective. However, enhanced design in New Zealand has tended to focus on the concepts of low-damage or repairable design. The philosophy of low-damage or repairable design places emphasis on rapid repair of structural elements (e.g., via replaceable "plug-and-play" structural fuses) and reduction of expected residual drifts.

While low-damage and repairable design can be an integral part of design for functional recovery, in practice, functional recovery tends to lead to far greater design interventions for non-structural systems. Those systems can dominate recovery times for well-engineered and robust, even conventional structural systems. Many items which may be repairable within a low-damage structural design philosophy may still have significant recovery or repair times.

It is the opinion of the authors that the development of New Zealand Resilient Design Guidelines or a Seismic Performance Framework should incorporate functional recovery considerations. Non-structural elements make up a large portion of a building value and are essential for continued use. The USRC framework provides a quantitative measure of the importance of non-structural design on the resulting seismic resilience of a building. This has been demonstrated through the case study Archives facility. A holistic, all-encompassing view of building behaviour provides the most comprehensive and realistic measure of seismic performance.

6 CONCLUSION

The application of the USRC rating system to the Archives building provided a comprehensive assessment of the facility's capacity to withstand and recover from seismic events. With an emphasis on quantifying safety, damage and functional recovery metrics, the star rating system offers a clear and consistent approach for communicating holistic seismic performance to stakeholders and the wider public. The case study highlighted several challenges and considerations when applying the USRC rating system in a New Zealand context, including the sourcing of seismically certified equipment, development of a fragility database tailored to local design practices and definition of appropriate hazard levels. The challenge for New Zealand industry is to develop an adaptive framework for the quantification of seismic resilience that simultaneously achieves several disparate outcomes:

- Provides a framework for quantifying relative seismic performance that is not overly onerous or computationally intensive and is practical to implement with the goal of broad industry-wide adoption.
- Considers the critical aspects of safety, damage and functional recovery and how they contribute to the holistic seismic resilience of a building.
- Is universally applicable to a diverse range of building typologies and importance levels to meet differing seismic performance objectives.
- Encourages a collaborative approach between all design parties, manufacturers, and contractors for both structural and non-structural systems.
- Presents seismic resilience in a manner that clearly and concisely communicates performance expectations to the public so that this information is readily digested and understood.

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