Informing Clients on the Business Case for Seismic Resiliency

J.M. Stanway, P. Steneker, W. Parker, M. Le Heux, M. Mery, D. Arnold, P. Campbell, T. Ghodsi, C. Jacques, W. Johnston, R. Mastschuch, & Y. Morales

WSP NZ, Christchurch, NZ. CEP Forensics, Ottawa, Canada. WSP NZ, Wellington. WSP USA, Los Angeles, USA. WSP Chile, Santiago, Chile. WSP Canada, Ottawa, Canada. WSP NZ, Auckland, NZ. WSP USA, Los Angeles, USA. WSP Canada, British Columbia, Canada. WSP Canada, British Columbia, Canada. WSP Canada, British Columbia, Canada. WSP Chile, Santiago, Chile.

ABSTRACT

The role of structural engineer has been to ensure life safety of building occupants during a seismic event. In the past, a singular focus on this performance target has resulted in structures that relied on the dissipation of seismic energy through controlled damage imposed on selected components of the structural system, resulting in safe but non-resilient systems and damage to non-structural elements. Recent seismic events have highlighted the negative impact of this narrow focus and lack of resiliency on building owners, as post-event recoveries have incurred lengthy downtimes and high repair costs, even following moderate levels of shaking. Developments in the seismic design of structural systems and non-structural elements provide opportunities to target business continuity objectives in addition to life safety. Furthermore, advances in methods of estimating seismic losses can link structural performance to non-engineering metrics, such as expected average downtime and repair cost considering multiple hazard levels.

This paper aims to present the various discussion points available to engineering professionals to support building owners in business continuity planning. Various non-engineering metrics are presented to use when conducting a performance comparison of alternative seismic structural systems. By leveraging the combination of low-damage structural systems and awareness of the seismic performance of non-structural element along with advances in damage estimation, engineers can provide a wider variety of structural alternative options to their clients, leading to overall building performance which is more closely tailored to a client's performance expectations.

1 INTRODUCTION TO RESILIENCY

The development and implementation of modern building codes has historically targeted life safety as the performance objective. This objective ensures that no life-threatening scenarios, such as a building collapse, occurs during an earthquake with a specific likelihood of occurrence. This is typically achieved through energy dissipation which requires permanent deformation and damage to critical structural elements. Whilst this approach achieves the life safety performance, this type of performance results in costly repairs or replacements and lengthy downtimes.

As such, businesses within these buildings can suffer direct losses from repairs, indirect losses from interruptions, and second order indirect losses from loss of market share, breakdown of processes, and staff turnover (Forrester 2019). Many clients are often not aware of the limitations of the life safety performance objective and may have performance expectations which are out of step from the design. This asynchronism of performance expectation and design target is also recorded within the wider public, as shown in (Brown et al. 2022), which summarised the results of a wide scale survey of the New Zealand public to record their expectations for acceptable interruption time for key economic sectors. This survey reveals a public which expects a significantly shorter interruption of businesses than what is targeted by most building codes.

Improving the performance of structures beyond the life safety performance objective of Codes provides resiliency to the building and the functions it hosts. This increase in resiliency is shown visually in Figure 1, which summarizes the difference in response recovery of several building designs. The typical code targeted structure, shown in red, has dissipated energy through plastic deformation without collapsing, but requires demolition. Some structures are designed for higher demands than prescribed by codes, or when typical buildings are subjected to earthquake loading lower than the code design earthquake, as shown in orange, may require extensive repair before resuming functionality. Finally, resilient structures, shown in green, can provide full or partial functionality, following a targeted earthquake event, without interruption, providing business continuity to the occupants.

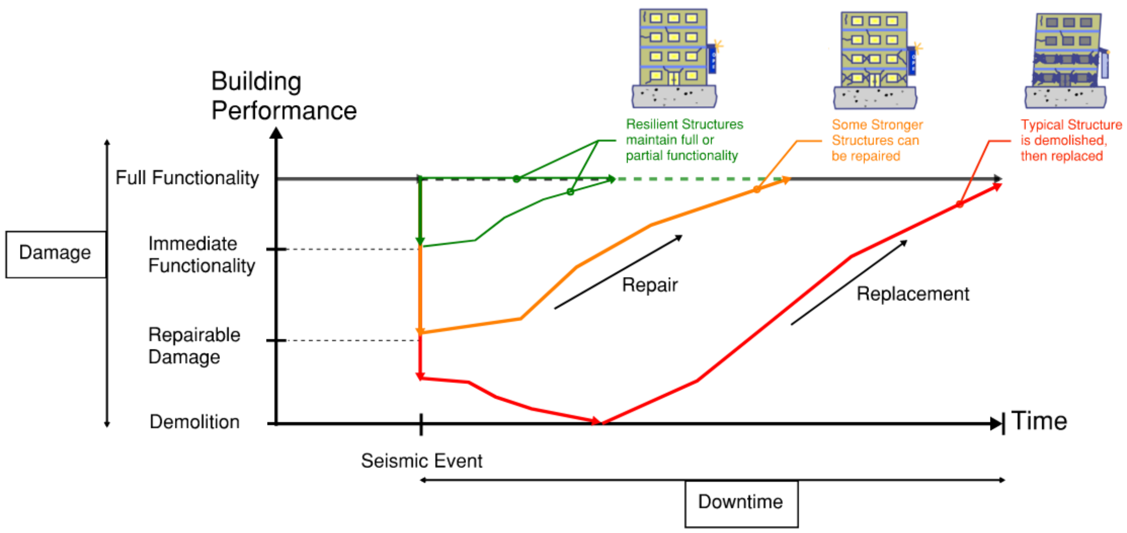

Figure 1: Concept of Resiliency. Modified from (Bruneau et al., 2003) and (FEMA 2003)

In recent decades, new technologies, materials, and design strategies have been developed to provide alternative strategies to achieve the seismic resiliency performance of structures. Unlike more traditional construction, these buildings achieve a higher performance objective by a) dissipating the seismic energy using repeatable mechanisms which do not impart permanent damage to the structure or its contents, or b) designing the primary structure using traditional structural systems but improving the design of non-structural elements, therefore resulting in improvements to their resiliency at various levels of shaking. The use of these systems in common projects is limited, typically due to a) the higher capital costs for energy dissipating structural systems b) lack of knowledge on damage limits for non-structural elements and systems and c) the design process for full coordination of all disciplines from concept design through to completion of construction is not common.

In addition to the development of these resilient strategies, analytical methods have been introduced which allow engineers to estimate the expected seismic losses of individual buildings (FEMA 2012). These analytical methods account for inputs of unique engineering design parameters such as the structural system and the building's site seismic hazard, and outputs both the average annual loss and losses from earthquakes with specific intensities. These losses are measured in values of downtime and dollars of damage, metrics which are more easily integrated into a business model.

2 RESILIENCY ADVISORY PROCESS

A framework is proposed for guiding communications between consulting engineers and clients to motivate decisions that lead to more resilient businesses. The proposed framework is divided into individual phases, each having specific targeted outcomes. This separation provides an illustrative sequence of the type of information transferred to either the client or the engineer. A flow chart of the process is shown in Figure 2, and each step is described in the following sections.

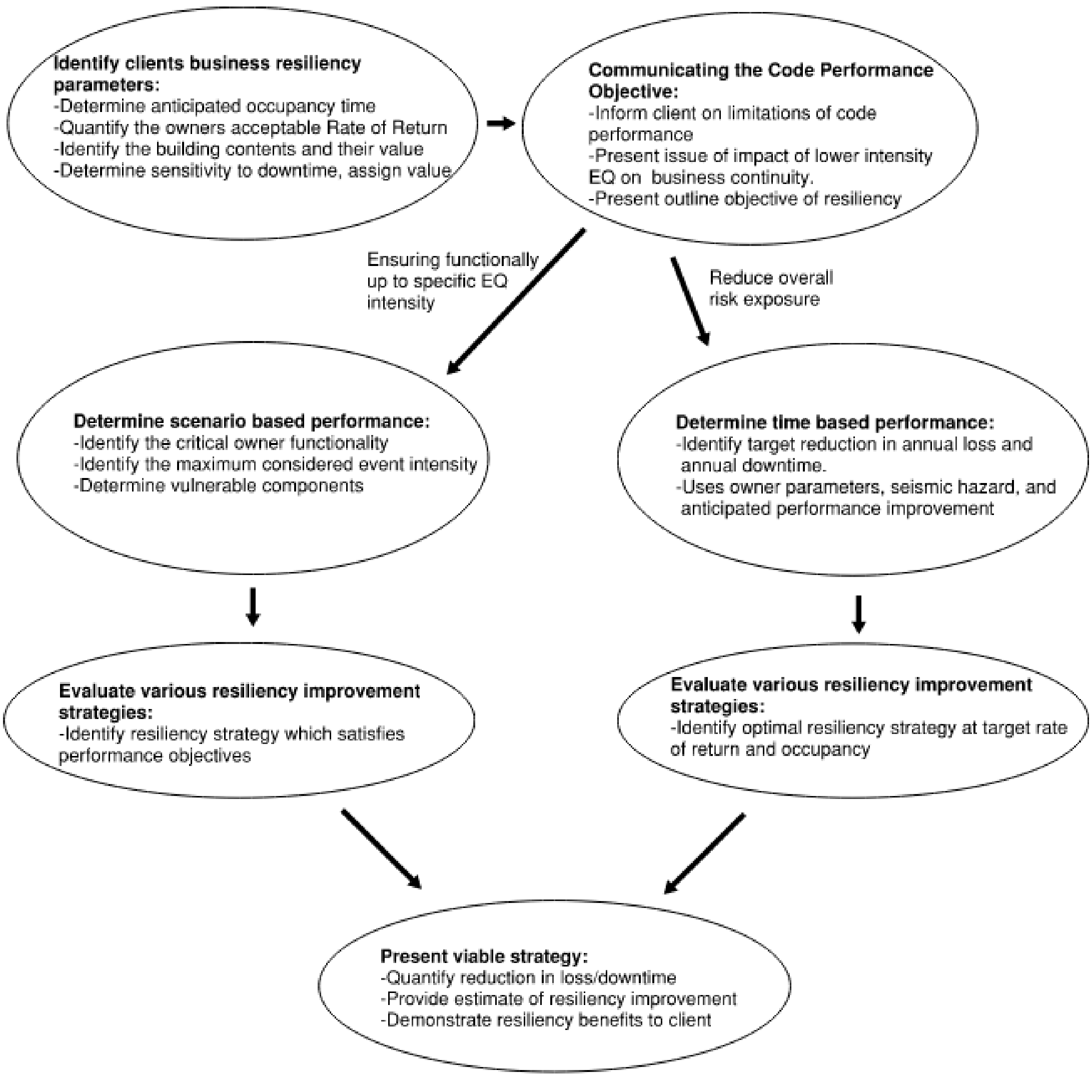

Figure 2: Process to determine performance requirements and a viable strategy

2.1 Interpretation of client's business resilience plan to identify engineering parameters

This phase focuses on understanding the importance of the building in the client's overall business model. An understanding of the business case which supports the function of the building is required to properly contextualize the implementation of appropriate resiliency strategies. A few key metrics are required by the engineer when assessing a business's vulnerability to seismic risk. However, these metrics should not be generated by the engineer as they are within the business metrics of the client. These are obtained with the following questions:

- What is the building intended occupancy function?

  Knowledge of the size and location should already be ascertained by the engineer, but additional information regarding the usage of the building must be understood. The expected occupancy of the space should be recorded as an allocation of area e.g. office, midscale hospitality, etc. Other engineering variables, such as the population of components, their estimated value, and their seismic performance can generally be obtained from existing databases. However, the value and location of unique components within the building which are critical to the client's function should be identified.
- What is the anticipated time to re-occupy the building following a defined earthquake hazard?

  An evaluation of risk exposure requires knowing the expected exposure time of the asset to said risk. As seismic risk is typically quantified on an annualized basis, the anticipated occupancy time is required for a proper life-cycle analysis.
- How sensitive is the business to downtime and interruptions?

  Sensitivity of a business to downtime can be measured using a combination of indirect daily losses in revenue and previously mentioned second order effects of indirect losses. While the indirect daily losses can be explicitly estimated by known daily revenue rates, obtaining the second order losses is a task better evaluated by individuals familiar with the client's market conditions. The engineer should keep in mind that most analyses of second order losses will identify increasing rates of losses with longer interruption duration (Forrester 2019).
- What alternatives are available to de-risk the client's exposure?

  Investments in resiliency is not the only method of lowering a client's risk exposure to specific consequence functions, particularly when seeking to reduce direct financial losses. In these cases, other strategies may also be available, such as purchasing insurance or providing additional business redundancy, and these may be more viable based on the targeted performance of the client. The option of investing in resiliency should be evaluated against the total life-cycle cost of these other strategies to properly assess the opportunity cost of the resiliency investment.
- What are the clients current and projected opportunity or borrowing costs?

  This parameter is important as it provides a context of the client's time value of money when contemplating allocating more capital to invest in resiliency of their building. Since the investment into resiliency is an allocation of additional capital, it's cost to the client is quantified either by borrowing costs of the capital or compared to other potential revenue streams.

2.2 Communicating the code performance objective

This phase focuses on ensuring a common understanding between client and engineer on the performance target when designing to the minimum code objective. The result of this phase is providing a client with an understanding of the performance their building is expected to achieve when satisfying only the code prescriptions and how this performance may contrast with their expectations. Here are several points used by these authors when communicating this difference in performance to their clients:

- Present expected extent of earthquake damage to structure in a design level event:

  A presentation of the expected response of the building when it experiences a design level seismic event is illustrated. The behaviour of critical elements of the structure are shown and a general estimation of downtime and damage cost is often provided. This is usually obtained from past project estimations and reconnaissance experience.
- Present expected extent of earthquake damage to non-structural components:

  Following the discussion of structural damage, a summary of expected damage to the non-structural components is shown. The relative cost of these components is presented, as well as the impact of these components on downtime, and the traditional mitigation strategies are summarized along with their limitations. These parameters are evaluated from past project estimations and reconnaissance experience.
- Present issue of higher frequency but lower intensity hazard risk:

  A major limitation of codes when ensuring seismic performance is the singular focus on ensuring life safety performance at a specific but rare intensity level. The lack of consideration for the behaviour of buildings during seismic events with lower intensities but higher frequency of occurrence discourages any effort to ensure business continuity, leading to potentially unanticipated expensive and lengthy business interruptions due to these more frequent events. This gap in traditional assessment should be communicated to the client to clarify the potential discontinuity between the client's expected ability to continue to operate in their building to the expected performance achieved during these lower intensity events.
- Present the target of resiliency:

  A clear definition of resiliency should be presented to the client. As noted in Phase One, the process must start with a focus on identifying the business resiliency objectives and how they may be influenced by the building's performance. The engineer then discusses the building resilience in terms of the performance of structural and non-structural components and how the required performance for a clients desired performance may not be aligned with the performance objective of the Codes. This can be achieved in a variety of methods but should include a discussion of the probabilistic nature of these loss evaluation methodologies.

2.3 Determine scenario or time-based performance

In conjunction with the client, the engineer can now use these parameters to identify the targeted optimal performance objective. These targets are separated into two categories whose selection is informed from the parameters:

- Scenario Based Assessments:

  This evaluation method targets the continuity of pre-identified building functions immediately following earthquakes up to a certain intensity. This performance objective can be nuanced to a client's specific business needs, such as specifying different performance objectives at different intensities. This assessment is usually selected for clients with more sensitivity to downtime of their building, particularly when the downtime poses large second order existential risks, such as a significant loss of market share or difficulty in being able to relocate the business to a different building following an event increases the risk of business interruption following earthquake events.
- Time Based Assessments:

  This evaluation method targets reducing the average overall risk of the building to all earthquake intensities. This type of analysis accounts for damage occurring from the total seismic risk of a region, which is defined both by earthquakes with a high intensity but low frequency of occurrence, and earthquakes with a low intensity but higher frequency of occurrence. This assessment evaluates the impact of resiliency improvements on the reduction of estimated damage across the entire intensity range. This assessment is usually more relevant for clients with long occupancy time who are seeking to secure overall returns on their investment by lowering their risk exposure but are not as sensitive to specific function downtime.

The result of this phase is the formalization of a performance objective which targets a specific goal within one of the two assessment categories. Example targets experience by the authors include:

- Determine the minimum resiliency investment to ensure continuous functionality of the building following an earthquake up to a 10% probability of occurring within the expected occupancy time, or
- Optimize the resiliency investment to reduce the estimated average annual losses while assuming an interest rate of 4% and occupancy time of 40 years.

2.4 Identify and evaluate resiliency improvement strategies

Following the identification of a client targeted performance objective, the engineer determines a series of viable resiliency improvement strategies to achieve the objective. Several different strategies can be developed, and each is evaluated using a probabilistic loss estimation methodology (FEMA 2012a). The cost of the resiliency improvement strategy is often not reliably known, and therefore the evaluation of viability of the resiliency investment will output the maximum possible value, or the "break-even" cost. Finally, the use of some alternative resiliency strategies can provide immediate benefits to the structural system by reducing the seismic forces and/or required material energy dissipation of the seismic force resisting system. Each viable strategy is ranked by the engineer, where the highest maximum acceptable investment value is the most viable strategy.

2.5 Present viability of resiliency strategy

The final phase of the framework is presenting the viability of the proposed resiliency improvement strategies to the client. This presentation uses the non-engineering metrics which were targeted in the evaluation of the strategy, allowing the engineer to present the benefits of the resiliency improvement as a measure of the reduction in life cycle cost and downtime. The proposed resiliency improvement strategy should also rank the viability of other non-engineer de-risking strategies, such as insurance or redundancy. This provides a complete decision matrix to the client.

3 CASE STUDIES

Three types of clients are presented as case studies to illustrate how unique conclusions are obtained for various client types. Each of these client types includes a real-life example of an interaction in which one of the authors provided resiliency consultation either before or after the seismic event. The client types are summarized below:

- Legacy institutions (building provides long term & secure investment, owners typically government or long-term tenants, low borrowing costs),
- Network node (building enables purpose of business, low to medium borrowing costs, sensitive to downtime as can cause severe loss in market share), or
- Primarily commercial (purpose of building to maximum short-term benefits from building, high borrowing costs).

3.1 Owner Category 1 – Legacy Institutions

This client type includes building owners with multi-decade occupancy durations and who are willing to invest in achieving further stability in their investment. Examples could include large real estate investment trusts, governments, insurers, and academic or other institutional owners. The main target is a reduction of annualized risk which is motivated by high value occupancy, by a financial incentive of securing a rate of return from the reduction of risk or safeguarding an investment target. The assessments of improved seismic performance should be evaluated on a time-based assessment which targets the reduction of yearly exposed risk. This yearly reduction of risk can be compared to the capital expenditure by converting the yearly reduction to a net present value, as shown in Equation 1.

$$NPV = \frac{EAL}{R}\left(1 - \frac{1}{(1+R)^t}\right)$$

Where the EAL is the estimated annual loss, R is the rate of return, and t is the occupancy time. This equation can be used to compare the total risk reduction benefit obtained from resiliency improvement strategy to its total implementation cost. Furthermore, several optimization methodologies have been developed to determine the most viable overall resiliency improvement strategy (Steneker et al., 2020), (Steneker et al. 2022).

The results of several optimization studies reveals that the extent and cost of the optimal resiliency improvement strategy is highly dependent on the rate of return, occupancy time, and seismic hazard. An example of this is provided in the study by (Steneker et al., 2020), where the project considered the retrofit of an existing a three-story office building with steel structure (a traditional non resilient steel seismic resisting system). The analysis then considered several alternative details to improve the performance of the structure, resulting in a determination of an optimal total upgrade strategy and its cost at several different targeted rates of return. This resulted in the identification of unique viable upgrade strategies with scopes ranging from major structural interventions to limited upgrades of existing building services.

3.2 Owner Category 2 – Network Node

This client type includes facilities which are well integrated into a supply chain or operate within a competitive product market. Examples would include manufacturers, resource producers, transportation hubs, and data centers. Typically, these client business models are extremely sensitive to downtime, where a significant interruption in business results in a market shift to an alternative supplier, resulting in a permanent loss of market share. This can lead to significant second order losses and a potentially existential risk to the business. Therefore, these clients are motivated to improve the resiliency of their facilities as maintaining business continuity following an earthquake would be critical to the survivability of their business. The maximum consequence cost associated to earthquake downtime could be as large as the total value of the business.

Examples of damage causing significant business interruption is shown in Figure 3, where each scenario resulted in losses to the business which were beyond the direct cost of the visible damage. One such example is the Port of Kobe, where at the time of the 1995 Kobe earthquake, it was the world's 4th largest container port and by 2010 had dropped to number 49 (Itoh 2013). Following the Kobe earthquake, the damage to the Port meant they were unable to achieve business continuity within sufficiently short timeframe and hence trade moved to other ports, and by the time they had restored capacity they were unable to regain much of the lost trade.

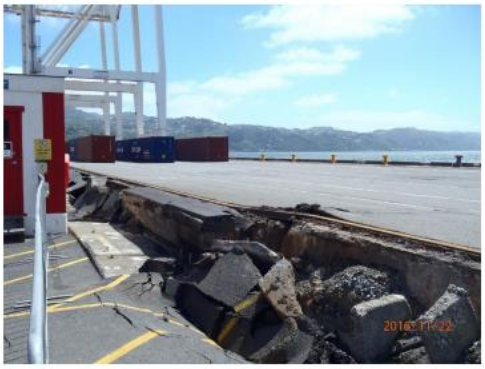

Figure 3: Examples of Type 2 seismic risk: (a) Damage at winery resulted in restricted production and reduced future market share (FEMA 2012b), (b) Damaged port facilities resulted in lengthy downtime (Stanway et al. 2021)

Another series of examples were projects completed by the WSP Chilean team where the upgrade of several industrial facilities was conducted to improve the seismic resiliency of the manufacturers. This ensured the continuity of their business within a few hours of a major seismic event. The project was a hallmark of the local industry and the requirement for business continuity following the design level seismic event has been recently implemented in the Chilean code for industrial structures, principally motivated by the second order indirect consequences as these structures support vital economic activity for the country.

3.3 Owner Category 3 – Primarily Commercial

This client type includes businesses who typically operate on much shorter timelines and have less-critical downtime consequence functions, such as retail commercial establishments or non-critical service centers. These client types typically benefit from inherent redundancy as they operate multiple locations within the same geographical area. This systemic redundancy provides an alternative service provider, resulting in some resiliency as it reduces the ultimate downtime consequence cost to the business. The total value of the contents which are at risk is usually lower and replaceable as these establishments are at the end of their product supply chain. Finally, the second order effects caused by downtime are localized and limited as the business can either regain market share or restructure their business model.

When evaluating the viability of the resiliency improvements, the typical borrowing cost of these establishments is higher than clients in other industry sectors (Liu et al., 2018), and their occupancy time is shorter on average (U.S. Bureau of Labour Statistics 2012). Furthermore, the authors experience has been that the clientele is usually more accepting of risk as they can often recapitalize the replacement cost due to the shorter expected life cycles of the buildings. While each client can have unique characteristics which can influence the final recommendation, the optimal resiliency strategy for these client types is often not linked to the physical building but is based on reducing financial risk using relevant insurance policies, reducing downtime with the formulation of rapid response policies, and relying on local geographic redundancies for overall function resiliency.

4 DISCUSSION

The three client types summarized in the previous sections all have unique business requirements and parameters. This results in each of these types having a unique set of resiliency improvement recommendations as the viability of these improvements varies based on the viability of each business building performance objective. However, some generalization can be obtained from past experiences. The most straightforward case is clients with large consequence values, such as those described in type 2, where the cost of resiliency improvements can be more easily justified when compared to the consequence of specific scenarios. This justification is frequently apparent in high seismic zones, it also extends to areas with moderate seismicity. In contrast, resiliency improvement is difficult to justify for type 3 clients who have high capitalization costs and short expected occupancy as they are not expected to meet the payback period on the investment, even in areas of high seismicity. The evaluation of resiliency improvements becomes much more nuanced when targeting overall risk reduction as a client's unique economic characteristics become relevant, beyond those directly related to the asset. The viability of these improvements is also highly correlated to the seismicity of the location.

5 CONCLUSION

The ability to quantify the benefits of resiliency improvements to a client's business model provides an opportunity to evaluate design decisions across the life-cycle cost of the building, rather than only measured as a singular capital expense. While this paper focuses on seismic resiliency of a client's buildings, the principles of business continuity planning and how resilient design can be integrated into a business model can extend to other hazards affecting a client's physical assets, as the occurrence of most hazards and their consequence can be quantified probabilistically. Therefore, the quantity of capital invested for the construction of a physical asset should be determined by including the impacts of the assets life cycle cost based on the client's business model and business continuity plan, including interruptions due to the potential catastrophic loss of the building. Structural engineers with relevant loss estimation experience can assist with resiliency advice in the preliminary stages when a business is considering acquiring a physical asset. This provides an opportunity to optimize the design of an asset to a client's desired performance target.

6 REFERENCES

Brown C, Abeling S, Horsfall S, Ferner H, Cowan H, (2022). "Societal expectations for seismic performance of buildings". *The Resilient Buildings Project.* NZSEE https://www.nzsee.org.nz/news-activities/technical-activities/resilient-buildings-project/

Bruneau M, Chang S, Eguchi R, Lee G, O'Rourke T, Reinhorn A, Shinozuka M, Tierney K, Wallance W, Winterfeldt D (2003). "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities" *Earthquake Spectra*, **19**(4): 733-752. https://doi.org/10.1193/1.1623497

FEMA (2003). "NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures", prepared by *Building Seismic Safety Council for the Federal Emergency Management Agency*. Rep. No. 450-2. Washington, D.C. https://www.nehrp.gov/pdf/fema450provisions.pdf

FEMA (2012a). "Seismic performance assessment of buildings—Methodology*". Prepared by Applied Technology Council for the Federal Emergency Management Agency*. Rep. No. P-58. Washington, DC. https://www.academia.edu/23498464/Seismic_performance_assessment_of_buildings_Volume_1_Methodology

FEMA (2012b). "Reducing the risks of nonstructural earthquake damage—A practical guide." Rep. No. E-74. Washington, DC: FEMA. http://www.fema.gov/earthquake-publications/fema-e-74-reducing-risks-nonstructural-earthquake-damage

Forrester (2019). *"*The Real Cost of Planned and Unplanned Downtime*"*. Rep. No. L57KW7ND. *Forrester Opportunity Snapshot: A Custom Study Commissioned by IBM*.. *https://www.ibm.com/downloads/cas/L57KW7ND*

Itoh, H (2013). "Market Area Analysis of Ports in Japan: An Application of Fuzzy Clustering." *The IAME2013 Annual Conference*, 3-5 Jul 2013, Marseille, France. pp.1-21. https://hal.science/hal-00918672

Liu Y, Ou S, Kanthan K (2018). "Industry credit risk: recent trends for global non-financial corporations" *Moody's Investors Service. https://www.moodys.com/sites/products/ProductAttachments/corporates-credit-risk.pdf*

Stanway J, Auld M, Chalmers G, Delaney A (2021). "Using Lessons Learned from Past Earthquake Performance to Develop Real World Resilience Strategies for Ports and Port Structures". Australasian Coasts & Ports 2021 Conference, 30 Nov – 3 Dec, Christchurch, New Zealand.

Steneker P, Filiatrault A, Wiebe L, Konstantinidis D (2020). “Integrated Structural–Nonstructural Performance-Based Seismic Design and Retrofit Optimization of Buildings” *Journal of Structural Engineering*, **146**(8): 04020141-1-13. https://doi.org/10.1061/(ASCE)ST.1943-541X.0002680

Steneker, P., Wiebe, L., Filiatrault, A., Konstantinidis, D. (2022). “A framework for the rapid assessment of seismic upgrade viability using performance-based earthquake engineering,” *Earthquake Spectra*, https://doi.org/10.1177/87552930211065771

U.S. Bureau of Labour Statistics (2022). “Establishment Age and Survival Data” *Business Employment Dynamics*, Retrieved 10/03/2023. https://www.bls.gov/bdm/bdmage.htm