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Informing Clients on The Business Case for Seismic Resiliency

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ABSTRACT

The role of structural engineer has been to ensure life safety of building occupants during a seismic event, and this has been typically achieved by preventing the collapse of a structure and catastrophic failure of its contents. In the past, a singular focus on this performance target has resulted in the prevalence and codification of structural designs which have a predictable behavior during severe seismic events. These structures relied on the dissipation of seismic energy through controlled damage imposed on selected components of the structure's system, resulting in safe but non-resilient systems. 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. This impact has been somewhat unexpected by building owners, particularly as a large contributor to this disruption is damage to non-structural elements such as ceilings, partitions and HVAC systems which in many seismic countries receive little attention during design of the primary structure. Recent developments in the design of seismic structural systems 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. These tools enable a nuanced discussion on the optimum structural performance tailored to a building owner's business at the concept stage of a project.

This paper aims to present the various discussion points available to engineering professionals who seek to support building owners in business continuity planning and use this to integrate decisions about seismic performance into the building owner's overall model. Various non-engineering metrics are presented to use when conducting a performance comparison of alternative seismic structural systems, and case study examples are used to illustrate the benefits of early client involvement when selecting an appropriate performance target. By leveraging the combination of low-damage structural systems with advances in damage estimating, engineers can provide a wider variety of structural alternative options to their clients, compared using relevant metrics, leading to an overall building performance which is more closely tailored to a client's performance expectations.

Keywords: Performance based design, Business integration, resilient design

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, two example of which are shown in Figure 1 and 2 which are an examples of minimum building code acceptable response to an earthquake.

(a) *(b)*

Figure 1: Example of targeted code behavior (a) Hotel Casa Grande, Mexico, before 1995 Colima-Jalisco earthquake, (b) after the earthquake. No deaths were reported at this location, but the earthquake shut down the business (Photos from Andy Metten)

(a) *(b)*

Figure 2: Example of targeted code behavior of the BNZ building after a 2013 Mw6.1 earthquake (a) photo showing that the superstructure performed well, but (b) interior damage caused business interruption. Again, no deaths were reported, satisfying the life-safety criteria. [1]

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 [2]. 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 [3], 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.

One example of widespread failure to meet societies needs occurred in Christchurch New Zealand following the February 2011 earthquake. The public lost confidence in the built environment, with massive interruptions to employment. An example is an owner/operator in Christchurch wanting a replacement building which would incur less downtime following moderate levels of shaking, as each event required evacuation of their building. The frequent evacuations during the Canterbury earthquake sequence resulted in a loss of revenue and reduced productivity through disruption and low staff morale.

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 3, 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.

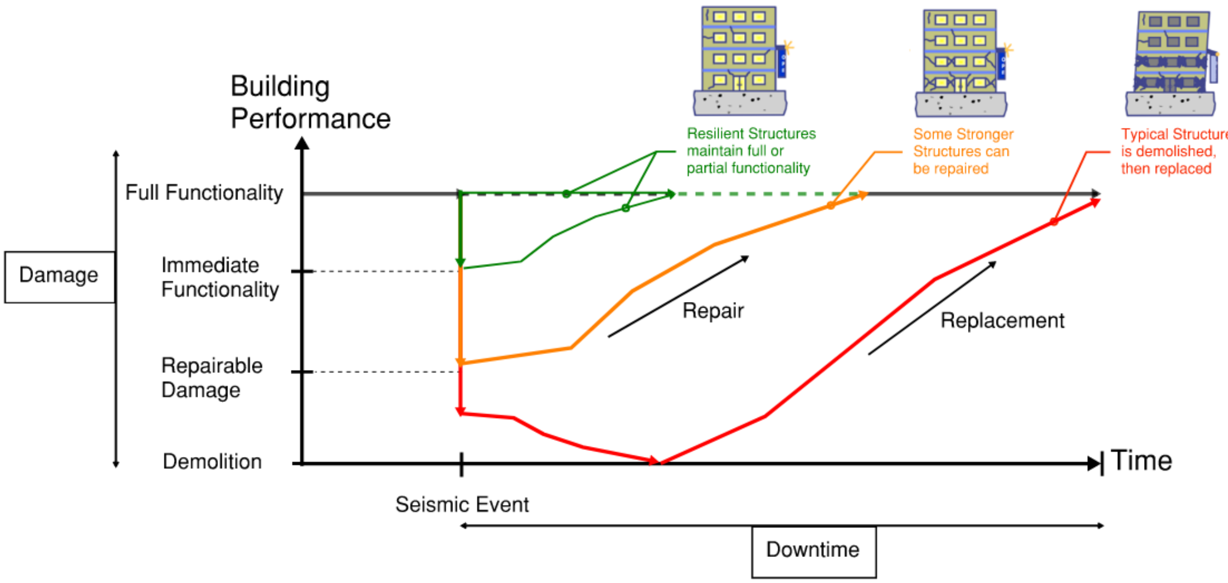


Figure 3: Concept of Resiliency (Modified from Bruneau et al. [4] and FEMA [5])

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. However, the recent implementation of these systems has been limited to specific cases of buildings with either post-disaster functionality or having high societal/cultural value. 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.

(a) *(b)*

Figure 4: Examples of alternative strategies for seismic resiliency (a) seismic isolation (From Seo [6]) and (b) supplemental damping (From Taylor Devices [7])

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 [8]. 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. This paper proposes a framework for how an engineer can utilize these newly developed loss estimation tools to evaluate the viability of improved asset resiliency in their client's business model. The phases of the framework are presented along with anecdotal evidence provided by the multiple contributing authors whenever possible. Three different client types are summarised as illustrations of various resiliency implementation recommendations. Finally, a discussion on how this framework can be extended to evaluate the viability of resiliency investments for other risks is presented.

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 5, and each step is described in the following sections.

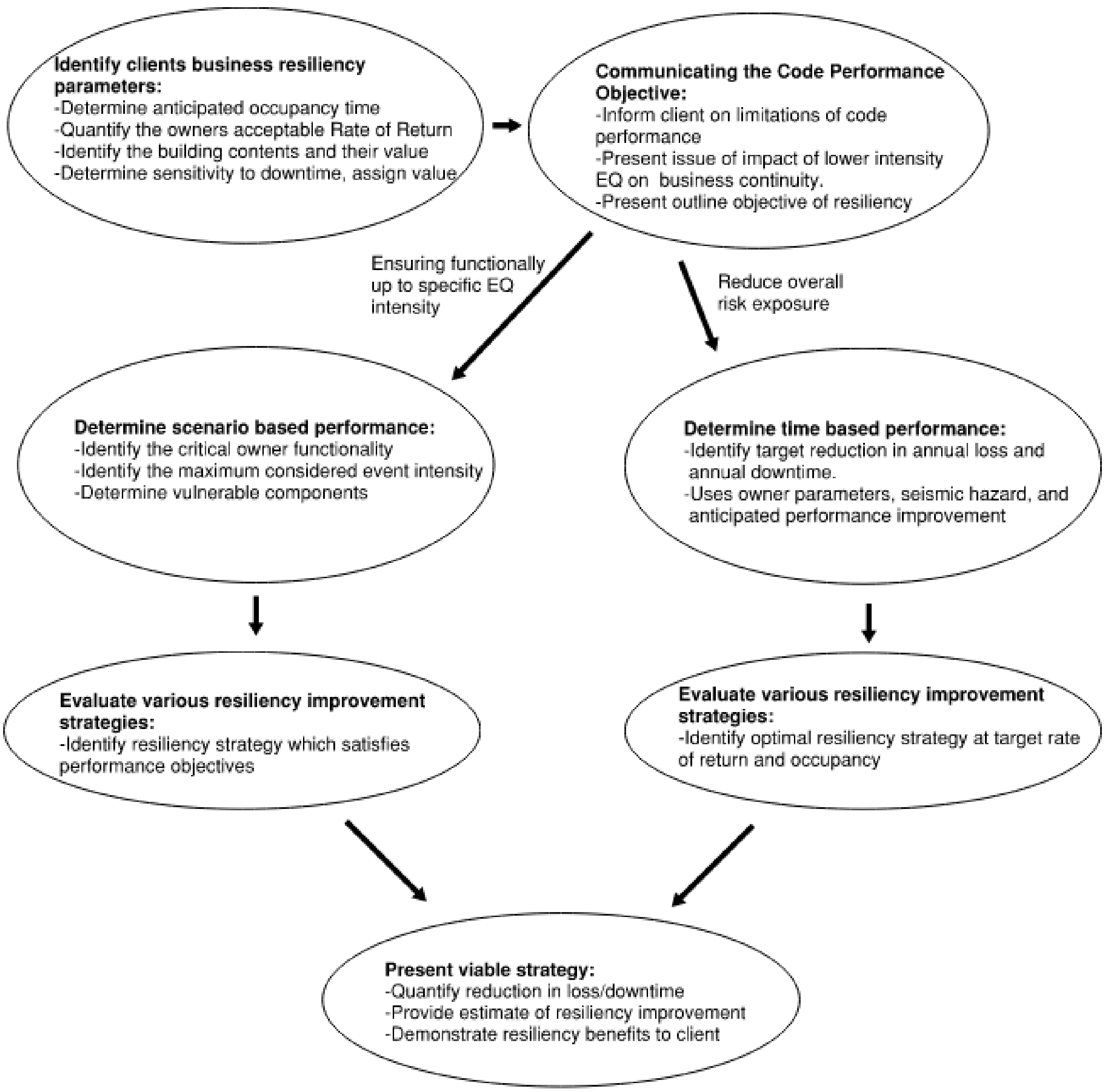


Figure 5: Flow chart of resiliency advisory framework

Interpretation of Clients 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 square footage level of detail (ex: class A 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 [9].
- 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.

Communicating the Code Performance Objective:

This first 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 behavior 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 behavior of buildings during seismic events with lower intensities but higher frequency of occurrence discourages any effort consideration of ensuring 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.

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.

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 [8]. 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.

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.

CASE STUDIES

Three types of client 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 in Table 1, followed by a short description of the concluding strategy.

Table 1. Summary of Owner Category parameters.

Owner Category	Legacy institutions (Type 1)	Network Node (Type 2)	Primary Commercial (Type 3)
Typical Business Motivation	Building provides long term & secure investment	Building enables the purpose of business	Maximize short term benefits from building
Examples of clients/user	-Governments -Property Management	-Manufacturer -Transportation hubs -Utilities	-Restaurant -Non-Critical Public -Retail
Occupancy Time	Long Term (30-40+ years)	Medium-Long Term (20-30+ years)	Short Term (<10 years)
Capital Availability	Lower Borrowing Costs	Low to Medium Borrowing Costs	High Borrowing Costs
Primary Risk Tolerance	Very risk averse as they seek reliable rental income/usage	Medium as they can recapitalize if required	High risk acceptance as turnover is expected
Sensitivity to Second Order Consequences	Minimal as they are end user of space	High as downtime causes severe loss in market share	High as downtime causes direct loss in revenue
Resulting Resiliency Objective	Reduction in yearly expected loss	Reduction in downtime to specific EQ intensity	Reduction in downtime to specific EQ intensity

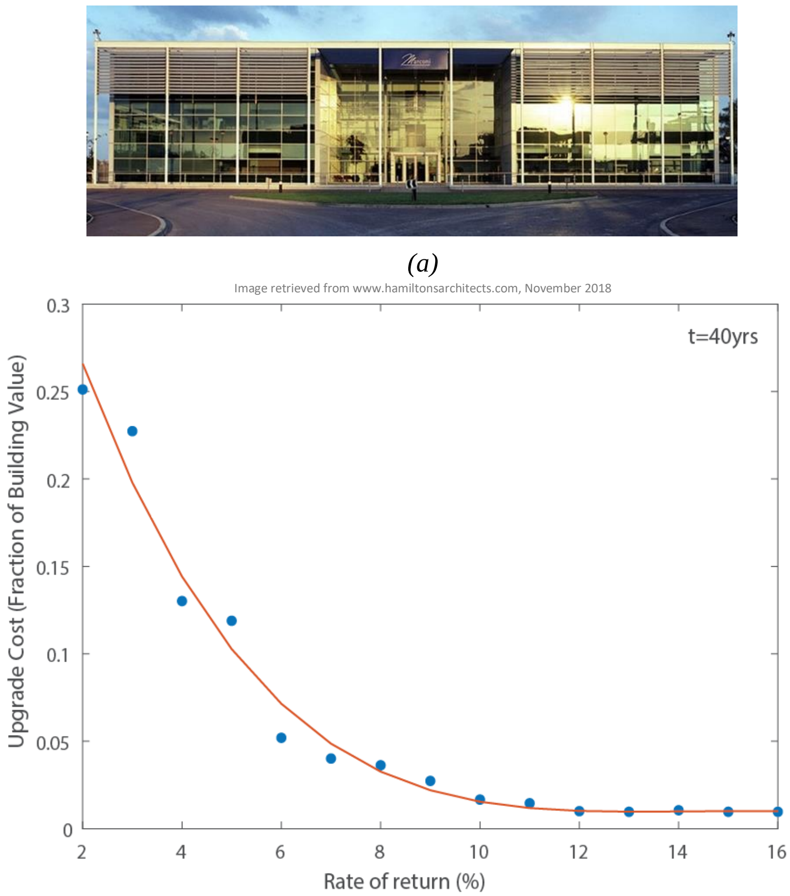
Owner Category 1

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 (REIT), 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

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

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 [10], [11].

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 result is illustrated in Figure , which summarizes the optimized life-cycle resiliency improvement strategy for a three-story office building. The project considered the retrofit of an existing steel structure (a traditional non resilient steel seismic resisting system), shown in Figure 6(a). 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 as shown in Figure 6(b). This resulted in the identification of unique viable upgrade strategies with scopes ranging from major structural interventions to limited upgrades of existing building contents, as shown in Figure 6 (c), where the numerical value indicates the relative priority of the intervention. Details of the study are available in Steneker et al. 2020 [10].



High Priority

Low Priority

Category	Component	Economic R=2%	Economic R=4%	Economic R=8%	Economic R=12%	Economic R=16%
Structural SCSHJ	First Floor Structural					
	Second Floor Structural					
	Third Floor Structural					
Structural 10% VD	First Floor Structural					
	Second Floor Structural					
	Third Floor Structural					
Structural 25% VD	First Floor Structural	100	100	90	30	
	Second Floor Structural	100	100	90	10	
	Third Floor Structural	100	100	70	10	
Structural BRB	First Floor Structural					
	Second Floor Structural					
	Third Floor Structural					
Mech. Equip.	Chiller	100	100	100	100	100
	Cooling Tower	100	100	100	100	100
	Air Handling Unit	77	77			
	Control Panel	100	100	60	40	40
	Motor Controller	100	100	100	70	60
	Low Voltage Transformer	75	75	40		
	Distribution Panel	100	100	90	90	90
Plumbing	Potable Piping	35	35			
	Large Diam. Heat Piping	100	100	35		
	Small Diam. Heat Piping	35	35	35		
	Sanitary Piping	35	35	35		
	Sprinkler Piping	70	70	70		
	Sprinkler Head	70	70	50		
Contents	Lighting	100	100	35		
	Desktop Equipment					
	Office Furniture					
Finishes	Suspended Ceiling					
	Raised Floor					
	Curtain Glazing					
	Wall Partitions					
	Roof Covering					
HVAC	Large HVAC Duct					
	Small HVAC Duct					
	HVAC Diffuser					
	Stairs					
	Elevator					

(b) *(c)*

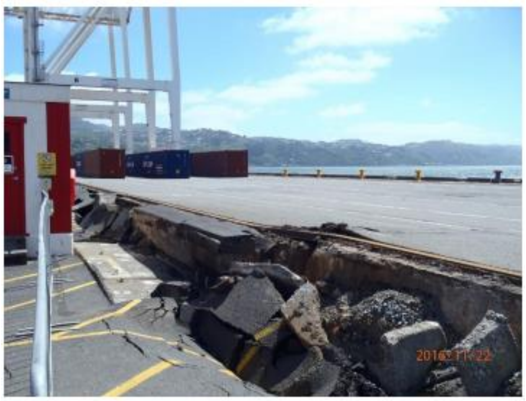
Figure 6: Summary of optimized resiliency strategy for 3 story building (Steneker et al. 2020)

Owner Category 2

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 67, 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 [12]. 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.

(a)

(b)



(c)

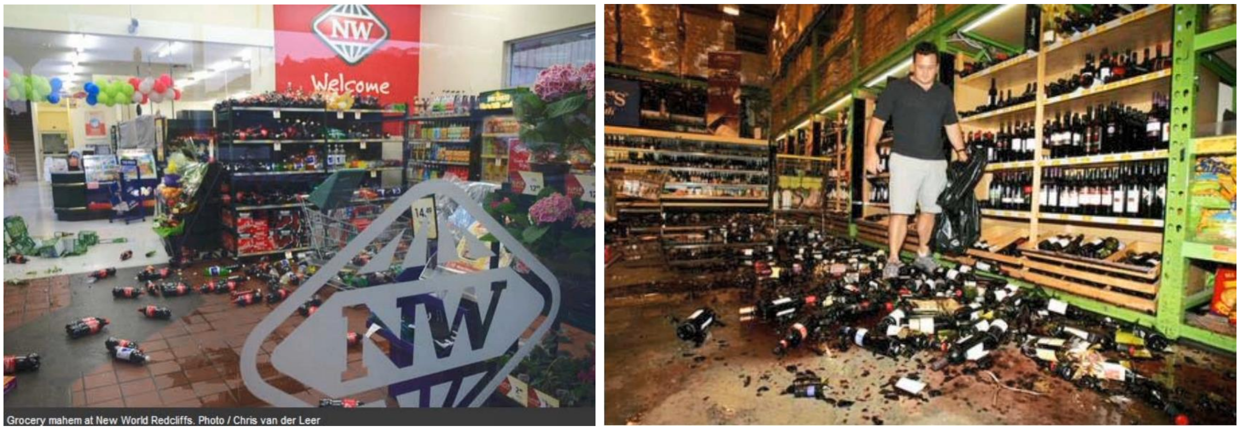
(d)

Figure 6: Examples of Type 2 seismic risk: (a) Damage at winery result in restricted production and reduced future market share [13](b) Damaged equipment at chemical producer results in supply chain interruption and loss of supplier status [13] (c) Damaged port facilities results in lengthy downtime (d) Damage to data center results in loss of users due to perceived reliability [14]

The authors have experience with several projects where the business continuity performance objective was identified as critical by the client. One such project was a seaport retrofit which began with a holistic understanding of the likely response of their assets along with the identification of the vulnerability of critical services. The authors then helped prepare a business continuity plan and identified a targeted resiliency investment strategy to ensure a post-earthquake event priority port business continuity. Following this study, a recent major nearby earthquake caused damaged which aligned with earthquake damage predictions. It demonstrated the benefit of pre-developing business continuity plans, such that the client was able to rapidly respond and focus on the continuity of specific functions to ensure survival of their business and support the regional recovery. 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.

Owner Category 3

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. Examples of these loss types are shown in Figure 87.



(a) *(b)*

Figure 87: (a) Loss of product caused temporary downtime of franchise location [15], (b) Loss of product caused temporary downtime, but business shifted to alternative product (unlike example in Figure 6 (a)) [15]

When evaluating the viability of the resiliency improvements, the typical borrowing cost of these establishments is higher than clients in other industry sectors [16], and their occupancy time is shorter on average [17]. 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.

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 pay back 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. Finally, other relevant aspects, as discussed below, have not yet been discussed in this paper but will be further examined:

1. Due to the increased awareness of the general benefits of resilient design, existing resiliency ratings such as those published by the USRC (United States Resiliency Council) have become more prevalent in recent years. The economic loss in the USRC framework is presented as the expected repair cost of a structure based on a standardized scenario-based hazard. Additional business continuity economic loss is presented in the form of expected time to repair the building prior to functional recovery, which can subsequently be utilized by a building owner to convert to a financial loss. This standardized method that can be used by ESG rating agencies generally in support of the Governance dimension of ESG ratings.

2. The quantification of the environmental benefit of resilient design as it inherently encourages a sustainable approach to a building's response to extreme events since it supersedes the current implemented strategy of replacement. As the shift towards quantifying the additional environmental cost of construction persists, the inclusion of the reduction in carbon will contribute to the life-cycle benefit cost analysis of resiliency improvements. Furthermore, investments in this type of design can benefit from the current investing climate as environmental and sustainable development is supported through various ESG funds, providing clients with a willing source of capital.
3. The quantification of the societal benefits since the goal of the built infrastructure is to support vibrant and functional communities. For this to occur a base level of needs must be met. These needs are summarized by the framework of Maslov's hierarchy, shown in Figure 9, where the needs directly related to the built infrastructure community are highlighted. Only one of these needs is mandated by the code (i.e., breathing).

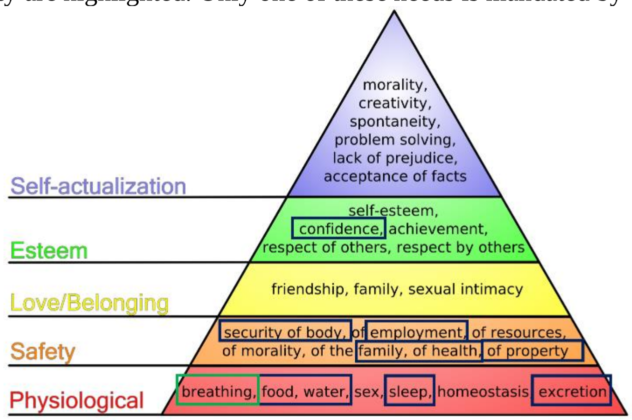


Figure 9: Maslov's hierarchy of needs. The boxed items are within the direct purview of the built environment. The single green box represents the one resiliency limit state mandated by code. [18]

The response in Christchurch to the shortcoming of performance to satisfy these needs was express as a public demand for better performance, including enhanced confidence demonstrated evidenced of structural resiliency using visible structural elements. By exhibiting the structural features that lead to resiliency, building occupants are instilled with a sense of confidence of safety, increasing the perceived value of the building. The public desired better performing buildings, measured intrinsically in terms of life safety and sometimes downtime, and reward owners who satisfy this need. The Christchurch case study is largely possible because the local citizens and building owners had a shared trauma of what happens when buildings are not resilient. outside of this shared experience, the call to engineers to provide justifications for resiliency remains. The authors hope that methodologies shared in this paper may help bridge that gap.

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.

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