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Demystifying the Barriers and Motivators for the Adoption of Base Isolation Systems in New Zealand

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Abstract: A base isolator is a proven system that can significantly reduce any damage to a building in the event of an earthquake. Despite their efficacy, seismic isolators are not widely used in New Zealand, with only about forty systems in use during the 2010 and 2011 Canterbury Earthquakes. This study seeks to investigate why base isolation systems are not frequently used in seismic strengthening projects and buildings in New Zealand. It also focuses on determining ways in which seismic isolators could become more widely used in New Zealand due to increased seismic activity. This study used an exploratory sequential mixed method design, in which qualitative data were collected first through in-depth face-to-face interviews, analysed, and used to construct the quantitative instrument, which was an online questionnaire. Data were obtained from construction professionals such as architects, engineers, site-based construction personnel, and quantity surveyors. The findings of this study indicated the need for an increased awareness of base isolation systems and improved universal guidelines for the design of seismic isolators. The motivators identified include provision of monetary incentives, such as reduced insurance premiums and financial subsidies, to encourage the adoption of seismic isolators. The factors preventing the adoption of base isolation systems in New Zealand were classified as human-related, safety and design-related, and cost-related. The study's implication is that providing a universal guideline for seismic isolators can enhance designers' confidence. Likewise, incentives may be provided to property owners to lower the cost of implementing a base isolation system.

Keywords: base isolation system; barriers; motivators; seismic strengthening; New Zealand

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1. Introduction

New Zealand is a seismically active country located on the Pacific Ring of Fire, with over 14,000 earthquakes occurring each year [1]. Mitigating earthquake risks is an unavoidable requirement of New Zealand's built environment. Earthquake disasters in the last few years in New Zealand have caused injuries and deaths as well as significant damages to buildings and infrastructure. The insufficient seismic capacities of buildings and infrastructure have been identified as key contributors to earthquake losses [2]. Therefore, the subsequent rebuild of the affected areas in Canterbury, Marlborough, Kaikoura, and Wellington regions has increased awareness and vested interest in technologies and approaches that will help improve the overall resilience of the New Zealand built environment. There are several approaches available to reduce the negative effects of earthquakes, particularly on individuals and communities. These include combining structural and non-structural mechanisms. Design and implementation of engineering solutions, as well as the maintenance and restoration of susceptible structures and infrastructure to withstand lateral stresses from seismic events, are all structural interventions [3,4]. Non-structural interventions include purchasing earthquake insurance, securing household contents, installing disaster forecasting and monitoring devices, and implementing policies and regulations to control seismic provisions and development in earthquake-prone areas [2,5,6]. Engineering solutions include several structural engineering measures or structural elements, such as moment resisting frames, diaphragms, seismic isolator system, shear walls, braced frames, energy dissipating devices such as elastomeric dampers, visco-elastic dampers, and, hysteretic-loop dampers, and bracing of non-structural elements [7–11].

The rebuilding of Christchurch provided a remarkable opportunity to not only draw from its mistakes, but also to improve and increase resilience to immense damage. Learning from the Canterbury earthquakes, several buildings performed well in damage resistance, while others experienced a total collapse. The Christchurch Women's Hospital (CWH) is an example of a building that sustained very minor damage and was fully operational after the Canterbury 2010 and 2011 earthquakes and a series of aftershocks. According to Mayes et al. [12], the CWH was built with a seismic isolator resilience system, hence the reason why it could perform well during the earthquake event. Meanwhile, the Christchurch hospital built with a different seismic resistance system was significantly damaged, with an estimated repair cost of NZD 87.361 million and completion work in 2017 [13] (p. 63). Globally, buildings constructed with seismic isolation systems have performed well in large magnitude earthquakes compared to alternative seismic resistance methods. Examples of these buildings include the University of Southern California (USC) Teaching Hospital in California, USA, the Ministry of Post and Telecommunications Computer Centre in Kobe, Japan, the Abiha Gökçen Airport Hangar in Istanbul, Turkey, and the Women's Hospital in Christchurch, New Zealand [14]. These buildings reported very minor to no damages, including no disruption of services after being subjected to earthquakes with significant ground accelerations [12,15]. The performance of the CWH during the earthquake swarms suggest that the potential loss estimation and benefit analysis of the use of BIS in buildings could outweigh the consequences of non-use, especially in buildings that must remain operational after a significant earthquake event.

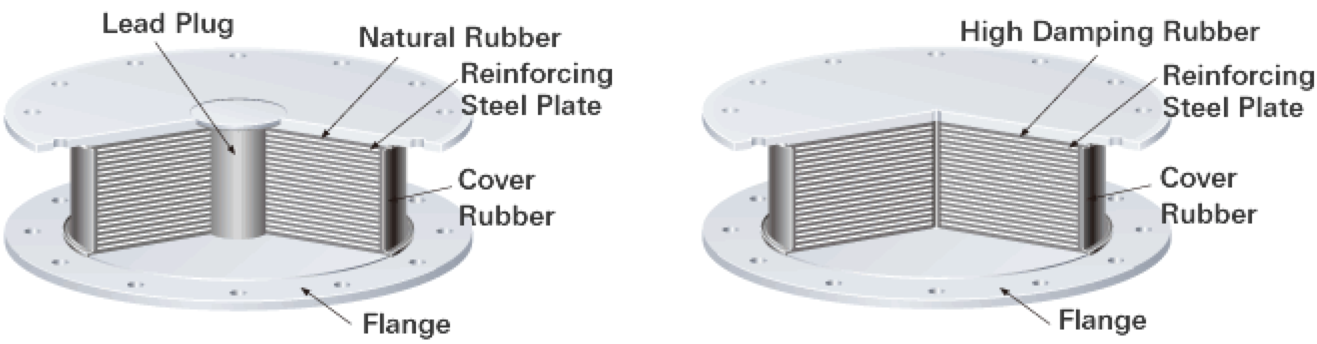
It is plausible to expect that base isolation system (BIS) would be readily used in new and older buildings, considering New Zealand's unique vulnerability and history of major earthquake events. As of 2015, New Zealand has only ninety-four isolated structures, including buildings, bridges, industrial, and new projects [16]. This number is quite small when compared to other similar earthquake-prone countries like Japan, China, Russia, Italy, and the USA [17]. Japan has implemented over nine thousand seismic isolation systems in various buildings and infrastructure; China has about four thousand seismically isolated buildings and four hundred bridges; Russia has over six hundred applications; and the United States has approximately two hundred and fifty seismically isolated buildings and infrastructure [18]. Despite being home to Robinson Seismic Limited, a trailblazer in the technological advancement of base isolation since 1970, New Zealand still lags. Base isolation is a technology that does have a track record of success in mitigating earthquake damage around the world. Its track record is especially important when making design decisions for buildings that serve significant purposes. Despite these benefits, there is low uptake and diffusion of the BIS in New Zealand, when compared to other earthquake resistance systems and other seismically active countries [19]. The question now is—should there be more of an active stance on earthquake risk mitigation? Are there choices and trade-offs for BIS among building owners, design professionals, and the public? It is against this backdrop that this study seeks to examine: (i) barriers affecting the low uptake of BIS in New Zealand, and (ii) investigate strategies that would provide insights into increasing its rate of adoption. Although BIS has been successfully implemented in many buildings and structures including bridges, nuclear power plants, boilers, and oil platforms [20,21], this research is focused solely on the utilisation of base isolation in buildings. This investigation will determine whether base isolation is worth the investment made by building owners and whether it is feasible to implement on a larger scale in New Zealand.

2. Literature Review

2.1. Base Isolation System (BIS)

BIS is one of the seismic design strategies that can be used to buffer the impact of seismic hazard to a building while still allowing it to operate after a major earthquake. Charleson and Allaf [22] described base isolation as an inert seismic control method that uses a catalogue of structural components to isolate the footings or foundations from the superstructure, allowing the latter to move freely of the former in an earthquake shaking. The system's key feature is the addition of versatility and damping to the structure during an earthquake event. Base isolators substantially decouple a building from its foundations and lessen the earthquake forces exerted on the superstructure, resulting in less damage to the building [11]. Warn and Ryan [23] noted that the concurrent reduction in velocity and displacement expectations attained with base isolation in a large and infrequent earthquake event renders it among the most efficient seismic resistance systems for achieving "operational" or "fully operational" performance.

A variety of BIS for seismic protection have been developed and implemented in different types of structures. Elastomeric and sliding–bearing systems are the two types of BIS [24]. Elastomeric bearings are frequently made of natural or synthetic rubber bonded to intermediate steel shim plates. This process operates by detaching the structure from the lateral force of the earthquake shaking by encasing a layer with reduced beam strength between the superstructure and the substructure [25]. The elastomeric layers offer lateral versatility as well as elastic force restoration [26]. Elastomeric bearings are classified according to their primary damping characteristics and constituents, which include: (i) natural or synthetic rubber bearings and lead rubber bearings, and (ii) low-damping and high-damping rubber bearings [23,26]. Common types of elastomeric bearings include the Natural Rubber Bearing (NRB), Lead Rubber Bearings (LRB), High-Damping Rubber Bearing (HDRB), and Steel Laminated Rubber Bearing (SLR) [27]. It is worth noting that New Zealand was a pioneer in the development of base isolation techniques. In the late 1970s, lead–rubber bearings were developed and used for the first time in New Zealand [28] and have been used around the world since then [29]. The cross-sectional views of these elastomeric bearings base isolators are illustrated in Figure 1a,b. The design, performance, and real-life experimental testing of the different varieties of elastomeric bearings have been documented in literature [25,30,31].



(**a**) (**b**)

Figure 1. (**a**) Lead–Rubber Bearing. Source: [32]. (**b**) High-damping Rubber Bearing. Source: [32].

The sliding–bearing method functions by reducing shear force transfer throughout the isolation interface and supporting the structure's weight on a bearing that sits on a sliding interface [23]. Flat slider bearings and curved slider bearings are the two types of sliding bearings, depending on their sliding surface geometry. The Friction Pendulum Bearing (FPB) and other derivatives, such as multi-spherical bearings, are common examples of sliding bearings systems (see Figure 2 [33]). These systems have been extensively used for buildings, bridges, and other structures [23,34].

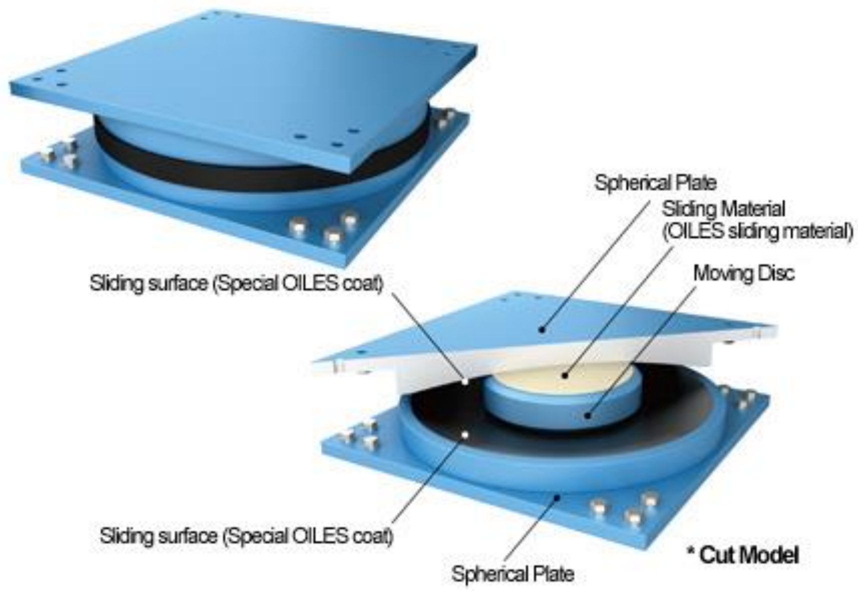


Figure 2. Friction Pendulum Bearing. Source: [33].

It is established that the BIS have been used in many buildings and structures over the last three decades. Likewise, its performance has been extensively researched and tested both in real-life earthquake events and shake table, making it a worthy alternative for seismic damage resistance. Plausibly, the BIS can be considered a matured technology. In comparison to Japan and China, where over 6100 isolated projects have been completed, there is no evidence in New Zealand that its uptake is increasing. A review of the factors affecting the rate of uptake of BIS in New Zealand is therefore necessary to proffer possible solutions.

2.2. Theoretical Underpinning of the Study

To explain the process of adopting or accepting a new product or technology, several theories and frameworks have been developed. They include Technology Acceptance Model [35,36], Theory of Planned Behaviour [37], Theory of Reasoned Action [38], Unified Theory of Acceptance and Use of Technology [39], and Diffusion of Innovations theory [40]. The ability of these models to predict user behaviour or intention to accept or adopt a new product or technology is shared by all of them. These models have been used in a multitude of fields, including information and communication technology, healthcare, nursing, substance abuse, manufacturing, engineering, and construction. The diffusion of innovation model, which sets out the framework for assessing BIS acceptance in New Zealand, underpins this study.

Theory of Diffusion of Innovation

To understand the theory of diffusion of innovation, it is important to first describe the keywords: innovation, diffusion, and adoption. Innovation involves the introduction of new methodologies, new thoughts about performance targets, and new products/services, or technology [41]. Innovation can be categorised as tangible or intangible [40]. Tangible innovations are physical objects such as robots and smart phones, whereas intangible are non-physical objects such as Building Information Modelling and Big Data. In view of this, seismic isolation system can be described as an example of in-tangible innovations in earthquake engineering. Buckle and Mayes [42] referred to it as a significant innovative development in civil engineering, which indicates that its adoption would be beneficial. Adoption is therefore described as “full use of an innovation as the best course of action available” [40] (p. 177). Similarly, Straub [43] defined it as individual’s integration of an innovation. This implies that a seismic isolation system can be adopted if identified, viewed, or perceived as innovative. According to Rogers [40], adoption can either be continued or discontinuance. The former implies continuous adoption of an innovation while the latter refers to rejection after initial adoption. The causative factors for an innovation's continuance or termination are classified as "relative advantage", "compatibility", "complexity", "trialability", and "observability" [44] (p. 208). Relative advantage implies how an innovation is preferred to other alternatives; compatibility is the idea that an innovation meets the need, status, and core values of adopters; complexity is the level of difficulty of use of an innovation; trialability encompasses the potential test and experiment of an innovation; and observability indicates results visibility of an innovation [44].

An innovation must go through a communication process known as diffusion before it can be widely adopted [40]. Diffusion takes place over time and may depend on the varying characteristics of the adopters. To increase the likelihood of widespread adoption of an innovation, it is critical to consider and comprehend the features of the population. In the case of seismic isolation systems, it is important that the characteristics of all stakeholders in the construction industry are considered. There are five types of adopters as established in the literature. These are innovators, early adopters, early majority, late majority, and laggards [40]. Innovators take risks and always try an innovation without any persuasion; early adopters are agents of change who believe in a need for an innovation and are keen to adopt such innovation; early majority are evidence-based adopters who are only convinced by success stories of the effectiveness of an innovation; late majority are adopters who rely on information from people that have tested, tried, and adopted an innovation; and laggards are change-resistant adopters who are comfortable with the status quo and require a lot of persuasion to adopt an innovation [40].

Knowledge, persuasion, decision, implementation, and confirmation are the five sequential stages that determine the diffusion of innovations [40]. The prospective adopter seeks more evidence about the innovation during the knowledge stage. The adopter forms an opinion about the innovation during the persuasion stage, and the decision to accept or abandon the innovation occurs during the decision stage. If the innovation is rejected, the diffusion process ends abruptly. If accepted, it proceeds to the next stage, which deals with the innovation implementation, whereas the last stage reinforces adopter's decision. As a result, it is critical to identify factors influencing the diffusion process to enhance the successful adoption of innovations.

To accelerate the adoption of innovations, the diffusion of innovation theory has been adapted in the construction and engineering sectors. May [45], for example, used the theory to investigate the obstacles to the implementation and application of performance-based seismic engineering technologies. Similarly, Ogunmakinde [46] used diffusion of innovation theory to develop a circular economy waste prevention guideline for adoption in the construction industry in Nigeria. This suggests that the theory is suitable for studying the uptake of BIS in New Zealand.

Based on the literature, factors affecting adoption of innovations can be categorised into four, namely: external system, individual, innovation, and industry/firm. Common barriers to the adoption of innovations are highlighted in Table 1, and these barriers can be adopted for the BIS.

Table 1. Common barrier to the adoption of innovations. Source: Adopted from [47].

Category	Barriers to Innovations
External system	Government policy and regulations
	Financial incentives and rewards
	Inter-systems

Table 1. *Cont.*

Category	Barriers to Innovations
Organisation/Firm	Absorptive capacity
	Leadership styles and attributes
	Networks
	Culture, norms, and values
	Size and structure
	Social climate
	Inter-organisations/firms
	Trainings
	Change-readiness
Innovation	Complexity, perceived benefits, and reliability
	Cost-effectiveness and practicability
	Proof and interoperability
	Enablers and impediments
	Fitting innovation with user standards and beliefs
	Risk
	Trialability, significance, and simplicity
Individual	Connection with workplace culture
	Attitudes, motivations, and willingness for improving quality and reward
	Implementation and integrity feedback
	Characteristics of individuals
	Characteristics of Managers
	Social network

2.3. Barriers Impeding the Uptake of BIS

Base isolation has been demonstrated as a highly effective system for improving the earthquake performance of both existing and new buildings. Recent studies in New Zealand have reported an increased interest and application of base isolators in the technology after the 2011 Canterbury earthquakes [48]. However, when compared to other seismically active countries such as Japan and the United States, the rate of implementation in New Zealand's construction sector has remained low [49]. The discourse on the barriers to the adoption of base isolators has been gaining traction.

Barriers hindering the adoption and diffusion of BIS in seismically active regions have been investigated by several researchers and practitioners. The works of Mayes et al. [14,50] are prominent among the studies on the subject. Likewise, the occurrence of major global earthquake disasters such as the Northridge earthquake of 1994, the Great Hanshin earthquake disaster of 1995 and the Canterbury earthquake of 2011 have led to an increase in the numbers of scholars and studies on the topic. Cost, extent of use, design requirements, and design concept and strategy have been identified as common barriers, which are discussed in subsequent sub sections.

2.3.1. Cost of BIS

Base isolation can be built into new buildings as well as retrofitted into existing structures. In appropriate circumstances, such as heritage buildings and hospitals, Mayes et al. [51] observed that base isolation is a more cost-effective retrofit option than other alternatives. They also discovered that since base isolation is limited to the basement, the building's occupants will not be disrupted, and thus there will be no need to relocate them to another building to keep working. Usually, base isolation retrofits are installed in high-value buildings. This is due to the high cost of delivering the layer of safety that base isolation provides, and it would be appropriate only for a building that would continue to be used and have its critical functions maintained within it [19]. The Supreme Court in Wellington, New Zealand, for example, was retrofitted with lead–rubber bearings in 2007. The Christchurch Women's Hospital was the only base-isolated building in the South Island prior to the Canterbury Earthquakes of 2010 and 2011 [11].

In the literature, the cost of implementing BIS in both new and existing buildings has been identified as a major barrier [11,14,19,22,50,52,53]. Following the proven performance of isolated buildings in major earthquake disasters, several studies have suggested that a lower construction cost could improve the uptake of BIS. Though some of the methodologies adopted for costs comparison have been subjective [51,54], a few authors have argued that the initial construction cost of an isolated building when compared to a fixed-based building should not be the only criteria for cost comparison, but rather the economic feasibility, cost-benefit, or life-cycle analysis should be used [42,51,52]. The cost of an isolated building tends to be low with these analyses. For instance, attempts to compare the cost-benefit or life-cycle analysis of an isolated and a fixed-based building has showed some cost savings [31,55], whereas others have been inconclusive [19,22,56].

On the other hand, Tsiavos [57,58] have demonstrated the efficiency of a polyvinyl chloride (PVC), "sandwich", low-cost seismic isolation system, which is based on the encapsulation of a thin layer of sand between two PVC surfaces, experimentally, on a large scale. This method makes use of the rolling mechanics of sand grains and materials that are easily available locally to facilitate low friction sliding of a building's foundation and seismic protection of the superstructure [57,58]. As suggested by Tsiavos [57,58], the proposed low-cost BIS slab configuration would consist of only one reinforced concrete floor above the isolation system and a 5 cm thick unreinforced blinding concrete layer below. This system would provide structural stability at a lower cost.

According to Mayes et al. [51], the parameters used for the cost-benefit estimation should be beyond the comparison of structural elements performance adequacy. The structural elements of a typical building accounts for about 20% of the construction cost. Mayes et al. [12] revealed that an isolated building frequently accounts for the protection of structural and non-structural elements, building contents including architectural/heritage features, electrical and mechanical components, and the operational performance of the building after an earthquake event, whereas a conventional fixed-base building rarely meets these requirements. Kilar et al. [59] explained that the total building costs should not only be considered for the construction itself but should also include the estimated costs in terms of possible deaths, downtime, and repairs. Vinci et al. [31] added that the benefits from reduced social costs arising from a major disaster by an isolated building should also be included in the analysis. The estimation of the overall costs of a BIS should include initial cost of construction, earthquake insurance premium, expected repairs costs, business downtime cost, heritage preservation cost (if applicable), expected social costs, and potential liability to occupants (loss of lives and injuries).

2.3.2. Extent of Use of Base Isolators in Buildings

Significant historical buildings or structures with unique functional requirements have been the only ones to use base isolation in the last two decades. Base isolators have been successfully used in structures such as oil platforms, nuclear power plants, and bridges, but their use in engineered buildings in New Zealand is limited [20,21]. Following the 2011 Canterbury earthquakes, there has been an increase in the need to strengthen buildings to mitigate impacts of future seismic disasters. According to Mayes et al. [12], base isolation is a mitigation strategy that is well-suited for use in healthcare facilities and other buildings that must continue to function following a seismic disaster. This is due to the fact that these facilities are absolutely essential and should stay functional and operational during or after a catastrophic event [15]. However, Moretti et al. [15] contended that base isolation should be used only for buildings classified under Important Level 4 (IL4) of the New Zealand Building Code (NZBC). They added that other buildings such as schools should incorporate the use of base isolation because their failure in an earthquake event would have substantial hazard to humans due to their occupancy levels. Studies have found post-traumatic behaviour problems in children and young people who were affected by the Canterbury earthquakes and post-disaster reconstruction [60]. Earthquake exposures are expected to increase the incidence of persistent symptoms of post-traumatic stress because they relate to ongoing aftershocks, as well as extended periods of disturbance due to infrastructure damage and disruptive reconstruction [61,62]. The vulnerability of children and adolescents resulting from traumatic experiences, as well as their resultant mental health issues in adulthood, are earthquake-induced, psychologically, and has social outcomes, such as monetary impacts, that are difficult to quantify.

2.3.3. Base Isolation Seismic Design Guidelines

A review of the AS/NZS 1170.5 Structural Design Actions Part 5: Earthquake actions–New Zealand [63] and other relevant regulatory provisions show that standards exist for designing isolated structures in New Zealand [53,64,65]. This regulation's primary functions are to provide approaches for structural engineers to determine seismic load-carrying levels and their specifications, as well as to predict specific seismic loads for particular locations in New Zealand [63]. Unfortunately, the New Zealand Building Code (NZBC) does not have authorised design specification for isolated structures. Rather, the design comes under the purview of an AS/NZS 1170.0 [64] special study. This suggests that deciding on a standard to adopt is the designer's responsibility. Holmes Consulting Group (a construction company in New Zealand) published the only related document, titled "A design guideline for base isolation". The document provides background details about base isolation, its principles, design methods, two scenarios, and testing [66]. Existing research also suggest that the absence of a design standard or guidelines for the implementation of base isolation limits the adoption of the technology in New Zealand [53,65,67]. A lack of such standardised guidelines in the construction industry often reduces the confidence of engineers in adopting the technology [67], increases their professional risk and liability, and often leads to variations in seismic design practices [68]. There is a particular emphasis on design processes, codes and standards, and structural performance measures. A lack of standardised guidelines may be a source of inconsistency in performance measures and compliance design processes. This may restrict the technology's widespread adoption in New Zealand. However, there is need to include design guidelines for base isolation in the NZBC. Similarly, Whittaker and Jones [65] advocated for the design criteria to be standardised, adding that designers use various international requirements to complete their designs.

The lack of standardised design guidelines was reported in the USA in the 1990s [50,69]. Major changes and approaches have been implemented in the past decade to establish next generation performance-based design standards, including seismic isolation technologies, which are summarised in ASCE Standard 2017 [70]. It is surprising to note that although New Zealand was one of the early pioneers of the base isolation system in 1970s, there are currently no codes of practice or guidance, forty years later. The first New Zealand guideline for the design of seismic isolation systems for buildings is currently being prepared to be used as part of alternative solution designs for compliance with the NZBC [63] and New Zealand Standards 1170.5 [48]. Other barriers relative to issues around seismic design philosophies are lack of guidelines for the design and implementation of base isolation, administrative bureaucracy, lengthy design and approval process, and the designer's reluctance to embrace new innovation [14,45,68].

This study builds on the findings of May [14,45] that identified barriers to the adoption of performance-based earthquake engineering (PBEE). Table 2 also lists crucial barriers to adoption of innovations, particularly in the construction and engineering fields.

Table 2. Barriers to the adoption of BIS.

Category	Common Barriers	References
Technical-related	Capability to forecast the adverse effects of earthquakes on a structure	[14,45,66]
	Capability to translate those adverse effects into visible physical change	
	Ability to translate those damages into outcomes such as casualties, injuries, building functionality, and reparability	
Decision-related	Design of a technique that is helpful in providing useful categories of options.	[14,45]
	Information on the costs of achieving various results	
	Decision makers' belief that the buildings will perform as expected	
Regulation-related	Seismic safety goals	[14,42,45,50,53,67–69]
	Building regulation system	
	Establishment of regulatory standards	
Cost-related	Seismic isolation is perceived to be expensive.	[11,14,19,22,42,45,50,52,67]
	Concerns about the technology	
	Lack of standards and guidelines for the technology	
	Perception that the technology is expensive	
	Perception that the technology is time consuming	

2.4. Gaps in the Literature

As noted by Devine [19], seismic isolation systems are used sparingly in New Zealand, despite the negative effects of the 2011 Canterbury earthquakes and the advantages of the BIS. Seismic isolation is a useful technique for reducing the cost of earthquake damage. Regrettably, it has not been used as frequently as it could. It has earned the label "expensive", but in actual fact, it has proven to be effective in previous seismic isolated structures that witnessed large earthquakes [19]. When it comes to seismic isolation, the adage "time is money" has never been more accurate. Whereas BIS minimises the real damage caused by an earthquake on a building, it also allows the building to continue operating normally, ensuring that businesses operating out of it can still make money [71]. These demonstrate the importance of incorporating effective seismic damage mitigation into buildings throughout New Zealand. However, the low adoption rate of seismic isolation system has not justified its advantages. Some factors or barriers are responsible for this, and it would be worthwhile to identify these factors.

Also, there is a lack of appropriate design standards for designers to follow when proposing seismic isolation designs for new builds [72]. This may be responsible for its low adoption rate. Similarly, Kelly [66] observed that engineers' lack of technical training on the design and implementation of seismic isolation may be another reason for its lack of widespread adoption in New Zealand. Design professionals are also known to be reluctant in embracing innovation [68], which further explains the lack of utilisation of seismic isolation in New Zealand. The BIS presents an opportunity for construction professionals to construct earthquake-damage-resistant buildings. To improve the reduced rate of seismic isolation adoption in New Zealand, it would be beneficial to identify the factors responsible and address the challenges.

3. Research Method and Materials

The objectives of this research are to investigate the barriers impeding BIS adoption in New Zealand and to proffer potential solutions to these barriers. For these purposes, a mixed method approach comprising both quantitative and qualitative approaches have been adopted. The research design followed an exploratory sequential design. The qualitative approach collected data on barriers impeding adoption of base isolators in New Zealand. These barriers were fed into the quantitative instrument to identify their level of criticality and to categorise them. The choice of a mixed methods approach for this study is to provide deeper understanding about the research problem and to make up for the weakness of each approach [73].

In-depth face-to-face interviews were used for the qualitative data collection, while an online questionnaire was used for the quantitative data collection. The face-to-face interviews allowed for deep exploration of participants' thoughts and experiences on the topic and to explore new concepts [74]. The online questionnaire enabled opinions to be ranked based on questions formulated from the interviews. In addition, it is easy, convenient, and flexible for respondents, which increases engagement and response rates. Prior to data collection, this study was approved by Massey University's human research ethics committee. In addition, all participants were given and asked to review a written informed consent form.

The target population consisted of professionals involved in the design (structural and architectural), costing, and construction of large multi-storey buildings in New Zealand. Structural engineers, quantity surveyors, construction management personnel, and architects, were among the professionals involved. Data were sourced from four sampling frames comprising members of professional organisations such as: (i) Institute of Professional Engineers New Zealand (IPENZ), (ii) New Zealand Institute of Building (NZIOB), (iii) New Zealand Institute of Quantity Surveying (NZIQS), and (iv) New Zealand Institute of Architects (NZIA).

3.1. Data Collection

Empirical data were collected from Auckland, Wellington, Christchurch, and Dunedin cities in New Zealand. These cities have high levels of construction activities and different levels of vulnerability to earthquake disaster, as shown in Figure 3.

3.1.1. Qualitative

Participants for the interviews were purposely selected due to their expertise and experience in implantation and design of seismic isolation systems. Purposeful sampling strategy allows the involvement of experienced participants in the subject matter [75]. A total of eighteen face-to-face interviews were conducted. An interview protocol was employed to ensure consistency during the interviewing process, which varied between sixty and ninety minutes. With the interviewees' permission, the interviews were recorded and transcribed. However, effort was made to ensure that the information given by the interviewees was accurately transcribed and validated by them.

Overall, seventeen themes (thirteen barriers and four motivators) affecting the uptake of seismic isolation in New Zealand were systematically evaluated through a review of the literature and interviews. These themes (see Table 3) were developed into close-ended questions, which were further explored in the quantitative strand of this study. The barriers identified by participants in the interviews were grouped into three, namely: individual/organisation-related, regulatory-related, and innovation-related barriers.

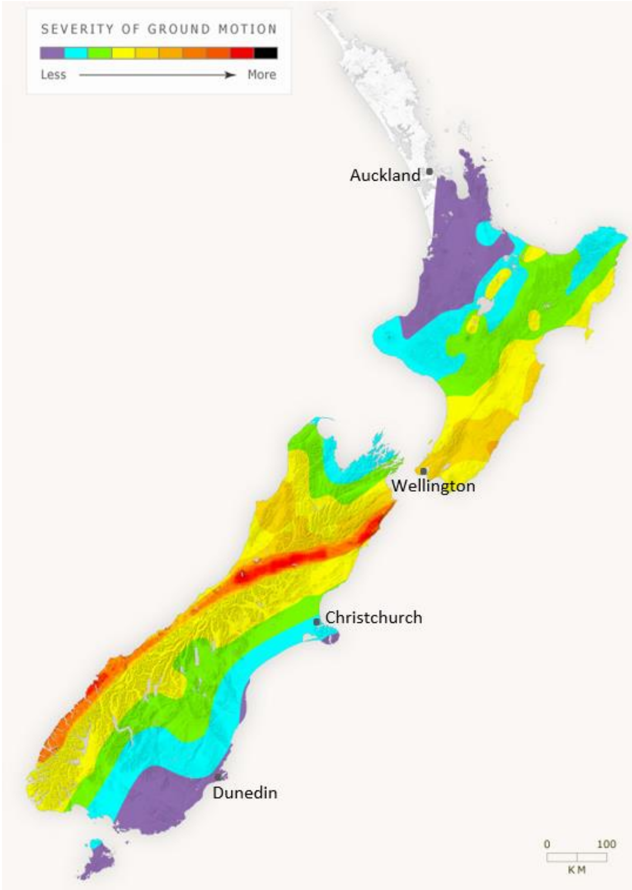


Figure 3. Map showing severity of ground motion in New Zealand. Source: Adapted from McSaveney [1].

Table 3. Barriers and motivators for BIS.

Category	Code	Barriers
Individual/ Organisation	B1	Safety concern of base isolated buildings
	B2	Hands-on experience of base isolation systems
	B3	Attitudes to base isolation systems
	B4	Market availability for base isolation in New Zealand
Regulatory	B5	Increased awareness of earthquake risks and potential damage
	B6	Current building code requirements are unsuitable for earthquakes
	B7	Lack of confidence in designing base isolation caused by a lack of universal design standards
	B8	It is advantageous to use universal design standards for base isolation
Innovation	B9	Base isolation is too expensive
	B10	Base isolation is more expensive than alternative solutions
	B11	Projects too small to justify the expense of base isolation
	B12	Unpredictability of earthquakes discouraging clients from considering base isolation
	B13	Retrofitting base isolation is less expensive in terms of costs and time.
Category	Code	Motivators/Opportunities
Adoption	M1	Reduced insurance premiums
	M2	Government subsidies (e.g., import tax, GST etc.) for retrofitting and new builds
	M3	Recognition on an earthquake building safety
	M4	Monetary incentives

3.1.2. Quantitative

An online questionnaire was adopted as the quantitative data collection instrument due to its advantages, including the ability to reach many respondents within a short period and ability to generalise results to a wider population. The questionnaire was carefully designed to be concise to encourage adequate and prompt participation of respondents who are known to be very busy. In addition, too many questions were avoided to prevent skewed answers and loss of interest. The questionnaire comprised three sections, which are: demographics, barriers, and motivators. A five-point Likert scale was adopted that included an "unsure" option, to prevent false positives being reported. The questionnaire was pre-tested and was subsequently modified in accordance with feedback and suggestions from respondents in the pilot test. For a period of twelve weeks, the questionnaire was hosted on the Survey Monkey website. An email invitation comprising the information statement and a link to the online questionnaire was randomly sent to members of IPENZ, NZIA, NZIQS, and NZIOB. Consent was implied by voluntary completion and submission of the questionnaire. A stratified random sampling approach was employed to alter the minimum sample sizes required, as the membership directories were not uniformly sizeable [73]. The interview participants were carefully excluded from the questionnaire as they share same demographics as the respondents.

3.2. Data Analysis

Qualitative data were first analysed as a condition of the exploratory sequential mixed method design adopted for the study. The interview transcripts were analysed using content analysis and pattern matching techniques. These techniques enabled a comparison of the text codes and the identification of trends or themes that appeared or were repeated in the interviews [76]. To ensure consistent coding and interpretations, data were coded using NVivo 11 software and a coding scheme based on relevant variables identified during interviews and a literature review.

The quantitative data analysis was completed in several stages using some statistical tests conducted in IBM SPSS v24.0. First, preliminary analysis was performed to ensure that potential questionnaire-specific issues (such as missing data and normality) are addressed. Second, univariate (descriptive) statistics were used to explain the characteristics of central tendency and data variation by summarising the data with arithmetic means, variance, and standard deviation. In descending order of importance, the mean score ranking technique was employed to classify barriers as experienced by the respondents, while the normalised values of the mean score were calculated to identify important barriers and motivators. Lastly, exploratory factor analysis (EFA) was used to assess the relationships [77] between the identified variables (barriers and opportunities). The Kolmogorov–Smirnov normality test was conducted to measure goodness of fit. In this data set, the significant p-values are <0.05, which indicated a normal distribution. This result supports the normality assumption for EFA that has not been violated. The use of EFA is crucial in this study, given that no priori study has examined the patterns of relationships among the identified barriers and motivators relating to the uptake of BIS in New Zealand.

3.3. Response Rate

For the qualitative strand, all eighteen proposed interviews were conducted at a convenient time and location, as suggested by the participants. This implies a 100% response rate, which further justified interviews as an effective method when high response rate and open-ended data are desired. As for the quantitative strand, a total of 318 emails were sent to potential respondents and only 109 responses were received. Five responses were incomplete with a missing value ratio greater than 15% and were deleted according to the criteria suggested by Hair et al. [78]. Therefore, 104 completed questionnaires were used for the quantitative data analysis, which represents a 33% response rate; however, a low response rate is common with studies involving construction professionals.

4. Results

4.1. Demographic Profile

The demography of participants and respondents in the interviews and online questionnaires are described in Table 4. The largest proportion of responses from both the interviews and questionnaire were engineers and architects (see Table 4). This implies that their relevance to the design and implantation of base isolators cannot be overlooked. They are primarily involved in the project's early stages, contributing to the design and selection of the preferred seismic resistance system. The engineer begins the seismic design of the structural elements, while the architect ensures that the system is compatible with the overall client's objective regarding the design, functionality, and aesthetics of the structure.

Table 4. Participants' characteristics.

Category		Interviews		Questionnaire	
		Frequency	%	Frequency	%
Professional discipline	Engineering	6	33.3	37	35.6
	Architecture	6	33.3	32	30.7
	Quantity Surveying	2	11.1	21	20.2
	Construction Management (e.g., Project managers)	4	22.2	14	13.5
Geographical location	Auckland	4	22.2	12	11.5
	Wellington	2	11.1	6	5.8
	Christchurch	10	55.6	71	68.3
	Dunedin	2	11.1	4	3.8

According to an evaluation of the participants' official positions in their organisations, the majority are directors or chief executives (46%), senior managers (38%), and mid-level managers (16%). Many of the participants are employed by medium-sized firms (61%), followed by small firms (28%), and large firms (11%). The participants' firms provide consultancy services (44%), construction (32%), project management services (18%), and regulatory and approval services (6%). The participants' average years of industry experience is 18 years, with a maximum of 25 years and a minimum of 3 years, and more than half (57%) have personally been involved in large projects worth more than US$30 million. The geographical location of respondents is predominantly within Christchurch (68.3%), which confirms the on-going post-disaster rebuilds in New Zealand as at the time of data collection. The participants' demographics also revealed the involvement of key professionals with significant working experience in the industry and can provide reliable information to the research findings.

4.2. Quantitative Data Results

This section presents results of the two approaches that have been used to analyse the barriers and opportunities to the adoption of base isolation in New Zealand. These approaches are mean score ranking, normalised values, and factor analysis. The first part of this section deals with the results of the mean score ranking and normalised values, whereas the results of the factor analysis are presented thereafter.

4.2.1. Results of Ranking Analysis and *t*-Test

The mean score ranking of the barriers and opportunities to the adoption of base isolation in New Zealand is presented in Table 5. The mean score for barriers ranges from 1.69 to 3.48 whereas the mean score for opportunities is from 2.79 to 4.19. Overall, there are thirteen barriers and four motivators. Significant barriers and motivators are identified as normalised values greater than 0.50. Table 5 shows that 11 out of 13 barriers have normalised values above 0.50 and are deemed significant. Similarly, three out of four motivators have values greater than 0.50, indicating that they are significant motivators.

According to the findings, "attitudes to base isolation" (B3) was ranked first (MS = 3.48), implying that construction professionals' attitudes towards base isolation systems are the most significant barrier preventing their adoption in New Zealand. As ranked by respondents, B4 (market availability, MS = 3.42), B5 (awareness of base isolation, MS = 3.33), B8 (universal design guidelines, MS = 3.13), and B2 (hands-on experience, MS = 3.12) were ranked second, third, fourth, and fifth barriers, respectively. On the other hand, "reduced insurance premiums" (M1) was ranked first (MS = 4.19), which indicates that a reduction in the current cost of premiums is the most significant motivator to adopting BIS in New Zealand. The second ranked motivator was "government subsidies" (MS = 3.85), whereas "recognition" (MS = 3.48) was ranked third. These results suggest that there is a relatively high number of barriers limiting the adoption of the seismic isolation systems in New Zealand.

Table 5. Ranking of barriers and opportunities to base isolation's adoption.

Barriers	Mean Score	Standard Deviation	Rank	Normalisation [a]
B3	3.48	0.577	1	0.74 *
B4	3.42	0.667	2	0.71 *
B5	3.33	0.678	3	0.78 *
B8	3.13	0.908	4	0.78 *
B2	3.12	1.231	5	0.53 *
B1	3.10	0.721	6	0.55 *
B12	2.62	0.796	7	0.54 *
B6	2.40	0.995	8	0.60 *
B7	2.27	0.910	9	0.56 *
B11	2.08	1.026	10	0.52 *
B10	2.00	0.816	11	0.67 *
B13	1.81	0.886	12	0.45
B9	1.69	0.853	13	0.42
M1	4.19	1.030	1	0.79 *
M2	3.85	1.036	2	0.71 *
M3	3.48	1.163	3	0.62 *
M4	2.79	1.035	4	0.45

[a] Normalised value = (mean − minimum mean)/(maximum mean − minimum mean). * Normalised value ≥ 0.50 (Critical).

4.2.2. Factor Analysis Results

The eleven significant barriers were subjected to factor analysis using IBM SPSS software v24.0. The Kaiser–Meyer–Olkin (KMO) test result for this study's sampling is 0.531, which suggests that the degree of common variance among the barriers is considered significant. It also satisfies the minimum requirement of 0.50 for factor analysis as recommended in the literature [79–81]. In addition, the result of the Bartlett's test of Sphericity (x^2 = 120.433, df = 55, $p \leq 0.001$) demonstrates validity and suitability of factor analysis in this study. To extract the factors, a principal component method was employed with varimax rotation. Factor loadings above 0.50 were used as recommended in the literature [82,83]. Most barriers exceeded 0.50 except three factors (B6, B8 and B12), which were removed because of low communality value of less than 0.50. After this iterative removal process, the remaining barriers all have factor loadings above 0.5.

Table 6 reveals the three underlying groups with an Eigenvalue greater than 1.00 extracted from the eight variables, which explained 53.48% of the variance. Group 1 consists of four variables (B2, B3, B4, and B5), which accounts for 19.884% of the variance. Group 2 accounts for 19.499% of the variance with two variables (B1 and B7), whereas group 3 comprise two variables (B10 and B11), which accounts for 14.100% of the variance. Cronbach's alpha values for these groups ranged between 0.414 and 0.582, which suggests an acceptable reliability of the extracted factors [84]. Factor loadings, communalities, Eigenvalue, and Cronbach's alpha values were all greater than the specified cut-off values, indicating a higher level of confidence and reliability in the data. To discuss, the three groups are labelled as follows:

1. Group 1: Human-related barriers;
2. Group 2: Safety and Design; and
3. Group 3: Costs-related barriers.

Table 6. Results of the rotated component matrix for factor analysis.

Codes	Barrier Groups		
	Human-Related	**Safety and Design**	**Cost-Related**
B2	0.567	-	-
B3	0.675	-	-
B4	0.581	-	-
B5	0.727	-	-
B1	-	0.652	-
B7	-	0.711	-
B10	-	-	0.780
B11	-	-	0.780
Eigenvalue	2.187	2.145	1.551
Variance (%)	19.884	19.499	14.100
Cumulative variance (%)	19.884	39.384	53.484
Cronbach's Alpha	0.552	0.414	0.582

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 4 iterations.

5. Discussion

5.1. Implications of Barriers Affecting the Uptake of Seismic Isolation Systems

The findings reported in this section highlight the perspectives of construction professionals on factors impeding the adoption and uptake of the seismic isolation resistance systems in New Zealand. Findings from both qualitative and quantitative data are integrated in the discussions in the following subsections.

5.1.1. Group 1: Human-Related Barriers

This group highlights construction professionals' perception of base isolation systems. Their perception is represented by four significant barriers, which are: (1) hands-on experience of BIS, (2) attitudes to BIS, (3) market availability for base isolation in New Zealand, and (4) awareness of BIS. These barriers emphasise issues relating to what construction professionals think about the effectiveness and implementation of BIS. This group explains 19.884 of the variances, which indicates that it is highly relevant among the three groups. From the results, attitudes to BIS are the key barrier in this group, while the least critical is awareness of BIS.

The findings suggest that many construction professionals do not have hands-on practical experience with base isolation systems. It is impossible to overestimate the value of practical experience in the implementation of a base isolation system. This is due to the technicality involved in both designs and fabrication, and actual installation. Though construction professionals may have extensive theoretical knowledge of BIS, it may not be adequate for successful adoption and implementation. Therefore, the requirement for practical experience may be responsible for low adoption of BIS in New Zealand. Likewise, the lack of practical experience could have resultant effects on operatives, who depend on construction professionals for guidance, especially on new techniques and methods. This finding is consistent with prior studies that found a lack of technical know-how as a major barrier preventing the adoption of BIS [14,42,45,66]. Although BIS is not a new technology, it is just gaining traction as a potential solution to mitigating disaster risk. To improve the adoption of BIS, it is important for construction professionals to have hands-on practical experience, which can be acquired through training. The experience when acquired can then be passed on to operatives and others as necessary.

Construction professionals' attitude to base isolation system is another critical barrier identified in this study. Attitude is described as "a relatively enduring organisation of beliefs, feelings and behavioural tendencies towards socially significant objects, groups, events or symbols" [85] (p. 150). In the context of the adoption of BIS, attitude plays a significant role. Rogers [40] emphasised the importance of attitudes, especially at the persuasion stage of an innovation. Construction professionals may exhibit either positive or negative attitudes to BIS. Positive attitudes may involve favourable consideration or conception that the system would be effective when implemented. Professionals who demonstrate this attitude towards BIS are risk takers and may be referred to as innovators or early adopters as recommended by Rogers [40]. On the other hand, negative attitudes may result from unfavourable consideration or misconception about the effectiveness of the system. Professionals who exhibit this type of attitude are commonly referred to as laggards; they are change-resistant and require a lot of persuasion and individual conviction to change their attitude [40]. The adoption of BIS in New Zealand is at the persuasion stage, with construction professionals are developing interests. However, negative attitudes to the BIS may be responsible for the low rate of adoption. To change construction professionals' attitude, there is need for continuous persuasion through the provision of up-to-date information about the system and education. In addition, incentives may be provided to encourage positive attitudes.

The lack of awareness of BIS among construction professionals reflects their level of adoption. Awareness in this context can be likened to knowledge, which Rogers [40] identified as the first step in the diffusion of innovation theory. BIS adoption is heavily reliant on awareness, particularly among construction professionals who are expected to introduce clients to the system. Without adequate knowledge of base isolation, construction professionals might find it difficult to convince their clients to adopt it. Most clients rely on construction professionals' recommendations or specification of current technology or materials in the industry, especially as it relates to cost, strength, and aesthetics. Therefore, construction professionals' lack of awareness of BIS would indirectly impact a client's knowledge and awareness of BIS. More so, it could affect government regulations regarding best practices for disaster mitigation. Since the industry makes recommendations for policy makers, it would be impossible to recommend the use of BIS if construction professionals are not aware of it. Consequently, there is need for the industry to increase awareness of the BIS among its professionals and other stakeholders through continuous professional development (CPD) training and education. This could promote the adoption of BIS and possible inclusion in the building code and guidelines.

The findings revealed a lack of market for base isolation as a critical barrier. This suggests that there is low demand for BIS despite the high disaster vulnerability. The implication is that the technology will thrive when there is high demand. In addition, the product (i.e., BIS) may not be readily available in the market due to low demand. Client preference and demand for BIS are important factors influencing adoption rates. The lack of awareness of the characteristics of BIS including its relative advantage, compatibility, and ease of use [40] may be responsible for low demand and product availability. As a rule of thumb, when there is low demand, manufacturers will reduce production, which will affect product availability and in the long run will reduce the adoption rate. Therefore, to increase the adoption rate, there is a need to increase product awareness, which may directly increase demand and product availability concurrently. This suggests that market availability is highly essential for the successful adoption of BIS in New Zealand.

5.1.2. Group 2: Safety and Design-Related Barriers

This group highlights the safety and design fears of base isolation system and is represented by two critical barriers, which are: (1) safety concern of BIS, and (2) lack of confidence in base isolation design. This group explains 19.499 of the variances, which suggests that it is relevant among the three groups. From the results, both factors are critical barriers and are related to pre- and post-designs of BIS.

The safety concerns of BIS inhibit its adoption in New Zealand. The implication is that most construction professionals are uncertain about the strength and effectiveness of the technology, and as a result, they cannot guarantee its safety. This will negatively affect the level of adoption of the BIS. It also indicates that construction professionals are less likely to take the risk of adopting a technology that has not been tested and proven to be efficient. This category of construction professionals aligns with the group of adopters that Rogers [40] described as late majority. It is common for construction professionals to be unsure about a technology, especially when they have no first-hand practical experience of such. The safety concern of BIS may be directly related to a low adoption rate among construction professionals in New Zealand because safety is highly important in disaster-risk reduction. From this finding, the BIS may not be adopted without strong evidence of its performance during an earthquake. Therefore, to convince construction professionals about the safety capacity of BIS, there is need for increased awareness, training, education, and practical simulation of its performance. This may increase the adoption rate because "the more diffused a certain technology in the construction market, the less risky it will become to implement it" [86] (p. 7).

Lack of confidence in BIS design is identified as a critical barrier. There are no specific design requirements for seismic isolation in New Zealand as stated by most of the respondents. This shows that construction professionals lack understanding of what is required, and as such, they have little or no confidence in the design. Designers in New Zealand tend to improvise in the absence of a prescribed guideline, by either employing international standards or by producing a unique design for the project under NZS 1170.5 [72]. This could make seismic isolation less appealing for new construction projects. Though the current NZBC requirements may be suitable for seismic retrofitting, it does not provide design guidelines for BIS. The lack of confidence in base isolation design could explain why most construction professionals have safety concerns about the technology. Many of the engineers mentioned that they often adopt international codes citing examples from United States and the European Union. This approach may not be appropriate as there could be differences in structural conditions and engineering practices between New Zealand and the United States or European countries. In addition, resistance to change due to liability issues [87] may be another reason for their lack of confidence. This is common among construction professionals because they find it easy to stick to a system that worked best than a new system that has not been tried and tested. Similarly, it would be a challenge for designers to introduce a system or technology that they cannot design. It would be deadly to do such thing, especially when safety is of high priority. To boost the confidence of designers in the use of BIS, there is need for universal design guidelines that will be comprehensive. This may be incorporated into the building code and guidelines for ease of accessibility. As the BIS is gaining traction among New Zealand construction professionals, it is critical to build the trust of designers and other stakeholders through design incentives. Similarly, the industry may adopt a seismic certificate (similar to an energy certificate) for seismic retrofitting and new construction to boost professional and stakeholder confidence. The councils may issue this certificate in a manner similar to development application approval after construction professionals (e.g., civil and/or structural engineers) certify that the proposed new build/retrofit meets all seismic performance objectives and design requirements. This would increase users' safety for a wide range of disaster events.

5.1.3. Group 3: Cost-Related Barriers

This group consists of two critical barriers, which are: (1) base isolation is expensive than the alternatives, and (2) base isolation is too expensive for small projects. Both factors relate to the perceived high cost of BIS. This group however explains 14.100 of the variances. Generally, cost is considered as an important factor in any project. Clients tend to be more conservative with cost, particularly if the project is running on a low budget. Some projects have been abandoned while some are yet to start due to cost issues. This suggests that most clients want quality projects at moderate or low costs. However, high cost is a critical barrier not only to the adoption of BIS but to construction projects. The perception that BIS is more expensive than alternatives in seismic retrofitting and disaster risks reduction is emphasised by most respondents and participants in this study. There is no evidence to show that the cost of BIS is more than the alternatives. It is a mere belief, with no substantiated evidence by some industry practitioners. Their lack of awareness and experience of seismic isolation on projects may be responsible for the negative perception. Construction professionals considered cost in terms of supply and installation of seismic isolation, as well as the disruption of occupants (if applicable) that may happen throughout the retrofitting phase. While the work is being done, building owners may be required to provide alternative accommodation for the occupants. Alternatively, they may pay a premium for after-hours work to avoid disrupting their tenants. Cost should not be considered in financial value, but in terms of emotions and feeling of ease that BIS would provide. Furthermore, safety was emphasised more than cost by some of the participants. For example, one of the participants noted that: "I don't think this should be related to costing or the size of the project; it is people's lives". The perception that base isolation is expensive could hinder its adoption. This finding supports previous studies [12,42,52] that identified a high perceived cost of construction of base isolation as problematic for its adoption. This cost barrier may be dealt with through increased exposure to the design, installation, and performance of BIS. Practical application would reveal the actual cost or the real cost of BIS.

The perception that base isolation systems are too expensive for small projects is a critical factor affecting its adoption in New Zealand. BIS is considered a perfect fit for large projects such as hospital, stadium, and airports [15]. This is based on the notion that large projects fitted with base isolators could minimise the number of causalities in the event of a natural disaster. Therefore, the cost of BIS for large projects are assumed to be just right. There is no clear definition of a small project, but residential buildings, such as a two-bedroom or three-bedroom homes may be considered a small project. It goes without saying that most cities in New Zealand and across the globe have more small projects than large projects. Considering this, the perception that BIS is too expensive for small projects could explain the reason for its low adoption in New Zealand. The introduction of financing schemes in the form of incentives could help small project owners incorporate BIS. To make it more accessible to small project owners, the government may provide tax rebates or tax exemption to manufacturers of BIS to reduce the cost of production and provide easy accessibility for small project owners. Non-governmental organisations could also provide financial support to both manufacturers and building owners in a bid to reduce the cost of production and procurement of BIS. The finding of this study suggests that BIS could minimise disaster risks. However, there is need to consider its application in small projects. There is no small project when safety is of high priority. It is reasonable to assume that building owners are only concerned with the most cost-effective way to build projects (small or large) and are not interested in what might happen in the future.

5.2. Motivators for the Uptake of Base Isolated Systems

5.2.1. Reduced Insurance Premium

As shown in Table 5, reduced insurance premium ranked first with a mean score of 4.19 out of 5.00. This indicates that most respondents were highly receptive to lower property insurance premiums for seismic isolated building. As reinforced by some of the participants, a seismic-isolated building would have a higher level of protection against earthquake damage. This is similar to the security and fire alarm application, which reduces house insurance premium costs. Reduced premiums could be applicable to building owners and tenants who would insure their contents while operating inside the building. As suggested by Charleson and Allaf [22] and Devine [19], reduced premiums could take on similar percentages as seen in Japan, which has a 30% reduction in insurance premiums for contents insurance.

5.2.2. Government Subsidies

From Table 5, the availability of government subsidies was ranked second with a mean rating of 3.85. This indicates that many of the respondents are of the opinion that government subsidies could encourage the adoption of BIS. Seismic isolators could be subsidised by the government in a variety of ways, including exemption from taxation if imported from overseas, exemption from Goods and Services Tax (GST) for seismic isolators manufactured in New Zealand, and grants made available for installing seismic isolators in heritage buildings. The total contribution of the government to the Christchurch rebuild is projected to be NZD 15.4 billion [88]. If a subsequent earthquake of similar magnitude strikes a different city, the government could be in financial strife. This suggests the need for Government to be proactive in protecting the populace and buildings in New Zealand's cities. Therefore, it would be beneficial for the government to ensure that buildings could withstand catastrophic damage and not require costly repairs/replacements by providing subsidies for new construction and retrofitting of existing buildings. This would not only encourage the adoption of BIS, but it would also help to reduce disaster risk.

5.2.3. Recognition

Recognition as proposed by participants during the interviews was ranked third with a mean score of 3.48 (see Table 5). The proposed earthquake safety recognition website or database, which is a register of seismic isolated buildings, generated mixed responses from the participants. This incentive would provide a social recognition for building owners who adopt seismic isolation to encourage others to do so. In addition, it could provide reassurance to the public about the safety of a building because would-be occupants can search for information about the building online. Importantly, the implementation of such a website for acknowledging contributions towards earthquake risk mitigation, particularly the adoption of seismic isolators and strengthening of earthquake-prone buildings, could initiate some form of pro-social mitigation behaviour. Goodwin et al. [89] explained that this behaviour includes actions taken by an individual or a group of individuals to support an action, which may include advocating for public acknowledgement of earthquake disaster mitigation efforts. It is possible advocates for public recognition believe that they or the society is vulnerable to earthquake risk. Therefore, implementing seismic actions to prevent disaster consequences, such as adopting seismic isolators and retrofitting vulnerable buildings, would benefit the public. People who exhibit pro-social mitigation behaviour relate more to the values that are ascribed to a particular attribute protecting life in a disaster event. Recognition of their actions may encourage the adoption of BIS.

5.2.4. Incentives

As shown in Table 5, monetary incentives were the least rank (Mean score = 2.79). The implication of this result is that monetary incentives are not appealing to the respondents. This may be because of their previous experience relating to documentation and requirements for the incentive. Likewise, it may be the inability of the incentive to meet pressing needs as revealed by one of the participants: " … *it will be difficult for councils to provide monetary incentives to everyone because there's no amount they give that will be sufficient*". This may be interpreted as an underlying view that the application and installation of seismic isolators is an "expensive" structural solution. This implies the need for councils to explore other options to encourage disaster risk mitigation, especially the adoption of BIS. As one of the respondents pointed out, seismic isolators are not a one-size-fits-all structural solution, as they may not be appropriate for all types of building in tandem with conditions of the site: "*Not all site conditions and structure types are necessarily suitable for seismic isolators. Seismic isolators are not a magic bullet. They are an excellent option in many situations but not all*". Consequently, it would be appropriate for councils to devise effective ways of encouraging the use of seismic isolators for appropriate buildings, such as hospitals, government buildings, and key infrastructure buildings (e.g., national telecommunications, museums, and art galleries). As reported in this study, monetary incentives may not encourage the adoption of seismic isolators; however, reduced insurance premiums, government subsidies, and recognition may increase the use of BIS.

6. Conclusions and Limitations of the Study

Base isolation systems have been identified as one of the engineering solutions to minimising earthquake disaster risk. It has recorded successful trials and adoption in some earthquake-prone countries. However, there is a low adoption rate of seismic isolators in New Zealand due to some barriers. To improve the rate of adoption, these barriers need to be identified and addressed. Therefore, this study sought to identify the barriers affecting the low uptake of base isolation systems and the strategies that would provide insights into increasing its uptake. This study followed a sequential mixed method design, where qualitative data were collected through interviews and analysed first, and the findings were fed into the quantitative data collection instrument. A total of thirteen barriers were identified from the interviews and fed into the questionnaire, which was administered to construction professionals in four cities (Auckland, Wellington, Christchurch, and Dunedin) in New Zealand. Of the thirteen barriers, eleven are critical as revealed in the results, with the greatest being attitudes to base isolation system, market availability, and awareness of base isolation systems. In addition, factor analysis of the eleven critical barriers revealed three underlying groups (human-related, safety and design-related, and cost-related barriers), with a total of eight critical barriers. The most significant of this group was the human-related factors, which suggests the need for increased awareness of base isolation systems among construction professionals through training and education. Four motivators including reduced insurance premiums, government subsidies, recognition, and monetary incentives were identified as potential opportunities to improve the uptake of base isolation systems in New Zealand. Data integration occurred during the research design, methodology, data collection and analysis, and findings discussion.

This study adds to the current domain of research about the costs and design of seismic isolators, particularly identifying an industry desire for several fundamental design standards for seismic isolators, as well as financial rewards that could be used to mitigate seismic isolator construction costs and motivate more property owners to invest in them. It demonstrated that there is room for improvement in base isolator design standards to encourage the use of BIS. If this is done, it can help designers identify when the suitable design circumstance is taking place. Subsequently, the use of seismic isolators in structural designs may become more common. Furthermore, this research showed that monetary incentives may not encourage the adoption of seismic isolator due to its inability to meet the perceived high cost of implementation.

The study's findings could help to increase the adoption of base isolation systems among construction professionals and stakeholders in New Zealand. It will provide valuable reference for policy makers in developing standards and regulations to boost the adoption and implementation of base isolation systems in both small and large construction projects. More so, it will assist industry practitioners to take appropriate measures in minimising the barriers to the adoption of base isolation system. The motivators identified in this study might aid organisations and individuals in advocating the use of base isolation systems, hence reducing disaster risks in the long run.

The limitations of this study are worthy of note, especially in interpreting and generalisation of the results. Though the sample size of 104 was adequate, as revealed by the KMO value, a larger sample size would have improved the value. Future research may include other professionals and stakeholders in the construction industry to collect a large sample. Also, the Cronbach's Alpha value of one of the underlying groups was not satisfactory. Items in the group may have been poorly worded or one of the factors does not belong there. However, this does not affect the internal consistency of the groups, but future studies may need to carefully word items or ensure that appropriate factors are grouped together. The findings of this study represent the opinion of construction professionals from four cities in New Zealand, and future study may include more cities for a wider coverage and generalisation of results. In conclusion, this paper confirmed the low adoption rate of base isolation systems in New Zealand by identifying the barriers. It also highlighted strategies to improve the uptake of base isolation. Therefore, the development of a framework for the adoption of BIS in New Zealand would be appropriate as a future study. The challenges associated with BIS implementation, particularly for seismic retrofitting of existing buildings, may be investigated, using case studies in New Zealand, as well as the cost estimate for the construction and implementation of BIS to residential buildings.

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