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Strategic case for national testing facilities for non-structural elements in NZ

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Executive summary

The purpose of this report is to assess the need for new commercial multi-functional testing facilities in New Zealand for seismic qualification of non-structural elements (NSEs). This assessment was based on consultation with industry professionals. This study follows the strategic white paper produced by the Building Innovation Partnership on issues related to NSEs in the New Zealand construction industry (Stanway et al. 2020). The white paper recommends the development of a high-performance testing facility to provide an investigative platform for commercial and research purposes. This recommendation was investigated in this study.

Twenty-four professionals related to the building sector in New Zealand industry, with different expertise, were consulted to assess the need for new testing facilities. The consulted professionals included structural engineers, fire engineers, mechanical engineers, electrical engineers, architects, technical advisors, product manufacturers, managing directors of major suppliers in the country, academics and building control officials.

The study found that there is not enough knowledge about the seismic performance of non-structural elements, and particularly how this performance relates to their primary function in the building. Therefore, this study could not ascertain what test facilities would be needed to quantify seismic performance. So, investment in commercial test facilities cannot be recommended at this time. However, there is a case for further investment in research capacity and capability, including testing facilities, to define relevant performance measures. Such facilities should include the ability to test interacting NSEs.

There was a range of views among the participants on the establishment of a commercial national testing facility as the first major step toward improvement of seismic design practices. The discussion around the need for such a test facility seemed premature as several participants cited non-structural testing not being an industry-wide requirement (due to lack of regulation). The participants identified the inconsistent procedures for seismic qualification of NSEs as more pressing problems. Based on this reasoning, the immediate need for such a facility was questioned, particularly by suppliers.

It has been found that, at times, building projects require test facilities and associated guidance, but this need seems to be limited to specific projects. However, the limited number of test facilities in New Zealand does cause significant increased risk and cost to these projects. Test facilities are available in New Zealand with varying capabilities and capacities. These are not always considered adequate by consulting engineers and clients for a small number of specific projects. This results in the need to send some components overseas for testing.

The major finding from this study is that there is a need for a national seismic qualification framework for NSEs. This is based on unanimous support from the participants. The framework should be a guidance document for the characterization, specification and quality assurance of NSEs. The findings also suggest that the development and implementation of the framework may create the impetus for a dedicated test facility if the existing test facilities are deemed inadequate. It is recommended that the proposal for a commercial national testing facility should be reconsidered once this framework has been developed and adopted within the industry. This framework would be the foundation of any future compliance pathways.

Purpose

Non-structural elements are components of, and systems within, a building facility that render the facility liveable and functional during different environmental conditions. The purpose of this report is to scope the need for a multi-functional national testing facility in New Zealand for seismic qualification of different non-structural elements (NSEs) based on consultation with industry professionals. The investigation has been broad and generic in nature: it was neither limited to a certain type of NSE, nor was it conducted in the context of a certain performance for building facilities.

Introduction

In New Zealand, there has been greater awareness of the importance of seismic design of NSEs in buildings because of the experience of 2010-2011 Canterbury earthquakes, the 2013 Seddon earthquake and the 2016 Kaikoura earthquake. With a few exceptions, most of the building stock achieved the primary aim of preventing human casualties in line with the New Zealand Building Code. Many of the inspected buildings had minor structural damage but could not be re-occupied or used to deliver their intended services due to damage to, and failure of, NSEs. Such damage led to considerable financial losses in the form of repair and business interruption costs.

The earthquake damage has highlighted the need to consider the adequacy of current design and construction practices to inquire if these are delivering buildings that meet the needs of our communities. In this regard, the Strategic Review White Paper produced by Stanway et al. (2020) identified eight key issues that confront the sector and contributed to the observed poor performance of NSEs in recent seismic events. The issues identified represent a system-wide change to deliver buildings that meet the needs and expectations of our communities regarding seismic performance. The identified issues are:

1. Risk
2. Procurement methodologies
3. Limitations in knowledge of code minimum performance requirements versus low-damage and resilient options
4. Lack of coordination between disciplines and sub-trades
5. Construction and installation behaviours
6. Lack of independent quality assurance
7. Gaps in regulation
8. Lack of knowledge, skills

Lack of knowledge

The eighth and last recommendation was to carry out research to fill the gaps in technical knowledge that are essential to improving the reliability of design provisions in the New Zealand standards for NSEs. A significant amount of academic research on the seismic performance of traditional designs, and the development of low-damage solutions for different elements, has been ongoing in New Zealand for more than a decade (Arifin et al. 2020; Baird 2014; Bhatta et al. 2022; Bhatta et al. 2020; Mulligan et al. 2020; Pourali et al. 2017; Rashid et al. 2022; Tasligedik et al. 2015; Yeow et al. 2016). Further, research work has been contributing towards development of better formulations of floor spectra, design provisions, injury and loss assessment tools (Haymes et al. 2020; Khakurel et al. 2019; Rashid et al. 2021; Yeow et al. 2016).

However, there is a serious lack of knowledge and understanding about selection, design and installation of NSEs based on a demand-capacity relationship. Demand here refers to the required function of an NSE in a facility at a defined shaking level and capacity represents the ability of an NSE to deliver that function at that shaking. This knowledge gap, in part, is due to the lack of appropriate tools to determine the suitability of NSEs. One such primary tool is the ability to test NSEs to determine their capacities at various performance targets. It was in this context that Stanway et al. (2020) recommended the development of at least one high performance testing facility for commercial purposes. Before a business case for the establishment of such a testing facility could be presented to relevant authorities, it was considered important to consult various industry experts on the need for a testing facility. Twenty-four professionals from New Zealand with different expertise were consulted for this purpose. The consulted professionals included structural engineers, fire engineers, mechanical engineers, electrical engineers, architects, technical advisors, product manufacturers, managing directors of major suppliers in the country, academics and building control officials.

Scope of non-structural elements in this report

This report deals with NSEs as a broad category of building elements (except structural elements) that are all essential to the ability of a facility to deliver its different services under different environmental conditions. No classification regarding the function of NSEs or importance level of buildings has been considered to keep the findings generic. This approach has been adopted as every NSE is expected to perform in a certain manner at a given shaking intensity regardless of the building importance level. The process of characterization and specification (rating) of seismic performance through testing could be applied to almost all NSEs. This process is referred to as seismic qualification in this report. Though a component can be qualified for seismic actions using means other than testing, herein the primary focus is on physical testing given the scope of this study. Further, the term *seismic performance* is not used only in the context of strength or detailing requirements for an NSE but is rather employed in a broad sense incorporating mechanical characteristics and function; for example, the performance considerations for a generator would include the strength of its anchors and its functionality post-earthquake.

To determine the need for a national testing facility, it is first important to identify the different qualification procedures adopted in the industry that employ different testing schemes. In this regard, a traditional classification system based on the way NSEs interact with the supporting structure is adopted here, i.e., acceleration and drift-sensitive NSEs (Taghavi and Miranda 2003). Such a classification system is needed to discuss the types of seismic testing that would be required in a test facility in addition to other testing requirements related to fire, acoustics, weather-tightness, thermal, etc. The classification does not restrict the applicability of the findings reported here to any specific functions or building importance levels. The acceleration and drift-sensitive NSEs are defined below along with some typical examples of the two categories given in Table 1.

1. Acceleration-sensitive NSEs: Building elements that are subject to the inertial forces resulting from the horizontal and vertical floor accelerations but are not affected by the inter-story drift of the floors of supporting structure.
2. Drift-sensitive NSEs: Building elements that are subject to the inertial forces resulting from the horizontal and vertical floor accelerations but are affected by the inter-story drift of the floors of supporting structure.

Distributed NSEs, such as ceilings and piping systems, are mostly acceleration-sensitive. However, some distributed NSEs have components that are also drift-sensitive, such as riser pipes in piping systems.

It is challenging at this point to classify NSEs according to their function or the importance level of the building. The range of NSEs in a facility depends on the function of the facility and function (and/or occupancy) determines the importance level of the building. The determination of the exact role of each element to the different performance objectives of a facility or the different NSEs required for a specific performance is a multi-disciplinary task and would require a comprehensive study of its own. The NSEs falling under the two categories in Table 1 can be associated with one or multiple functions that could be related to the target performance of buildings of different importance levels. Therefore, the findings reported in this report could be treated as generic and applicable to building infrastructure as a whole.

Table 1: Examples of acceleration and drift-sensitive NSEs (Taghavi and Miranda 2003)

Response Sensitivity	**Example NSEs**
Acceleration-Sensitive	Parapets
	Suspended ceilings
	Ducts
	Boilers

	Chillers
	Tanks
	Elevators (machine room)
	Light fixtures
	Electrical systems in horizontal pipes or cable trays (data, electrical, telephone, etc.)
Drift-Sensitive	Masonry walls
	Windows
	Interior doors
	Partitions
	Floor finishes (tile or wood)
	Plaster ceiling
	Electrical system with partitions (data, electrical, telephone, etc.)
	Doors
	Elevator cabin
Acceleration and Drift-Sensitive	Precast elements (e.g., claddings)
	Fire sprinklers (riser pipes)
	Cold and hot water pipes
	Gas pipes
	Waste water pipes
	Elevators (counterweight and guide rails)

The need for testing

NSEs are mostly proprietary products, i.e., these are manufactured (e.g., the functional design of a generator), proportioned (e.g., sizing of a brace element and its attachments) and detailed (e.g., the connections between a gypsum board and the tracks in a partition wall) by individual manufacturers. Unlike structural elements, these are not always custom-designed for a particular demand. For installation in a building facility, a NSE needs to be selected from a set of options available in the industry based on its capacity relative to the demand expected in the structure. Each component has a set of acceleration or drift capacities corresponding to different performance levels. Such capacities can be estimated through static or dynamic testing or engineering calculations depending on the nature of the component and the performance measure under consideration. The considerations for the capacity of a component are not limited to seismic actions but also include other actions, such as fire and acoustics in the case of partition walls, and wind and rain for glazing.

A review of the functional and structural design of common NSEs leads to the understanding that physical testing is the only option to determine certain capacities. For example, engineering calculations can be utilized to design the supports or restraints for a boiler but will not provide any information on its functional performance. Similarly, the determination of drift demand at which the weather-tightness of a glazing panel is compromised is a complicated process and can only be reliably estimated through structural testing. These representative examples, among numerous others, highlight the importance of testing to the determination of seismic performance of NSEs.

Existing labs & limitations

Structural testing labs are available across the country with varying capacities. Single-degree-of-freedom shake tables are available at the University of Canterbury (UC), University of Auckland (UoA), Auckland University of Technology (AUT) and BRANZ. Holmes Solutions has two tables: one for horizontal shaking along two axes and the second table for vertical shaking. Similarly, equipment and other necessities are available for static-cyclic testing of different building elements across the country. The facility at UC has been utilized to test a variety of NSEs including ceilings, partition walls, cladding, glazing (seismic with weather-tightness), contents and sprinkler piping systems for research purposes (Arifin et al. 2020; Baird 2014; Bhatta et al. 2022; Bhatta et al. 2020; Mulligan et al. 2020; Pourali et al. 2017; Rashid et al. 2022; Tasligedik et al. 2015; Yeow et al. 2016). Holmes Solutions has considerable experience in dynamic testing of equipment using AC156 motion (ICC-ES 2010) along with expertise in testing ceilings and partitions.

The testing experience at UC could be used to identify limitations of dynamic testing capability in the country as the shake tables available across the country are not vastly different in capabilities. In a recent experimental study at UC (Rashid et al. 2022), it was found that the shake table has limitations regarding achieving shaking intensities consistent with NZS 1170.5 when using the AC156 protocol (ICC-ES 2010). Similar limitations were faced in the use of recorded building floor motions, which hindered the assessment of performance at higher shaking intensities. A study is required to investigate if other shake tables across the country have the capacity to test equipment at different intensity levels. Another limitation encountered at UC has been the small size of the shake table, which makes it impractical to test ceiling and piping systems at an actual scale (Pourali et al. 2017; Rashid et al. 2022). This is a serious limitation as the seismic performance of these systems is very much dependent on a real representation of the mass of these systems. Though not reported by Holmes Solutions but given the similarity in size of their table to the table at UC, it can be inferred that similar limitations with regard to scale and mass will be encountered. Holmes Solutions has also been involved in testing fire performance of certain components after dynamic testing.

Regarding static-cyclic testing, it has been found that product developers use commercial labs, in-house testing facilities or erect test rigs on an ad-hoc basis. Since test facilities in NZ with capabilities for static-cyclic testing are better equipped, and are larger in number, the concerns expressed were not very serious. Multiple labs across the country are involved in static-cyclic testing of different drift-sensitive NSEs, such as Holmes Solutions, BRANZ, APL, Altus, WE, Oculus's lab, FTNZ, Facadelab amongst others. It is important to realize that testing drift-sensitive components can require unique setups; for instance, the setup for testing a partition wall under seismic demands could be entirely different from the setup required for testing a glazing. Recent static-cyclic testing of NSEs at UC required considerable financial and time investments in the development of unique setups for partitions, cladding and glazing for research purposes. However, once such setups are utilized, the lack of storage capacity requires them to be dismantled and discarded. Though the problem of storage is not unique to test setups for NSEs but is mentioned here to highlight that repeated construction of rigs requires repeated time and financial investments. The problem of storage at university labs could be one major obstacle to their adoption for commercial testing.

One aspect that was stressed by interviewees was the need for assessing the performance of various NSEs together in one setup as an interacting system. This is because many NSEs are essentially part of a network that would deliver its function only if each element is working properly. The interaction between different elements is also important to understand how to avoid damage from interaction, which has been colossal in some events. Such investigations would require the inclusion of both acceleration and drift-sensitive elements, and the test setup should have the capacity to exert target acceleration and drift demands in one test. Such capacities are completely non-existent across New Zealand.

Regarding the availability of labs, the structural labs at universities are continuously occupied with post-graduate research projects, and there seems to be little to no room for commercial testing of NSEs. No serious issues were reported by the personnel of some commercial labs with regard to time constraints for commercial testing. However, the scenario could become different and demanding if a regulation is put in place which makes testing a necessity for NSEs.

Current state of practice in seismic qualification & testing

This section presents findings on practices related to seismic qualification of different NSEs in New Zealand.

Acceleration-sensitive components

There is a growing trend towards the seismic qualification of equipment, particularly for critical facilities such as hospitals. Most acceleration-sensitive equipment is procured from abroad, and depending on the source country, these components may or may not be pre-tested for seismic performance. In cases where products are not pre-tested, both local and foreign testing facilities are utilized for testing. In local tests, the AC156 test motion has been used for seismic qualification. However, there is considerable ambiguity as to how the test results are related to the relevant NZ standards both with regard to loading and performance requirements. Discussions also revealed that seismic qualification for some components is not considered a concern at all. This is primarily because of the lack of clear guidance in NZ standards on the role of different components with regard to life-safety and functionality and the absence of relevant regulation.

If evidence from dynamic testing regarding seismic performance is not available, engineering calculations are utilized to determine the seismic capacity of equipment, which is usually reported in terms of peak floor acceleration. Such reports do not clarify what performance the capacity represents. It is obvious that such calculations can only provide information on the strength of seismic restraints (e.g., anchors) and cannot provide essential information on the functionality of equipment. It has also been identified that different equipment in the same building facility could be qualified using different sources of information; for example, one piece of equipment can be chosen based on its reported capacity determined using shake table testing, while another piece of equipment is installed based on its capacity determined from another dynamic environment, e.g., vibrations from a ship or a truck.

All the interviewees were in favour of testing equipment before their installation in buildings. However, majority of the interviewees did not think a dedicated facility is needed due to little or no local production and because components could be pre-tested by the manufacturers abroad. Further, the commercial sustainability of such a facility was doubted by interviewees with a commercial background (e.g., local major suppliers) due to limited local production. It was informed that the cost of testing could also be a major factor in the commercial viability of such a facility.

Acceleration-sensitive distributed systems

Brace assemblies from both local and foreign brands are used for distributed NSEs. These assemblies are mostly pre-tested under static cyclic loading either according to protocols published by Factory Mutual Insurance Company (FM Global) or by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 2017; FM 2013). It was stated during the interviews that in some instances manufacturers are not keen to provide information relevant to the capacity of their products, in which case testing becomes a necessity. However, the lack of guidance as to how and where to test, and funds for such testing are impediments in such cases. It was found that a local brand of brace assemblies utilized both local and foreign test facility facilities for determination of seismic performance. Considerable time and financial restraints were reported to be associated with testing outside New Zealand. Further, the absence of a regulatory framework in New Zealand to require local manufacturers to follow a seismic qualification protocol, encourages the sale of products that are not proven to be qualified for use. Concerns were raised about the lack of guidance with regard to the analysis and design of the system itself, such as the determination of displacement demand on a duct and its comparison with some acceptance criteria consistent with the performance target of the ducting system. However, such concerns are more related to engineering approaches in design offices than testing, though the development of acceptance criteria would require experimental research and test facilities.

Drift-sensitive systems

It was realised during the interviews that static cyclic tests on drift-sensitive NSEs is not as challenging to product developers or engineers as shake table testing. This is possibly because of the technical ease with which product developers manage to erect ad-hoc test setups, availability of labs with the required equipment, and use of in-house testing facilities. Interaction with research teams at UC is one source of technical information about the seismic performance of detailing practices for drift-sensitive elements. Some professionals expressed concern about the possible use of inconsistent testing protocols and assessment criteria in different circles that leads to uncertainty about the reliability of products. Emphasis was placed on the need for a holistic approach to assessment of NSEs and the provision of such information by the manufacturers and product developers, for example, specification of drift and fire performance of a partition wall. Further, if a component is uniquely configured or designed for a certain building facility, the lack of information as to how and where to test is a major obstacle to evaluate the performance in such cases. Though existing test facilities are capable to meet typical challenges, such as the testing of planar components, the participants deemed these facilities inadequate with regard to scale, configuration and interaction of some components.

The response from participants regarding seismic qualification of drift-sensitive NSEs was relatively clear and confident compared to the same with regard to acceleration-sensitive NSEs. This could be due to the availability of design standards, guidance documents and larger testing experience. With the recent increase in focus on the performance of NSEs, the participants believed the development of a testing facility will help meet emerging challenges (scale, configuration & interaction) with regard to seismic qualification due to the recent increase in focus on performance of NSEs.

Interacting non-structural elements

As mentioned earlier, the industry identifies considerable need for seismic testing of NSEs that interact with each other. However, from engineers associated with electrical subsystems to those dealing with architectural building elements, no information could be found on how seismic qualification is investigated and reported for interacting NSEs.

Summary of findings from interviews

The findings are based on an amalgamation of the views of participants. There was generally strong agreement on a number of aspects related to the industry-wide problem of NSEs.

The need for a commercial testing facility

There was a range of opinions among the participants on the establishment of a national testing facility as the first major step toward improvement of seismic design practices. A few participants were in strong favour of a test facility, and these mostly represented engineers with experience in overall building design, design standards or product development. Majority of the responses were non-committal, and no participant opposed the development of a test facility as such. The discussion around the need for a test facility seemed premature as several participants cited non-structural testing not being an industry-wide requirement (due to lack of regulation) and the inconsistent procedures for seismic qualification of NSEs as more pressing problems. Based on this reasoning, the commercial viability of such a facility was questioned, particularly by suppliers. It has been found that at times building projects require test facilities and associated guidance, but this need seems to be limited to specific projects. However, the limited number of test facilities in New Zealand does cause significant increased risk and cost to these projects. Test facilities are available in New Zealand with varying capabilities and capacities but are not always adequate resulting in the need to send components overseas for testing.

There was due acknowledgement of the need for an investigative platform and the risks associated with non-structural damage in future earthquakes. However, a business case for investment in a commercial national testing facility does not seem viable. The findings from this study suggest that the development and implementation of a qualification framework may create the impetus for a dedicated test facility if the existing test facilities are deemed inadequate. It is recommended that the proposal for a commercial national testing facility should be reconsidered once the framework has been developed and the industry begins to adopt it.

The need for a framework

There has been unanimous agreement from the participants on the need for a national framework for seismic qualification of NSEs. This framework could become the foundation for compliance pathways including testing.

Currently, there is significant ambiguity and lack of guidance in this area. Until a framework is conceived and is put into practice, it seems unlikely that a dedicated test facility for NSEs would improve the state-of-practice regarding seismic qualification. The framework is tentatively defined here as a guidance document for characterization, specification and quality assurance of NSEs.

Characterization

1. Description and clarification of performance requirements for individual NSEs. What constitutes failure (mechanical and functional), and the possible consequences of failure, should be discussed to clarify the link between component failure and the target facility performance. Such descriptions of performance are needed regardless of building importance level for NSEs that are common to all building facilities. This is clearly a multi-disciplinary task and would require collaboration with other engineering and/or non-engineering groups (fire, electrical, HVAC engineers etc.).
2. Methodologies for quantifying the acceleration and/or drift capacities related to different performance levels for different NSEs. For example, the requirement of dynamic testing and associated protocols for determining the acceleration at which a generator remains functional; similarly, the requirement of static-cyclic testing and associated protocols for evaluating the drift capacity at which a glazing unit cracks. The test protocols, such as the floor spectrum for shake table testing or the differential air pressure for water penetration test must be consistent with the relevant NZ standards.
3. Engineering approach for distributed NSEs: piping systems, cable trays and alike cannot be tested for practical reasons, and instead should be designed for the target demand to fulfil design criteria using an engineering approach. The design criteria must be consistent with the performance target of the system specified in the relevant NZ standard. For instance, NZS 4219 requires that liquid fuel and water piping should be functional at the design loading specified. However, examination of the design standards reveals that, with the exception of design forces and ductility factors, there are no suitable damage-related criteria (e.g., deformation limits) specified, nor rational design requirements.

Specification

1. Once designed and tested, NSEs from different manufacturers can be classified into different categories based on their acceleration and/or drift capacities as illustrated by Table 2 for acceleration-sensitive NSEs (Rashid et al. 2021; Sullivan et al. 2020). Such a specification scheme would require that the capacities of similar components from different manufacturers be determined through a specific methodology (e.g., shake table testing) for fixed design criteria (e.g., what constitutes functionality). Guidance will be required on expressing equivalency between existing data and the requirements established in the framework.

Table 2: Tentative PFA values and clearance requirements proposed for the seismic classification of acceleration-sensitive NSEs in NZ (modified from Sullivan et al. (2020))

NSE Class	Peak Floor Acceleration Capacity (g)		Installation Clearance Requirements (mm)	
	SLS (No damage)	ULS (Life safety)	Short Period (T<0.1s)	Medium Period (T=0.1s)
A1	0.1	0.25	5	50
A2	0.25	0.60	10	100
A3	0.50	1.0	15	150
A4	0.75	1.50	20	200
A5	1.0	2.0	30	300

Some aspects of the required framework have been discussed in detail by Sullivan et al. (2020) and Rashid et al. (2021), including a complete design procedure for distributed acceleration-sensitive NSEs in Rashid et al. (2021). The proposed classification system in Table 2 is considered to have practical advantages. The approach will help improve the communication of seismic capacity requirements for NSEs. The classification system will clearly identify the NSEs required, and with time, it is expected that the costs and time required to achieve different capacity classes will be well understood. The installation of NSEs in buildings will thus be based on the capacity of a chosen element corresponding to the required performance.

Quality Assurance

Quality assurance process and documentation will need to be developed to support industry-wide compliance to the framework.

Requirements for adoption

Once the framework is drafted and meets industry critique, there should be an assessment of the available tools and infrastructure across the country that could enable designers, manufacturers, suppliers and product developers to conform to the framework for various NSEs. The findings in this report related to the available test facilities could be used as an initial assessment of the current state-of-art. The future development of a new facility or the enhancement of existing facilities should be considered as a requirement for the adoption of the framework and not a separate task.

Conclusions & recommendations

The following conclusions and recommendations have been drawn from the findings of this report.

1. There is a need to invest in research to support the development of a national seismic qualification framework for non-structural elements. The framework should be developed considering current building regulations and ongoing developments regarding whole-of-building performance. The framework will enable demonstration of compliance with the Building Code. Its development would require financial support for experimental work and the requisite capabilities.

2 The need for new commercial national NSE testing facilities cannot be fully assessed until industry and the building regulator agree on a national framework for the seismic qualification of NSEs. The need for new national testing facilities should be reconsidered once the framework has been developed and adopted by industry.

3 The cost of developing and operating new NSE testing facilities should be considered against the annual national investment in the building sector and the risks associated with non-structural damage in future earthquakes.

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