Proceedings of International Structural Engineering and Construction, 9(2), 2022
Achieving Technical Excellence with Data Analytics
in Materials, Structural Engineering and Construction
Edited by Vimonsatit, S., Askarinejad, H., Singh, A., and Yazdani, S.
Copyright © 2022 ISEC Press
ISSN: 2644-108X
www.doi.org/10.14455/ISEC.2022.9(2).AAE-07

BASE ISOLATION: MIND THE GAP

RONWYN A. COULSON, ERIC SCHEEPBOUWER, and JACOBUS D. VAN DER WALT

Dept of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand

Base Isolation is used in seismically active countries around the world to successfully minimize damage caused by large earthquakes, safeguarding both people and property. Yet, while the technology is understood by earthquake engineers, base-isolated buildings are designed by multi-disciplinary teams, and owned, operated, and maintained by stakeholders who are not typically trained in earthquake engineering. This research examines the use of BI in buildings from a whole of life perspective, specifically investigating the consequences of having a differing design life between the building and base isolator components. The research studies the historic performance of base isolated buildings, the rules that govern base isolation design in New Zealand, and the risks arising in building performance for the whole life of the building. Through an integrative literature review of academic research, engineering guidance notes, building legislation and base isolator manufacturer literature, the research highlighted key risks, the most concerning being a lack of rigorous and independent assessment of base isolator durability, conditions under which base isolators need to be replaced, limited research into the multi-disciplinary design implications of base isolator inspection and replacement, and a gap in literature around the asset management of base isolated buildings generally.

Keywords: Earthquake design, Seismic design, Building resilience, Base isolator durability, Base isolation asset management, Maintenance.

1 INTRODUCTION

Base isolation (BI) is a resilient, low damage, solution and is now widely adopted in seismically active countries around the world to successfully dissipate the energy caused by large earthquakes, safeguarding both people and property. Base Isolation is essentially a mechanism for separating the foundations from the superstructure, allowing for movement and energy dissipation at the isolation level, thereby protecting the superstructure above (Kelly 1998). The primary drivers for base isolation are safety of occupants and protection of property "*to provide life safety during the earthquake and a high seismic resilience and business continuity following the earthquake*"(Carr and Puthanpurayil 2021).

Base isolators, have a dual function (Nakazawa *et al.* 1991), which is not often recognised:

1. To isolate the superstructure from the foundations and ground motions.
2. To function as supportive structural materials for the building superstructure.

If base isolators do not remain functional in both respects for the design life of the building, the structural performance of the building will be compromised. There is currently a differential between the design life of the building (typically 50 years), and the proven durability of base isolators (typically tested to 30 years). While one could argue that there are numerous building

CC BY NC ND

components that may only have a 5,10 or 20 year design life, the building structure is required, under New Zealand law, to meet a 50 year design life. Beyond durability, there are other conditions under which base isolators may need to be replaced, such as fire damage and large earthquake events. The design of the building must therefore accommodate the replacement of base isolators within the design life of the building, whatever the cause, and this has implications for multi-diciplinary design, construction methodology and asset management.

2 RESEARCH AIMS AND OBJECTIVES

The research aim is to examine the use of BI in buildings from a whole of life perspective, specifically investigating the consequences of having a differing design life between the building and base isolator components. The objectives of this paper are to:

1. Study the literature around historic performance of base isolated buildings from a whole building life perspective.
2. Investigate the rules that govern the use of base isolators in New Zealand.
3. Identify the risks that result from differing design lives.

3 RESEARCH METHODOLOGY

An integrative literature review, as defined by Snyder (2019), was selected "*with the aim to assess, critique and synthesize the literature*" on base isolation "*in a way that enables new theoretical frameworks and perspectives to emerge*.", allowing for a broader approach to data selection, combining insights from other disciplines. The literature review follows the guidelines for writing an integrative literature review set out by Torraco (2005).

3.1 Academic Literature Review

A search was conducted in the first instance using respected academic databases such as Scopus and Science Direct for academic literature about base isolation, looking specifically for research conducted into base isolation beyond the field of structural engineering design, and focusing on whole of life base isolated building performance. Further searches were conducted using multi-search and Google Scholar and then cross-checking references with Scopus for academic merit. Both recent and older literature were included in the search to ensure that earlier valuable work was not excluded. A search exercise of peer-reviewed journal articles demonstrates the resounding prominence of structural and/or earthquake engineering design articles on base isolation, and minimal research or total gaps in base isolation research regarding whole of life perspective – durability, asset management or maintenance, or multi-disciplinary design implications of base isolation. The design of modern rubber/neoprene and steel base isolators goes back to the 1970's (Buckle and Mayes 1990, Kelly 1998, Robinson 2000), and yet in almost 50 years, there has been minimal research on whole building life aspects or multi-disciplinary design implications of base isolation.

3.2 Design Guidelines

A search was conducted into literature published by the New Zealand Central government, Local government, and Crown Entities, including earthquake engineering guidance notes by the NZ Society of Earthquake Engineering (NZSEE). These searches returned valuable information on guidance for the design of base isolated buildings, asset management and durability advice, but notably in draft form only at this stage.

cc BY NC ND

© 2022 ISEC Press

3.3 Legislation Review

A thorough investigation of legislative requirements (New Zealand Building Act 2004 2021) was also carried out to assess current legislation covering base isolated buildings, specifically the building codes B1 Structure, and B2 Durability.

3.4 Manufacturer Data Sheets

The manufacturer technical specifications and warranty conditions from various international base isolator manufacturers were reviewed with the purpose of gathering information on both design implications (specifically as it relates to special requirements) and maintenance or warranty implications.

3.5 Final Literature Database

The database of academic articles on base isolation was shortlisted to a sample of 60 articles with information that was relevant to the research. The academic literature, together with the design guidelines, New Zealand Building Code and manufacturer data sheets formed the final research database for the analyses.

4 THE HISTORIC PERFORMANCE OF BASE ISOLATED BUILDINGS FROM A WHOLE BUILDING LIFE PERSPECTIVE

As many base isolated buildings were built in the last 20-30 years, there are limited examples in literature of design life assessment. The lack of literature does not prove that there is a problem, but it does indicate that durability is not yet proven.

4.1 Traditional Rubber Bearings

The first base isolated building in the world was the Pestalozzi School Building in Skopje, Macedonia, was built in 1965. Obviously the much larger traditional bearings, lacking the support of steel plates, were subjected over time to a large amount of deformation, and a greater surface area for oxidation, but this was to be expected. The reason given for the bearings being removed after 40 years was that they were showing signs of "*permanently propagating cracks due to ozone and fatigue"*(Gjorgjiev and Garevski 2012). Because of the cracks, the bearings were expected to disintegrate at displacement in another earthquake event.

4.2 Rubber and Steel Bearings

The Takenaka Corporation Building outside Tokyo was built as a base isolated structure in 1987. One bearing was replaced in 1996, after 10 years, and 2 further bearings were replaced in 2008, after 22 years. The bearings were tested and found to match the expected degradation rate in terms of hardness, tensile strenth, shear and adhesion of the rubber to the steel plates. The authors acknowledged that 22 years only represents half the expected lifetime of isolation devices and that a periodic study would be conducted in the future.

4.3 Neoprene and Steel Bearings

Neoprene isolators are not used extensively in buildings in New Zealand. However, they are used in bridges and nuclear plants around the world. Some of the earlier nuclear plants, built in the mid-eighties, have surpassed the 30-year durability test results now. Original, unused neoprene steel bearings from a 1981 experimental program by Kelly were tested after 30 years, after having been

© 2022 ISEC Press

stored unloaded at room temperature for that period (Van Engelen and Kelly 2015). The bearings were tested against the original accelerated aging tests, and the results differed from the original results. An increase in horizontal stiffness and decrease in damping was recorded, exceeding the original acceleration results, although it was postulated that this may be owing to the unfilled core. The vertical compressive force was also less than the original 30 year acerated aging tests predicted. The article terminates with the following recommendation: *"It is critical to determine if the performance of a base isolated structure with aged neoprene elastomeric isolators is still within satisfactory limits"*.

4.4 Discussion

Concerns about durability have been identified by several researchers in recent years (Pan *et al.* 2005, Hamaguchi *et al.* 2009, Van Engelen and Kelly 2015, Mazza 2019). Various researchers have also addressed the subject of changes to mechanical properties of BI impacting performance (Gheryani *et al.* 2015), and tests have shown that base isolators do not perform as designed for 2 months after an earthquake owing to cyclic straining history on the rubber, and draws attention to the implications for pre-earthquake and aftershock events (Siringoringo and Fujino 2015). There is generally a lack of rigorous and independent research around the subject of base isolator durability, inspection, and replacement.

5 THE RULES THAT GOVERN THE USE OF BASE ISOLATORS

Under the New Zealand Building Act 2004 (2021), the structural design of a base isolated building is governed by two building codes relevant to this study – Clause B1 Structure, and Clause B2 Durability.

5.1 Clause B1 Structure

Clause B1 Structure (MBIE 2021) addresses the structural design of buildings to safeguard against structural failure, loss of amenity caused by structural behaviour and the protection of other property from physical damage. Clause B1.2 states that "*buildings, building elements and sitework shall withstand the combination of loads that they are likely to experience during construction or alteration and throughout their lives"*. Clause B1.3.4 states that "*Due allowance shall be made for (a)the consequence of failure, (b) the intended use of the building, (d) variation in the properties of materials…"*. Clause 17 of the Building Act states that *"All work must comply with the building code"*. Further to this, Clause 22 (2) requires that *"A person who complies with an acceptable solution or a verification method must, for the purposes of this Act, be treated as having complied with the provisions of the building code to which that acceptable solution or verification method relates"*.

5.2 Clause B2 Structure

Clause B2.2 (MBIE 2019) requires that *"Building materials, components and construction methods shall be sufficiently durable to ensure that the building, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the building."*. Clause B2.3.1 states that "*Building elements must, with only normal maintenance, continue to satisfy the performance requirements of this code for the lesser of the specified intended life of the building, if stated, or: (a) The life of the building being not less than 50 years, if: (i) Those building elements…provide structural stability to the building…"*.

© 2022 ISEC Press

5.3 Design Guidelines

According to the NZSEE Guidelines for the Design of Seismic Isolation Systems for Buildings (NZSEE 2019), "*Isolators and their attachments should have adequate durability to meet the relevant performance requirements of Building Code Clause B2 Durability*".

5.4 Discussion

For base-isolated buildings to meet the requirements of clause *B1 Structure*, and *B2 Durability*, buildings *must* comply with the building code, and therefore base isolators must be specified, tested, and procured to ensure that buildings will "*withstand the combination of loads…throughout their lives",* for a duration of 50 years. The NZ Building Act 2004 (2021) does not currently require evidence of compliance with either B1 Structure or B2 Durability with respect to base isolators. Further to this, there is currently no legislation around either the regular inspection or replacement of base isolators. Base isolators require annual inspections to ensure that there is no degradation of the rubber or steel through oxidation, as well as other issues such as displacement after an earthquake event. The NZSEE guidelines recommend that inspection and maintenance of base isolators is added to the compliance schedule for Building Warrant of Fitness (BWoF) (NZSEE 2019), and this recommendation is supported by the research.

6 THE RISKS THAT ARISE FROM DIFFERING DESIGN LIVES

6.1 Building Failure in an Earthquake Event Resulting from a BI Durability Shortfall

The dual function of the base isolators, namely isolation and support, may both be compromised if the durability of the base isolation system does not meet the design life of the building, posing a risk to life and property.

6.2 Building Failure in an Earthquake Event, or Reduced Building Life, resulting from a Lack of Timely Base Isolator Replacement as Required

The lack of spatial provision for base isolator replacement gives rise to a risk of reduced building life if the base isolators cannot be replaced, or risk to life and loss of property in an earthquake if the building continues to be used after the base isolators are no longer functional.

6.3 Building Failure in an Earthquake and/or Voided Base Isolator Warranty or Insurance Resulting from Lack of BI Inspections

If the BI's are not inspected (typically annually or bi-annually), both the base isolator warranty and building insurance may be voided, base isolators not being replaced when required, ultimately leading to building failure in an earthquake.

7 CONCLUSION

This research examines the use of BI in buildings from a whole of life perspective, specifically investigating the consequences of having a differing design life between the building and base isolator components. The results show that there is uncertainty around the proven durability of base isolators and the need for regular inspection and potentially replacement of base isolators within the design life of the building, whether through degradation, fire, or earthquakes. Failure to inspect and replace the base isolators, when required, presents a risk of structural failure in an earthquake, presenting a threat to life and property, and leaving building owners exposed. More

© 2022 ISEC Press

research is needed to establish a more robust practice in base isolation design from a whole building life perspective.

References

Buckle, I. G., and Mayes, R. L., *Seismic Isolation: History, Application, and Performance—A World View*, Earthquake Spectra, 6(2), 161-201, 1990.

Carr, A. J., and Puthanpurayil, A. M., *Base Isolation: the Good, the Bad and the Ugly*, NZSEE 2021 Annual Conference, New Zealand, 2021.

Gheryani, M. H., Razak, H. A., and Jameel, M., *Dynamic Response Changes of Seismic Isolated Building due to Material Degradation of HDRB*, Arabian Journal for Science and Engineering, 40(12), 3429-3442, 2015.

Gjorgjiev, I., and Garevski, M., *Replacement of the Old Rubber Bearings of the First Base Isolated Building in the World*, 15th World Conference on Earthquake Engineering, Lisbon, Portugal, September 24-28, 2012.

Hamaguchi, H., Aizawa, S., Samejima, Y., Kikuchi, T., Suzuki, S., and Yoshizawa, T., *A Study of Aging Effect on a Rubber Bearing after About Twenty Years in Use*, AIJ Journal of Technology and Design, 15(30), 393-398, 2009.

Kelly, J., *Seismic Isolation of Civil Buildings in the USA*, Progress in Structural Engineering and Materials, 1(3), 279-285, 1998.

Mazza, F., *Effects of the Long-Term Behaviour of Isolation Devices on the Seismic Response of Base-Isolated Buildings*, Structural Control and Health Monitoring, 26(4), e2331, 2019.

Ministry of Business, Innovation and Employment (MBIE), *New Zealand Building Code Clause B2 Durability*, 2nd Edition, Amendment 12, Wellington: New Zealand Government, 2019.

Ministry of Business, Innovation and Employment (MBIE), *New Zealand Building Code Clause B1 Structure*, 1st Edition, Amendment 20, Wellington: New Zealand Government, 2021.

Nakazawa, M., Nagano, T., Kato, A., Kobatake, M., and Ohta, K., *Study on Seismic Base Isolation for LWR Plants (Durability Tests of Laminated Rubber Bearings)*, 1991.

New Zealand Building Act 2004 No. 72 Version 15 November 2021 (2021).

New Zealand Society for Earthquake Engineering (NZSEE), *Guideline for the Design of Seismic Isolation Systems for Buildings*, 2019.

Pan, P., Zamfirescu, D., Nakashima, M., Nakayasu, N., and Kashiwa, H., *Base-Isolation Design Practice in Japan: Introduction to the Post-Kobe Approach*, Journal of Earthquake Engineering, 9(1), 147-171, 2005.

Robinson, W., *Seismic Isolation of Civil Buildings in New Zealand*, Progress in Structural Engineering and Materials, 2(3), 328-334, 2000.

Siringoringo, D. M., and Fujino, Y., *Long-Term Seismic Monitoring of Base-Isolated Building with Emphasis on Serviceability Assessment*, Earthquake Engineering & Structural Dynamics, 44(4), 637-655, 2014.

Snyder, H., *Literature Review as a Research Methodology: An Overview and Guidelines*, Journal of Business Research, 104, 333-339, 2019.

Torraco, R. J., *Writing Integrative Literature Reviews: Guidelines and Examples*, Human Resource Development Review, 4(3), 356-367, 2005.

Van Engelen, N. C., and Kelly, J. M., *Retest of Neoprene Seismic Isolation Bearings after 30 Years*, Structural Control and Health Monitoring, 22(1), 139-151, 2015.

© 2022 ISEC Press