

Recent developments in New Zealand in seismic isolation, energy dissipation and vibration control of structures (2017)

D. Whittaker

Beca Ltd, Christchurch, New Zealand.



2017 NZSEE
Conference

ABSTRACT: Recent activity in the implementation of seismic isolation, energy dissipation and vibration control of structures in New Zealand is summarised. Following the severely damaging Canterbury earthquake sequence of 2010 and 2011, owners and structural engineers are now more commonly applying earthquake protection technologies such as seismic isolation and energy dissipation to provide better damage control and repairability of new buildings. Lead-rubber isolators and concave slider (pendulum) isolators, are the most common isolation technologies being implemented. A number of building projects have incorporated supplemental damping such as viscous dampers and buckling restrained braces. The paper summarises recent projects in New Zealand that have incorporated seismic isolation and energy dissipation earthquake protection systems. The NZSEE-led New Zealand seismic isolation design guideline has now been drafted and will soon be available for practitioners to use. The guideline draws on content from US and European codes of practice and makes recommendations for how engineers should design isolated buildings to meet the performance requirements of the New Zealand Building Code and associated structural design standards. The government agency MBIE is leading the development of an industry guideline for low-damage design of building structures.

1 INTRODUCTION

This paper summarises recent progress and developments in the application of seismic isolation, energy dissipation and vibration control for seismic protection of structures in New Zealand, as at 2017. It follows previous progress reports by the author to ASSISI conferences since 2007, primarily focussed on seismic isolation. Although New Zealand engineers were instrumental in inventing seismic isolation technology, implementation in New Zealand has been predominantly only for significant public buildings and other special buildings or bridges. Following the severe earthquakes that occurred in Christchurch in 2010 and 2011 there has been a significant increase in the application of isolation and other energy dissipation technologies for earthquake protection of new and existing buildings across New Zealand.

Following recent large earthquakes that have affected New Zealand and caused loss of life, significant property damage and economic losses, owners and engineers are now seeking effective means to reduce earthquake damage to buildings, and where damage does occur, to make it more easily repaired. These objectives are leading to greater attention to damage control in the design approach and application of isolation, supplemental damping and other protective technologies.

2 M7.8 KAIKOURA EARTHQUAKE 14 NOVEMBER 2016

The M7.8 earthquake which occurred on 14 November 2016 caused strong and prolonged ground shaking across a substantial area of the northern part of the South Island. Maps showing the Modified Mercalli Intensity (MMI) isoseismals and the inferred fault rupture plane obtained from USGS are shown in Figure 1.

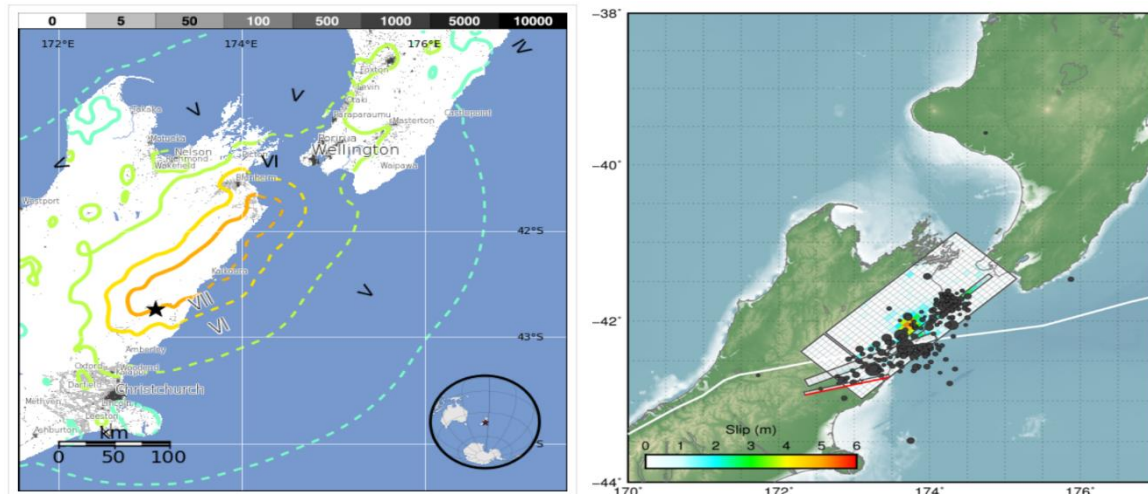


Figure 1. M7.8 Kaikoura Earthquake MMI isoseismals and fault rupture plane estimates (from USGS)

The earthquake caused extensive land-sliding and disruption to transportation infrastructure along the Kaikoura Coast. The main coastal highway and railway line were severely disrupted and are presently unusable, and it will likely take until the end of 2017 to restore service to this infrastructure.

Significant damage was caused to a number of buildings in the Wellington area, particularly on reclaimed land around the Wellington City waterfront. A number of buildings have been vacated and several have been demolished as a result of severe damage. Buildings in Wellington with seismic isolation or other protective systems appear to have performed well with little damage reported.

The earthquake also caused extensive damage to wine silos in the Marlborough region.

3 RECENT NEW ZEALAND PROJECTS WITH SEISMIC ISOLATION, ENERGY DISSIPATION AND SUPPLEMENTAL DAMPING

As at 2017 there are almost 100 isolated structures in New Zealand. Figure 2 shows the approximate growth in numbers of isolated structures over time including the types of structures and isolation types. Most isolated structures are bridges and there is a steady increase in the number of isolated structures since 2010.

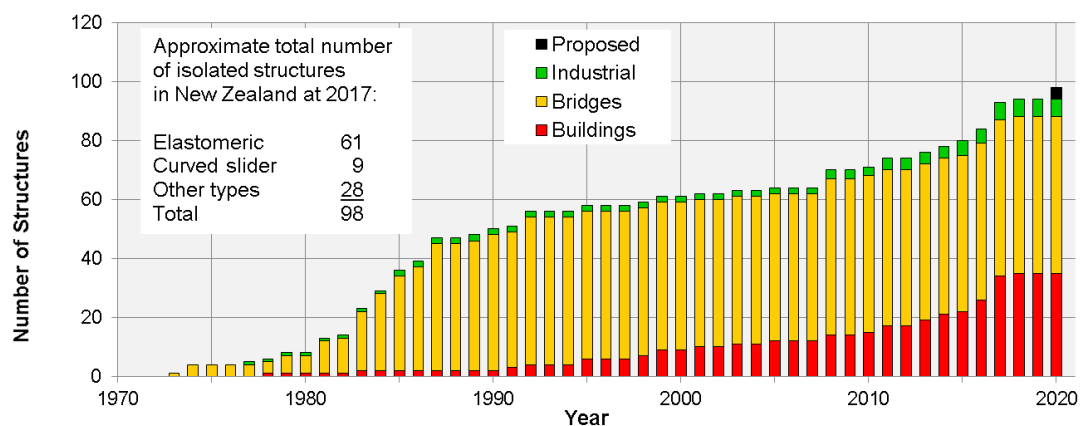


Figure 2. Growth in numbers of structures with seismic isolation in New Zealand

Table 1 summarises some recent projects New Zealand incorporating seismic isolation. Table 2 gives summaries of other building projects including energy dissipative technologies. Table 3 gives details of a recent bridge project using energy dissipation devices and Table 4 gives details of the use dissipative devices to anchor wine silos.

Table 1. Examples of recent seismic isolation projects in New Zealand

<p>Project Name: ANZ Office, Christchurch.</p> <p>Project Description: Commercial office building, 4 storeys + basement. Steel moment frame.</p> <p>Engineer: Beca.</p> <p>Isolation devices: Double concave slider (Mageba).</p> <p>Project Status: Completed 2017.</p>	
<p>Project Name: 133 Molesworth St retrofit, Wellington. (ex William Clayton Building).</p> <p>Project Description: Increase of floor area and seismic rating. 50% existing isolators replaced.</p> <p>Engineer: Beca.</p> <p>Isolation devices: Lead rubber (Robinson Seismic).</p> <p>Project Status: Completed 2016.</p>	
<p>Project Name: National Biocontainment Lab, Upper Hutt.</p> <p>Project Description: high-containment laboratory.</p> <p>Engineer: Dunning Thornton Consultants.</p> <p>Isolation devices: Lead rubber and flat slider. (Robinson Seismic)</p> <p>Project Status: Under construction.</p>	
<p>Project Name: PwC Centre Site 10, Wellington.</p> <p>Project Description: 5 Storey Office building. Combination of steel braced frames/trusses and concrete moment frames.</p> <p>Engineer: Dunning Thornton Consultants.</p> <p>Isolation devices: Lead rubber and sliders (DIS)</p> <p>Project Status: Under construction.</p>	
<p>Project Name: 20 Customhouse Quay, Wellington.</p> <p>Project Description: New 14 Storey Office Building. Perimeter steel/concrete composite diagrid structure.</p> <p>Engineer: Dunning Thornton Consultants.</p> <p>Isolation devices: Lead rubber (Robinson Seismic).</p> <p>Project Status: Under Construction.</p>	
<p>Project Name: Tui Brewery Tower, Eketahuna.</p> <p>Project Description: Retrofit of existing infilled concrete frame structure supported on 6 bearings.</p> <p>Engineer: Dunning Thornton.</p> <p>Isolation devices: Triple Pendulums (EPS).</p> <p>Project Status: Under Construction.</p>	

Table 1 continued. Examples of recent seismic isolation projects in New Zealand






Project Name:	Armagh Apartments, Christchurch.	
Project Description:	9 storey apartment building.	
Engineer:	Holmes Consulting.	
Isolation devices:	Lead rubber and flat slider.	
Project Status:	In design.	
Project Name:	93 Cambridge Terrace, Christchurch.	
Project Description:	New four storey office building with isolation above habitable ground floor.	
Engineer:	Aurecon.	
Isolation devices:	Triple friction Pendulum (EPS).	
Project Status:	Construction nearing completion.	
Project Name:	Grand Central, Christchurch.	
Project Description:	New six-storey office building with isolation in a basement rattle zone.	
Engineer:	Aurecon.	
Isolation devices:	Triple friction Pendulum (EPS).	
Project Status:	Completed.	
Project Name:	151 Cambridge Terrace, Christchurch.	
Project Description:	New five-story office building with basement.	
Engineer:	Aurecon.	
Isolation devices:	Triple friction Pendulum (EPS).	
Project Status:	Completed.	

Table 2. Examples of projects with dissipative braces

Project Name:	University of Canterbury Regional Science and Innovation Centre, Christchurch.	
Project Description:	20,000 m ² 4-level teaching building for College of Sciences.	
Engineer:	Beca.	
Technology:	Buckling Restrained Braces.	
Project Status:	Construction nearing completion.	
Project Name:	PwC Centre, Christchurch.	
Project Description:	6 storey steel framed office building.	
Engineer:	Beca.	
Technology:	Buckling Restrained Braces.	
Project Status:	Complete.	


<p>Project Name: Opus Building, Christchurch.</p> <p>Project Description: New 4-storey office building.</p> <p>Engineer: Opus International.</p> <p>Technology: Viscous Dampers (Taylor Devices).</p> <p>Project Status: Completed 2016.</p>	
<p>Project Name: Cuba/Dixon Development, Wellington.</p> <p>Project Description: New 6-storey teaching building with 2-storey façade retention.</p> <p>Engineer: Dunning Thornton.</p> <p>Technology: Buckling Restrained Braces.</p> <p>Project Status: Under Construction.</p>	
<p>Project Name: Victoria University Gateway, Wellington.</p> <p>Project Description: 4-storey. 2-way moment frames.</p> <p>Engineer: Dunning Thornton.</p> <p>Technology: Project specific/tested mini BRB's.</p> <p>Project Status: Under Construction.</p>	
<p>Project Name: Nelson Airport terminal building.</p> <p>Project Description: Bracing through rocking timber blade columns with friction energy dissipaters.</p> <p>Engineer: Dunning Thornton.</p> <p>Technology: Sliding Friction Joint (Tectonus).</p> <p>Project Status: Out to Tender.</p>	
<p>Project Name: 56 The Terrace, retrofit, Wellington. (formerly Unisys House)</p> <p>Project Description: Retrofit and strengthening of mid - 1970s 19-storey steel moment frame.</p> <p>Engineer: Holmes Consulting.</p> <p>Technology: Fluid Viscous Damper (Victor Seismic).</p> <p>Project Status: Complete.</p>	
<p>Project Name: New Education Building, Univ. of Cant.</p> <p>Project Description: Retrofit of ductile RC moment frame.</p> <p>Engineer: Holmes Consulting.</p> <p>Technology: Fluid Viscous Dampers and BRB.</p> <p>Project Status: Under construction.</p>	
<p>Project Name: Christ's Coll. Sir Miles Warren building</p> <p>Project Description: Slotting beam RC MRF with supplement BRB energy dissipation.</p> <p>Engineer: Holmes Consulting.</p> <p>Technology: Small scale BRB (Victor Seismic, NZ).</p> <p>Project Status: Complete.</p>	

Table 3. A recent bridge with damage control technology



Project Name:	Wigram-Magdala Link overbridge	
Project Description:	\$30m, 100 metres long, three-span bridge over Curletts Road near Christchurch.	
Engineer:	Opus.	
Protective system:	Rocking piers with vertical post-tensioning and replaceable energy dissipators.	
Project Status:	Completed Sep 2016.	

Table 4. Recent industrial projects with energy dissipation devices

Project Name:	OnGuard wine tank restraints.	
Project Description:	OnGuard anchors for seismic restraint and protection of wine silos.	
Engineer:	OnGuard.	
Isolation devices:	Ductile tension and compression dissipative anchor.	
Project Status:	Many constructed.	

4 NZ GUIDELINE FOR DESIGN OF SEISMIC ISOLATION SYSTEMS FOR BUILDINGS

A guideline for the design of seismic isolation systems for buildings in New Zealand is currently being prepared, with funding by government agencies MBIE, EQC, and technical societies NZSEE, SESOC and NZCS. The group preparing the document is drawn from the major consultancies designing base-isolated buildings. The guideline has been drafted and is currently being edited following a first round of international peer review.

The guideline is intended to be used as part of Alternative Solution designs for compliance with the New Zealand Building Code and is based on NZS 1170.5 with suitable selection of design parameters, such as Structural Performance Factor S_p , and design ductility factor μ (and k_μ) for isolated buildings.

Four isolated building types are designated and designers must determine which type they will design for, as summarised in Table 5.

Table 5. NZSEE Seismic Isolation Guideline - Isolated Building Types

Type	Designation	Description
1	Simple	Regular and low-rise superstructures. Design to remain elastic and using simple equivalent static analysis.
2	Normal	Superstructures not meeting Type 1 requirements. Designed for nominally ductile behaviour and using at least modal response spectrum analysis.
3	Complex	Superstructures and those for which some ductility may be assumed, or the isolation plane does not provide the full displacement demand on the system. Nonlinear Time History Analysis is required.
4	Brittle	Brittle (ie non-ductile) superstructures including existing structures with little available ductility capacity.

Isolator device types covered by the guideline include elastomeric (including lead rubber) bearings together with flat sliders, curved surface sliders, and viscous damper devices in combination with isolation devices.

The guideline recommends additional limit states to be considered for isolated buildings that are not specifically required by NZS 1170.5 for normal buildings. These include a Damage Control Limit State (DCLS) and a Collapse Avoidance Limit State (CALS). It is recommended that the overall building, including isolators and rattle space, is explicitly designed to sustain the displacement demands for the rare earthquake event referred to in NZS 1170.5.

The guideline includes changes to the long period portions of the NZS 1170 hazard spectra, which typically govern the design of isolated buildings. The corner period at which the constant displacement part of the hazard spectrum starts has been extended from 3 seconds to 4 or 5 seconds for some locations, increasing displacement demands on isolation systems in those areas.

Both acceleration and displacement spectra are provided, allowing designers to represent seismic demands in acceleration-displacement response spectra (ADRS) format. This format is convenient for designing isolated structures using simplified capacity spectrum methods for determining base shear and displacement demands and system response. ADRS demand spectra are further modified for isolated structures to account for increased (hysteretic) damping that will be available from typical isolation systems.

Acceptable types of numerical analysis to be used for each isolated building type are given. Preliminary analysis for all isolated building types would typically start with single degree of freedom analysis of a rigid building on a flexible isolation layer, followed by more detailed analysis using equivalent static, modal response spectrum or nonlinear time history analysis, depending on the type and complexity of the building.

Isolator property variability (upper and lower bound) is required to be considered in addition to nominal isolator properties. Upper bound properties lead to maximum force demands on the structure, and lower bound properties lead to maximum displacement demands on the isolators.

Design methodologies are provided for each isolated building type considering performance design of the isolated building overall, the isolator devices and connections to the primary structure, rattle space, substructure and superstructure.

Guidance is provided for the structural design basis to carry over to the materials standards for design of foundation, substructure and superstructure. A minimum level of ductile detailing and capacity design will generally be required in the superstructure to allow for inelastic demands under rare earthquake events.

A sample technical specification is also provided to assist with procurement of isolation systems and devices, based on content from international standards from the US (ASCE) and Europe (EN 15129). Designers are advised to select the type and number of isolators to be provided and to prepare a performance-based specification giving the combinations of design forces and displacements that isolators are to be supplied for. It is strongly recommended that actual design of the isolators is left to the supplier in accordance with an approved international standard. Qualification, prototype and production testing sequences and acceptance criteria are to be specified. Full-scale testing of isolators or similar prototypes is generally required, together with suitably qualified independent technical overview.

5 MBIE LOW DAMAGE DESIGN GUIDELINE

The Canterbury Earthquakes Royal Commission recommendations 66-69 called for MBIE to promote further knowledge and guidance around the use of low damage design technologies, of which seismic isolation is arguably the best proven.

MBIE is currently developing a low-damage design guideline and the author has participated in the formative stages of this work. The guideline includes recommendations for specific performance objectives and performance assessment criteria to apply to building design. An important part of the low damage design approach is to not only delay the onset of damage to the building as a whole, including secondary elements and fit-out, to a chosen target level of shaking, but to also consider how to make any damage repairable within targeted cost and time constraints. An important principle is to

communicate the damage control objectives with the building owner and occupants through a Design Features Report.

6 CONCLUSIONS

The rate of application of seismic isolation and other energy dissipation technologies has increased markedly in New Zealand following the damaging Canterbury earthquake sequence of 2010 and 2011. Owners and engineers have recognised the significant performance and life-cycle cost benefits that these technologies bring to earthquake protection of buildings and their contents. The benefits include increases in safety, as well as reductions in the frequency and severity of damage and downtime to repair any damage that does occur. The emerging “low-damage design” philosophy for buildings, also considers the performance of non-structural elements, building fabric and fitout and disruption to contents as well as the primary structure.

Experience is being gained by New Zealand engineers designing isolation systems for buildings, using mostly lead rubber and concave slider systems. Preparation of a New Zealand design guideline for isolations systems is underway to promote design of seismic isolation in a consistent manner. Many new applications of seismic isolation can be expected across New Zealand in the near future.

Other energy dissipation and supplemental device technologies include wide use of buckling restrained braces and increasing use of fluid viscous dampers.

Full scale testing of both isolation and energy dissipation devices remains difficult to carry out in New Zealand.

There is a currently a strong focus in New Zealand on developing low-damage design approaches and protective technologies that improve the seismic performance of buildings beyond the current code minimum requirements for damage avoidance.

7 REFERENCES

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