HERA

innovation in metals

HERA Report No R4-150:2017

The seismic performance of structural steel buildings in the 2016 Kaikoura Earthquake

In collaboration with:

tangent consulting

The Seismic Performance of Structural Steel Buildings in the 2016 Kaikoura Earthquake

Alistair Fussell, BE (Hon), ME, MIPENZ, CPEng

Senior Engineer and Director Tangent Consulting

Document control: revision history

Revision	Description	Date	Originator	Reviewer	Approver
A	For client review	11/12/2017	AJF		
A	Wolfgang Scholz / Nandor Mago review		WS		
B	Incorporation of client feedback. Ammendment to damage case 1 discussion and correction to referencing	19/12/2017	AJF	CC / WS	TC
B+C	Review for B + C – Charles Clifton Final review C – Wolfgang Scholz	1/1 /2017 8/1/2017		CC / WS	TC

Publisher

New Zealand Heavy Engineering Research Association (HERA)
17-19 Gladding Place
Manukau, 2104
Auckland, New Zealand

P +64 9 262 2885
F +64 9 262 2856
E info@hera.org.nz

www.hera.org.nz

HERA ISBN 0112-1758

About us

Serving the New Zealand metal-based industry

HERA creates value by being the stimulus for research, innovation and development – delivering a trusted national centre for design, manufacturing technology, inspection and quality assurance.

Our commitment to help our members stay one step ahead is strengthened by our vision to be the leading catalyst for metals innovation internationally.

Our specialists in heavy engineering research, industry development, training, advocacy and marketing allow us to partner with our members and clients across the globe – to create opportunity and lead bigger picture thinking.

Industry owned. Member driven. Future focused.

Disclaimer

Every effort has been made and all reasonable care taken to ensure the accuracy and reliability of the material contained within this document. However, HERA and the authors of this report make no warrantee, guarantee or representation in connection with this report and will not be held reliable or responsible in any way – and hereby disclaim any liability or responsibility for any loss or damage resulting from the use of this report.

Copyright

Contents

Appendices

1. Executive summary

Following the 2016 Kaikoura earthquake, the Heavy Engineering Research Association (HERA) commissioned Tangent Consulting Ltd to investigate the seismic performance of heavy gauge steel structures in the Wellington region during this event. This report presents the findings, observations and recommendations from this investigation.

The investigation consisted of field observations by the author; data collected from building officials, structural engineers, steel fabricators, university academics and from a literature review (media, technical publications and websites).

Structural steel buildings in the Wellington region performed well during the earthquake with one notable exception. Four examples of damage to steel buildings were noted during the course of this investigation. For reasons of commercial sensitivity, the identity of individual projects has not been disclosed.

The earthquake highlighted the vulnerability of gusset plate connections to a sway mode of behaviour. There is currently no recognised robust gusset plate design procedure that appropriately accounts for this mode of failure. Research is required to support the development of such a procedure. In light of this shortcoming, a recommendation has been made for the HERA to investigate the seismic behaviour of gusset plate connections.

Aside from deficiencies in gusset plate connection design for sway effects, the reported damage does not indicate deficiencies in New Zealand seismic design practice for steel building structures as there were no unexpected incidents of poor performance. It does highlight the importance of following the established procedures and avoiding the use of details with known poor seismic performance and restrictions on their use, such as eccentric cleats in compression, in seismic resisting systems.

Recommendations have been made to prepare practice notes for design engineers to promote good detailing practice with respect to tension only braces and to highlight the need to consider out of plane actions when designing gusset plate connections in seismic load resisting braced frames.

Building damage information was difficult to obtain. Building owners and other parties associated with damaged steel buildings were reluctant to disclose information for reasons of commercial sensitivity and legal liability. This led to the recommendation to investigate the feasibility of a confidential industry reporting mechanism for design and construction problems to facilitate learning from such incidents.

Acknowledgements

The contribution of various parties is acknowledged in sourcing images and information about the performance of steel buildings during the 2016 Kaikoura earthquake. These include Derek Baxter from Wellington City Council, Associate Professor Dr Charles Clifton University of Auckland, Dave McGuigan MBIE, Steel Construction New Zealand, Wellington based structural engineers and SCNZ fabricator members.

2. Introduction

2.1 The 2016 Kaikoura Earthquake

The magnitude 7.8 2016 Kaikoura Earthquake struck the North-Eastern region of the South Island on November 14th [1]. This event resulted in damaging ground shaking that lasted over 90 seconds. It was the largest earthquake in New Zealand since 1855. The earthquake involved the rupture of over six faults [2] and the rupture zone extended 200 km. The closest point of the rupture zone to Wellington was 60 km.

The ground shaking resulted in between 80,000 and 100,000 landslides. These landslides blocked the coastal road and rail route to Kaikoura. There were two fatalities attributable to the earthquake in Kaikoura.

Winery facilities in the upper South Island were damaged by the shaking and at least 2 houses were severely damaged. In one instance a surface ground rupture passed through a house, and in another an unreinforced brick house collapsed [2].

2.2 Scope of report

While the Kaikoura earthquake resulted in shaking over a wide region of New Zealand, the focus of this report is on damage to heavy gauge structural steel buildings located in the Wellington region.

Light gauge steel framed buildings, as typically used in residential construction, have not been part of this investigation. However, reports indicate little if any damage to light steel framed houses.

Damage to reinforced concrete buildings [3] in the Wellington region and to winery facilities [4] in the Marlborough region is discussed in the New Zealand Society for Earthquake Engineering Bulletin [5].

3. Seismic demand

The 2016 Kaikoura earthquake resulted in seismic demand in excess of ultimate limit state (ULS) force based elastic design levels for some buildings. Buildings with natural periods of vibration between 0.8 and 2 seconds were most significantly affected [6]. This corresponds typically to 8-15 storey buildings, or as low as five storeys for moment framed buildings, which are more flexible. Due to the long distance from the earthquake source to Wellington city, the short period shaking was filtered out. The presence of deep soils across parts of the Wellington Central Business District (CBD) resulted in significant ground shaking amplification compared to rock sites in the city [6].

For structures with periods less than 0.8 seconds or greater than 2 seconds, the shaking was typically less than the ULS designed level; a 500 Year return event according to NZS 1170.5 [2].

The most affected building stock was reinforced moment frames with pre-cast concrete floors built in Wellington from the early 1980's [3] onwards. Following the earthquake, the Wellington City Council has required invasive investigation including removing floor and wall coverings for 72 reinforced concrete framed buildings meeting this profile [7]. This targeted assessment programme is discussed in section 4.0.

No site-specific information has been obtained to determine if any structural steel buildings were subject to seismic demands in excess of design levels. However, advice from Dr Charles Clifton is that the level of demand was in excess of the ULS force based elastic design level for many steel framed buildings designed for structural ductility factors ≥ 3.

4. Building safety assessments post earthquake

In contrast to the 2011 Christchurch earthquake, no state of emergency was declared following the 2016 Kaikoura earthquake event. This was due to the limited building damage and to avoid the significant economic disruption experienced in Christchurch after the CBD was evacuated for an extended period of time [2].

Building owners were left to arrange their own building safety assessments. These rapid post-earthquake assessments by engineers typically did not involve any invasive investigations such as removing linings which can be costly to repair. Apart from several buildings that were identified with critical damage conditions (*e.g*. shear failure of columns, partial floor collapse), most buildings were reoccupied within a short period of time.

During the earthquake, Statistics House, a building located by the Port, suffered partial collapse of two floors. The Chief Executive of the Ministry of Business, Innovation and Employment (MBIE) commissioned an independent expert assessment into the performance of this building during the earthquake to understand implications for the building regulatory system [8]. The expert panel quickly established that the building typology (pre-cast flooring, reinforced concrete moment frames) was a common form of construction in Wellington and that many other similar buildings may be vulnerable to the damage experienced in Statistics House [7]. It should be noted that Custom House, situated alongside Statistics House and of a similar number of storeys and floor plan area and with a pre-cast concrete floor onto gravity concrete and some steel framing and with rocking concrete shear walls connected with steel active link coupling beams, suffered very little structural damage. Its damage consisted of extensive yielding of the coupling beams in one direction. These have subsequently been replaced to return the building to full post-earthquake strength.

Legislation was passed to grant emergency powers to the Wellington City Council to initiate a targeted assessment programme. Initially 80 buildings were identified as containing similar characteristics to Statistics House; a number which was eventually reduced to 72. The owners of these buildings were required to undertake a more detailed targeted damage evaluation of their buildings [7].

The Council's primary responsibility is building safety. Once the targeted assessment was undertaken of the buildings, owners and their insurers decided whether to retrofit or to demolish damaged buildings.

One of the implications of the decision not to declare a state of emergency post the earthquake, was that it was much more difficult to obtain information about damaged buildings. Building owners were reluctant for their professional advisers (Structural Engineers) to disclose information about building damage.

As a final comment on the post-earthquake building safety evaluation process, there are limitations to the rapid post-earthquake assessments process employed. As noted previously, this typically does not involve removing architectural finishes. Engineers commonly rely on damage to non-structural wall finishes and other evidence of large inter-story displacements to infer structural damage. This may work well in many instances. However, experience following the Northridge (1994) earthquake demonstrates that significant damage to structural elements may remain hidden for a number of years if this approach is solely utilised to detect damage to seismic load resisting structure. This has led some to suggest there is merit in requiring building designed to include easy access to the critical locations of key structural elements following an earthquake [9].

5. History of steel construction in New Zealand

McRae's conference paper [10] provides a helpful overview of steel construction in New Zealand. From the early 20th century until 1960, riveted steel frames were a popular form of construction. From the late 1950's, welding and bolting replaced riveting as a means of constructing steel frames.

These types of frames were used until the mid-1970's when industrial relations issues, particularly the BNZ Building in Wellington, effectively stopped the use of structural steel in commercial and residential construction. By the early 1980's the market share by supported floor area of steel framing was close to 0%. It was not until the 1990's before there was a gradual increase in structural steel construction in New Zealand.

The most common forms of structural steel seismic load resisting systems are moment resisting frames, eccentrically braced frames, and concentrically braced frames, see Figure 1.

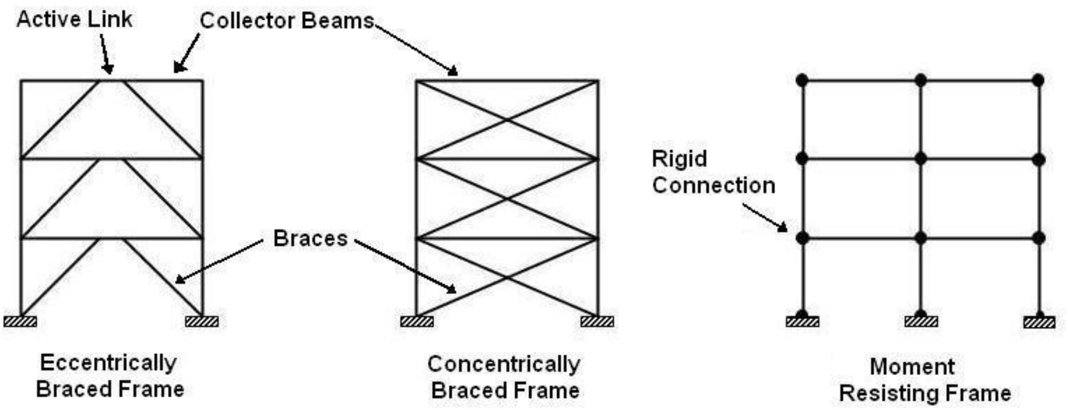

Figure 1 - Structural steel seismic load resisting systems. Image courtesy of Steel Construction NZ

Modifications have been made to these traditional lateral load resisting systems to improve their earthquake performance. Such technologies are known as low damage technology. Some examples of these included concentrically braced frames with controlled rocking, eccentrically braced frames with removable links, concentrically braced frames with buckling restrained braces, and moment resisting frames with sliding hinge joints. In addition, there have been a number of base isolated steel framed buildings and a steel moment framed building with viscous dampers. A brief explanation of some of these new seismic load resisting technologies is included in Appendix A.

Prior to the 2010-2011 Canterbury Earthquakes, the market share of structural steel in the Christchurch multi-level construction market was very low. This was due to the abundance of low cost aggregate for concrete and the strong emphasis on the teaching and researching of reinforced concrete construction at the University of Canterbury Civil Engineering School. Structural steel has played a significant role in the rebuild of Christchurch with its market share by floor area currently exceeding 80%. This has been primarily due to the good seismic performance of the limited number of structural steel framed buildings constructed prior to the 2010-11 earthquake series. The national market share of structural steel in multi-level construction is currently over 60%.

6. Steel structures in the Wellington area

6.1 Multi-level buildings

The number of multi-level structural steel framed buildings in the Wellington region is unknown. Based on the results of the Steel Construction New Zealand (hereafter referred to as SCNZ) CBD Market Share Survey, this has been a relatively popular form of construction in Wellington in the past decade. Of the 77 buildings constructed since 2005, structural steel has featured as the predominant floor framing system in 50 of them. Unfortunately, there is limited information from this survey on the seismic load resisting system of these buildings. It is known that a number of these buildings feature concrete shear walls.

Due to the legacy of the construction of the Bank of New Zealand Building in the 1970's, which was plagued by industrial relations problems, the number of multi-level buildings constructed in structural steel in the Capital from 1975 to 1995 was very low. During this period, reinforced concrete dominated the multi-level construction market. Some exceptions include 8 and 12 storey office buildings constructed in the late 1980's in Lower Hutt and the Wellington CBD respectively.

Figure 2 - Gateway Building - hysteretic dampers connect truss bottom chords to columns. Image courtesy of SCNZ

Table 1 - Notable Steel Structures in the Wellington Region

A feature of multi-level structural steel buildings constructed in Wellington in the past 12 years is the use of low damage seismic load resisting systems such as moment resisting frames with sliding hinges joints, rocking steel braced frames and a moment frame trussed structure with hysteretic dampers (Figure 2). Table 1 provides a listing of significant known multi-level buildings in the Wellington region, including the CBD and Victoria University.

Table 1 Notable steel structures in the Wellington region

Project name	No. of stories	Seismic load resisting system
Te Puni Village Student Accommodation, Victoria University	11	Braced frame with controlled rocking and moment frames with sliding hinge joints
Gateway Building, Victoria University	4	Two-way moment frames incorporating vierendeel trusses and hysteretic dampers
Holiday Inn	17	Eccentrically braced frames and reinforced concrete shear walls
Elevate Apartments	15	Braced frames with controlled rocking and moment frames with sliding hinge joints
Bellagio's Apartments	8	Moment frames incorporating sliding hinge connections
Chews Lane	14	Eccentrically braced frames
20 QC	14	Base isolation and external diagrid frame, see Figure 3

Figure 3 - 20 QC - External diagrid structure. Image courtesy of SCNZ

6.2 Industrial buildings

Structural steel portal framed buildings are a common form of construction for industrial facilities. The number of such buildings in the Wellington region is unknown. Such buildings typically feature some form of roof and wall bracing systems.

6.3 Seismic retrofit

A number of Wellington buildings have been earthquake strengthened using structural steel braced frames. An example is the McKenzie Building which was retrofitted with eccentrically braced frames in 2010 (Figure 4).

Figure 4 - Seismic retrofitting to the McKenzie Building

7. Research methodology

The investigation for this report consisted of field observations by the author, enquiry of various parties and a literature review (media, technical publications and websites).

The rationale for selecting various parties to make enquiry of is outlined as follows. Firstly, City Councils were approached because they have responsibility for post emergency building safety evaluation. Structural Engineers were selected because these are the professional advisors for building owners who undertake post-earthquake building assessments. Finally, fabricators were approached because they are typically called upon to undertake repair of structural steel framed buildings.

SCNZ was asked to assist HERA to make enquiries of structural engineers and fabricators. This was because of their established communication channels and longstanding relationships with these sectors. Furthermore, SCNZ has undertaken a Wellington CBD market share survey since 2005 and provided useful and relevant information on structural steel buildings construction in the period 2005 to the present and the identity structural designers for these projects.

The following is a summary of the parties contacted and the means by which they were contacted.

Table 2 - Parties contacted to supply building damage information

Sector	Type of request	Means of communication
Buildings officials – Wellington and Hutt City Councils, MBIE	General requests for information on damaged steel buildings	Phone and email
Engineers	General request for information	Email to SCNZ and HERA engineer member databases
	Targeted request to engineers identified in Wellington CBD survey[1] as designers of structural steel buildings	Email, phone, and office visits
Fabricators	General request for information	Email, phone, and industry events (SCNZ Fabricator forums, AGM, and annual conference)

1 For an explanation of the SCNZ CBD Market Share Survey refer to Appendix B.

8. Literature review

A literature review was undertaken of media coverage of the Kaikoura earthquake and its impact on buildings and the publications of technical societies and reports for MBIE and the Wellington City Council.

8.1 Media

The only media coverage of a damaged steel building related to the Queensgate cinema and car parking complex damaged by ground shaking. Initially, temporary strengthening was proposed to ensure stability of the structure during aftershocks. Further damage assessment led to a decision to demolish the building. No information was provided as to the reasons for the decision to demolish the building. However, Dr Charles Clifton confirms that he was advised that the damage to the steel framed seismic resisting system played only a small part in this decision.

A summary of media reporting of post-earthquake building assessments is presented in Appendix C.

8.2 Technical publications

2016 Kaikoura Earthquake Technical Clearinghouse

The clearinghouse operation is a partnership between four organisations: Earthquake Engineering Research Institute (EERI); New Zealand Society of Earthquake Engineering (NZSEE); GNS Science; and QuakeCore. To facilitate sharing of data and reports from experts conducting reconnaissance for this earthquake and its aftershocks, physical and virtual clearinghouses in the form of meetings were convened and a website developed. A total of five clearinghouse meetings were held between 16th November 2016 and 22nd January 2017.

The minutes of these five clearinghouse meetings were reviewed [10]. The only mention of damage to steel buildings occurred at meeting two where reference was made to at least one industrial building suffering rod bracing damage. It is possible this is the second case of damage presented in section 8.0.

The clearinghouse website hosted a joint QuakeCore, Geotehnical Extreme Responses Reconnaissance Association (GEER), and EERI Earthquake Reconnaissance Report [11]. This report discussed building impacts in Wellington. The report noted short stiff buildings experienced below design level demand and as a result were untested and experienced little damage. The earthquake did test buildings with fundamental periods near 1.5 seconds.

Early earthquake assessment indicated that damage was concentrated in 5-15 storey reinforced concrete buildings with precast floors.

New Zealand Society for Earthquake Engineering bulletin

A full NZSEE bulletin was dedicated to the 2016 Kaikoura earthquake [5]. The bulletin covered a wide range of topics related to this event including seismology, geotechnical, infrastructure and buildings. Reconnaissance reports were prepared for various types of structures. These included:

- damage to concrete buildings with pre-cast floors;
- damage to non-structural elements;
- performance of early masonry, cob, and concrete buildings;
- performance of winery facilities;

- log house performance; and
- performance of road bridges.

None of these articles discuss damage to steel buildings structures.

8.3 Summary of literature review

The Wellington building stock most affected by ground shaking from the Kaikoura earthquake was 5 -15 storey reinforced concrete moment framed buildings with pre-cast flooring. The literature review only identified damage to two structural steel buildings.

9. Results of enquiry

This section provides a summary of the building damage data reported by various parties including Building Officials, Engineers, and Fabricators. This section is divided into two parts; the first of which is a summary of the response statistics. The second section is a summary of the reported damage.

9.1 Response statistics

Responses to requests for information, with to respect to steel building damage, were received from Wellington Council, Structural Engineers and Fabricators. These responses are summarised below.

9.2 Building officials

Wellington Council advised there were no concerns with structural steel buildings in the Wellington region and that they were not part of their Targeted Assessment Programme.

9.3 Structural engineers

Responses were received from nine out of twelve structural engineers noted in the SCNZ CBD survey. These Structural Engineers were part of the design team for the vast majority of structural steel buildings constructed in the Wellington CBD since 2005, based on floor area and building numbers.

Responding engineers were responsible for the design of:

- 47 out of 50 buildings with structural steel as the sole or primary framing system;
- ten out of ten projects featuring structural steel as the secondary framing system;
- 96% by floor area of structural steel framed construction

No responses were received from other Wellington engineers or engineers from the rest of New Zealand.

9.4 Fabricators

33 out of 80 SCNZ fabricator member companies either responded by phone, email or were asked at industry events to advise if they had been involved in the repair of damaged structural steel buildings. These companies include most of the medium to large sized fabricators in New Zealand. More significantly, this included all the fabricators based in the Wellington region.

9.5 Reported damage

The reported damage presented in this section consists of a description of the specific structural damage sustained by steel buildings. Note that one of the cases of damage reported relates to a structural steel element in a principally concrete building.

Table 3 – Reported steel building damage

	Building description	Primary framing system	Seismic load resisting system	Damage
1	Three storey building	Structural steel framing	Eccentrically braced frames	Brace/collector beam gusset plate eccentric cleat connections buckled out of plane
2	Single storey industrial building	Structural steel portal frames	Tension only rod bracing	Rod bracing failure
3	Seven storey office building	Reinforced concrete	Coupled reinforced concrete shear walls.	Yielding of structural steel coupling beams

An industry source advised of another industrial building that sustained damage, but was unwilling to provide details for publishing in this report. It is believed this damage has been repaired.

10. Discussion of results

This section discusses the observed building damage.

One point to note is that due to commercial sensitivities, the amount of information disclosed by sources was limited. The author was only able to visit one of the three buildings reported in this section.

10.1 Damage case 1 - Buckled gusset plate connections – eccentrically braced frame

Project description

Connection damage was reported in a multi-level mixed use building. The primary lateral load resisting system in this building consists of eccentrically braced frames in the transverse and longitudinal directions. The principal energy dissipation mechanism in eccentrically braced frames is intended to be shear yielding in the active links, see Figure 1.

Details of lateral load resisting system description

a. Frame configuration – the frame consists of hot rolled I-section collector beams and circular hollow section (CHS) braces.

b. Connection details - Then go to your 'reference' tab, and click on the 'insert caption' button - the connection of the brace to the collector beams consists of a stiffened gusset plate welded to the underside of the collector beam. An unstiffened cleat plate is birds mouthed and welded into the end of the CHS member in an eccentric configuration; a type of connection specifically not recommended by HERA for use in seismic resisting systems [15]. The connections were site bolted. The details of the connection at the column end of the brace are unknown.

Observed damage

A number of the brace to collector beam gusset plate connections buckled out of plane; see Figure 5. It is not known if the structure experienced other forms of structural damage. Nor is it known if the active links yielded during the ground shaking.

Discussion of damage

The observed buckling is consistent with a gusset plate sway mode of failure.

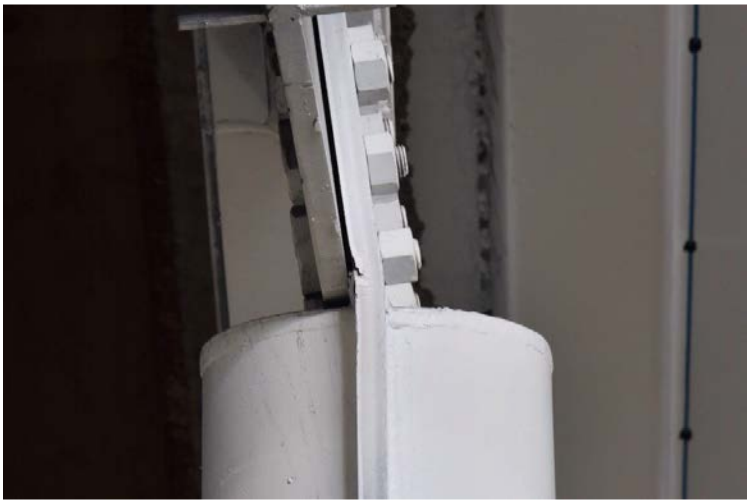

Figure 5 - Out of plane buckling of eccentric cleat connection

The seismic behaviour of gusset plate connections in structural steel braced frames is not well understood. As a consequence, there is a lack of robust design procedure that accounts for the key parameters that govern the compressive capacity of such connections. In particular, current design methods do not appropriately model a sway mode of behaviour. This mode of failure has been observed in laboratory testing even for concentric connections [15].

Sway buckling behaviour is a global stability phenomenon in which the brace system comprising brace and end connections forms a collapse mechanism, see Figure 6. Several collapse mechanisms are possible, but the mechanism with the lowest capacity will be the critical case. Under such a failure condition, the gusset plate is subject to out of plane actions arising from various sources such as:

a. initial imperfection in the brace (out of plumb) and out-of-flatness of the gusset plate;

b. out-of-plane seismic drifts. Researchers have only recently recognised the significance of ou- of-plane drifts on the behaviour of gusset plate connections [13]; and

c. eccentrically in the connection.

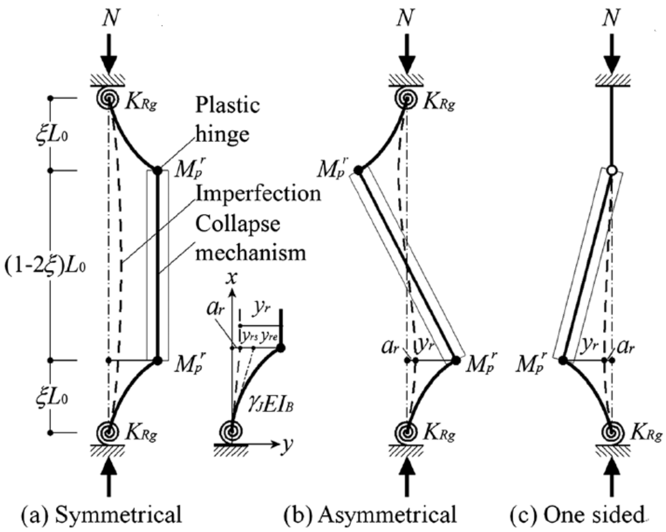

Figure 6 - Collapse mechanisms for braces with gusset connections [13]

For Damage Case 1, the significance of factors a) and b) is unknown, while factor c) was present.

The unstiffened cleat at the end of the brace would have offered limited out-of-plane strength and stiffness. Once the cleat buckled, forming a hinge between the end of the brace and the gusset plate, the compressive capacity of the system would have been limited by the rotational strength and stiffness of the gusset plate and its support structure, represented by springs in Figure 6. The gusset support structure consisted of an I-beam with full depth stiffeners and a bottom flange lateral restraint element (angle section) at each end of the active link. It is likely the top flange of the collector beam was connected to the slab via shear studs.

It is unknown how the gusset plate support structure performed; based on the observed damage it appears to have insufficient rotational strength and stiffness to prevent the mechanism forming.

It is also unknown how the brace connections to the frame columns performed.

No calculations have been undertaken of the connection capacity to determine if it possessed adequate strength for the over strength design actions from the yielding of the active link.

Lesson

The observed damage highlights the vulnerability of gusset plate connections to a sway mode of failure. The presence of an eccentric connection would have very significantly increased the out-of-plane actions the gusset plate connection was subject to during the earthquake. The design of such connections must appropriately consider out-of-plane design actions and eccentric cleats in compression for other than category 4 seismic resisting systems are specifically not recommended by HERA [15].

Eccentrically braced frame system generally performed well during the Canterbury earthquake sequence of 2010 and 2011. This type of gusset plate connection failure was not observed in Christchurch. This is likely attributable to differences in frame and connection details. In particular, open section braces (Universal Columns) and fully welded brace/ collector beam connections were commonly used, see Figure 7. These types of details provide not only a concentric connection detail, but the brace itself with a welded connection to the underside of the collector beam provides reasonable resistance to out of plane buckling modes of behaviour.

Figure 7 - UC braces welded to the underside of collector beam

10.2 Damage case 2 - Rod bracing failure

The second case of reported building damage occurred in a single storey industrial building. The building featured engineering rounds as braced elements in tension-only concentric bracing systems. This type of system is designed to dissipate energy by yielding of the tension-only brace elements. This is a very common form of seismic load resisting system for industrial buildings.

Threads are rolled onto the ends of engineering rounds to allow connection to the braced frame to tensioning devices, such as turnbuckles, and in the case of this project, to connect to couplers splicing two lengths of rounds. The reason for the coupling device is that the length of an individual engineering round is insufficient for the geometry of the bracing bay. An example of a coupling device similar to that used in the project is shown in Figure 8. The coupler is installed by screwing each end of the round to be spliced halfway into the coupling device. Note that there are no locking nuts to prevent unintended loosening of the coupling device.

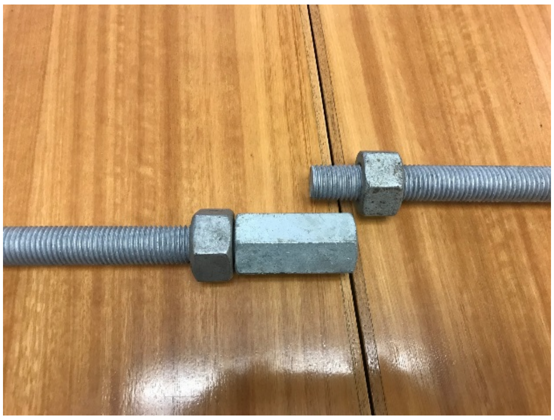

Figure 8 - Engineering round coupler detail. (Note: lock nuts not used in braces that failed)

Observed failure

The damage reported for this building was the failure of the bracing coupler devices that unscrewed during the earthquake. It appears there was sufficient structural redundancy to ensure that the structure remained stable with reduced lateral load resistance following failure of some of the brace coupling devices.

It is likely that the coupler unscrewed as a result of the rod buckling and straightening as the brace load cycled (compression/tension) during the earthquake.

Similar problems were observed with a proprietary bracing system during the Canterbury earthquake sequence of 2010 and 2011, where the connection failures were attributed to the restraining nuts being loose prior to the earthquake and so causing impact loading on the bracing system during the earthquake.

Lesson

This failure highlights the importance of using lock nuts in connection devices in tension only bracing elements to prevent connection failure during cyclic loading.

10.3 Damage case 3 – Yielding of coupler beams

Project description

The third and final case of reported damage occurred in a seven-storey building featuring pre-cast flooring, concrete gravity frames and coupled shear walls. The only structural steel elements in the building were structural steel coupling beams cast into the concrete shear walls, see Figure 9. These coupling beams were the primary yielding elements in the structure. They were designed to dissipate energy through shear yielding.

Observed damage

The coupled shear walls behaved as designed with evidence of shear yielding (paint flaking) in the wall coupling beams, see Figure 9. In the East-West direction the active links underwent some 8% plastic strain and were cut out and replaced. Links in the north-south direction underwent negligible visible yielding [13]. Studies undertaken by Dr Charles Clifton using the procedure developed for eccentrically braced frames (EBF) post-earthquake assessment [16] showed the links were at the threshold of needing replacement and the decision was made to replace them; this was done in 2017.

Figure 9 - Structural steel coupler beam exhibiting evidence of yielding (paint flaking)

10.4 Summary of damage

It has been difficult to obtain information about building damage, principally due to commercial concerns by building owners who were reluctant for their technical advisors (engineers) to disclose information about building damage.

Building demolitions have been well publicised in the media, therefore, it is unlikely that more than one structural steel building has been demolished as result of damage sustained during the Kaikoura earthquake. There is still a possibility that steel buildings have been repaired post-earthquake or will need repairing in the future as a result of as yet undetected damage that has not been noted in this report.

There are a significant number of industrial and commercial structural steel framed buildings in the Wellington region. The amount of building damage reported as result of the 2016 Kaikoura earthquake is low.

11.Key findings and recommendations

The key findings from the investigation into the performance of steel buildings in Wellington during the 2016 Kaikoura earthquake are summarised in this section and specific recommendations related to technical and market development matters are made where appropriate.

11.1 Structural steel buildings performed well during the earthquake

The seismic performance of structural steel buildings in the Wellington region during the 2016 Kaikoura earthquake event was very good apart from one notable exception. This finding is consistent with the performance of Christchurch structural buildings during the 2010 and 2011 Canterbury earthquake series. No structural steel buildings were part of the Wellington City Council Targeted Building Assessment programme [7].

This statement about the good seismic performance of structural steel buildings needs to be qualified by noting that no assessment of the seismic demand experienced by structural steel buildings during the earthquake has been undertaken. Short stiff buildings, including those designated as earthquake prone experienced low seismic demand and consequently suffered little damage.

Recommendation 1
That the good performance of structural steel buildings is reported widely to benefit public safety and also to support structural steel construction market development activities.
The poor seismic performance of pre-cast flooring is the Achilles heel of traditional reinforced concrete construction. This contrasts with the excellent seismic performance of composite metal deck slabs, particularly during the Canterbury earthquake series. Metal deck slabs in conjunction with steel framing create a lightweight seismically resilient flooring system which is ideally suited for construction in regions of high seismicity such as Wellington. A new Steel-Concrete Composite Structures Design Standard has been published in late 2017 [17], incorporating the state of the art design recommendations for this form of construction.

11.2 Seismic design of gusset plate connections

Damage Case 1 has highlighted the vulnerability of gusset plate connections to buckling sway modes of failure. There is currently no robust design procedure that accounts for this failure mode. It is likely that the buckling behaviour was exacerbated by the eccentric cleat connection that introduced additional out of plane actions on the cleat.

Recommendation 2
That HERA researches the seismic behaviour of gusset plate connections in steel braced frames with a view to developing a step by step design procedure for use by practicing engineers and remind practitioners of the restrictions in HERA Report R4-142 on the use of eccentric cleats in compression.

Recommendation 3
That HERA and SCNZ develop a Practice Note for design engineers emphasising the need to consider a sway buckling failure in the design of gusset plate connections used in structural steel braced frames. The Practice Note should recommend avoiding eccentric connections to reduce out-of-plane actions.

11.3 Locking nuts for tension braces connections or couplers

Damage Case 2 highlights the importance of using lock nuts in tension-only brace connections, tensioning devices such as turnbuckles and coupler devices in seismic applications.

Recommendation 4:
That HERA and SCNZ develop a Practice Note for design engineers recommending the use of locking nuts in tension only brace connections, tensioning devices, and couplers.

11.4 The difficulty obtaining building damage information

It has proven very difficult to obtain building damage information, particularly due to commercial sensitivity with building owners reluctant to allow their professional advisors to disclose such information. One steel building has been demolished to date. It is unlikely any other steel buildings will have been demolished without this fact becoming public knowledge. What is less certain is that this report has captured all the repairable damage that occurred during the 2016 Kaikoura earthquake event. The author is aware of at least one such project, alluded to by an industry source, however, this source was reluctant to have the project details published.

Recommendation 5
That HERA and SCNZ investigate the feasibility of a confidential industry reporting mechanism for design and construction problems to facilitate learning from such incidents e.g. similar to the Confidential Reporting on Structural Safety CROSS initiative in the UK that was established in 1976 [18]. This will assist future research programs.

12. Future research

Research is required into seismic behaviour of gusset plate connections in structural steel braced frames. It needs to consider the key parameters that govern the compressive capacities of such connections. This includes imperfections and out-of-plane seismic drifts. Note that an experimental testing programme on this is underway as of 2017 at the University of Auckland funded by the Natural Hazards Research Platform.

13.Conclusions

The 2016 Kaikoura earthquake resulted in seismic demand above design levels for some structures (5-15 storey) in the Wellington region. There are many low-rise and multilevel steel buildings in the Capital city. Overall, the seismic performance of structural steel buildings was very good with few reported cases of damage. There was one notable exception; a structural steel building which required demolition following engineering assessment in which the steel frame damage was partly responsible for the decision to demolish. The details of this project cannot be disclosed for legal and commercial reasons.

The good seismic performance of structural steel buildings in Wellington is consistent with that observed in Christchurch for steel structures subject to seismic demand during the 2010 and 2011 Canterbury earthquake series.

The above statements with respect to the seismic performance of steel buildings based on the 2016 Kaikoura earthquake need qualifying. No assessment of seismic demand compared to design levels has been undertaken for any steel buildings. The seismic demand on structures was very dependent on the characteristics of the building and the soil conditions under the structure. As consequence of this, structures considered vulnerable to ground shaking such as low-rise earthquake prone buildings did not sustain significant damage.

Aside from the deficiencies in the seismic design of gusset plate connections in steel braced frames, the observed damage has not highlighted deficiencies in current design practice or steel structures standards seismic provisions.

Wellington has many steel structures featuring low damage seismic load resisting technologies such as moment resisting frames with sliding hinge connections or braced frames with controlled rocking. To the author's knowledge, there is no evidence that the seismic demand was sufficient to initiate energy dissipation through frame rocking or significant connection sliding in the case of moment resisting frames with friction connections. The extent of joint movement in such friction connections is believed to be in order of 1mm [13]. Therefore, no definitive statements can be made about the performance of these systems under design level earthquake loading.

The 2016 Kaikoura earthquake has demonstrated the vulnerability of gusset plate connections in steel braced frame connections to buckle in a sway mode. There is a lack of robust design procedure for designing these elements. Urgent research is required to support the development of such guidance.

Parties associated with buildings that sustain earthquake damage are often reluctant to discuss details of the project either for reasons of commercial sensitivity (building owners) or legal liability (designers or contractors.) It has been suggested that industry investigate the feasibility of some confidential reporting mechanism that allows for information about issues to be disseminated without divulging details of the projects or parties involved as e.g. done by the UK Confidential Reporting on Structural Safety (CROSS) mechanism [18].

14. References

[1] L. Wotherspoon, A. Palermo, and C. Holden, " The 2016 MW 7.8 Kaikoura earthquake: An introduction," in *NZ Society for Earthquake Engineering Bulletin [5]*, NZ., 2017.

[2] M. Bruneau and G. MacRae. (2017). *Reconstructing Christchurch: A seismic shift in building structural systems* Available: http://resources.quakecentre.co.nz/wp-content/uploads/2017/11/DISTRIBUTION-COPY-of-Reconstruction-of-Christchurch-in-Steel-Nov-2017-2.pdf

[3] R. Henry, D. Dizhur, K. Elwood, J. Hare, and D. Brunsdon, "Damage to concrete buildings with precast floors during the 2016 Kaikoura earthquake," in *New Zealand Society for Earthquake Engineering Bulletin*, 50(2),NZ., 2017, pp. 174-186.

[4] D. Dizhur, G. Simkin, M. Giarettoa, G. Loporcaro, A. Palermo, and J. Ingham, "Performance of winery facilities during the 14th November 2016 Kaikoura earthquake," in *NZ Society of Earthquake Engineering*, 50(2), New Zealand, 2017, pp. 206-224.

[5] NZSEE, "NZ Society for Earthquake Engineering Bulletin, 50(2). ," in *NZ Society for Earthquake Engineering Bulletin*, NZ., 2017.

[6] MBIE. (2017, March). *Investigation into the performance of Statistics House in the 14 November 2016 Kaikoura earthquake. Ministry of Business, Innovation and Employment*. Available: http://www.mbie.govt.nz/publications-research/publications/building-and-construction/investigation-into-the-performance-of-statistics-house.pdf

[7] D. Brunsdon, D. Elwood, and R. Henry, "Wellington City Council targeted assessement programme following the Kaikoura earthquake," Wellington, NZ.14 November 2016 2017.

[8] C. Clifton, M. Bruneau, G. MacRae, R. Leon, and A. Fussell, "Steel structures damage from the Christchurch earthquake series" in *New Zealand Society for Earthquake Engineering Bulletin*, New Zealand, 2010 - 2011, pp. 297-318.

[9] G. MacRae, C. Clifton, and M. Bruneau, "Some NZ earthquake lessons and better building construction" in *Australian Earthquake Engineering Society Conference*, Melbourne, Australia, 2016.

[10] NZSEE, SESOC, NZGS, Quakecore, 2016, Kaikoura earthquake technical clearing house meeting #2 summary. Available: http://www.eqclearinghouse.org/2016-11-13-kaikoura/files/2016/12/Kaikoura-EQ-Clearing-House-Wellington-Mtg-2-Summary.pdf

[11] B. A. Bradley, M. Comerio, M. Cubrinovski, S. Dellow, D. Dizhur, K, Elwood, M. Giaretton, R. Green, N. Horsepool, M. Hughes, J. Ingham, L. Johnston, C. Massey, E. Seville, G. Simkin, J. Stevenson, R. Wilson and L. Wotherspoon, M7.8 Kaikoura, Earthquake reconnaisssance report: New Zealand Earthquake on November 14, 2016, Quakecore, GEER and EERI. Available: http://www.eqclearinghouse.org/2016-11-13-kaikoura/files/2017/04/QuakeCoRE-GEER-EERI-Kaikoura-Earthquake-Report.pdf.

[12] T. Takeuchi, H. Ozaki, R. Matsui and F. Sutcu, “Out-of-plane stability of buckling restrained braces including moment transfer”, EarthquakeEngineering and Structural Dynamics, 43, pp 851-869, 2014

[13] B. Zaboli, C. Clifton and K. Cowie, “Out-of-plane stability of gusset plates using a simplified notional load yield line method”, in New Zealand Society for Earthquake Engineering Conference, Wellington, New Zealand, 2017

[14] C. Clifton, "Private correspondence", ed, 2017.

[15] G. C. Clifton, N. Mago, and R. Z. El Sarraf, "Eccentric Cleats in Compression and Columns in Moment-Resisting Connections; HERA Report R4-142," New Zealand Heavy Engineering Research Association 0112-1758, 2009.

[16] Clifton, G.C. and W.G. Ferguson, *Determination of the Post-Elastic Capacity of an Eccentrically Braced Frame Seismic Resisting System*. 2015, The University of Auckland for the Natural Hazards Research Platform: Auckland, New Zealand.

[17] AS/NZS 2327: 2017 Composite Structures Standard. Standards New Zealand, Wellington, New Zealand

[18] Structural Safety Incorporating CROSS and SCOSS; http://www.structural-safety.org/

Appendix A Low damage structural steel seismic load resisting technologies

Low damage structural steel seismic load resisting technologies

A brief explanation is given in Appendix A of some low damage structural steel seismic load resisting technologies.

Braced frames with controlled rocking

Braced frames with controlled rocking systems employ rocking and energy dissipaters to resist severe shaking in an earthquake. In New Zealand, the award-winning Te Puni Village project at Victoria University has a braced frame with controlled rocking using ringfeder springs on concentrically braced frames and sliding hinge joints on moment-resisting frames, see Figure 10. A 16-storey apartment in Wellington also uses this system. In Christchurch, a medical centre employs a post-tensioned rocking braced frame solution as the seismic load-resisting system with viscous and hysteretic dampers.

Figure 1 - The Victoria University controlled rocking connection

Eccentrically braced frames (EBF)

Using EBFs with removable links, seismic energy is dissipated by the yielding of the active link zone between the intersection of the braces and the connector beam. The removable link features a bolted moment endplate connection to allow easy on-site removal and replacement after a major earthquake, if required, see Figure 11.

The first New Zealand example of EBF's with removable links were the two office buildings constructed at 335 Lincoln Road in Christchurch. In the event of earthquake damage, the links can be reasonably easily replaced – much like changing a fuse in a circuit box.

Figure 2 - Eccentrically braced frame removable link. Image courtesy of Ruamoko Solutions

Asymmetric friction connections

The innovative asymmetric friction connection is a fully tensioned, slotted and bolted connection that relies on frictional force between its components to provide joint strength.

A rigid connection is provided until the design level earthquake is exceeded, then the joint slides, dissipating seismic energy as friction between the sliding surfaces. The only likely structural repair is to replace stretched bolts. To date, the asymmetric friction connection joint has been used in moment-resisting frames, Figure 12, but could also be used in concentrically braced frame applications.

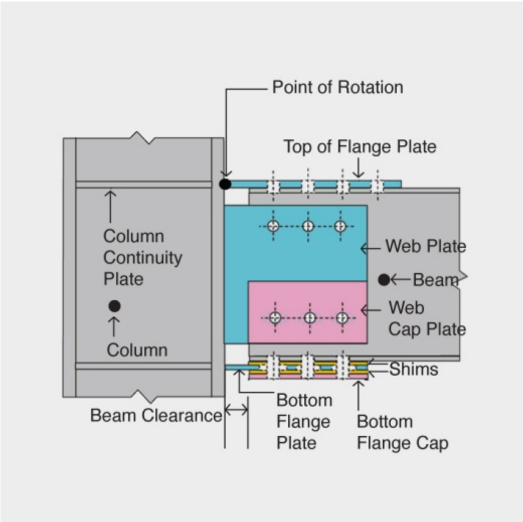

Figure 3 - Moment Frame with sliding hinge joint detail buckling restrained braces.

A system used internationally for 20 years that had little uptake in New Zealand prior to the 2010-2011 Canterbury earthquake series, the buckling restrained brace behaves consistently in both compression and tension.

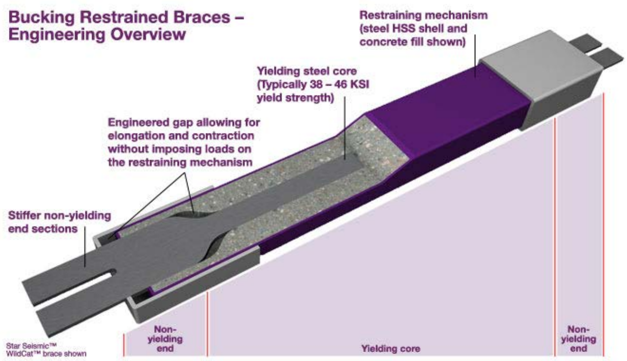

Figure 4 - Buckling restrained braces behave consistently in both compression and tension. Image courtesy of Star Seismic

It is manufactured with two main components that perform distinct functions while remaining decoupled. The load-resisting element is a steel core restrained against buckling by an outer casing filled with grout, see Figure 13. If damaged in a severe earthquake, they can be removed and replaced.
Following the Canterbury earthquakes, there has been increased interest in this system with buckling restrained braces used in projects in Christchurch and Auckland.

Viscous braced dampers

Viscous braced dampers, originally developed as shock absorbers for the defence and aerospace industries, have now been used extensively internationally for new and retrofit building construction in seismically active regions. A New Zealand application of technology is Opus House in Christchurch which features fluid viscous dampers in conjunction with steel moment frames, see Figures 14 and 15.

During a severe earthquake, the devices are activated, and seismic energy is converted to heat and dissipated. The principal benefit to a steel-framed building is that floor displacements and accelerations are reduced. Other low-damage solutions do not typically reduce floor accelerations – something that is important for minimising content damage, particularly to sensitive equipment.

Figure 14 Viscous damper detail

Figure 15 Elevation of Opus House

Appendix B SCNZ Wellington CBD survey

Background

The Wellington CBD survey has been undertaken annually by SCNZ since 2005. The survey was limited only to the Wellington CBD.

Survey methodology

The survey, which was completed by drive-by or on foot, identified buildings which were under construction at that time. Following the data collection, the Wellington City Council was visited and reviews were made of the consents for the surveyed buildings.

Summary of Survey

- 77 buildings were completed or under construction for the period at the time of July 2005 to July 2017. The total floor area associated with these buildings was approximately 547,000 m^2.
- 50 buildings featured structural steel as the predominant floor framing material. A further 10 included structural steel framing as the secondary floor framing material.
- No information was recorded for the lateral load resisting system material. A number of buildings recorded as featuring structural steel framing utilised reinforced concrete structural walls.
- A total of 12 engineers were responsible for the structural design of the 60 buildings featuring structural steel framing

Appendix C Summary of media coverage of building assessments and damage sustained during the Kaikoura Earthquake, November 2016

For the purpose of this media survey, news reports are arranged in chronological order. Although the reports are focused primarily on damage to buildings in Wellington, there are some reports from the Marlborough region. Key aspects are summarised and links made to the relevant sources.

Source: Stuff
Date: 14 November, 2016
http://www.stuff.co.nz/national/86416268/Earthquake-Deaths-major-damage-after-severe-7-5-quake-hits-Hanmer-Springs-tsunami-warning-issued
One of the initial reports on the earthquake, this report identifies the TSB Arena and BNZ Centre as the first buildings being damaged. Large chunks of masonry fell from a building on Wakefield St, opposite the Wellington City Council offices, but the article does not specify which building.

Source: Stuff
Date: 15 November, 2016
http://www.stuff.co.nz/national/nz-earthquake/86490123/historic-home-of-katherine-mansfield-closed-due-to-quake-damage
This article describes serious quake damage to Katharine Mansfield's historic house in Thorndon. A brick wall, which was identified as an earthquake risk in late 2014, collapsed against the house. Weatherboards on the home also buckled.

Source: Stuff
Date: 15 November, 2016
http://www.stuff.co.nz/business/86515075/Defence-Force-headquarters-closed-reportedly-uninhabitable
In this report, Defence House (also known as Freyberg house) in Aitken St was declared uninhabitable and expected to be closed for a period of approximately one year. This report was updated on 3 March, 2017, to say that the cost of repairs was considered to be uneconomic and the building would be demolished. Additional reports were filed in relation to this building as follows:

- The NZ Herald reported on 03/03/17 (http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11811572) that the building was set for demolition because while it was not beyond repair, "the cost of repairs is not economically viable."
- The Dominion Post on 13/06/17 (https://www.stuff.co.nz/dominion-post/news/93634292/Date-set-for-Defence-House-demolition) confirmed that demolition would begin in the coming weeks.

Source: Stuff
Date: 16 November, 2016
http://www.stuff.co.nz/national/nz-earthquake/86510017/Questions-asked-in-capital-but-engineers-say-no-such-thing-as-earthquake-proof
This report raised questions as to why the reasonably modern Statistics NZ building performed so badly. A Wellington based engineer, Terry Johnson of *Reveal Seismics*, indicated that some buildings "failed in an earthquake that was one-third of the intensity the structures were designed to withstand." The New Zealand Society for Earthquake Engineering's Win Clark indicates that the buildings on the waterfront's poor performance was a result of them being built on reclaimed land.

Source: NZ Herald
Date: 17 November, 2016
http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11750194
The Reading Cinemas car park, which also sustained damage in the 2013 Seddon earthquake, was deemed "likely to collapse".
Additional reports were filed in relation to this building as follows:

- Stuff reported on 16/12/16 (http://www.stuff.co.nz/national/nz-earthquake/87651512/Reading-Cinemas-car-park-demolition-to-begin-on-January-4-and-finish-in-March) that the demolition was set to begin in the New Year and continue until late March.
- The Dominion Post stated on 06/02/17 (http://www.stuff.co.nz/dominion-post/news/wellington/89131461/how-engineers-tried-to-find-ways-to-save-reading-cinema-car-park) that Aurecon provided two options for stabilisation including "wrapping and steel casing", but ultimately the building was deemed too unsafe, and they recommended on December 1 that "the work did not proceed."
- A Stuff article from 10/03/17 (http://www.stuff.co.nz/national/nz-earthquake/90291093/reading-cinemas-confirms-quake-damage-as-complex-prepares-to-reopen) stated that the complex was set to reopen on March 23 without its carpark.

Source: NZ Herald
Date: 17 November 2016
http://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=11750197
The above article stated that damage to the BNZ Harbour Quays building will take months to repair. Fletcher Building is named as the company overseeing the repairs. This building, along with Statistics House, is owned by Centre Port.

Source: IPENZ Media Release
Date: 18 November 2016
https://www.ipenz.nz/home/news-and-publications/news-article/engineers-says-wellington-s-mid-height-buildings-worst-affected
In this media statement, New Zealand Society for Earthquake Engineering [5] President, Peter Smith, stated that the worst affected buildings were between eight and 15 storeys. "Mr Smith says how buildings respond in an earthquake depends on their height, stiffness and the nature of the ground they are on." Many older, earthquake prone buildings suffered less damage due to the accelerations of the quake.

Source: Stuff
Date: 20 November 2016 Stuff
http://www.stuff.co.nz/dominion-post/news/wellington/86658777/cranes-move-into-wellington-as-demolition-set-to-begin-on-61-molesworth-st
This report states that a nine storey building at 61 Molesworth Street which suffered damage during the earthquake was set for demolition to begin on 21/11/16.

Source: Stuff
Date: 21 November 2016
http://www.stuff.co.nz/national/nz-earthquake/86674439/daily-earthquakeaffected-buildings-and-damage-updates-for-wellington-city
This report lists all the buildings which were closed directly in the wake of the earthquake. Additionally, Revera House, a 10 storey building, was closed for checks and expected to reopen, but the cost to repair was too great. Stuff reported on 03/04/17 that this building was set for demolition. (http://www.stuff.co.nz/national/nz-earthquake/91169581/revera-house-in-wellington-to-be-demolished-says-spokesman)

Source: Stuff
Date: 21 November 2016
http://www.stuff.co.nz/business/86681129/queensgate-mall-set-to-reopen-damage-to-car-park-repairable
This source states that damage to Queensgate Shopping Centre carpark makes it “structurally unsafe”. The property owner said it did not pose immediate danger, but could become compromised in the event of an aftershock. Beca recommended that structural strengthening take place.
A Radio NZ article from 25/11/16 (http://www.radionz.co.nz/news/national/318875/quake-aftermath-demolition-of-part-of-mall-confirmed) confirmed that the carpark was marked for “urgent demolition”. Demolition got underway at the beginning of December (Stuff, 04/12/17 http://www.stuff.co.nz/business/industries/87189661/demolition-of-part-of-hutt-mall-delayed-by-55-aftershock) and was expected to take two months. Radio NZ reported on 12/03/17 (http://www.radionz.co.nz/news/national/326428/future-of-demolished-queensgate-carpark-undecided) that the demolition work had been completed.

Source: Radio NZ
Date: 22 November 2016
http://www.radionz.co.nz/news/national/318670/quake-aftermath-11-buildings-red-stickered-in-marlborough
Eleven buildings in the Marlborough district were red-stickered in the aftermath of the quake. Of these, only one was a commercial property (39 Queen St, Blenheim). Stuff reported on 13/12/16 that this property was set for demolition. http://www.stuff.co.nz/business/87510187/quakedamaged-blenheim-building-to-come-down

Source: Stuff
Date: 14 February 2017
http://www.stuff.co.nz/national/nz-earthquake/89382786/tests-on-80-wellington-buildings-uncovers-earthquake-damage-but-no-threat-to-public
Tests were carried out on 80 quake damaged buildings. Those which had similar characteristics to the Statistics House building were prioritised. The parameters were established as: “Four to 15 floors high; with reinforced-concrete structures, particularly precast floors; and built on soft soils with flexible design.”

Source: Newshub
Date: 31 March 2017
http://www.newshub.co.nz/home/politics/2017/03/statistics-house-building-could-have-caused-fatalities-in-kaik-ura-earthquake.html
Newshub reported that Statistics House could have caused fatalities. The building's flaw was deemed specific to "highly ductile framed concrete buildings with pre-cast floor slabs and particularly those with multi bay frames."

Source: Stuff
Date: 26 July 2017
https://www.stuff.co.nz/business/95111871/unacceptable-performance-of-stats-house-in-2016-quake-building-minister-nick-smith
Additional reports were filed in relation to this building as follows:

- Speaking of Statistics House (5 storey building) which collapsed during the 7.8 earthquake, Nick Smith described its performance as 'unacceptable' when speaking at an earthquake conference in April 2017.
- An earlier news report also by Stuff from 31/03/17 indicates that Centre Port was aware of the design flaws as early as 2013. (http://www.stuff.co.nz/business/91056583/official-report-on-damage-to-statistics-house-due-to-be-released)

Source: Stuff
Date: 1 September 2017
https://www.stuff.co.nz/business/96394672/centreport-sees-bnz-and-statistics-nz-buildings-empty-until-at-least-2020
Stuff reports in the above article that BNZ Harbour Quays and Statistics House are likely to be closed until 2020. The BNZ building was also closed for an extended period of time following the 2013 Seddon earthquake. At the time of publication, engineers and insurers were still assessing the damage.

innovation in **metals**

HERA House, 17-19 Gladding Place
PO Box 76-134 Manukau, Auckland 2241
New Zealand

www.hera.org.nz