

POST-EARTHQUAKE STRUCTURAL DESIGN FOR FIRE – A NEW ZEALAND PERSPECTIVE

Gregory B. Baker*, Peter C.R. Collier*, Anthony K. Abu** and Brent J. Houston***

* BRANZ Ltd, Porirua City, New Zealand
e-mails: greg.baker@branz.co.nz, peter.collier@branz.co.nz

** University of Canterbury, Christchurch, New Zealand
e-mail: tony.abu@canterbury.ac.nz

*** Guardian Alarms, Christchurch, New Zealand
e-mail: brent@guardianalarms.co.nz

Keywords: Post-earthquake fires, Fire protection systems, Structural design, Fire sprinklers, Passive fire protection.

Abstract. *On Tuesday 22 February 2011, a 6.3 magnitude earthquake struck Christchurch, New Zealand's second largest city. The 'earthquake' was in fact an aftershock to an earlier 7.1 magnitude earthquake that had occurred on Saturday 4 September 2010. There were a number of key differences between the two events that meant they had dramatically different results for Christchurch and its inhabitants. The 22 February 2011 event resulted in one of New Zealand's worst natural disasters on record, with 185 fatalities occurring and hundreds more being injured. In addition, a large number of buildings either collapsed or were damaged to the point where they needed to be totally demolished. Since the initial earthquake in September 2010, a large amount of building-related research has been initiated in New Zealand to investigate the impact of the series of seismic events – the major focus of these research projects has been on seismic, structural and geotechnical engineering matters. One project, however, conducted jointly by the University of Canterbury, the Fire Protection Association of New Zealand and BRANZ, has focused on the performance of fire protection systems in the earthquakes and the effectiveness of the systems in the event of post-earthquake fires occurring. Fortunately, very few fires actually broke out following the series of earthquake events in Christchurch, but fire after earthquakes still has significant implications for the built environment in New Zealand, and the collaborative research has provided some invaluable insight into the potential threat posed by post-earthquake fires in buildings. As well as summarising the damage caused to fire protection systems, this paper discusses the flow-on effect for designing structures to withstand post-earthquake fires. One of the underlying issues that will be explored is the existing regulatory framework in New Zealand whereby structural earthquake design and structural design for fire are treated as discrete design scenarios.*

1 INTRODUCTION

When earthquakes occur, there are usually three key statistics quoted in the news media to characterise the event, namely the magnitude, the location (often referred to as the epicentre) and the depth of the earthquake below the earth's surface. It is generally the case that, the greater the magnitude, the closer the proximity of the epicentre, and the shallower the earthquake, then the greater the damage to buildings. The time of day that the earthquake occurs is also often quoted in news reports. While the former three parameters have a direct bearing on the damage that buildings will sustain and, indirectly, injuries and fatalities, the timing of an earthquake can have a dramatic bearing on the number of casualties.

The focus of this paper is the initial earthquake in the series, which occurred at 4.35 am on Saturday 4 September 2010, and a subsequent major aftershock, which occurred at 12.51 pm on Tuesday 22 February 2011. The September 2010 event had a magnitude of 7.1 and was centred 40 km to the west of the Christchurch central business district (CBD), near the rural town of Darfield, at a depth of 10 km. The aftershock in February 2011 had a magnitude of 6.3 and was centred 10 km south-east of the CBD near the port suburb of Lyttelton, at a depth of 5 km [1].

1.1 Darfield earthquake – September 2010

The key difference between the two seismic events was the proximity to the CBD area and, to a lesser extent, the depth of the earthquakes, which had a dramatic effect on the level of ground shaking that occurred. Earthquake ground shaking is measured in terms of acceleration, which is expressed as a proportion of the gravitational acceleration, g . In the September 2010 event, the impact was widespread and severe, but no major modern buildings collapsed and there was no loss of life. There was substantial damage to unreinforced masonry buildings in the CBD area, with the major hazard being falling masonry, but because of the time of day the earthquake occurred, there was no loss of life [1].

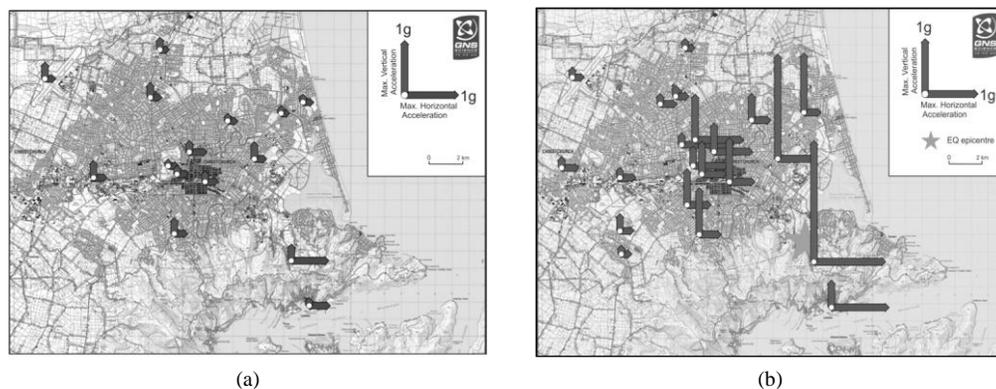


Figure 1. Peak ground accelerations: (a) September 2010; (b) February 2011 (courtesy GNS Science).

Figure 1(a) shows the horizontal and vertical peak ground accelerations (PGAs), which were recorded by a network of accelerometer measuring stations in and around Christchurch, for the September 2010 event. In the CBD area (shaded black in the centre of Fig. 1(a)), the PGAs are approximately 0.2–0.3 g .

1.2 Lyttelton aftershock – February 2011

In the February 2011 aftershock, severe damage occurred to buildings in the CBD and in eastern and southern suburbs. A large proportion of modern commercial buildings in the CBD area were significantly damaged, and many (older) unreinforced masonry buildings collapsed. At least two multi-storey buildings collapsed, and precast concrete stairs collapsed in at least four modern multi-storey buildings [1].

The vertical PGAs in the epicentral area were in the range 1.8–2.2 g – amongst the highest ever recorded in an urban area. The relatively short duration of the aftershock moderated the PGAs in the CBD area, where the vertical PGAs were in the range 0.5–0.8 g , as shown in Fig. 1(b). The horizontal PGAs near the epicentre exceeded 1.6 g , and in the CBD were between 0.4–0.7 g [1].

1.3 Seismic design

In a structural engineering context, buildings are designed to resist a combination of actions such as self-weight (dead), superimposed (live), snow, wind and earthquake loads. When these design actions are dominated by seismic forces, the building design is known as ‘seismic design’. Seismic loading is a low-likelihood/high-consequence scenario, and it is therefore uneconomic to design buildings for the maximum likely ground motion. Generally, therefore, buildings are designed to respond inelastically to

the ground motion but allowing sufficient ductility to prevent collapse [2]. Essentially this design approach seeks to prevent structural collapse, but accepting that significant, even irreparable, damage is likely to occur [1].

In New Zealand, buildings are designed in accordance with the seismic loadings standard [3], which is cited in the compliance document for New Zealand Building Code (NZBC) clause B1 *Structure* [4], using the limit state design method. The ultimate limit state (ULS) is achieved when there is a very low risk of: 1) structural collapse; 2) failure of parts or elements of the building that would be life threatening; or 3) failure of parts or elements whose function is critical for safe evacuation [5]. The annual probability of exceedance [6] for the ULS for a normal use building is 1/500 (500-year return period), i.e. these buildings are designed for earthquake ground shaking intensities expected to occur, on average, not more than once every 500 years [1]. For important buildings such as hospitals and the like, the corresponding threshold is 1/2500.

In Fig. 2, the elastic design spectrum (horizontal) from the seismic loadings standard [3] are shown for both a 1/500 event and a 1/2500 event for the ULS, as well as spectral accelerations (horizontal) for the February 2011 event from four measuring stations around the perimeter of the CBD area. It can be seen from Fig. 2 that, for normal use buildings in particular, the ground accelerations in and around the CBD exceeded the level required by the NZBC. The specific requirements in the seismic loadings standard to design for vertical acceleration are less stringent than the horizontal action. With regard to period, typical commercial/industrial buildings would be in the range 0.5–1.5 s.

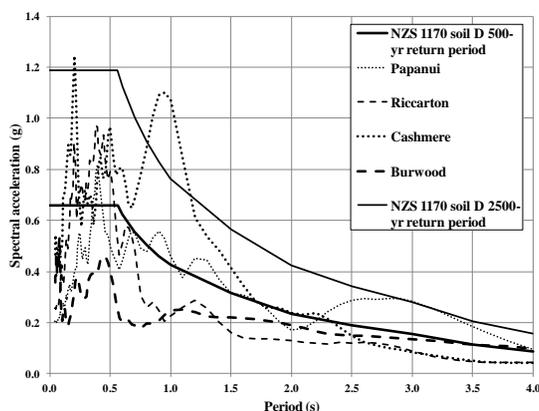


Figure 2. Design spectrum and recorded accelerations – February 2011 (recorded data courtesy GNS Science).

2 POST-EARTHQUAKE FIRES

Large fires in urban areas following earthquake are relatively rare events. The two largest post-earthquake fires in urban areas of the 20th century occurred in San Francisco, US, in 1906 and Kanto, Japan, in 1923 [7,8]. The 1906 San Francisco earthquake was magnitude 7.9, and there was a death toll of more than 3000 people. Eighty percent of the damage was due to fire, amounting to a burnt area of 12.2 km² and 28,000 buildings. In the 1923 Kanto earthquake, the magnitude 8.2 event resulted in 140,000 fatalities and a burnt area of 38.3 km² [7].

2.1 Northridge and Kobe earthquakes

In the later part of the 20th century, significant research has occurred in response to the post-earthquake fires that resulted from the 1994 Northridge (California), US, earthquake, as well as the Kobe (also known as the Great Hanshin or Great Hanshin-Awaji), Japan, earthquake in 1995 [7–13]. The two

earthquakes had a number of similarities such as magnitude, ground motions, affected population, time of day and season – the post-earthquake fire losses were quite different, however [9]. The Northridge earthquake was magnitude 6.7, and approximately 110 earthquake-related fires were reported, but relatively small post-earthquake fire losses occurred. The Kobe earthquake was magnitude 6.9, and approximately 200 (109 in Kobe City and 96 in cities other than Kobe) earthquake-related fires broke out, but the resulting damage was much more extensive [9–11].

In the Northridge earthquake, the majority of the earthquake-related fires occurred in the epicentral area of the San Fernando Valley [9,12]. Initially, the principal cause related to gas leaks [10,12], but subsequently, the major cause of ignition was electrical arcing as a result of short circuits [9]. In the Kobe earthquake, 43 percent of the total number of earthquake-related fires broke out within the first quarter hour and a further 42 percent in the next 4-hour period, with the balance of 15 percent over the remaining hours up until 24 hours after the event. In the initial quarter-hour period, the primary cause of ignition was due to gas leakage, but in subsequent hours, the primary cause of ignition was electrical as the electricity reticulation system was restored.

In the Northridge earthquake, between 1500 [13] and 3000 [9] leaks occurred to underground water reticulation pipes, while pump stations and storage tanks also sustained damage. This resulted in a shortage of firefighting water following the earthquake. Water tenders made up the shortfall, and also water was drawn from domestic swimming pools [9]. In the Kobe area, firefighting water was primarily supplied from the city water system. Seismic shut-off valves at reservoirs, for the purpose of conserving firefighting water in the event of earthquake, operated effectively, but approximately 2000 breaks in the reticulation system hampered the use of this water. The city also had approximately 1000 underground cisterns for disaster firefighting – in combination, these systems provided firefighting water for only 2–3 hours [9].

In the Northridge earthquake, virtually all earthquake-related fires were confined to the building of fire origin with only three instances of building-to-building fire spread in mobile-home parks [12]. All fires were brought under control within several hours of the earthquake [9]. The combination of light prevailing winds, building construction, building separation and Fire Service intervention were all contributory factors [12]. In contrast, in Kobe, major conflagrations occurred, and fires spread extensively. The response of the Fire Service was hampered by extreme traffic congestion, collapsed houses and buildings, and rubble in the streets, meaning that many areas had no vehicular access. Fire spread was via radiant heat and flame impingement between buildings, but because the wind was calm, the advance of fire fronts was slow. These factors, combined with the lack of firefighting water, resulted in damage to approximately 5000 buildings over a total estimated area of 1 km² [9].

3 PERFORMANCE OF FIRE PROTECTION SYSTEMS IN CHRISTCHURCH EARTHQUAKES

The recent earthquake series in Christchurch, New Zealand, has provided an opportunity to investigate the seismic resilience of fire protection systems. A collaborative research project involving the University of Canterbury, the Fire Protection Association of New Zealand (FPANZ) and BRANZ was therefore initiated in 2011 to investigate the performance of fire protection systems in the recent earthquake events. Although no significant fires occurred after the September 2010 and February 2011 earthquakes, very useful information was able to be gathered. In this context, the term ‘active fire protection’ relates to detectors, alarms and fire sprinkler systems, while ‘passive fire protection’ relates to items such as fire-rated compartmentation systems, fire doors, fire-stopping systems, fire-rated coatings on structural elements and the like.

3.1 Active fire protection systems

In the aftermath of both the September 2010 and February 2011 earthquakes, inspections of active fire protection systems were conducted in affected buildings in and around the city of Christchurch. With

regard to fire sprinkler systems, there are two main issues relevant to post-earthquake performance – whether the water supply had been disrupted and whether systems have been damaged.

In the Christchurch CBD, some sprinkler systems were required to have dual supplies due to the building height as a requirement of the automatic fire sprinkler standard [14] of the day. In most cases, the second supply was an additional independent connection to the mains water supply. In the September 2010 earthquake, water supply to the CBD area was temporarily disrupted but restored within a relatively short period of time. In the February 2011 event, however, the mains water supply to the CBD area suffered significant disruption. The most seriously affected central area (the ‘red zone’) was evacuated and more than a year later is still unoccupied as demolition work continues, and the water supply has not been restored. In commercial/industrial areas surrounding the red zone, the mains water supply took days or weeks to be restored.

In areas of the city away from the CBD and in surrounding rural areas, water tanks are often either the only water supply or form part of a dual water supply for fire sprinkler systems. Up until the 1980s, these tanks were mostly of concrete construction, and they generally performed well in the earthquakes.



Figure 3. Timber stave water tanks: (a) typical tank c. 1980s; (b) collapsed tank; (c) damaged tank (courtesy FPANZ).

In the 1980s and 1990s, the construction method was mostly timber stave tanks, with an example shown in Fig. 3(a). A significant number of the timber stave tanks were damaged and a number suffered catastrophic failures. In Fig. 3(b), a timber stave tank has collapsed, while in Fig. 3(c), the tank has moved sufficiently to pinch the bladder in the tank and release all the water.

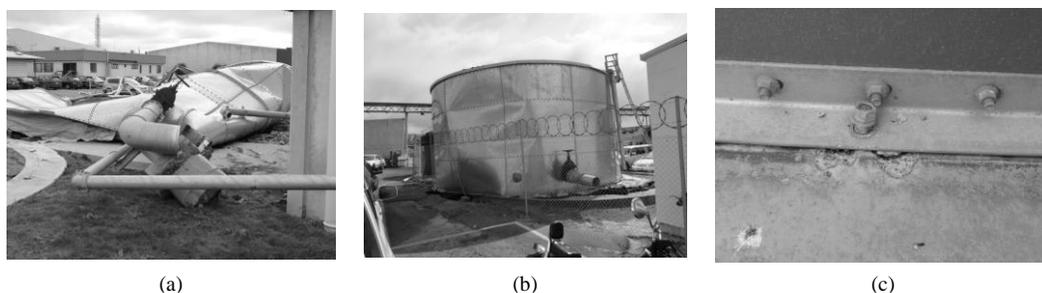


Figure 4. Steel water tanks: (a) collapsed tank; (b) damaged tank; (c) failed base fixings (courtesy FPANZ).

In the late 1990s, steel panel tanks became the norm. The performance of these tanks in the earthquakes was similar to the earlier timber stave tanks, with a collapsed steel tank shown in Fig. 4(a), a damaged tank in Fig. 4(b) and failed base fixings in Fig. 4(c).

A range of damage to fire sprinkler systems was observed following the 2010 and 2011 earthquakes in Christchurch. Some fire sprinkler systems require a booster pump to boost either the town’s main reticulation or tank supplies. In a number of cases, the basements where these pumps are generally housed

were flooded, and the pumps were rendered inoperable. In Fig. 5(a), the water level is shown in the foreground on a column, which submerged the booster pump system in the background.



(a)



(b)

Figure 5. Sprinkler system damage: (a) flooded basement; (b) collapsed ceiling (courtesy FPANZ).

Figure 5(b) shows a suspended ceiling where the lining has collapsed – in a number of cases, damage to sprinkler systems was observed where non-structural components and systems had collapsed, but in the centre of Fig. 5(b), the sprinkler head has actually remained operable.

In a number of cases, the roof cross-bracing in low-rise commercial buildings caused damage to sprinkler fittings. Figure 6(a) shows sprinkler heads that have been sheared off as steel angle cross-bracing has moved backwards and forwards in response to the cyclic earthquake ground motion, while Fig. 6(b) shows damage to sprinkler pipework due to vertical movement of steel cross-bracing ‘pounding’ the pipework.



(a)



(b)

Figure 6. Sprinkler component damage: (a) sprinkler heads sheared off; (b) pipe work damage (courtesy FPANZ).



(a)



(b)

Figure 7. Sprinkler systems: (a) pipework support; (b) collapsed racking system (courtesy FPANZ).

The 1996 edition of the automatic fire sprinkler systems standard introduced requirements for seismic design of sprinkler systems, and as a result, modern pipe systems performed well in the 2010/2011 earthquakes, as shown in Fig. 7(a). A number of racking systems collapsed in the earthquakes, and where in-rack sprinkler systems were present, these also suffered damage, as shown in Fig. 7(b).

Whereas only some types of commercial/industrial buildings require sprinkler systems, the vast majority require a fire alarm system. The most obvious issue identified during the course of the research related to alarm system cable routing. It was apparent that very little, if any, attention had been paid to the consequences of seismic movement of buildings when installing fire alarm cabling. Damage was observed where cabling passed through holes in or around cut edges of structural and secondary steelwork. Another example of damage to alarm cabling was where cyclic movement of building elements such as concrete tilt-up wall panels crushed cabling, as shown in Fig. 8.



Figure 8. Crushed alarm cabling (courtesy FPANZ).

Although very few fires actually occurred in both the September 2010 and February 2011 earthquakes, 600 and 450+ ‘fire’ notifications respectively were received from fire protection systems connected to the NZ Fire Service. (Note: the actual number of fire alarm notifications in February 2011 was probably significantly higher, but the serious damage affected the alarm transportation network.) These figures related to systems signalling a ‘fire’ condition, but the instances of other off-normal notifications from the respective systems increased this number to approximately 10,000.

3.2 Passive fire protection systems

Following the February 2011 earthquake, a series of inspections of passive fire protection systems in buildings were carried out. In some buildings, the damage had been so extensive that the passive fire protection was destroyed. The focus of the investigation was on damage in the low-to-medium range, i.e. where the building was structurally safe but where damage to passive fire protection had occurred, so that the impact of earthquake actions on passive fire protection could be quantified.

Fire doors were one area of focus for the site inspections, with a range of damage being observed. In Fig. 9(a), the gap down the door jamb has increased from 2–3 mm originally to 4–16 mm after the earthquake, while Fig. 9(b) shows damage to the fire-rated lining at the head of the door and Fig. 9(c) shows a 7 mm gap between the lining and door frame.

In a number of instances, damage to fire-rated walls was observed, as shown in Fig. 10. Figure 10(a) shows fire-rated lining having separated from the framing, Fig. 10(b) shows a wall-to-wall internal corner junction where a 15 mm gap has opened up in a fire-rated escape stairwell, and Fig. 10(c) shows the underside of a precast concrete stair where the junction to the fire-rated wall beneath has been crushed by earthquake-induced motion.

Inspection of concrete tilt-up wall panels in low-rise industrial buildings showed separation of fire-rated sealant joints, as shown in Fig. 11(a)–(c), increasing the risk of fire spread to neighbouring properties.

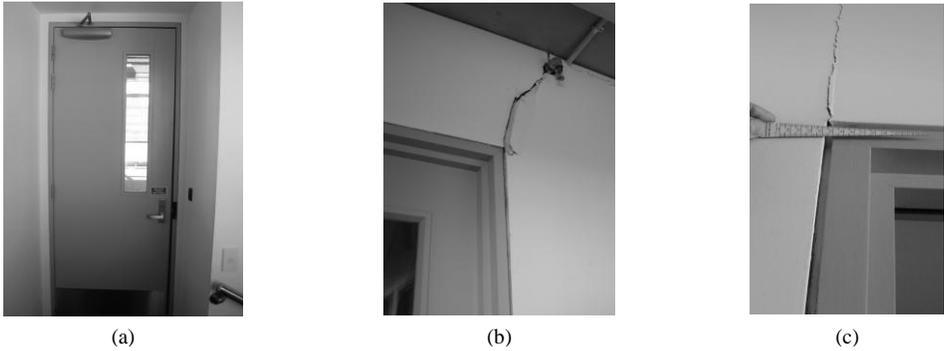


Figure 9. Fire door damage: (a) gap around door leaf; (b) diagonal crack; (c) gap between frame and lining.

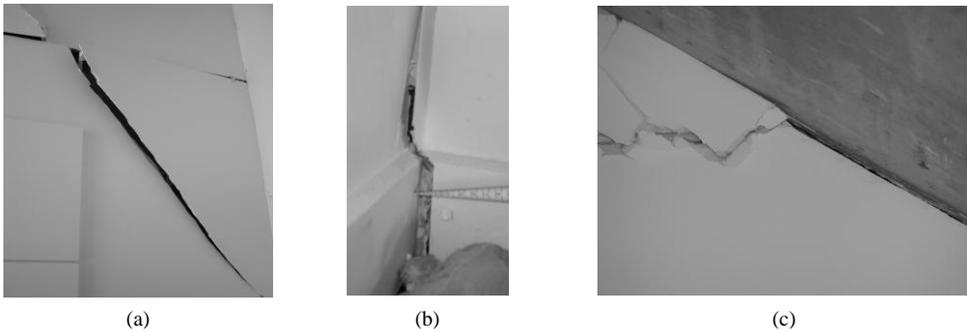


Figure 10. Compartmentation damage: (a) fire-rated wall; (b) stairwell; (c) stair soffit.

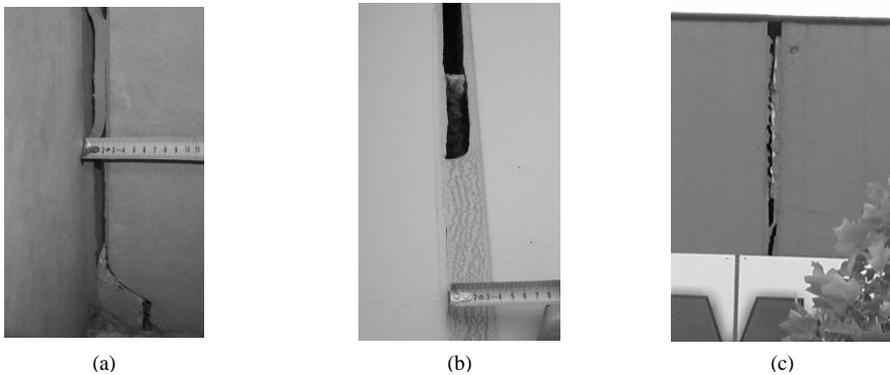


Figure 11. External walls: (a) wall corner junction; (b) wall panel butt joint; (c) wall panel butt joint.

4 STRUCTURAL DESIGN FOR FIRE

In New Zealand, there is a heavy reliance on fire sprinklers as part of the fire safety strategy in buildings. Based on very high levels of historic reliability [15] and comprehensive procedures for design, certification, inspections and maintenance, dispensations are given to the level of passive fire protection

systems when fire sprinklers are present. In many situations, a 50 percent reduction is permitted, for example, if a 2-hour fire resistance rating is required without sprinklers, a 1-hour rating is permitted when sprinklers are present [16].

In the February 2011 earthquake in particular, the municipal water supply was seriously disrupted. At the same time, approximately 40 percent of water tanks for supplying sprinkler systems were damaged – primarily timber stave and steel tanks of large diameter and volume. This would have meant that, if post-earthquake fires had broken out, the majority of sprinkler systems would have had no water supply, and the systems would have been largely ineffective.

The fire dynamics of post-earthquake fires is also likely to be different to typical fires in that the fuel is likely to be spread over a wider area, item-to-item fire spread is likely to be more rapid and glazing is likely to have been broken by the earthquake, thus providing additional ventilation. At the same time, compartmentation is likely to have been breached, thus allowing the fire to spread more rapidly to involve fuel that otherwise would not become involved so soon. In addition, there is likely to be a significantly reduced Fire Service response.

These factors in combination mean that earthquake-induced fires are likely to grow more quickly to high levels of heat output, i.e. have a greater severity, and have a longer duration. Where reductions in passive fire resistance ratings have also occurred, based on sprinkler systems being present, structural elements are likely to have to endure fire exposures that are of greater severity and for significantly longer periods of time than the elements were designed to withstand.

At the same time, it is also likely that passive fire protection to the member has been damaged. For reinforced concrete sections, the concrete cover, which provides passive fire protection to the steel reinforcing bars, is likely to have been badly damaged, exposing reinforcing, particularly in plastic hinge zones. For structural steel members, examples were observed during inspections where protective coatings had been damaged by earthquake-induced movement. In a general sense, structural elements in buildings that have been subjected to a design-level earthquake are going to have suffered significant damage, which weakens the members. This means that the structure of buildings is more vulnerable to fire-induced collapse than would be the case in non-earthquake fires.

The recommendation is that changes to two aspects of current practice be considered by the building regulator:

1. A sliding scale of reduction in fire resistance ratings when sprinklers are present be applied, i.e. a 50 percent reduction in areas of lowest seismic risk, up to 0 percent in areas of highest seismic risk.
2. Design fire scenarios, commensurate with the seismic zoning, where compartmentation has failed and egress routes compromised, thus becoming more onerous from an evacuation perspective, become mandatory

5 CONCLUSIONS

The fact that no significant fires occurred after the September 2010 and February 2011 earthquakes was due to a number of factors such as the time of day (reduced ignition sources from cooking), the time of year of the February earthquake being summertime (no ignition sources from space heating), and the low level of reticulated gas in Christchurch. Active fire protection systems still have an important role to play in post-earthquake fire safety. Therefore, in addition to the recommendations presented in Section 4 relating to structural design for fire, a number of relevant conclusions can still be drawn about the post-earthquake performance of active fire protection systems, based on the research reported in this paper:

1. Alternative strategies need to be considered to ensure the sprinkler water supply from in situ tanks is more reliable in the event of earthquakes and consideration needs to be given to retrospective upgrading based on individual risk assessment.
2. Alternatives to dual mains supply for existing sprinkler systems need to be considered (now not permitted by the 2007 edition of the automatic fire sprinkler standard).
3. Fire pump systems need to be installed so as to minimise the risk from basements flooding.

4. Trade practice with regard to routing of fire alarm cabling needs to be improved.
5. The seismic resilience of non-structural components and systems generally needs to be reviewed.

REFERENCES

- [1] New Zealand Government, “Technical Investigation into the Structural Performance of Buildings in Christchurch – Final Report”, Department of Building and Housing (DBH), Wellington, New Zealand, 2012.
- [2] Dhakal, R.P., “Report to the Canterbury Earthquake Royal Commission – Structural Design for Earthquake Resistance: Past, Present and Future”, University of Canterbury, Christchurch, New Zealand, 2011.
- [3] NZS 1170.5:2004, “Structural Design Actions Part 5: Earthquake Actions – New Zealand”, Standards New Zealand (SNZ), Wellington, New Zealand, 2004.
- [4] New Zealand Government, “Compliance Document for New Zealand Building Code Clause B1 Structure (Amendment 11)”, DBH, Wellington, New Zealand, 2011.
- [5] NZS 1170.5 Supp 1:2004, “Structural Design Actions Part 5: Earthquake Actions – New Zealand – Commentary”, SNZ, Wellington, New Zealand, 2004.
- [6] AS/NZS 1170.0:2002, “Australian/New Zealand Standard – Structural Design Actions Part 0: General Principles”, SNZ, Wellington, New Zealand, 2002.
- [7] Scawthorn, C., “Fire Following Earthquake”, *Fire Safety Science – Proceedings of the First International Symposium*, IAFSS, 971–979, 1984.
- [8] Borden, F.W., “The 1994 Northridge Earthquake and the Fires that Followed”, Thirteenth Meeting of the UJNR Panel on Fire Research and Safety, Vol. 2, NISTIR 6030, K.A. Beall (ed.), National Institute of Standards and Technology (NIST), Gaithersburg, MD, US, 303–312, 1997.
- [9] Scawthorn, C., “Fires Following the Northridge and Kobe Earthquakes”, Thirteenth Meeting of the UJNR Panel on Fire Research and Safety, Vol. 2, NISTIR 6030, K.A. Beall (ed.), NIST, Gaithersburg, MD, US, 325–334, 1997.
- [10] Sekizawa, A., “Post-Earthquake Fire and Performance of Firefighting Activity in the Early Stages in the 1995 Great Hashin Earthquake”, *Fire Safety Science – Proceedings of the Fifth International Symposium*, IAFSS, 971–982, 1996.
- [11] Hokugo, A., “The Performance of Fire Protection of Buildings Against the Fires Following the Great Hanshin-Awaji Earthquake”, Thirteenth Meeting of the UJNR Panel on Fire Research and Safety, Vol. 2, NISTIR 6030, K.A. Beall (ed.), NIST, Gaithersburg, MD, US, 313–323, 1997.
- [12] Evans, D.D, Walton, W.D., and Mowrer, F.W., “Progress Report on Fires Following the Northridge Earthquake”, Thirteenth Meeting of the UJNR Panel on Fire Research and Safety, Vol. 2, NISTIR 6030, K.A. Beall (ed.), NIST, Gaithersburg, MD, US, 273–281, 1997.
- [13] Ballantyne, D.B. and Crouse, C.B., “Reliability and Restoration of Water Supply Systems for Fire Suppression and Drinking Water Following Earthquakes”, NIST GCR 97-730, NIST, Gaithersburg, MD, US, 1997.
- [14] NZS 4541:2007, “Automatic Fire Sprinkler Standard”, SNZ, Wellington, New Zealand, 2007.
- [15] Marriott, H.W., *Fire A Century of Automatic Sprinkler Protection in Australia and New Zealand 1886–1986* (2nd ed.), Australian Fire Protection Association, Melbourne, Victoria, Australia, 90, 1988.
- [16] New Zealand Government, “Compliance Document for New Zealand Building Code Clauses C1, C2, C3, C4 Fire Safety (Amendment 9)”, DBH, Wellington, New Zealand, 109, 2011.