A RECONNAISSANCE REPORT

ON

THE DARFIELD (NEW ZEALAND) EARTHQUAKE OF SEPTEMBER 4, 2010

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On the behalf of JSCE
Earthquake Disaster Investigation Committee

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CONTENT

1 Introduction

An earthquake with a magnitude of 7.0 occurred near Darfield in Canterbury region in the South Island of New Zealand at 4:36 AM on New Zealand Standard Time on September 4, 2010. The city of Christchurch, New Zealand, and surrounding areas were heavily shaken. It is the most damaging earthquake in New Zealand since the Hawke's Bay earthquake in 1931, but there has been no loss of life. The earthquake occurred on an unknown fault. Although the earthquake was quite strong and happened in a populated region, two people were only injured. However, extensive ground liquefaction was observed in the city of Christchurch and Kaiapoi, causing extensive damage to buried lifelines and residential houses.

Figure 1: Location of the earthquake epicenter

2 Geography

The epicenter of the earthquake was near Darfield in the Canterbury Region of the South Island of New Zealand. The Canterbury Plains are flatlands between the Southern Alps and the Pacific Ocean. They were created as rivers running out of the mountains at the end of the last ice age.

The nearest town to the epicenter is Darfield with a population of 3000. Christchurch, which is about 40 km to the east of the epicenter, has a population of 360,000 people. The population of the earthquake-affected area is about 440,000 people.

There are three major rivers, named as Waimakariri, Selwyn and Rakaia. Waimakariri River pass through Kaiapoi and reaches sea at Kairaki. There are small rivers and creeks. Particularly the Avon River, which passes through Christchurch, has a great influence on the ground conditions of Christchurch City.

The foothills of Southern Alps High exist to the northwest of Darfield. There are remnants of two extinct overlapping volcanoes to the south of Christchurch. These extinct volcanoes belong to Miocene age and they are named remnants of Lyttelton in the northwest and Akaroa in the southeast. This area named as Bank Peninsula.

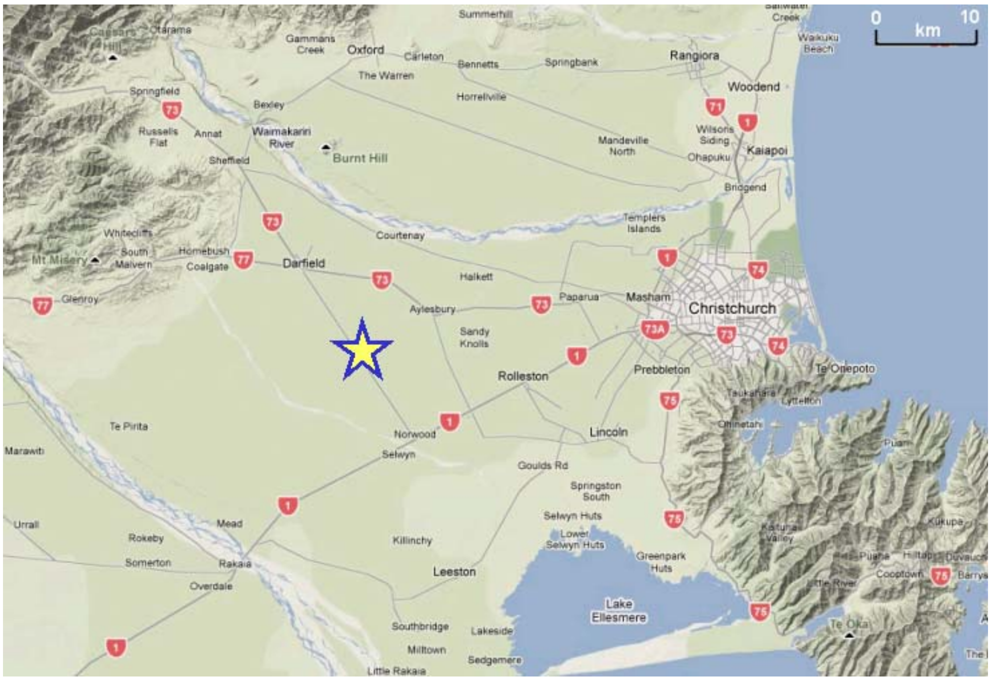


Figure 2. Topography of the epicentral area (base map from Google)

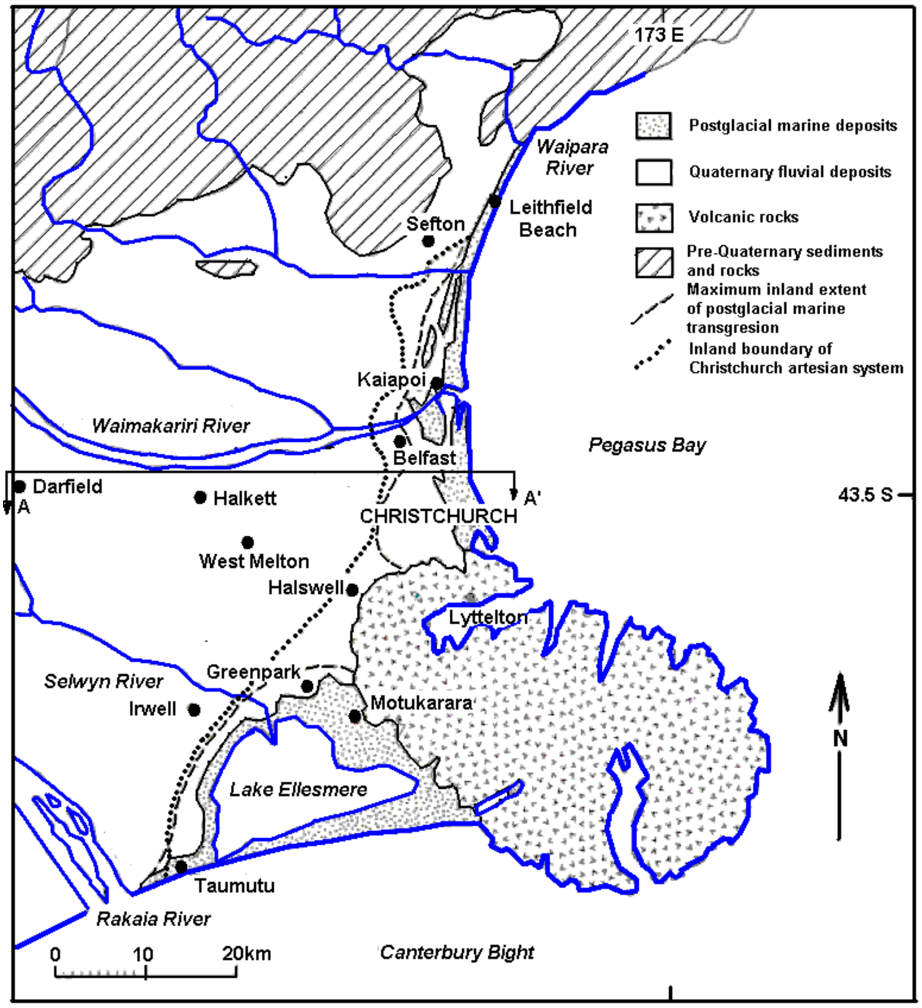
3 Geology

Forsyth et al. (2008) described the geology of the area in detail. The basement rock of is a deformed package of Carboniferous to Cretaceous sedimentary and metasedimentary rocks accreted to the Gondwanaland margin. The constituent Rakaia and Pahau terranes occur in the Christchurch map area, together with the Esk Head belt that is interpreted as a tectonic suture between the two. The only schistose rocks in the map area occur on northern Chatham Island. The greywacke islets of The Forty Fours are the easternmost emergent land of New Zealand.

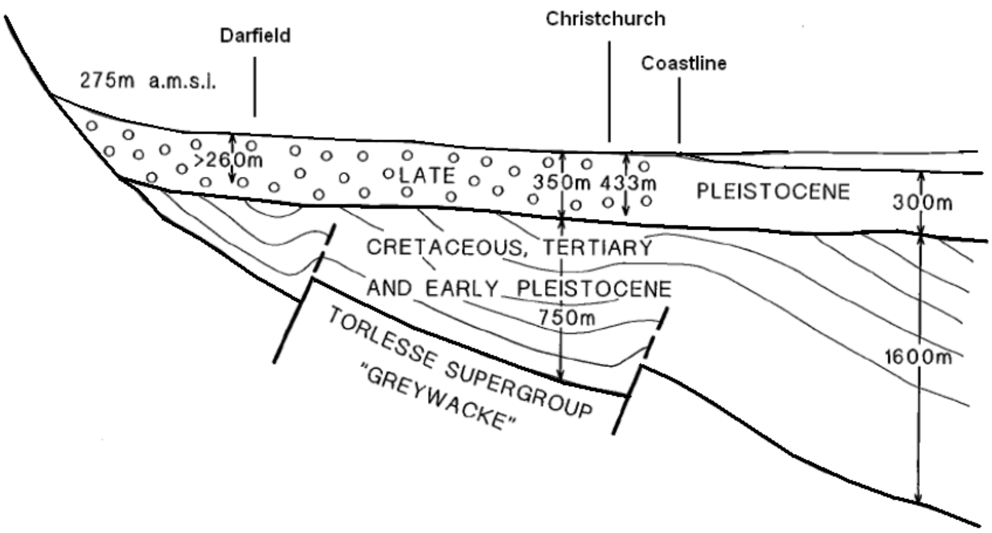
Most of the population centres are situated on alluvial plains. To the east, the Canterbury Plains abut the eroded volcanic massif of Banks Peninsula. Mid-Cretaceous volcanic, shallow intrusive and sedimentary rocks occur locally in the Canterbury foothills, beneath the Canterbury Plains, on Banks Peninsula and on the Chatham Islands.

The vast expanse of the Canterbury Plains comprises coalesced floodplains. Deposits of scree, consisting of unsorted angular blocky rock debris, and colluvium, comprising rock debris, sand or silt, are widespread in upland areas of Canterbury, including Banks Peninsula. Alluvial deposits consist of gravel, sand and silt, which have been laid down by rivers and streams. Compactness of the deposits generally increases with age. Late Holocene beach gravel and sand ridges are most extensive at Kaitorete Spit but are also mapped around Lake Ellesmere and at the heads of some bays on Banks Peninsula. Active gravel and sand beaches are wide enough to depict on the map in parts of Canterbury Bight, Pegasus Bay and in Hanson Bay on Chatham Island. Sandy deposits are found particularly in the vicinity of smaller rivers such as Avon River. The near-surface soils underlying Christchurch consist of clean and silty sands, with a high water table saturating these soils.

Post-glacial sea-level rise drowned the interfluve between the Rakaia and Waimakariri gravel plains, forming the Lake Ellesmere embayment. Initially an inlet of the sea, the embayment was progressively enclosed by growth of Kaitorete Spit. Kaitorete comprises beach gravel and sand transported by longshore drift northeast from the rivers and eroding coastline of the Canterbury Bight. Broad gravel ridges nearly parallel to the present coast dominate the barrier. A series of curved ridges at its inner margin formed during earlier phases of its evolution.



(a) Geology



(b) Cross-section along A-A’

Figure 3: A geologic map of Christchurch and its close vicinity

4 Tectonics and Crustal Straining

New Zealand is located along the boundary between the Indian-Australian and Pacific tectonic plates, which presents a significant seismic hazard to the Canterbury region. The two plates slip past each other in the South Island along the Alpine Fault having a dextral sense of slip. The Alpine Fault produces earthquakes with a magnitude greater than 8, having recurrence intervals of a few hundred years. This fault is located approximately 120km from Christchurch.

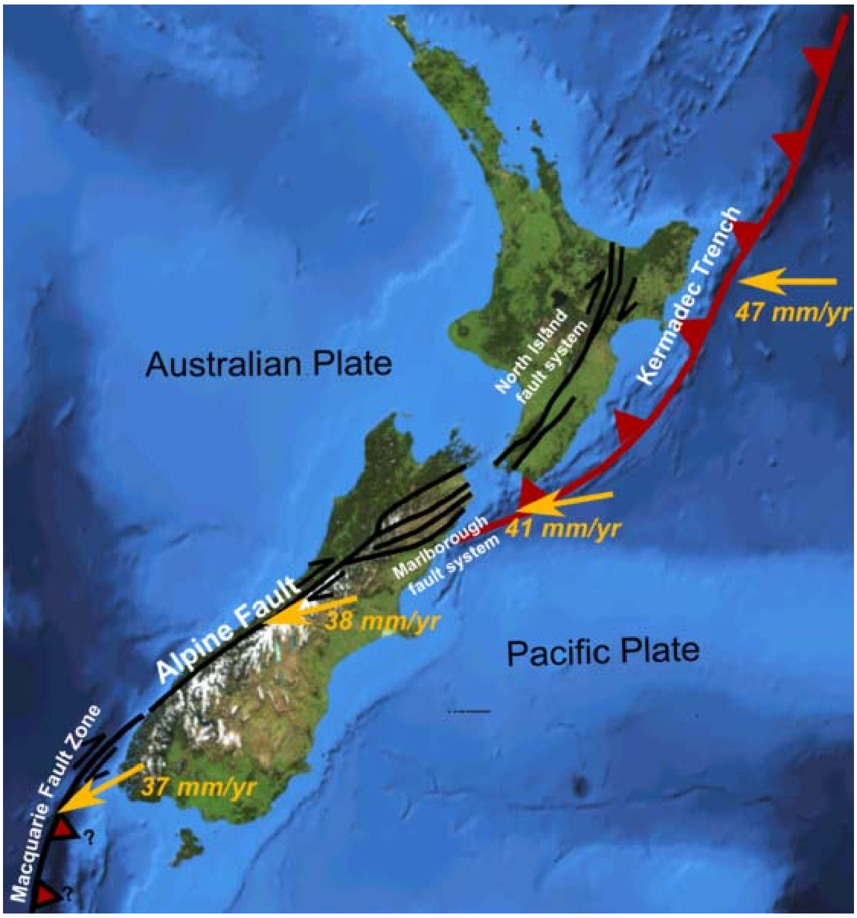


Figure 4: An illustration of plate tectonics model of New Zealand (from Wikipedia)

Figure 5 shows the active faults in the vicinity of Christchurch. The active faults mapped by GNS did not indicate the existence of any active fault in the epicentral area. In other words, the earthquake was induced by an unknown fault. The earthquake fault with surface rupture and its estimated extensions are also shown in Figure 5. The surface ruptures in the Porrit Park may also imply the extension of the fault beneath Christchurch.

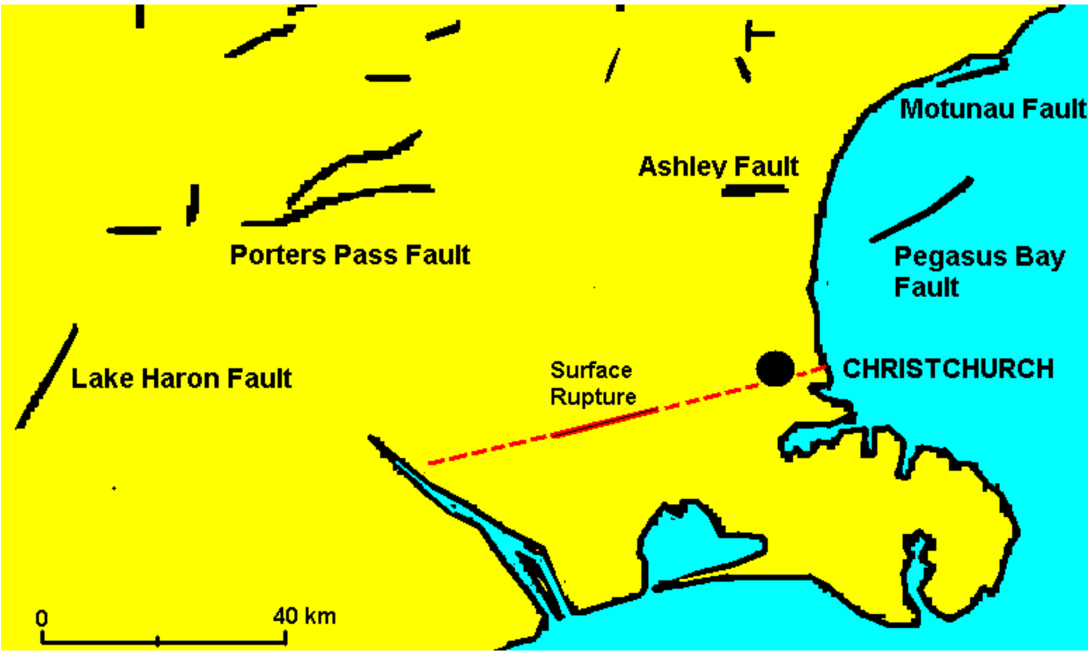


Figure 5: Active faults in the vicinity of Christchurch together with the earthquake fault

The crustal shortening is estimated to be 70 km in the central part of the collision zone, mostly accommodated by overriding of the Australian plate by the Pacific plate. Another consequence was the rise of the crust that underlies the Southern Alps, giving birth to the present mountain range. It is estimated that during that time total uplift may have been in excess of 20 km. However, due to high rates of erosion the maximum altitude of the Southern Alps may never have been higher than at present (3750 m).

Crustal straining rate of New Zealand have been evaluated using the deformation rates obtained from the GPS measurements. Figure 6 show the mean strain rate and maximum shear strain rate for 2003 (GNS). These evaluations do not indicate any anomaly in the epicentral area of the 2010 Darfield earthquake.

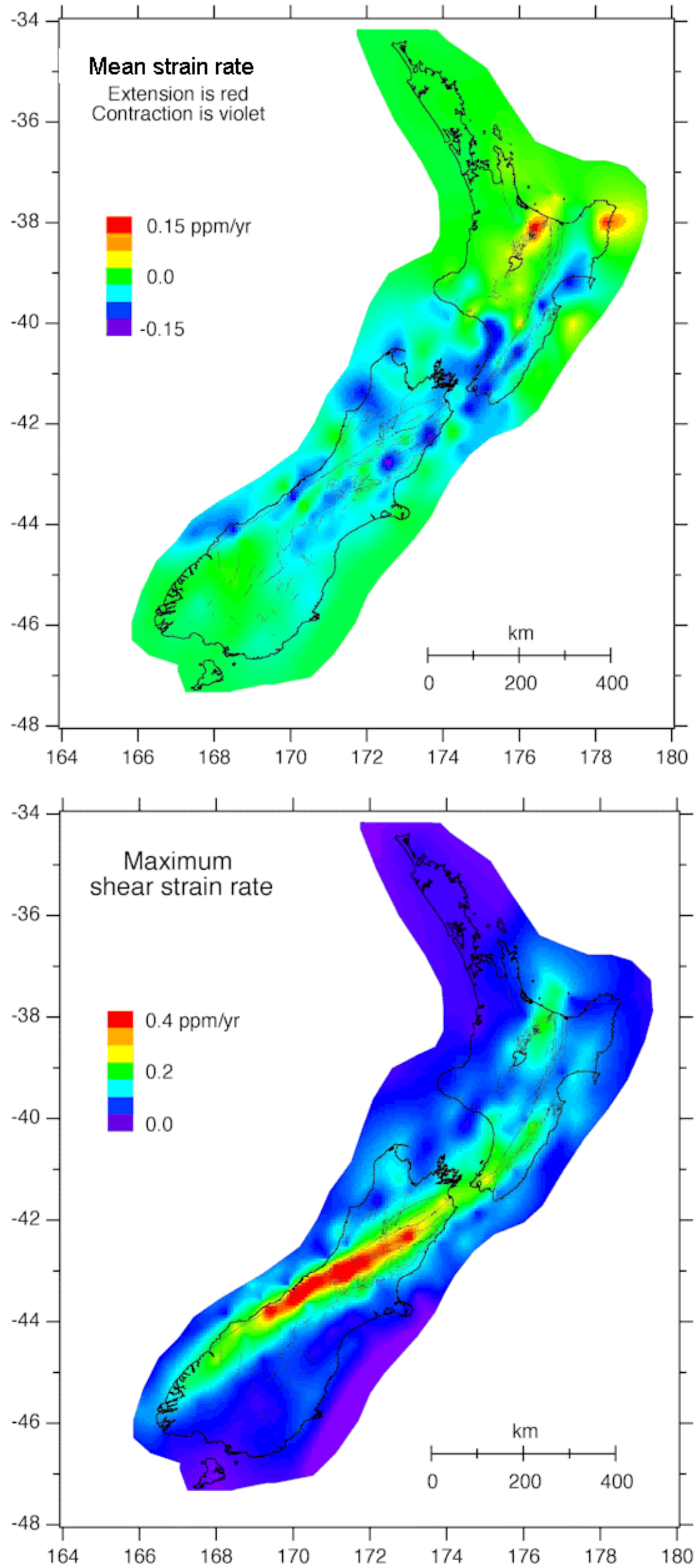


Figure 6: Mean and maximum shear strain rates for 2003 (from GNS)

5 Sesimcity

5.1 Seismicity of New Zealand

The instrumental seismicity of New Zealand has been studied by Anderson and Webb (1994). Figures 7 and 8 show the shallow seismicity and deep seismicity of New Zealand for the last 10 years, respectively. As noted from Figure 7 shallow seismicity occur mainly in the close vicinity of the Indo-Australian and Pacific plate boundary. However, the seismicity activity is scarce in the close vicinity of Christchurch. The high seismic activity is observed to the North of Christchurch.

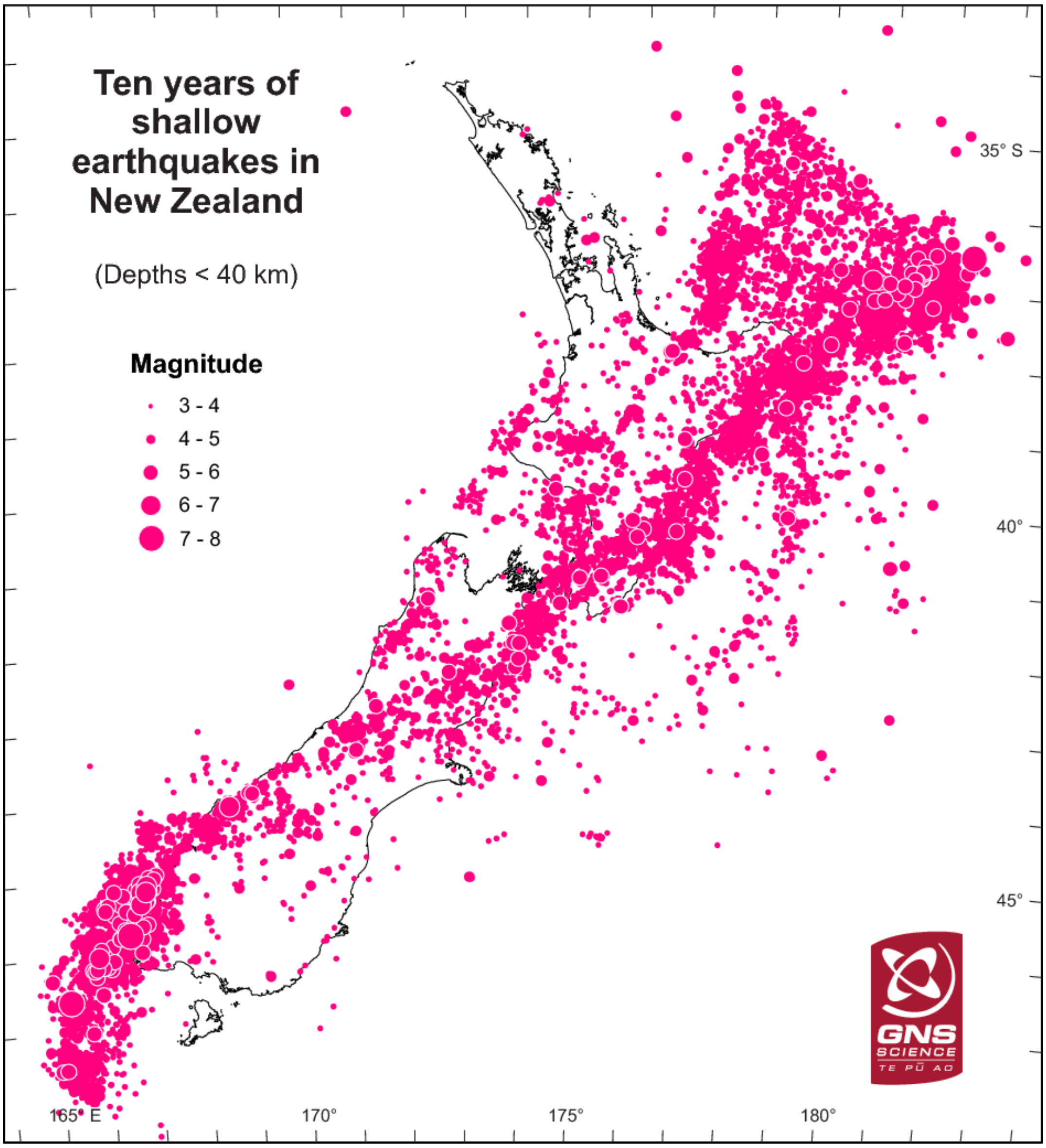


Figure 7: Shallow seismicity of New Zealand (from GNS)

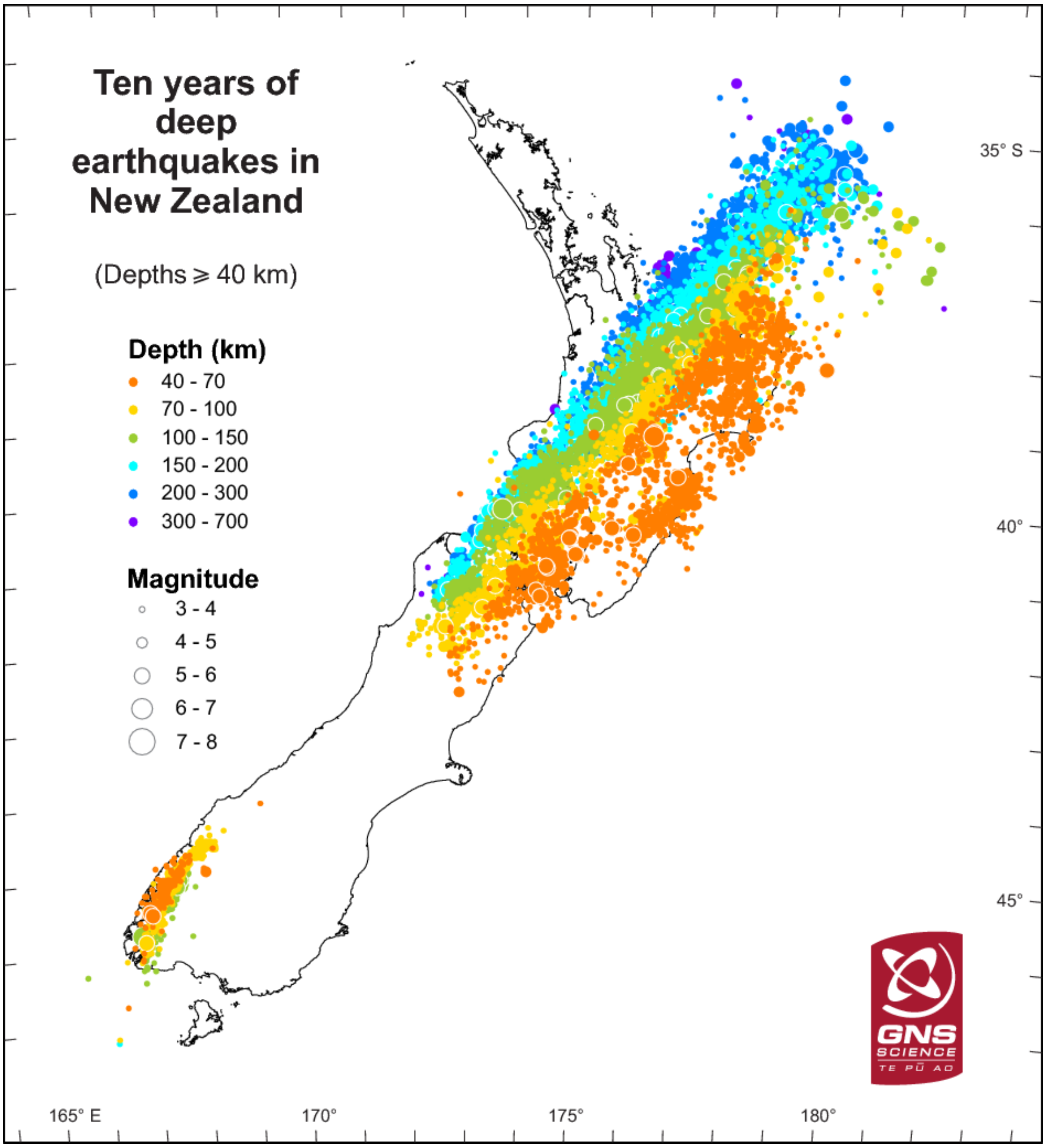


Figure 8: Deep seismicity of New Zealand (from GNS)

It is interesting to note a seismically quite section exist along the Alpine Fault in the South Island, which extends from Harihari to Jackson Bay. A band of earthquakes lying to the east of the fault north of Harihari may represent activity associated with the Alpine Fault at depth although this cannot be confirmed by existing data.

5.2 Pre-Post seismicity of Epicentral Area

Using the data released by the GEONET of New Zealand, the authors plotted pre-post seismicity of the epicentral area in Figure 9. Although several small earthquakes occurred in the epicentral area, the major seismic activity occurred after the September 4, 2010 event. As noted from the figure, the long and short axes of the ellipse of seismic active range between 60-70 km and 15-20 km, respectively. The seismic activity also implies an en-echelon activity of several faults rather than a single long segment. It is also interesting to note that there was no fore-shock before the main shock.

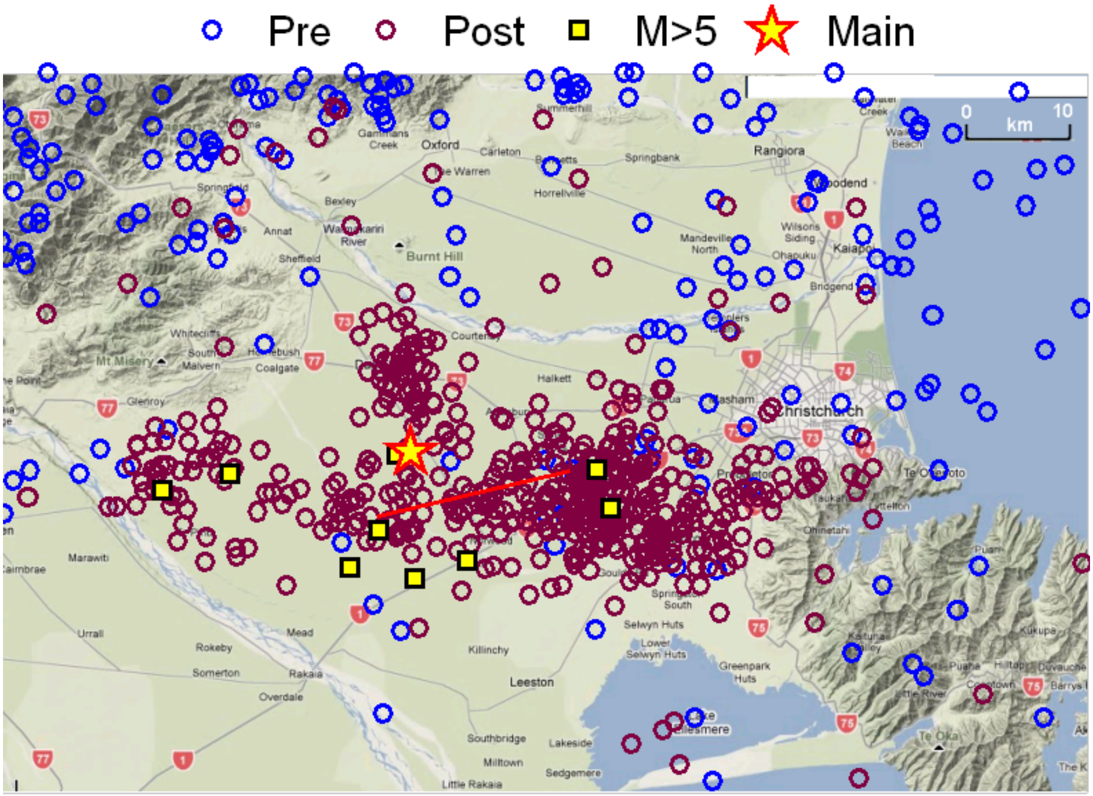


Figure 9: Pre-post seismicity of the epicentral area

Figure 10 shows the time series of magnitude and cumulative magnitude of the earthquakes in the area bounded by longitudes 171.5-173 and latitudes 43.25 – 44 S since 1940 using the data released by the GEONET of New Zealand. There are some seismic activities in 1989 and 1994. However, these seismic activity occur to the north of Christchurch. The cumulative magnitude following the M7.1 2010 event is almost equal to that since 1940. However, it is interesting to note that the cumulative magnitude was linearly increasing before the earthquake.

Figure 11 shows the variations of magnitude and cumulative magnitude with time. As expected, the cumulative magnitude would eventually become asymptotic to a certain value. Nevertheless, its overall increase tendency is step-wise with decreasing amplitude.

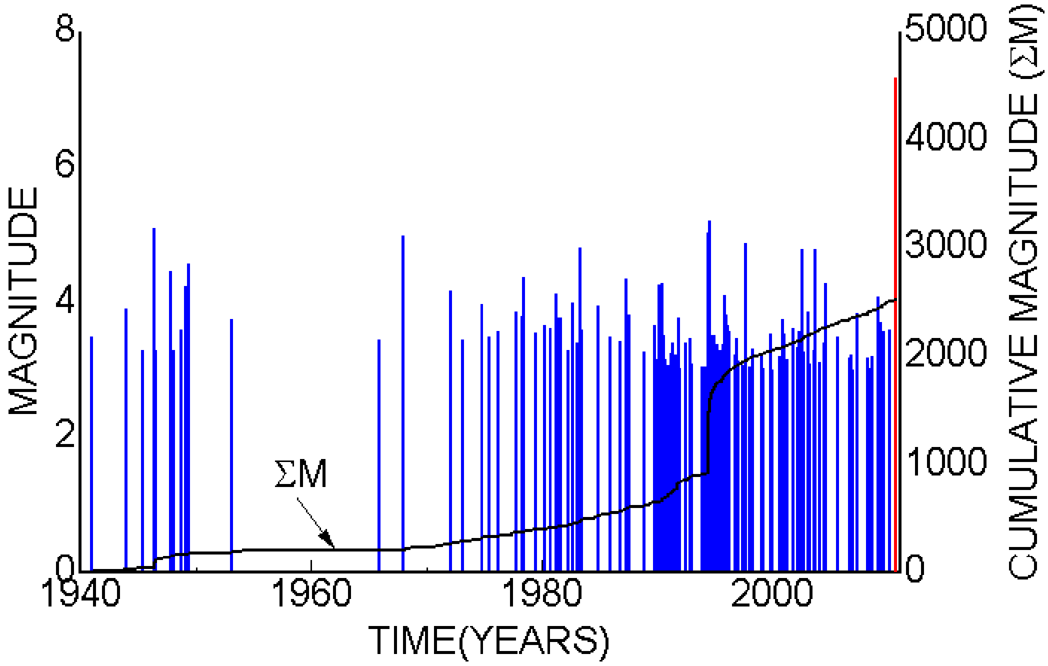


Figure 10: Time series of magnitude and cumulative magnitude in the epicentral area

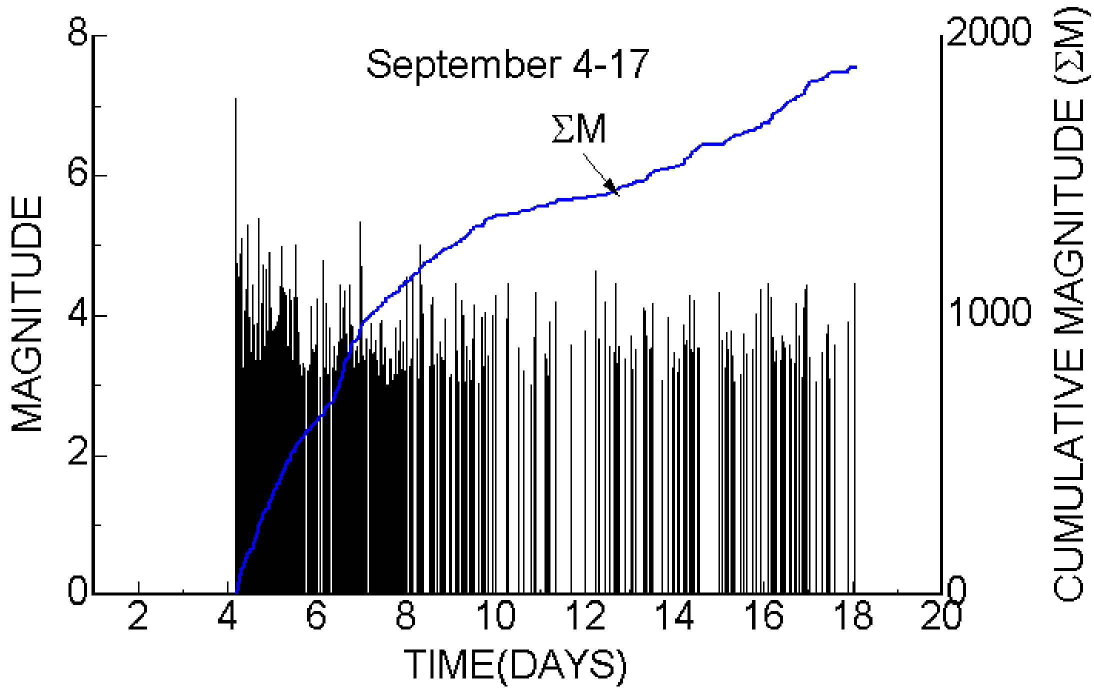


Figure 11: Time series of magnitude and cumulative magnitude in the epicentral area during the post-seismic activity between September 4 and 17, 2010

6 Characteristics of the Earthquake

The fundamental parameters of 2010 Darfield earthquake are determined by various seismological institutes worldwide and the results are summarized in Table 1. The estimations indicated that the earthquake was caused by a dextral strike-slip fault of 60-70km long (Figure 9). Although the estimated rupture duration estimated to be about 40 seconds, most of the energy release occurred within 18 seconds. The parameters measured by the reconnaissance team of the earthquake fault (Figure 12) are given in Table 1. It was particularly interesting to note that the parameters of the earthquake fault observed at several locations were almost the same as those of focal plane solutions estimated by several seismological institutes. Figure 13 shows the stress state and faulting mechanism of the earthquake inferred from observations using the method of Aydan (2000).

Table 1: Parameters of the earthquake estimated by different institutes

Institute	Latitude	Longitude	Depth (km)	Magnitude	Strike	Dip	Rake
HARVARD	43.57 S	172.12 E	12	Mw=7.0	NP1 88^o NP2 179^o	87^o 82^o	172^o 3^o
USGS	43.51 S	171.91 E	10	Mw=7.0	NP1 268^o NP2 178^o	87^o 77^o	166^o 3^o
ERI-TU	-	-	10	Mw=7.0	NP1 94^o	71^o	175^o
JSCE RT					257	90	180

Table 2 Rupture and slip characteristics of the earthquake fault

Reference	Magnitude	Length(km)	Slip(m)	Area(km^2)	Vr(km/s)	Tr (s)
USGS	7.0	50	2.4	50x24	2.94	17.0
ERI-TU	7.0	50	1.40	50x20		
HARVARD	7.0					14.8
Aydan (strike-slip-ssf)	7.0*	64	1.79	64x16	3.0	21.3

(* chosen)

Fault rupture propagation was inferred by various institutes and some of them listed in Table 2. The slip distributions inferred by USGS and ERI-TU. The estimation of amount of slip and fault length are generally less than 2.0 m and 50 km. The estimations for a

Mw=7.0 earthquake from the empirical relations by Aydan (2007), the slip and fault length are obtained as 1.79 m and 64 km, respectively.

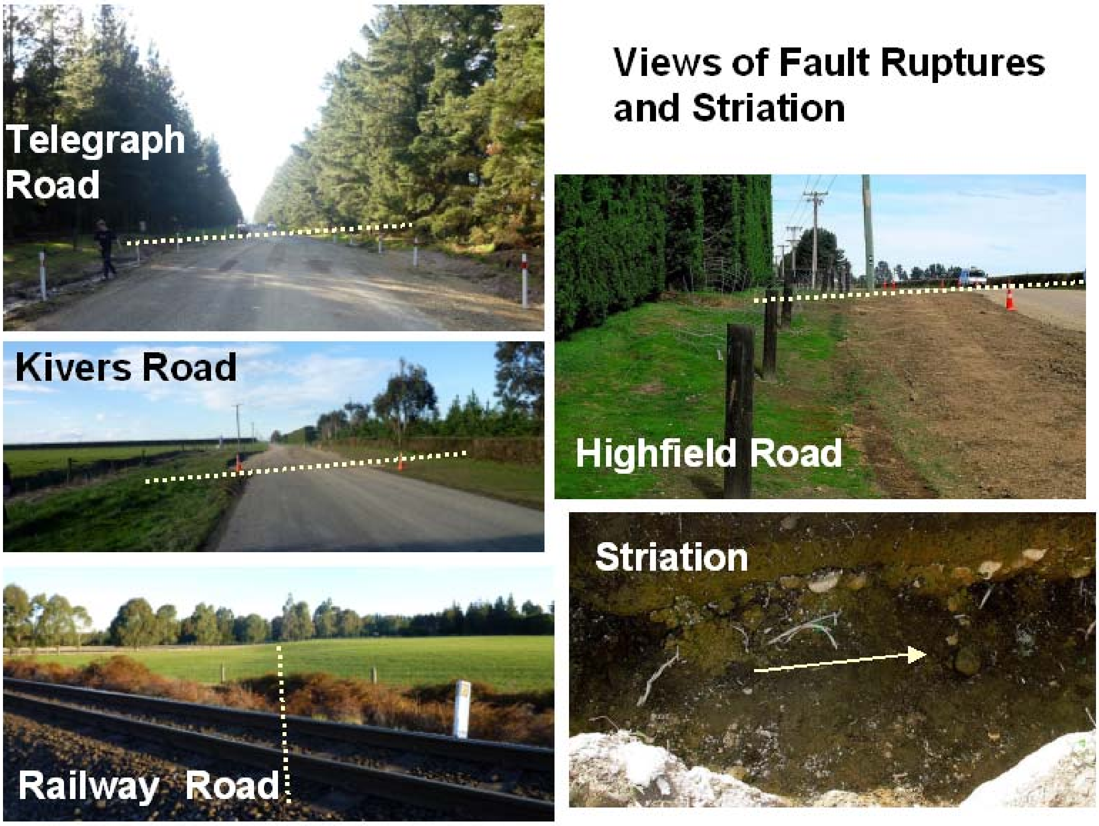


Figure 12: Views of faulting and striation

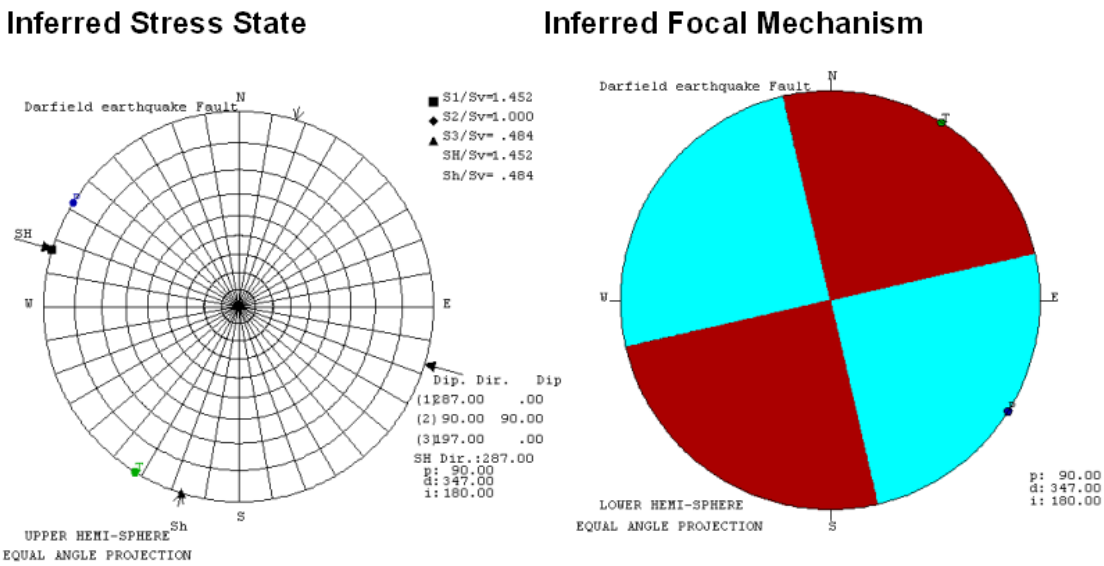


Figure 13: The stress state and focal mechanism of the earthquake inferred from Aydan's method

The maximum slip of the earthquake fault, named as Glendale fault recently by GNS, was 4 m with an average slip of 2 m. The observed surface rupture was 24 km while the aftershock activity was distributed over a length of 60-70 km.

7 STRONG GROUND MOTIONS

The epicentral area is well instrumented by two networks of strong ground motion (GNS and CU-. The data from strong ground motions were publicaly available to the earthquake engineering community. The maximum horizontal ground acceleration and velocity were 0.772g and 100 kines at Grendale station of the GNS network (Figure 14). This strong motion station is the nearest station to the earthquake epicenter. Figure 15 shows the spectral acceleration response of the records at Grendale station. As noted from the figure, structures having a natural period less than 0.2 seconds, should have been heavily shaked. On the other hand, the effect of the earthquake should not be intense on structures having larger natural periods. The good performance of high rise buildings could be also associated with the spectral acceleration characteristics of this earthquake.

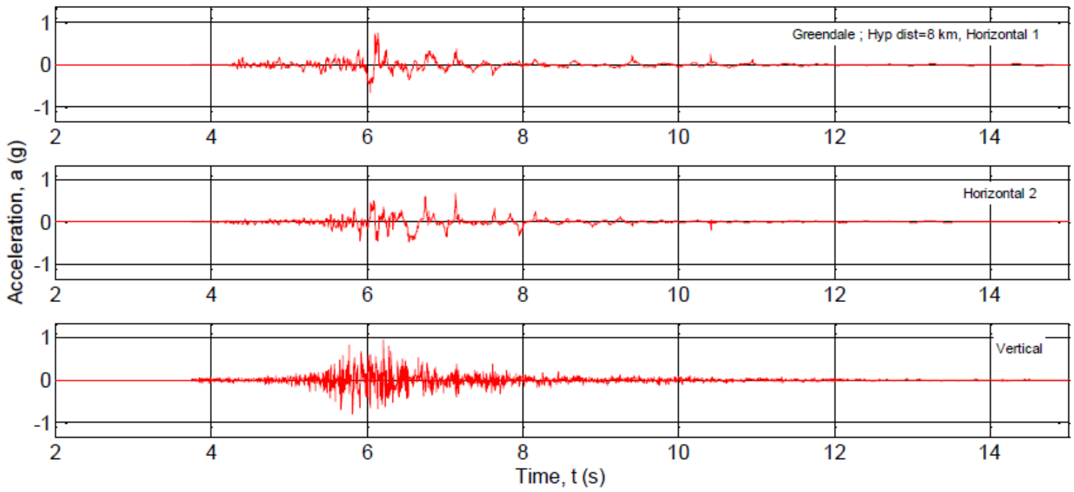


Figure 14: The strong motion records at Grendale strong motion station

Figure 16 shows the attenuation of maximum ground acceleration with distance using the attenuation relation proposed Aydan and Ohta (2006). Figure 17 shows the estimated maximum ground acceleration and velocity at surface of the ground with a shear wave velocity of 250 m/s. The observed ground motions are generally in accordance with these estimations.

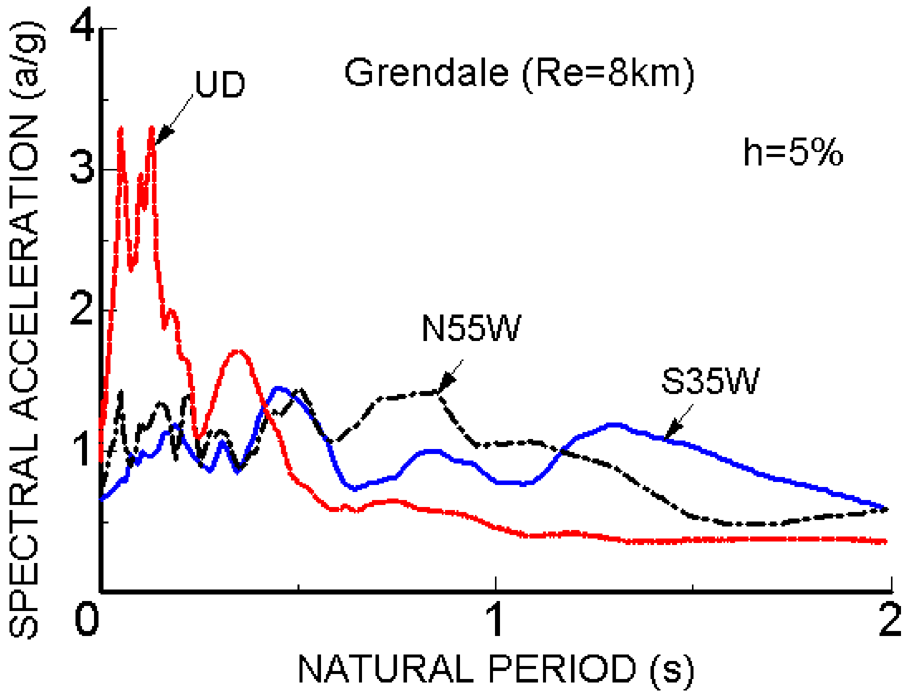


Figure 15: Spectral acceleration responses for the records of Grendale station

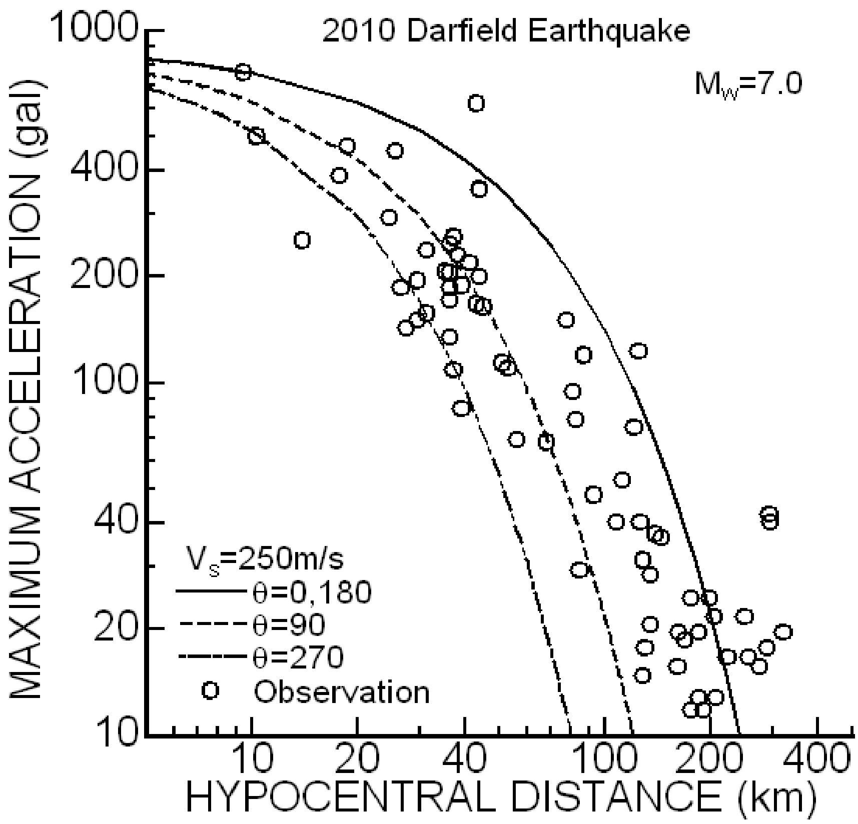
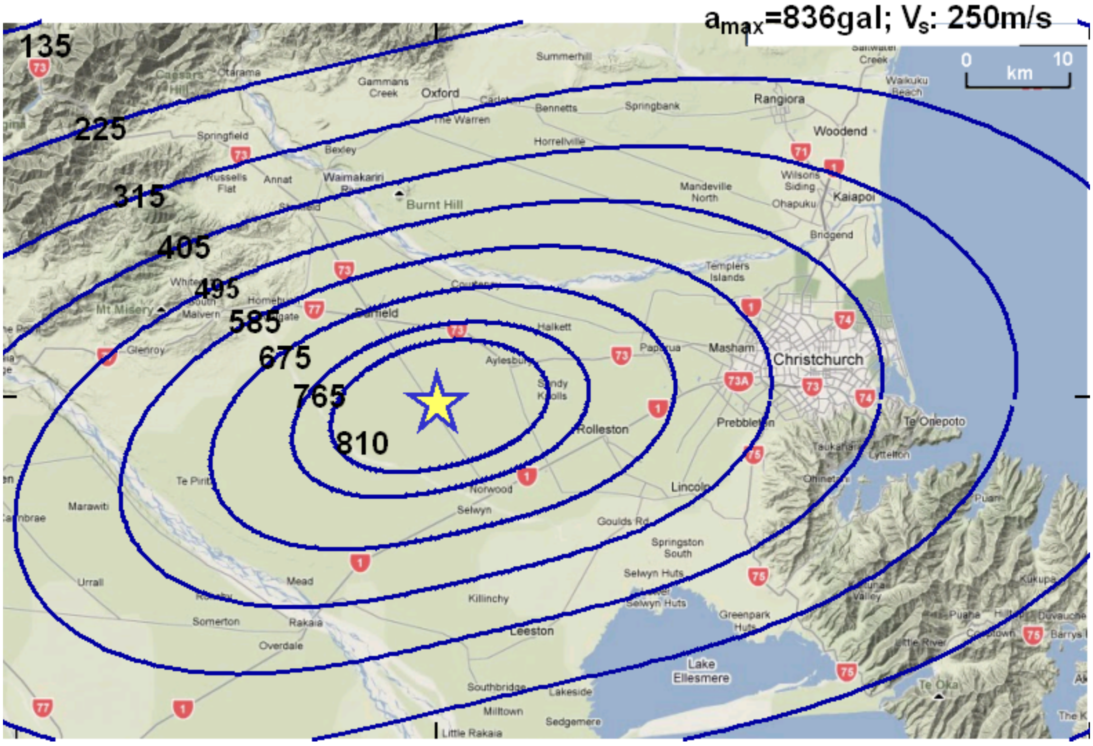
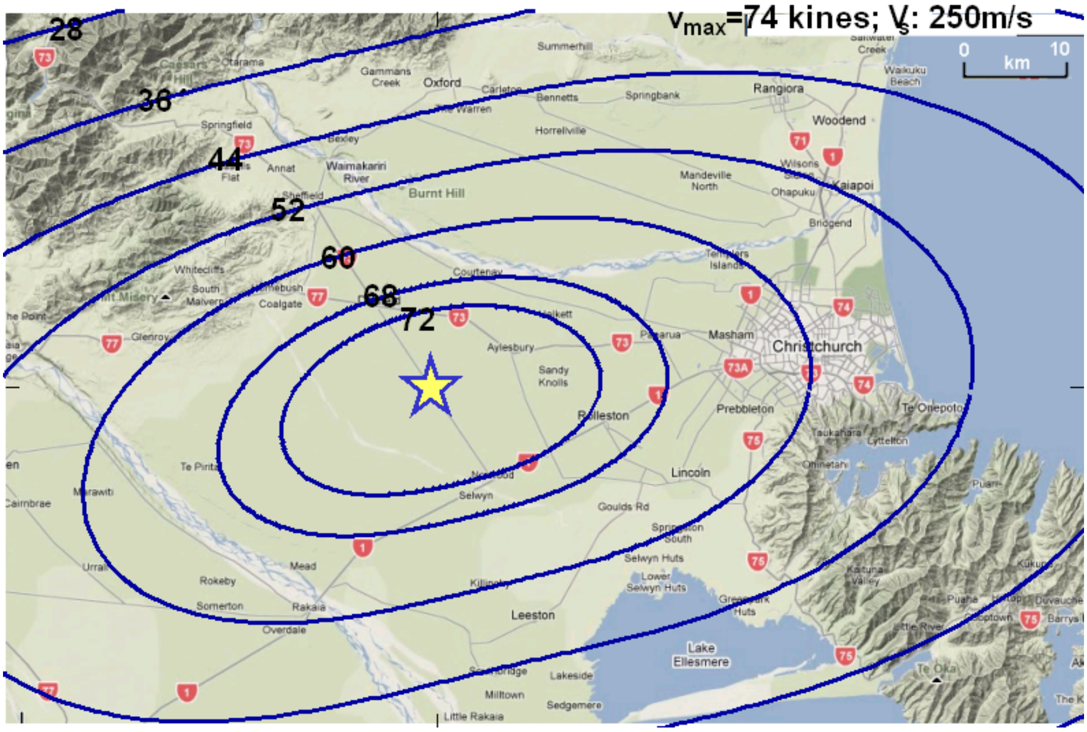


Figure 16: Attenuation of maximum ground acceleration



(a) Contours of maximum ground acceleration



(a) Contours of maximum ground velocity

Figure 17: Contours of maximum ground acceleration and velocity

7 Building Damage

Many of the worst-affected buildings in both Christchurch and the surrounding districts were older unreinforced masonry buildings (Figures 18 and 19). The low story timber framed residential houses except those on liquefied ground and new reinforced concrete or steel framed buildings were almost intact (Figure 20). These buildings are characterized as typically 2 or 3 stories. However, 2 story buildings are most common. The causes of damage to unreinforced masonry buildings may be classified as:

a) Out-of-plane failure of walls
b) Parapet failures
c) Anchorage failures
d) Chimney failures

It is estimated that 500 such buildings were damaged. 90 buildings in Christchurch Business District (CBD) were damaged. Some of retorfitted masonry buildings in the downtown of Christchurch performed well and there was almost no damage to such retrofitted masonry buildings. Nonstructural damage was due to partitions cracking, fall or toppling of ceiling tiles and lights in all types of buildings. Furthermore, glasses of windows with large span were broken. As the earthquake occurred in the early morning, there was no injury due to such broken window glasses.

Figure 18: Damage to unreinforced masonry buildings in Christchurch

(a) Ground liquefaction induced separation, lateral movement and settlement induced damage to a building

(b) Ground liquefaction induced separation, lateral movement and settlement induced damage to several buildings

Figure 19: Ground liquefaction induced damage to residential buildings in Kaiapoi

Figure 20: Views of high-rise buildings in the downtown of Christchurch

9 Geotechnical Damage

9.1 Ground Liquefaction and Lateral Spreading

One of the major characteristics of this earthquake is the extensive ground liquefaction over a wide-spread area. Extensive ground liquefaction was observed in the eastern suburbs of Avonside, and Shirley, and in Kaiapoi, Brooklands and the new suburb of Bexley (Figures 21 and 22). The ground liquefaction induced settlement and lateral spreading of ground (Figures 23-30). Residential buildings on liquefied ground and lifelines suffered extensive damage. The effect of lateral spreading of liquefied ground was quite heavy even in reinforced concrete structures such as Canterbury Rowing Club Building and Sport Facilities in Porrit Park. The light structures are uplifted while heavy structures sank into the ground. The ground liquefaction also caused extensive damage to bridges. Furthermore, the lateral spreading of ground induced failures of embankments and tidal gates. It is reported that ground liquefaction risk at the Pegasus Town site was identified in 2005 and the ground was compacted. These counter measures proved to be effective in Pegasus town and the ground liquefaction was reported.

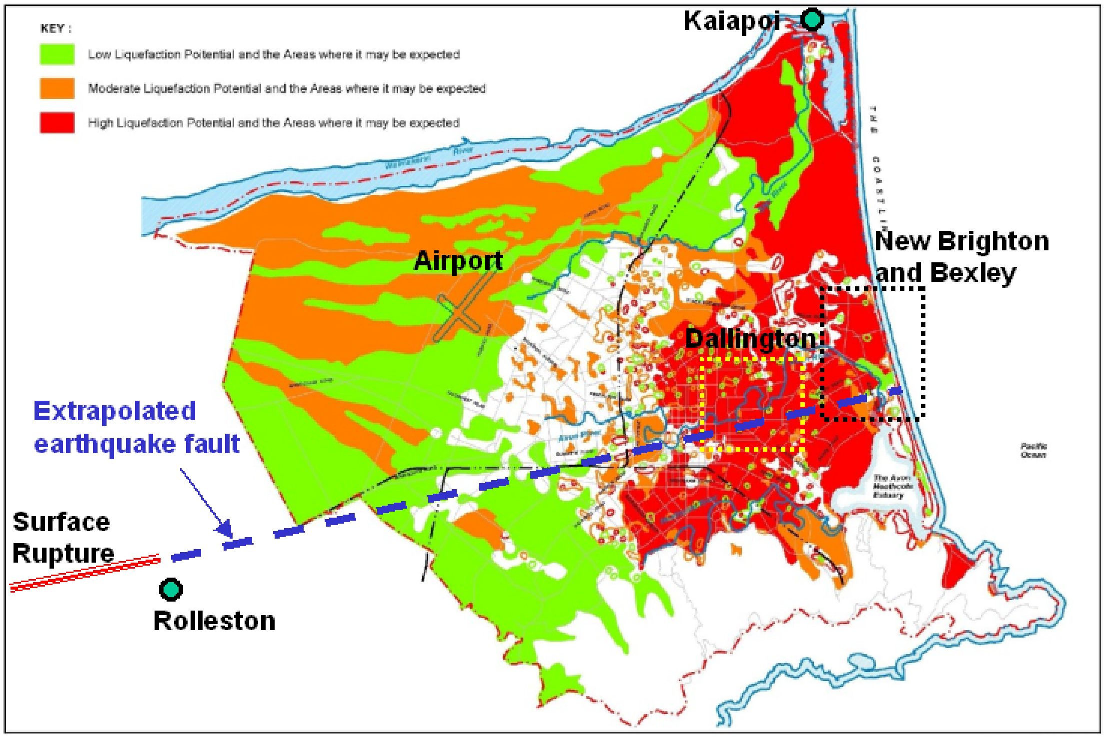


Figure 21: Liquefaction potential in Christchurch (modified from City Council)

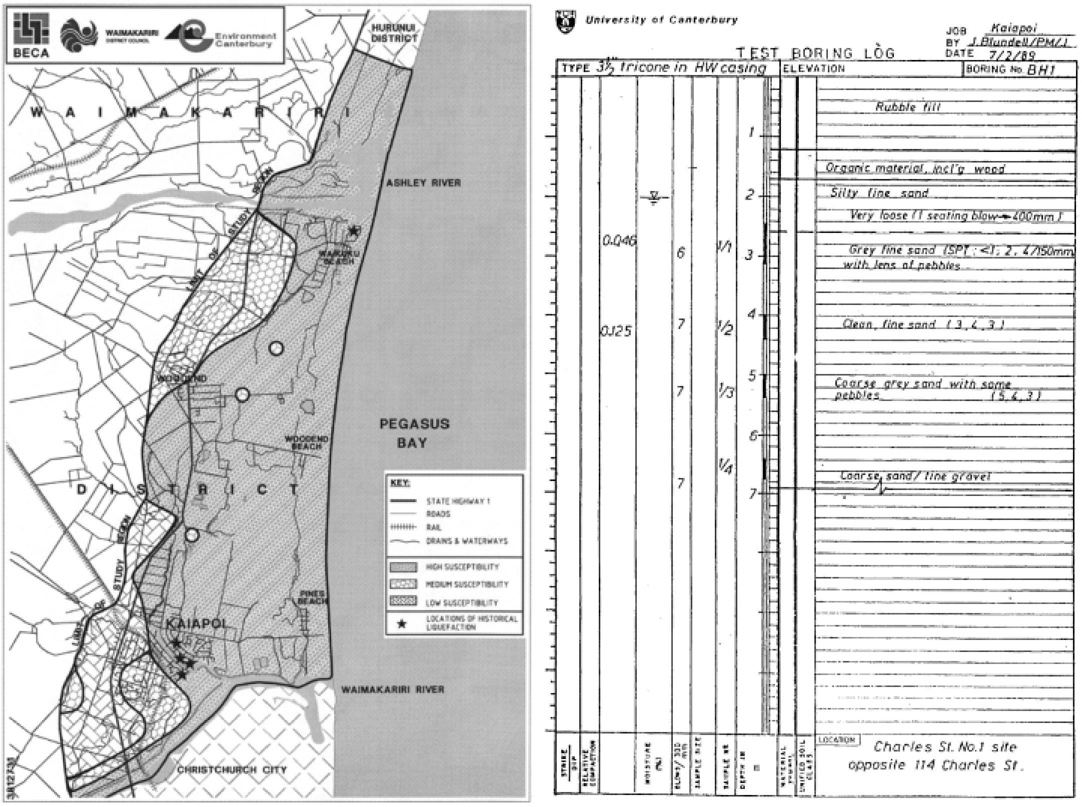


Figure 22: Ground liquefaction potential at Kaiapoi (arranged from Berrill et al., 1994)

Figure 23: Ground liquefaction along Avonside Drive

Figure 24: Ground liquefaction at Porrit Park

Figure 25: Lateral spreading induced damage at Canterbury Rowing Club building

Figure 26: Ground liquefaction in the vicinity of sport facilities in Porrit Park

Figure 27: Ground liquefaction in New Brighton

Figure 28: Ground liquefaction in Kaiapoi

Figure 29: Effect of ground liquefaction in Hilton Street of Kaiapoi town

Figure 30: Liquefaction induced damage on tidal gate

Figure 31 compares the grain-size distribution of samples obtained from sand volcanoes in Kaiapoi, Porrit Park and New Brighton with empirical bounds of liquefiable soils. As noted from the figure, grain-size distributions fall within the easily liquefiable limits. Figure 32 compares the observations with the relation between the earthquake magnitude and liquefaction limit distance proposed Aydan (2007). Once again, good correlations are observed between observations and estimations from the empirical relations.

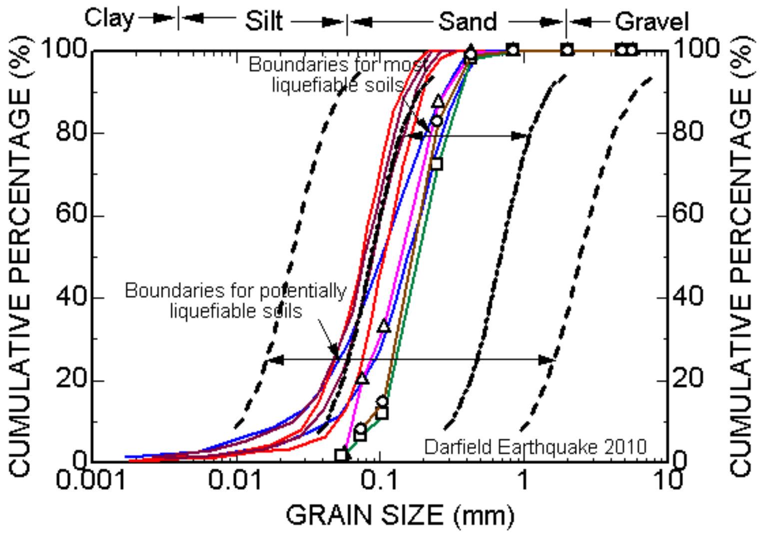


Figure 31: Comparison of grain-size distribution of samples with empirical bounds

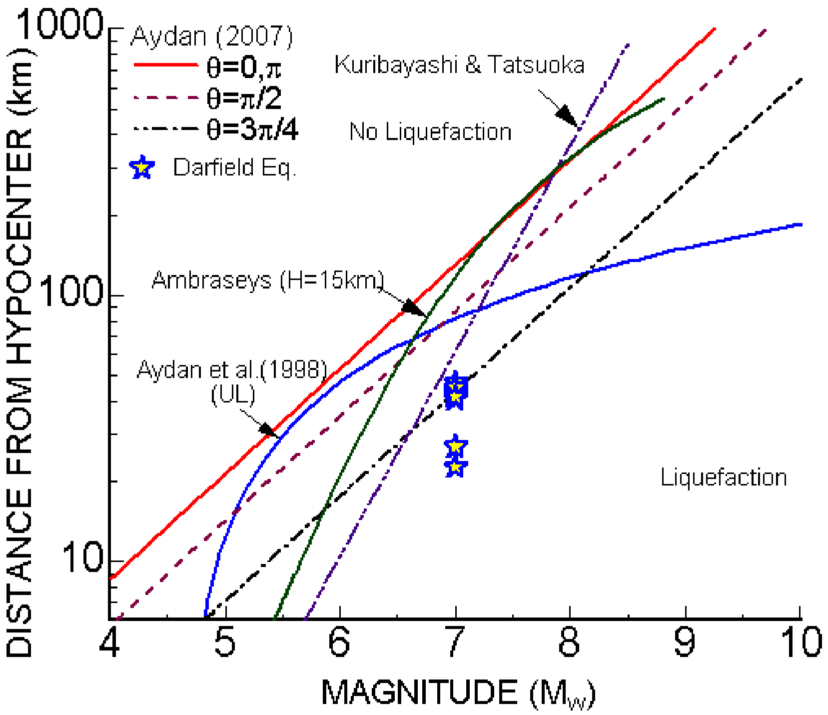
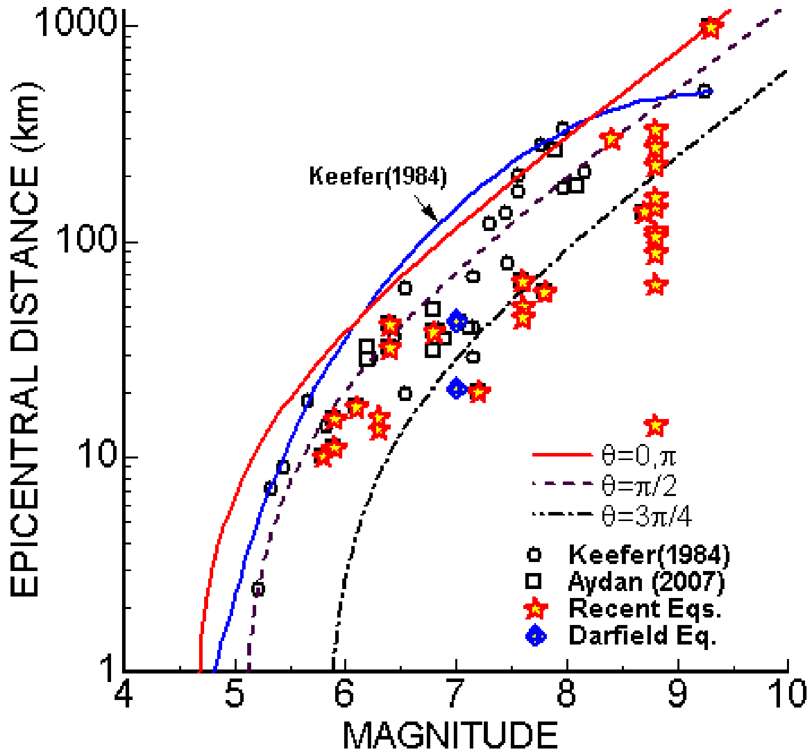


Figure 32: Comparison of observations with empirical relations

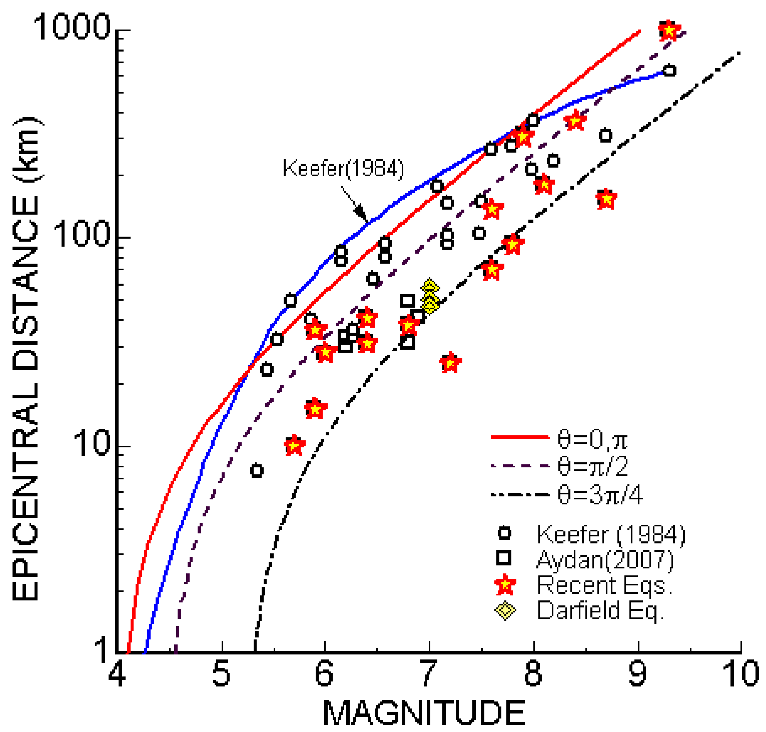
In addition to extensive ground liquefaction, retaining-wall failures, slope failures were also observed as seen in Figures 33 and 34. A slope failures was reported in the Rakaia Gorge, blocking State Highway 77. Some rockfalls reported at Castlerock, Lyttelton and Summit Road. Figure 35 compares the observations with empirical magnitude and epicentral limit distance relations for coherent and disrupted slopes. Once again, we note good correlations between observations and empirical relations.

Figure 33: Slope failures and rockfalls (compiled from various web sources)

Figure 34: Masonry retaining wall failure in Lyttelton (compiled from web sources)



(a) Coherent slopes



(b) Disrupted slopes

Figure 35: Comparison of observations with empirical relations

10 Transportation Facilities

10.1 Bridges

Bridges in the Canterbury area have suffered little damage and major bridges were found to be in structurally sound condition. The damage to bridges was mostly limited to the Christchurch and Kaiapoi area and it was due to distortion and sliding of the neoprene bearings, small cracks in the foundation (abutments and piles) and settlement of approach embankments due to soil movements (Figure 36). The bridge on Bridge Street connecting South Brighton to Christchurch suffered some damage to due to the settlement and tilting its abutments as well as the extensive cracking and settlement of approach abutments. This bridge was closed to traffic.

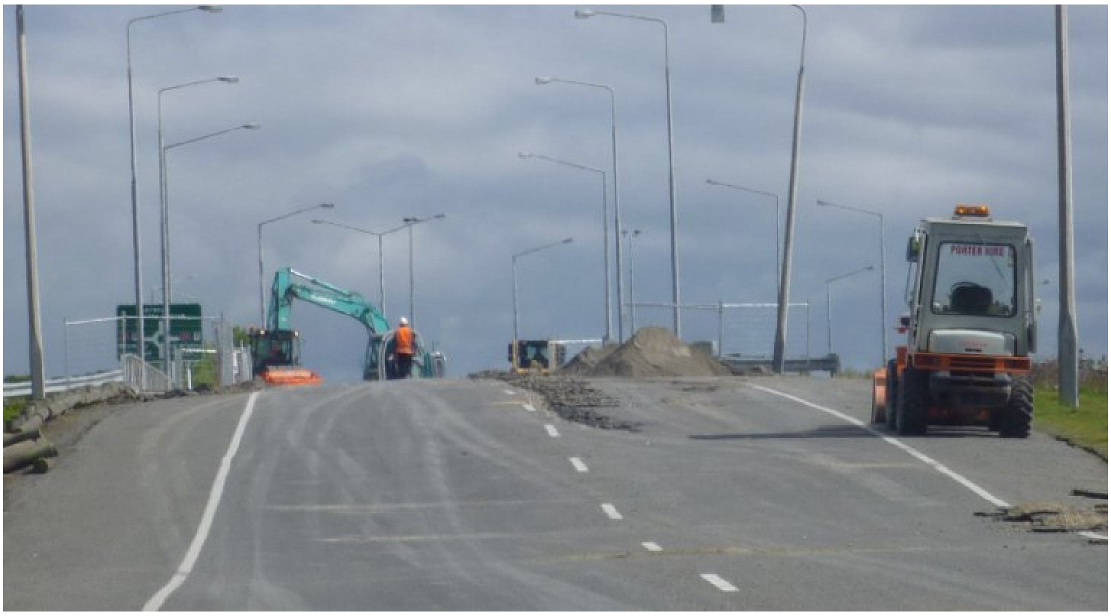
The authors had a chance to inspect two roadway bridges in heavily liquefied area in Kaiapoi (Figure 37). The bridges were all structurally sound except some settlement and movements of approach embankments at both sides and soil in the vicinity of piers.

The Selwyn roadway and railway bridges (about 250 m long) near the west end of the earthquake surface rupture built as a simple beam structures performed very well during the earthquake (Figure 38). While the bearings of the girders of railway bridges were all anchored to the piers in the construction stages, the roadway bridge girders were recently retrofitted by at both ends of the girder. The inspection on the site showed no damage to these two bridges.

The bridges on Avon River in the downtown of Christchurch were almost non-damaged. The authors inspected two old iron arch bridges and one stone-arch bridge (Figure 39). There were some settlement and cracking at one of the iron arch bridge while two other bridges suffered no damage.

Five pedestrian bridges in Kaiapoi and Dallington were either collapsed or suffered heavy damage due to ground liquefaction and associated lateral spreading (Figure 40). The piers of these pedestrian bridges were generally made of timber and they were embedded into shallow liquefiable soil. The both abutments of these pedestrian bridges moved toward the center of the rivers or creeks causing very high axial forces leading to the buckling of these bridges. It was also interesting to note that one of pedestrian bridges having steel piers probably extending to the firm ground below did not suffered any damage in-spite of ground liquefaction near its abutments.

(a) views of damage to the bridge (compiled from various web-sites)



(b) A view of the bridge being repaired (10 Sep. 2010)

Figure 36: Views of the bridge on Bridge Street in New Brighton

(a) Bridge on William Street in Kaiapoi (ground liquefied at both sides)

(b) Bridge on Smith Street leading to Chrischurch Nothern Motorway (1)

Figure 37: Almost non-damaged bridges in Kaiapoi except settlement at abutments

Figure 38: Non-damaged Selwyn road and railway bridges (6 km from the fault)

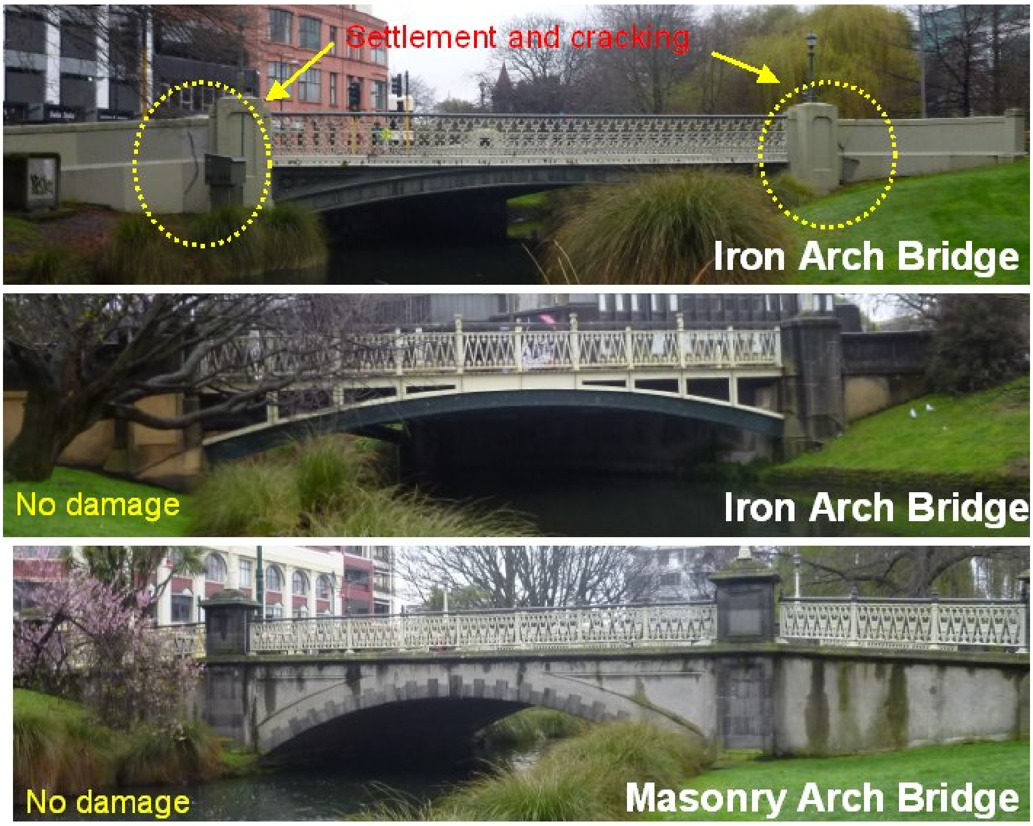


Figure 39: Views of damaged and non-damaged bridges in the downtown

Figure 40: Views of buckled pedestrian bridge in Kaiapoi

10.2 Roadway Damage

The settlement and lateral spreading of ground in liquefied areas or faulting, where surface ground ruptures were observed, mainly caused roadway damage (Figure 41). As they are built directly onto the ground surface, their temporary repair was quite quick. In areas where manholes were uplifted, the roadways were temporarily re-asphalted in order to eliminate the elevation difference between manholes and roadway surface. Open cracks were re-filled and buckled pavements were cleared away.

Figure 41: Views of damage to the roadways (compiled from various web-sites)

10.3 Railway Damage

The settlement and lateral spreading of ground in liquefied areas or faulting, where surface ground ruptures, were observed mainly caused railway damage (Figure 42). A 5 km section of rail track was damaged near Kaiapoi and there was lesser track damage at Rolleston and near Belfast. As a precaution, state rail operator KiwiRail shut down the entire South Island rail network after the earthquake, halting some 15 trains. KiwiRail Network established that the main damage to rail infrastructure was to 4 km of track and bridge abutments in the Kaiapoi area, and between Rolleston and Darfield. The damage near Kaiapoi was due to embankment failure caused by the lateral spreading of ground. The earthquake faulting damaged train tracks near Railway Road by Rolleston. Two locomotives running light (i.e. without any carriages or wagons) came to a stop just 30 metres short of a major buckle in the line. The railway station at Kaiapoi was tilted and laterally moved due to ground liquefaction.

The Main South Line was reopened with a 40 km/h speed restriction on evening of September 4, with the Midland Line west of Otira reopening after inspection the following day. Main North Line services were reinstated on September 7, until which time freight was sent by road from Rangiora to Christchurch.

Figure 42: Views of damage to the railways (compiled from various web-sites)

10.4 Airport

Christchurch International Airport was closed following the earthquake and flights in and out of it cancelled. It reopened at 1:30 pm, following inspection of the terminals and main runway. No damage to terminal buildings, control tower and runways were found although the fall of roof panels were observed in some of office buildings. It was closed to traffic until September 6, although the Airport was functional.

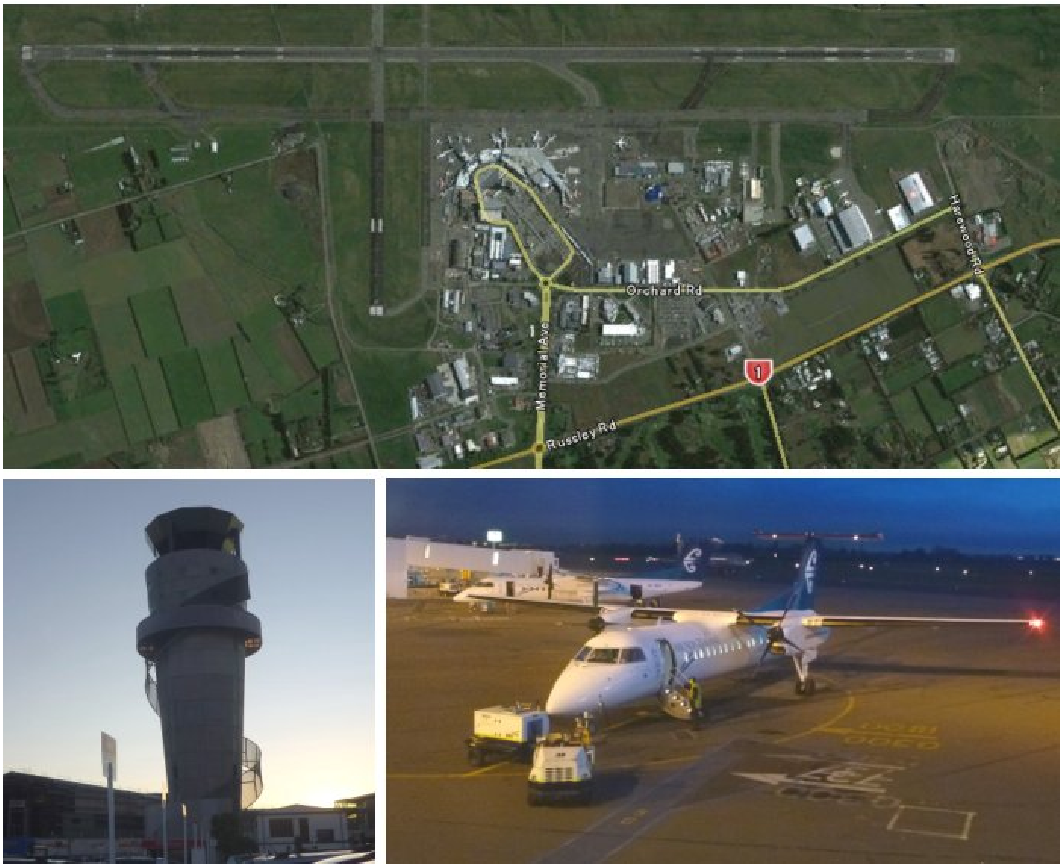


Figure 43: Views of the Christchurch Airport (satellite image from Google)

10.5 Tunnels

The Lyttelton rail and road tunnel links Christchurch and its seaport, Lyttelton (Figure 44). The single track railway tunnel was bored through the Port Hills to Lyttelton, opening in 1867. The double lane road tunnel was opened on 27 February 1964 and it is currently the longest road tunnel (1945 m) in New Zealand. The tunnel is part of State Highway 74. The Lyttelton railway tunnel was inspected by the KiwiRail engineers and it was found that there was no damage to the tunnel. The Lyttelton road tunnel was inspected by the New Zealand Transport Agency, and some cracks in the lining and sulphur smells were found. However, the tunnel was structurally sound in-spite of earthquake induced cracks. Recently Aydan et al. (2010) proposed some empirical relations to estimate the degree of damage level in tunnels. This empirical relations applied to assess the damage level in the Lyttelton tunnels. The observations were found to be consistent with empirical estimations as seen in Figure 45.

Figure 44: Views of the tunnels (arranged from various web-sources)

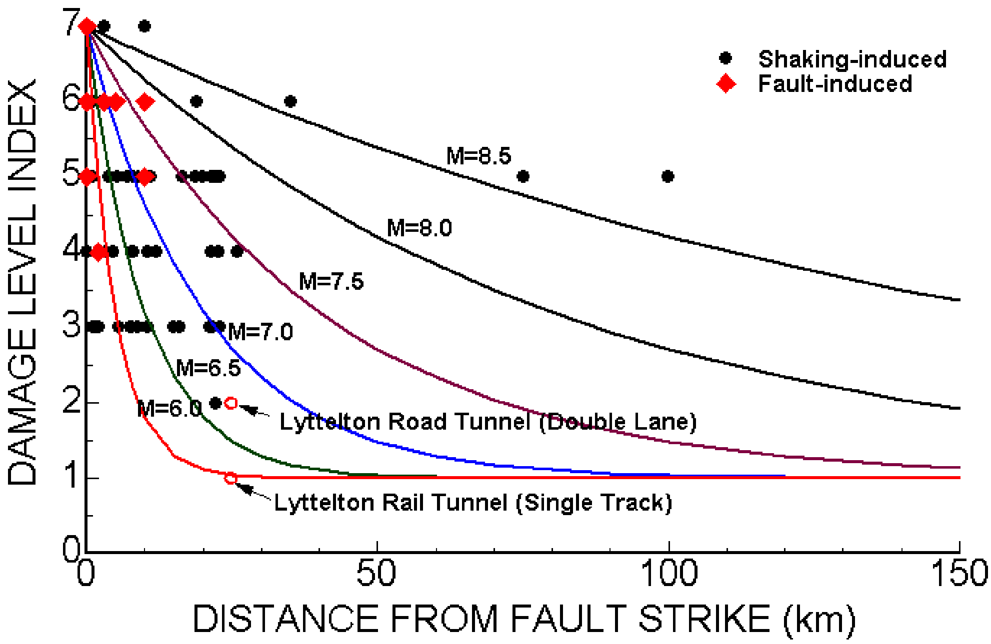


Figure 45: Comparison of empirical damage level index with observations

11.5 Port facilities

The main port facilities in Christchurch is located in Lyttelton in Banks Peninsula. Port of Lyttelton is the largest port in South Island, it is the port of export of coal and lumber, and import and export of goods through containers. The port was first constructed in 1970. The strong motion records at the port recorded maximum ground acceleration of 0.3g and maximum ground velocity of 19cm/s at a rock site during the main shock. Altough the ground conditions were relatively good in this port, There has been some damage to the wharves and coal conveyors at Port of Lyttelton. No crain damage was observed.

Figure 46: Views of the Lyttelton port (arranged from various web-sources)

11 Lifelines

Extensive damage was caused to lifelines due to ground liquefaction. Some of lifelines damage was caused due to relative settlement of the approach embankments and abutments of the bridges.

11.1 Electricity

Electricity supply is off in much of the area surrounding Christchurch in Sept. 4. The national distribution system was intact but damage to distribution transformers, some of which have been dislocated, delayed restoration. The power restored to 90% of the greater Christchurch area by 6:00pm the day of the earthquake. However, damaged areas of the CBD and Kaiapoi remained shutdown. In many towns outside Christchurch, the electrical grid was disrupted and the power was fully restored after two days.

Figure 47: Views of damage to electricity facilities (partly from some web-sources)

11.2 Water Distribution System

About 60 streets across Christchurch were without water on September 5. Almost a third of all jobs recorded relating to water and wastewater have been resolved in September 5. Teams used cameras to inspect pipes to identify the highest priority repairs.

In Rolleston the local council warned residents that their water supply has been contaminated. The contamination is due to cracks and leaks in the waste water pipes. A “boil water” notice is in place in parts of all affected areas. Water tankers are delivering water in the Waimakariri District and Christchurch City. Ruptured water mains and broken pipes caused surface flooding in several streets. Tanks of fresh water placed around the city

Figure 48: Views of damage to water pipe (partly from some web-sources)

11.3 Sewage

Sewerage and water supply infrastructure particularly affected in the low-lying eastern areas of Christchurch City and Waimakariri District as well as rural areas in Selwyn District. Sewerage pipes as well as water pipes have been leaking. All schools in the Christchurch, Waimakariri and Selwyn districts are closed until at least Wednesday. For Christchurch City, wastewater trunk mains were intact but there was significant localized damage, and the wastewater treatment plant was still running on bypass. Sewerage infrastructure had taken disrupted due to the damage at one pumping station and two wastewater treatment-pumping stations "beyond repair, some sewerage pipes had burst, raising fears of contaminated water. Portable toilets had been provided.

11.4 Telephone System

The telephone network was intact, with landlines continuing to operate where feeder lines have not been disrupted. The 111 emergency service operated 25 sites on Telecom's mobile network are inoperative and mobile networks were expected to slowly fail as battery supplies become exhausted. There have been a few minor glitches with cell towers switching to battery back-up power following larger aftershocks, but no major outages since the weekend. Payphones in the area are still free for mobile, local and national calls,

Figure 49: Views of damage to sewage system (partly from some web-sources)

12 Fires

One building on Worcester Street in downtown area caught fire after its electricity was turned back on, igniting leaking LPG in the building. The fire was quickly extinguished by the Fire Service before it could spread.

Figure 50: The fire of a building at Worchester Street (from various web sources)

13 Industrial Facilities

Skellerup Holdings, which has two factory locations in Woolston, just south of the city, had a shift working at the site when the 7.1 magnitude earthquake struck early on Saturday. It was reported that there was little or no significant damage to buildings or machinery. Christchurch electronics manufacturer “Tait Radio Communications” had its production lines running at 80 per cent and expects the situation to return to normal. The earthquake brought ceiling tiles to the floor but Tait's buildings did not suffer any significant structural damage.

Food producer Goodman Fielder says only its Christchurch flour mill received limited damage in the quake. Almost 70 silos have failed due to the earthquake. It was also reported that some damage occurred to some liquid storage tanks due to the ground shaking.

Figure 51: Views of damaged and non-damaged silos

14 Damage to Structures by Faulting

The fault that caused the earthquake on 4 September 2010 has been named the Greendale Fault. It is a previously unknown fault under the Canterbury Plains. The rupture on the fault broke through to the ground surface from many kilometers below and created a 29 km long east-west running scarp in the land between the Hororata River and Railway Road near Rolleston.

The trace comprises a series of en-echelon left stepping tears, and numerous cracks and pressure ridges. Patterns vary from field to field. There were numerous places where the offset could be measured – right lateral up to about 3 m, with variable vertical throw (mostly <1m).

The offset of the fault at the ground surface disrupted roads, rail and irrigation pipes that crossed the fault, and temporarily affected well water levels and quality as seen in some of figures presented previously. Some houses and sheds located on or near the fault scarp were also damaged, but none collapsed. It passes directly beneath two houses and a farm shed, close to at least two other buildings, and under high voltage transmission lines.

15 Conclusions and Lessons

- ✓ This earthquake clearly demonstrated that the preparedness against earthquakes as well as the strict implementation of seismic codes resulted in a limited damage without any casualty. It was also pointed out that the occurrence time of the earthquake was also another factor for the limited amount of damage and no casualty.
- ✓ Extensive ground liquefaction caused heavy damage on the embedded lifeline system, which may take at least one year in Kaiapoi area. As the buildings were light, the effect of lateral spreading did not cause any collapse of the buildings.
- ✓ The earthquake occurred previously unknown fault. This earthquake also clearly show the limitation of the current knowledge on the potential seismicity of areas.
- ✓ The total length of the earthquake fault was about 28 km. The deformation pattern deserve further studies in relation to the permanent straining in the rupture zone. The faulting did result in heavy damage to linear structures such as roadways, railways and water channels. Although there was major incident related to the faulting, the buckling of railways near Rolleston should deserve further studies in relation to the rapid transportation systems.

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