5. IMPACT ON BUILDING STRUCTURES

General

Major impacts to building structures during the Darfield earthquake of 4 September 2010 were related to unreinforced masonry or brick (URM) buildings and residential areas where ground failure below or nearby the foundation was observed. Modern structures supported on stable ground in general performed well. Many URM and brick structures, particularly in the Christchurch business district, suffered significant damage/partial collapse due to strong shaking (e.g. Figure 5.1). All of these structures were under 3 stories, with most being 1-2 stories (about 70%). Of the 595 URM buildings in Christchurch surveyed by city inspection teams immediately following the earthquake, 21% were assigned usability ratings of red, 32% yellow, and 47% green (Moon, 2010; Ingam and Griffith, 2010). The structural damage to URM and brick buildings, where ground failure was not observed, is being documented by the EERI and other post-earthquake reconnaissance teams. Interested readers should consult their reports for comprehensive documentation of the structural performance of buildings where ground failure did not impact performance.

Figure 5.1 Structural collapse of a URM in the Christchurch Business District, 184 Manchester St. (Photograph courtesy of Prof Jason Ingham)

Ground failure including liquefaction and lateral spreading resulted in extensive damage to both new and old construction, impacting houses, light commercial, school and church buildings within neighbourhoods. The most prevalent type of damage included extensive subsidence, tilting, and separation of the structural components of the building. Importantly, lateral spreading ground was observed to have detrimental impact on light residential construction. Slab foundations did not provide sufficient restraint of the ground movement to preclude extensive structural separation in many situations were excessive ground spreading features were observed. In this chapter of the report, several important cases that provide insight regarding the effects of ground failure on buildings are documented.

Kaiapoi area

Kaiapoi small business area

Small businesses line the fronts of Charles St paralleling the Kaiapoi River from approximately Jones St to Davie St (Figure 5.2). The vintage of these structures vary, however, most are single or 2 stories and constructed of light wood framing with brick façade, or stucco, or solely of concrete masonry block. Extensive lateral spreading parallel to the Kaiapoi River extended into the small business and residential regions impacting numerous structures within this community. Liquefaction was evident beyond the lateral spread as discussed in Chapter 4. The most severe damage to structures within the small business community along Charles St is shown in Figures 5.3-5.9. The Gospel Way church for example, a single story structure of brick construction, suffered separation of its heavy front structure from its orthogonal support walls due to lateral movement of the ground towards Charles St (Figures 5.3-5.5). The large lateral ground spreads extended northeast along the longitudinal axis of the building as evident in the adjacent parking area (Figure 5.4). This ground movement manifested into distinct shear cracks at the brick-mortar joints (Figure 5.5a). Structural separation such as that evident in Figure 5.5a was visible at several distinct locations extending along the longitudinal axis of the building. The most severe damage was evident at the front of this building, which settled approximately 15 cm, while the eastern length of the building remained approximately level (Figure 5.5b).

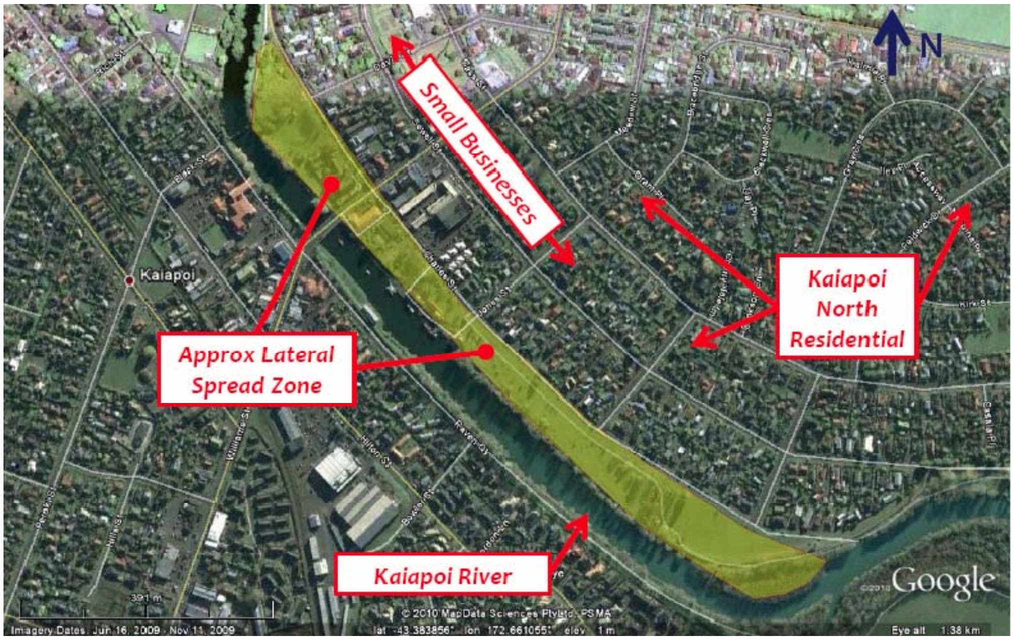

Figure 5.2 Kaiapoi North residential and small business region. The distance from the left to right edge of this image is ~1.4 km. (Annotated GoogleEarth image).

Figure 5.3 Front facing (view looking northeast) of the Gospel Way church in Kaiapoi along Charles St. (-43.3812°, 172.6579°; 1000 hrs on 11 September 2010)

Figure 5.4 Lateral spread patterns extending east along the longitudinal axis of the Gospel Way church in Kaiapoi along Charles St. (-43.3812°, 172.6579°; 1000 hrs on 11 September 2010)

(a) (b)

Figure 5.5 Gospel Way Church in Kaiapoi: (a) Shear crack pattern developed at brick-mortar joints along the northern side of the building and (b) separation (settlement and rotation) of the west face of the building. (-43.3812°, 172.6579°; 1000 hrs on 11 September 2010)

A small shopping area neighboring the New World supermarket in Kaiapoi (between Williams and Jones Streets north-south and Sewell and Charles Streets east-west) showed patterns of extensive ground damage and resulted in many business closures (Figure 5.6a). Closures were primarily prompted by extensive hardscape and interior flooring damage (Figure 5.6b). These buildings attached units of one story wood framed construction supported on slabs on grade and with glass front (open) facing as is common of walking business districts. The tallest structure to suffer damage in the direct adjacency to these business units was a red-tagged 3-story property and family law office constructed of concrete masonry block units (CMU) (Figures 5.7-5.8). This structure is rectangular in footprint with little to no lateral resistance along the longitudinal axis of the building (as evident from the perimeter full facing glass openings – Figure 5.7a). The short axis of the building provides resistance to lateral movement and loads via stiff full length CMU walls at exterior ends of the structure (Figure 5.7b). The front of this building appeared to have settled and rotated towards the direction (southwest) (Figure 5.8). Lateral spread ground failure and liquefaction ejecta were evident directly adjacent to this building (Figure 5.9). A sample of material taken adjacent to this building was tested using laser diffraction scanning (Figure 5.10, denoted WP24).

(a)

(b)

Figure 5.6 Small business attached units neighboring the Small World supermarket in Kaiapoi (52 Charles St): (a) View looking east showing ground damage pattern and (b) resulting hardscape damage at the front of one business unit. (-43.3827°, 172.6592°; 1045 hrs on 11 September 2010)

(a)

(b)

Figure 5.7 Property and Family Law Offices in Kaiapoi business district, 190 Williams St: (a) View looking northwest (at long axis end) of building and (b) view looking northeast showing shearwall ends of short axis of building. (-43.3812°, 172.6579°; 1100 hrs on 11 September 2010)

Figure 5.8 Property and Family Law Offices in Kaiapoi business district, 190 Williams St. View looking at west short axis end of the building (-43.3819°, 172.6591°; 1100 hrs on 11 September 2010)

Figure 5.9 Surrounding ground failure patterns directly adjacent to the Property and Family Law Offices in Kaiapoi business district. View looking southeast (43.3819°S, 172.6593°E; 1100 hrs on 11 September 2010)

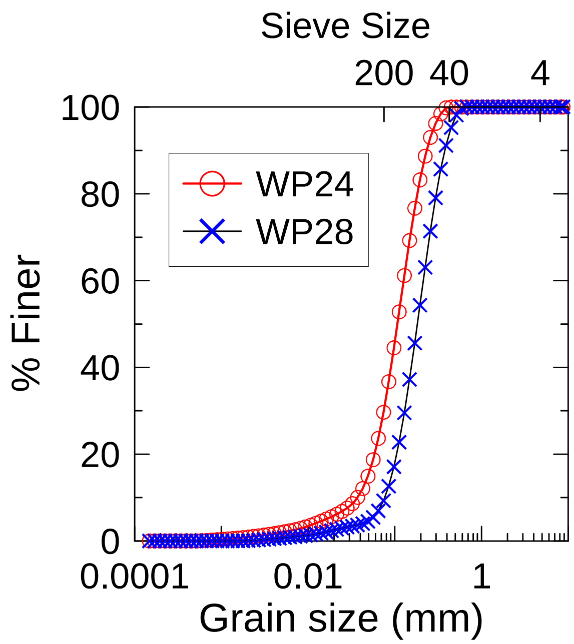

Figure 5.10 Grain-size distribution of samples taken from ejecta observed in Kaiapoi area (sample taken 11 September 2010 testing via laser diffraction). Sample WP24 taken at -43.381856°, 172.659149° (adjacent to law offices) and sample WP28 taken at -43.384723°, 172.661314° (adjacent to Kaiapoi wharf).

Movement of the Kaiapoi wharf resulted in damage to the historic Kaiapoi Railway Station, which is now renovated and used as the Kaiapoi Information Center (-43.3838°, 172.6596°) and its neighboring Harbor Building (-43.3834°, 172.6591°). The Kaiapoi Information Centre building is a renovated wood framed building on an elevated foundation (Figure 5.11). As a result of loss of ground support, this building tilted approximately 5 degrees northeast (away from the river). Rapid stabilization of the building had been complete by the time of the GEER-NZ Team's visit on 11 September 2010 in the form of concrete footings poured on the exposed (near river) foundation side of the building (Figure 5.11b). In addition, tension tie-backs anchored from newly poured concrete footings to a patio area were used to stabilize the upper pavement during the continuing ground movement. The Harbor building is a one-story masonry block building that suffered tilting towards the river and separation from the wharf of approximately 15-25 cm on its west face (Figure 5.12).

North of the Kaiapoi Information Center and Harbor Buildings, a two story wood frame building with subterranean parking (nearest to river) and a full floor level (nearest to Charles Street) currently housing the Bridge Tavern building was extensively damaged due to ground movement (Figure 5.13). Although movement of the retaining wall adjacent to the Kaiapoi River was not evident, the east embankment side, which supported the first story subterranean parking area showed evidence of ground settlement and cracking. This damage precipitated movement of columns supporting the upper story of the building (Figure 5.13b).

Soil samples taken from the largest visible ground ejecta features within the park adjacent to the Kaiapoi River are similar to the material observed within the small business district of Kaiapoi (Figure 5.10). These grain size distribution curves indicate the material directly adjacent to the wharf, and likely extending into the neighboring park, is a uniformly graded sandy soil with 10% to 30% fines (Table 5.1). In contrast material further from the rivers' edge (e.g. WP28 taken within the small business district of Kaiapoi) although similarly sandy and uniformly, graded contains a more appreciable amount of fines (30%). The largest content of fines of these samples approached 70% (WP169 taken at the Lyttelton Oil Terminal).

Table 5.1 Summary of laser diffraction testing results

WP	Location	GPS Coordinates	%Fines	D10 (mm)	D30 (mm)	D60 (mm)	Cc	Cu
WP24	Kaiapoi adjacent to wharf	-43.3819°, 172.6591°	30	0.037	0.075	0.129	1.179	3.486
WP28	Kaiapoi business	-43.3847°, 172.6613°	10	0.075	0.129	0.214	1.038	2.851
WP104	Bexley Residential	-43.5190°, 172.7202°	10	0.075	0.127	0.185	1.168	2.463
WP169	Lyttelton Oil Terminal	-43.6088°, 172.7142°	70	0.023	0.042	0.065	1.164	2.813

(a)

(b)

Figure 5.11 Renovated Kaiapoi Railway building now used the Kaiapoi Information Center, adjacent to the Kaiapoi Wharf. (a) View looking northwest and (b) view looking southeast (note the temporary elevated patio support tie-backs and newly poured footings at the front (river side) of the building. (-43.3838°, 172.6596°; 1300 hrs on 11 September 2010).

(a)

(b)

Figure 5.12 Harbor building adjacent to the Kaiapoi River and wharf structures: (a) View looking southeast and (b) view of the northwest corner of the building. Note the approximate 15-25cm gap between the pavement and building. (-43.3834°, 172.6591°; 1345 hrs on 11 September 2010).

(a)

(b)

Figure 5.13 Bridge Tavern adjacent to the Kaiapoi River: (a) View looking northwest at Williams St bridge and (b) view looking northwest at subterranean parking. (-43.3826°, 172.6582°; 1345 hrs on 11 September 2010)

Kaiapoi residential

The most severe structural damage to houses in the Kaiapoi residential neighborhoods was evident along Charles St paralleling the Kaiapoi River (Kaiapoi North) as well as along Courtenay Dr, which parallels a branch of the Courtenay Stream (east of Kaiapoi South) (Figure 5.14).

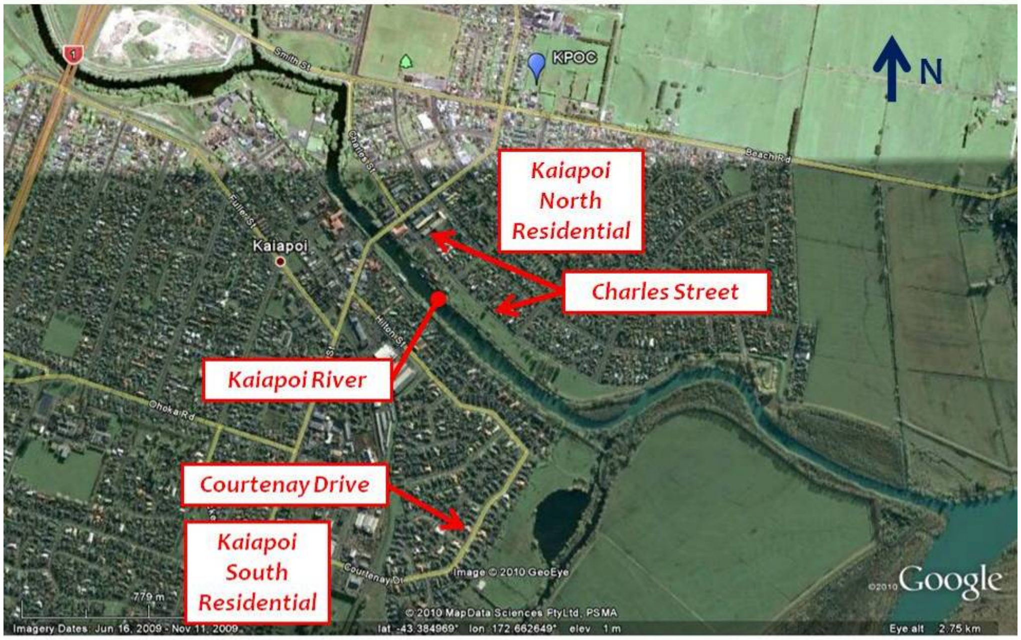

Figure 5.14 Kaiapoi North and South residential areas. The distance from the left to right edge of this image is ~3.2 km. (Annotated GoogleEarth image).

Kaiapoi North – Residential construction within the Kaiapoi North community consists of 1-2 story wood or concrete block framed houses. A number of houses are also constructed of brick or wood with brick façade units. The vintage of these homes appeared to extend as early as 1960's construction, to more recent completely rebuilt or remodeled homes. Uniform settlement of the heavier brick houses in this area, such as shown in Figure 5.15, were measured as large as 20-25 cm. Brick houses consistently observed shear cracking, discontinuities between window and door openings and brick, popped out and/or damaged glass windows, and damage to floor slabs and hardscape (Figure 5.16). Houses along Charles St at the time of the GEER-NZ Team's visit (11 September 2010) were either red or yellow tagged. Very few houses were occupied, with most suffering extensive sand ejecta surrounding the home as well as settlement. In a number of cases, residents of severely damaged homes had moved out completely (e.g. Figures 5.17-5.18). This house at Charles St experienced ~0.4 m of settlement along its North face (Figure 5.17b).

Sand ejecta were present surrounding most houses along Charles St and extending east into the North Kaiapoi residential area approximately 0.5 km.

(a)

(b)

Figure 5.15 Residence along Charles St: (a) Ejecta surrounding home and (b) owner points out shear cracking and gapping developed between window and brick due to structures movement. (-43.3836°, 172.6604°; 1115 hrs on 11 September 2010)

Figure 5.16 Residence along Charles St (same structure as Figure 5.16). Damage to glass windows and between window and wall. (-43.3836°, 172.6604°; 1115 hrs on 11 September 2010)

(a)

(b)

Figure 5.17 Red tagged residence on Charles St: (a) View looking east and (b) north end of house, view looking North-East. (-43.3838°, 172.6607°; 1130 hrs on 11 September 2010)

Figure 5.18 Red tagged residence on Charles St. Extensive surrounding ejecta at perimeter of house (43.3838°S, 172.6607°E; 1130 hrs on 11 September 2010)

Kaiapoi South – In general damage to building structures in the Kaiapoi South community was limited to Courtenay Dr between Kaikanui St and ending at Parish Ln. This is a residential neighborhood with relatively new homes, all constructed within the last ten years. Most houses are one-story light wood framing or brick supported on unreinforced slabs with perimeter stemwall foundations and light metal roofing. An example of the typical construction style in this area is shown in Figure 5.19. Liquefaction was reported to inundate the neighborhood north of Courtenay Dr towards Charters St, however much of this had been cleaned up by the time of the GEER-NZ Team's visit and appeared to have minimal impact on the houses. The impact to houses along Courtenay Dr however, and particularly those on the east side of the drive, with direct facing to a paddocks' field as well as a branch of the Courtenay Stream, was extensive. Ground failure in this region manifested in large lateral spread zones coupled with liquefaction (Figure 5.20). A manual survey by the GEER-NZ Team indicated that of the 44 houses along this drive 48% suffered severe structural damage induced by ground failure, while 15 (36%) suffered moderate and minor damage, respectively. Laterally spreading ground was observed to extend through the backyards of these houses, with the lack of reinforcement within slab foundations and general light construction styles resulting in severe separation of the home directly in-line with the ground failure. The residences shown in Figures 5.21-5.24 demonstrate the observed damage due to excessive ground movement. The structure shown in Figures 5.21-5.22 suffered excessive tilting and a separation of 1.5 m from its approach driveway to the front of the home (Figure 5.22a), while the rear of the house collapsed inward due to surrounding ground fissures (Figure 5.22b). Similarly, the residence in Figures 5.23-5.24 articulated little to no damage at the backside of the house (Figure 5.23), however the front entry of the house at the interface between the garage and main portion of the residence suffered a separation of about 1 m due to lateral ground movement (Figure 5.24).

Figure 5.19 Typical construction style of houses along Courtenay Dr in the South Kaiapoi residential community. (-43.389847°, 172.662049°; 1430 hrs on 11 September 2010)

Figure 5.20 Ground failure feature extending through the backyard of a house on the south side of Courtenay Dr in the South Kaiapoi residential community. (-43.3894°, 172.6633°; 1500 hrs on 11 September 2010)

(a)

(b)

Figure 5.21 Damage to a residence at Courtenay Dr in the South Kaiapoi residential community (front of house articulating excessive tilt and separation of foundation from surrounding hardscape). (-43.390920°, 172.662007°; 1545 hrs on 11 September 2010)

(a)

(b)

Figure 5.22 Damage to a residence at Courtenay Dr in the South Kaiapoi residential community (a) front of home (1.5-m separation between garage and approach slab) and (b) back of home. (-43.390920°, 172.662007°; 1545 hrs on 11 September 2010)

Figure 5.23 Damage to a residence along Courtenay Dr in the South Kaiapoi residential community. Backside of home facing Paddocks field articulates relatively no damage. (-43.391168°, 172.661894°; 1600 hrs on 11 September 2010)

(a) (b)

Figure 5.24 Damage to a residence along Courtenay Dr in the South Kaiapoi residential community. Front entry articulates extensive damage as large ground spreading subtends into the superstructure. (-43.391168°, 172.661894°; 1600 hrs on 11 September 2010)

Dallington Area

Dallington Residential

The Dallington residential community was heavily impacted by liquefaction, and where the Avon River meanders through the community, those structures nearest the river were impacted by lateral spreading (see Chapter 4 for details regarding liquefaction extent in this area). The structural impact on residences was largely localized to settlement and rigid body movement in these regions, with the exception of St. Paul's church and surrounding school (refer to subsequent section) and residences nearest to the Avon River, which suffered loss of ground support due to lateral spreading. Residential construction in this area appeared to be range in vintage, with the oldest houses constructed in the early 1900s and predominant construction dates from 1960s for the rest. Most structures were brick or light wood framing with stucco finish and 1-story. A few structures had been remodeled to incorporate a second story. The foundation system of these residential structures appeared to be stem walls with floating slabs or, in some cases, elevated wood flooring was apparent as viewed from access crawlspaces. Residents interviewed in this neighborhood indicated that a thick layer of sand ejecta was observed on their properties.

Two common types of damage to residential structures within this community are shown in Figures 5.25 and 5.26. Both of these structures are located near the Avon River. The residence shown in Figure 5.25a directly fronts the Avon River and experienced approximately 3 degrees of rigid body tilt directly south towards the river. Structurally the home was in good condition, though inspection of the interior articulated extensive floor and nonstructural damage. Lateral spreading extension features were observed at the front of the residence at the river and continued north behind this residence (Figure 5.25b). Transects taken by the GEER-NZ Team on 14 September 2010 at this location indicate 85 cm of lateral extension fronted the residence, with vertical offsets in extensions as large as 19 cm and cracks extending as great as 105 cm (T7 in Figure 5.27). Figure 5.26 shows a house in Locksley Avenue, which illustrates a loss of ground support subtended along the structure length. At this location lateral spreading towards the Avon River (behind the position from where the photo was taken) is evident in the driveway. Differential settlement along the length of the house manifests itself as shear cracking and separation of the mortar-brick within the brick veneer wall. This mode of deformation is similar, but less intense, to that imposed on the slab-on-ground foundations of the houses illustrated in Figures 5.20-5.24.

Detailed mapping of lateral spreading features extending from the Avon River into the Dallington residential community were performed by a NZ-GEER team on 14 September 2010. A map of these transect locations is shown in Figure 5.27. Future reports will include elevations and additional details of these ground features.

(a)

(b)

Figure 5.25 (a) Rigid body rotation of a residence in Dallington (Locksley Ave) due to liquefaction and (-43.5212°, 172.6731°); (b) lateral spread features directly fronting the home. Surveys of ground features at this location are associated with T7 (-43.5212°, 172.6731°) (refer to Figure 5.27).

Figure 5.26 Residence affected by lateral spreading along the driveway, which has induced differential settlement between the front and rear of the house. (Note that this is not a slab-on-ground house, and older style of construction with a concrete perimeter beam and the timber floor being supported on shallow foundations; Locksley Ave; -43.5194°, 172.6754°; 1130 hrs on 14 September 2010)

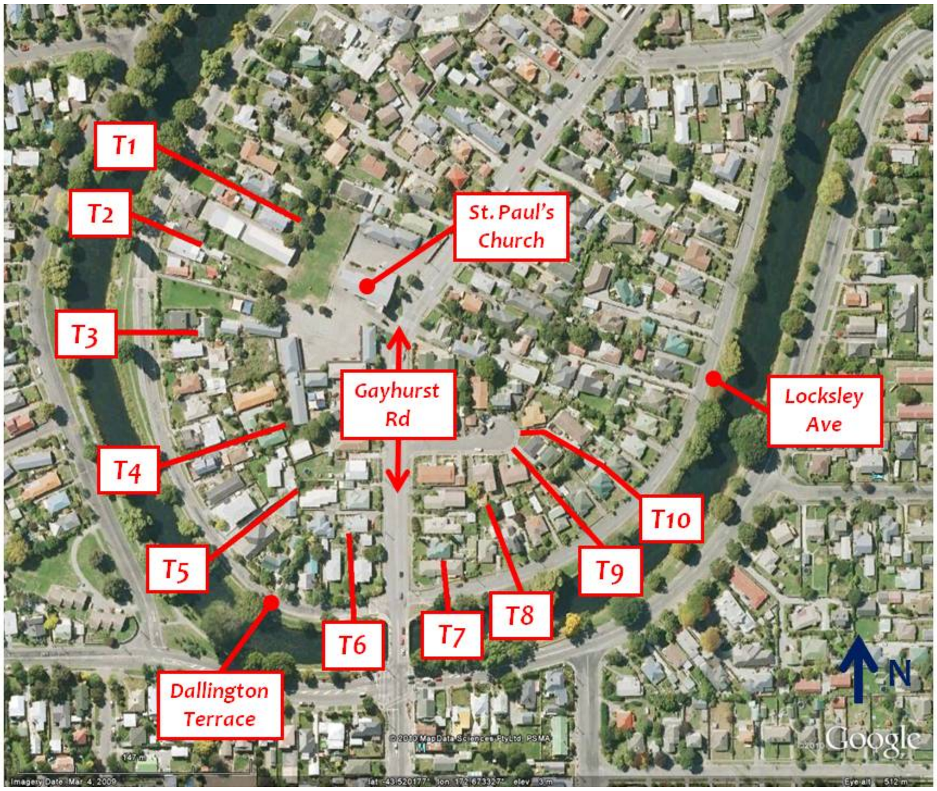

Figure 5.27 Ground feature mapping locations taken by the GEER-NZ Team on 14 September 2010. The distance from the left to right edge of this image is ~0.58 km. (Annotations overlaid with GoogleEarth image)

St. Paul's Church and School

A historically significant feature in the neighbourhood of Dallington is the St. Paul's church and surrounding school (Figure 5.28). St. Paul's church was severely damaged due to surrounding ground movement, which was precipitated by extensive liquefaction within the general area shown in Figure 5.28. Most significantly the structure suffered through building separation due to ground extension and vertical offset subtending north-south approximately one-third of the length along the west end (orange separation location denoted in Figure 5.29). This resulted in separation of the building into two distinct pieces. The West end of the building rotated 2 degrees south and 4 degrees west (Figures 5.30-5.33), resulting in 46 cm of settlement of the south-west corner (estimated with reference to prior ground elevation). No significant lateral translation of the building was measured at its perimeter, rather structural movement was confined to rotation and settlement as described in Figure 5.29. This relatively heavy single story structure was constructed of running bond brick perimeter walls, with a timber (truss) roof. Wall heights were approximately 10 m at the perimeter of the sloping roof and 7m at flat portions. An ~12-m tall tower is articulated at the southeast corner of the structure (Figure 5.33b). The ridgeline extends across the longitudinal axis (running approximately east-west) along the building. The north and south (long axis ends) of the building articulate approximately 25% glass windows. Similarly the East entry facing Gayhurst Road presents stained glass features surrounded by brick walls (Figure 5.33b). The foundation was not accessible at the time of the GEER-NZ Team's visit.

Surrounding St. Paul's church is an Integrated State School affiliated with the church (buildings denoted B1-B8 in Figure 5.28). Building B1 (Figure 5.34) and B6 (Figure 5.36) are constructed of running bond brick perimeter walls with light metal roofs, whereas buildings B4, B5, and B7 incorporate light wood framing along their longitudinal axes and brick along their transverse axes. Building B2 is constructed of concrete masonry block units (Figure 5.35). All structures within the school appeared to be supported on elevated stem wall footings with interior wood joists, with the exception of B2, which appeared to be at grade with a slab on ground. Buildings B1-B8 are all single story with wall heights ranging from 7-8 m. Stiff brick and CMU buildings within this school complex suffered shear cracking and in some cases significant separation of brick-mortar joints (e.g. Figures 5.35b and 5.36b). Likewise mixed construction structures, such as building B7 suffered damage due to relative movement between contrasting materials (Figure 5.37b). Flexible wood buildings suffered little observable structural damage with the exception of hairline cracks in stucco aligned with ground movement features.

Figure 5.28 St Paul's church and school in Dallington area (-43.5196°, 172.6725°). Notation "B#" is used for reference only to identify adjacent buildings (see discussion). The distance from the left to right edge of this image is ~0.17 km. (Annotated GoogleEarth image).

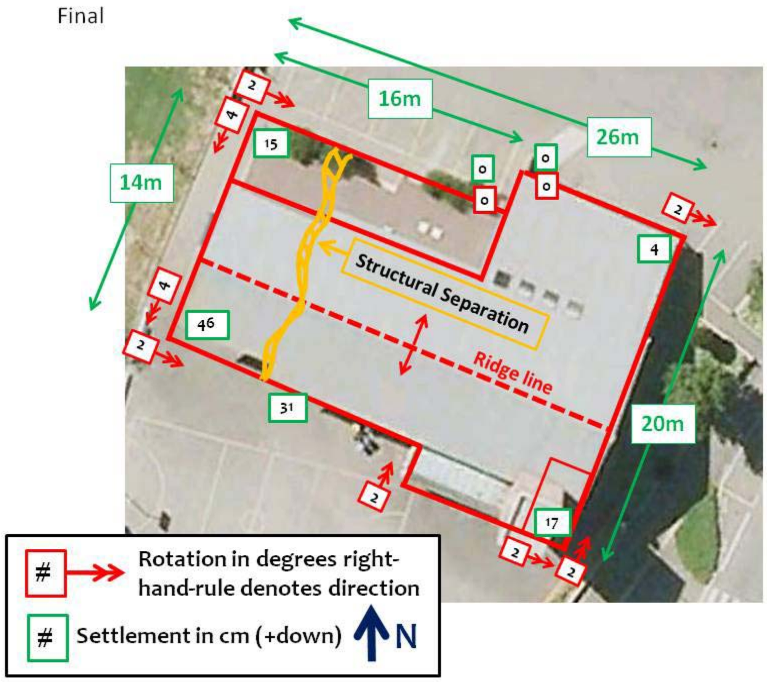

Figure 5.29 St Paul's church damage map – survey conducted 12 September 2010; Global dimensions approximate (extracted from GoogleEarth image), deformation obtained directly in the field.

Figure 5.30 St Paul's church in Dallington area - overall view of building looking north-east (-43.5196°, 172.6725°; 1345 hrs on 12 September 2010)

Figure 5.31 St Paul's church in Dallington area - view looking north at ground failure, which continued through building. (-43.5196°, 172.6725°; 1400 hrs on 12 September 2010)

(a)

(b)

Figure 5.32 St Paul's church in Dallington area - view looking north (a) far view of separated west end of building and (b) close-up view of structural separation. (-43.5196°, 172.6725°; 1400 hrs on September 2010)

(a)

(b)

Figure 5.33 St Paul's church in Dallington area: (a) view looking east at the west end and (b) view looking west at the east end (-43.5196°, 172.6725°; 1400 hrs on 12 September 2010)

Figure 5.34 St Paul's church and surrounding school - Building B1 (on left) and St Paul's church (on right). (-43.519262°, 172.672636°; 1345 hrs on 12 September 2010)

(a)

(b)

Figure 5.35 St Paul’s church and surrounding school - Building B2: (a) view looking west and (b) view from north side of building, looking south. (-43.5193°, 172.6717°; 1300 hrs on 12 September 2010)

(a)

(b)

Figure 5.36 St Paul's church and surrounding school - Building B6 view looking south: (a) overall view of building and (b) West end of building. (-43.5200°, 172.6724°; 1300 hrs on 12 September 2010)

(a) (b)

Figure 5.37 St Paul's church and surrounding school - Building B7: (a) view looking east and (b) view of south-west corner of building articulating column damage at wood-brick interface. (-43.5199°, 172.6726°; 1400 hrs on 12 September 2010)

Bexley Residential Area

In the residential area of Bexley, houses were significantly affected by lateral spreading (e.g. Figures 5.38-5.39). The lateral spreading was apparent from walking around the path along the southern boundary of the subdivision next to the wetland. Fissures of 300 mm or greater in width traversed the ground of several properties. A floor slab fissure (estimated width 50 to 75 mm, visible because the carpet had been lifted) extended across the full width of one house. Settlement had occurred but with relatively little tilting. Given that the fissure went through the concrete floor slab, there appeared to be relatively little damage to the walls.

Foundation details for one house in Bexley are shown in Figure 5.40. The system set-out in Figure 5.40 is a perimeter beam with two D16 bars, D10 starter bars 600-mm long at 600 mm centers around the edges. The cavity inside the perimeter beam is filled with coarse gravel, covered with dampcourse, and then topped with a 100-mm thick concrete slab, which, apart from the starter bars, is mostly unreinforced. The drawing in Figure 5.40 specifies mesh reinforcing in areas that are to be tiled or covered in vinyl. Nonetheless, reinforcing was not observed to cross any fissure as noted in the drawing.

For contrast, an open foundation construction in the Pines Beach area (near Kaiapoi) was observed on 12 September 2010. The perimeter footing had been completed and the gravel fill was in place, the concrete slab was yet to come. Assuming the top of the perimeter footing was close to level before the event, it was apparent that the footing was not capable of withstanding the ground deformation during the earthquake as the footing was no longer level (Figure 5.41). Two D16 reinforcing bars were observed in this footing where cracking had occurred.

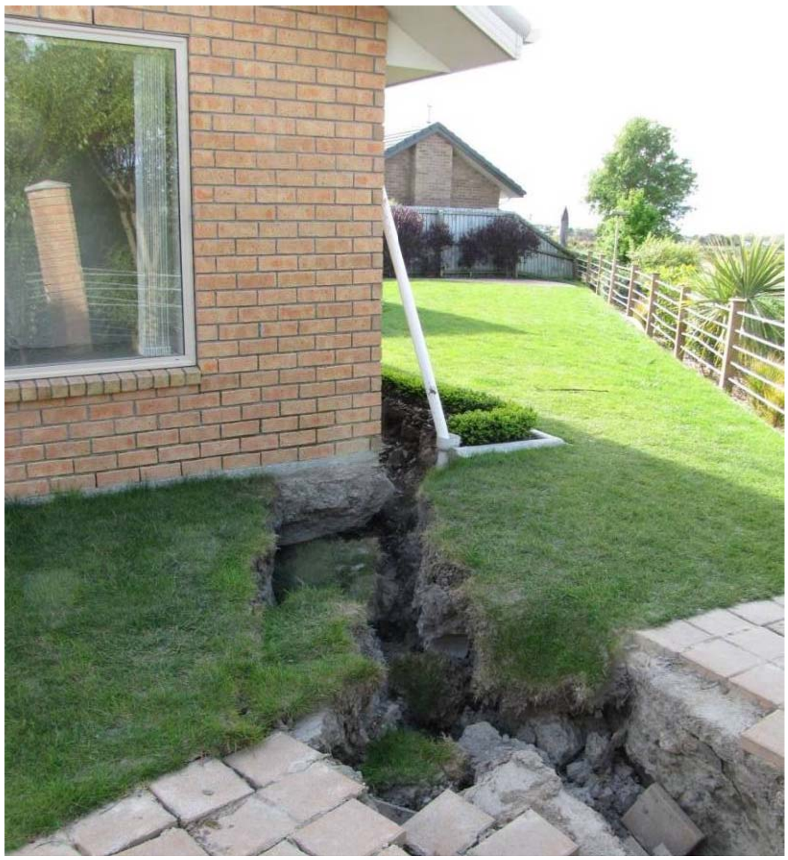

Figure 5.38. Lateral spreading compromising ground support beneath the concrete slab-on-grade house foundation. (Kokopu St; -43.5183°, 172.7220°; 1030hrs on 12 September 2010)

Figure 5.39. Fissure in concrete floor slab (to the left hand side passing beneath the ladder). (Same house as in Figure 5.38.) (Kokopu St; -43.5183°, 172.7220°; 1030hrs on 12 September 2010)

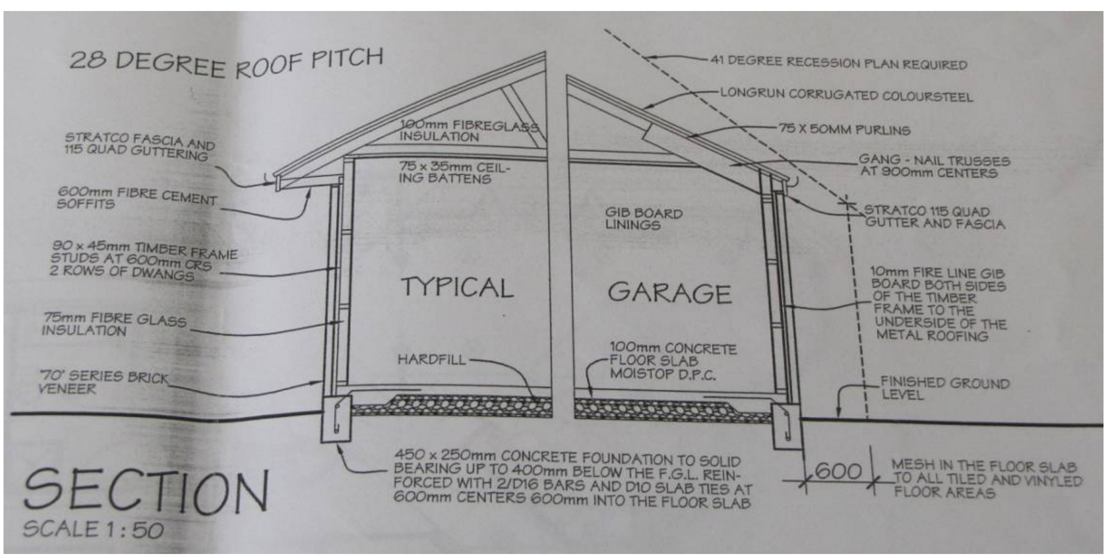

Figure 5.40. Concrete slab-on-ground details for the Bexley houses.

Figure 5.41. Site at Pines Beach which appears to be using the same slab-on-grade system as at Bexley (Chichester St; -43.3877°, 172.70304°; 1800hrs on 12 September 2010)

Concrete slab-on-grade foundations have been used in New Zealand for single and two story timber framed houses for more than 40 years. The current code covering this type of construction is NZS3604:1999 “Timber framed buildings”, which has evolved from previous versions dated 1984 and 1990. The slab-on-grade details shown in Figure 5.40 appear to be in compliance with the NZS3604 which allows, for single story dwellings, unreinforced floor slabs in dry areas but requires mesh in wet areas. The application of NZS3604 is based on the concept of “good ground”. If the site satisfies this condition, then no additional engineering design is required as the developer is able to follow the details set out in NZS3604. Site conditions that exclude the application of NZS3604 are specified as peat, soft clay and expansive clay, all of which are identifiable using rudimentary site investigation techniques. Liquefiable soil is not mentioned. Preliminary site investigations, conducted following this earthquake, indicate that the liquefiable layer is often deeper than 1 m and not infrequently deeper than 2 m (Figure 5.42). This means that the possibility of liquefaction is not as easily identifiable as the above three “good ground” exclusions.

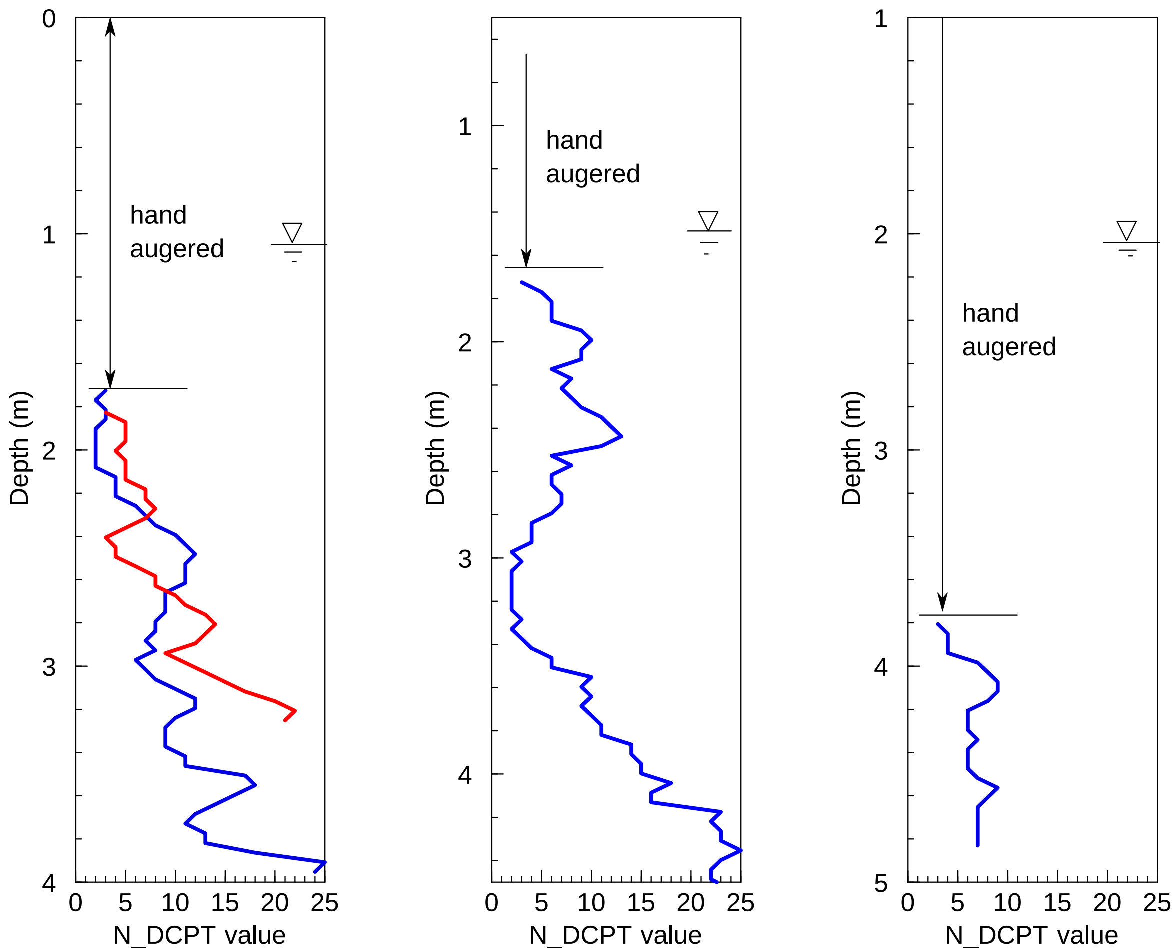

Figure 5.42. N_{DCPT} for the liquefiable layer for Spencerville (left: -43.43075˚, 172.693000˚; -43.431583˚, 172.693233˚), Bexley (middle: -43.518370˚, 172.722050˚) and Courtenay Dr (right: -43.390010˚, 172.662640˚)

Spencerville Residential Area

The residential communities of Spencerville and Brooklands were significantly impacted by liquefaction and lateral spreading. Lateral spreading was confined to regions along the Styx River (Figure 5.43), whereas liquefaction was pervasive throughout these two small communities, but particularly along the regions nearest the Brooklands Lagoon. Particularly significant structural damage due to laterally spreading was observed along Riverside Ln paralleling the Styx River (inset on right of Figure 5.43). Here five large and newly constructed (all within the last 10 years) houses were severely damaged due to laterally spreading (Figures 5.44-5.47). These houses were relatively large structures (200-300 m^2), compared to other developments in or surrounding Christchurch, and each appeared to be a custom design. All appeared to be resting on slab foundations with either light wood framing or brick/CMU walls.

Unlike other areas affected by the earthquake, little ejected sand was observed, however strain relief manifested in the form of large lateral spreading fissures up to 400-500 mm in width in the worst places. The houses suffered only minimal settlement, however the laterally spreading continued through the houses, tearing ground slabs apart and propagating structural damage upwards towards the roofline (the roofline damage pattern here was not unlike that seen at St Paul's church in Dallington). From perimeter and interior views of the foundations of these homes, no reinforcing steel appeared to be present in the main slab. Residential structures in this area with the most severe damage were those with their longitudinal axis in the direction of the lateral spreading. Lateral spread features were long and extended through many properties (e.g. Figure 5.48). One home oriented with its long axis perpendicular to the direction of lateral spread had some damage at the connection between the garage and the house proper, but, unlike the others, was still occupied.

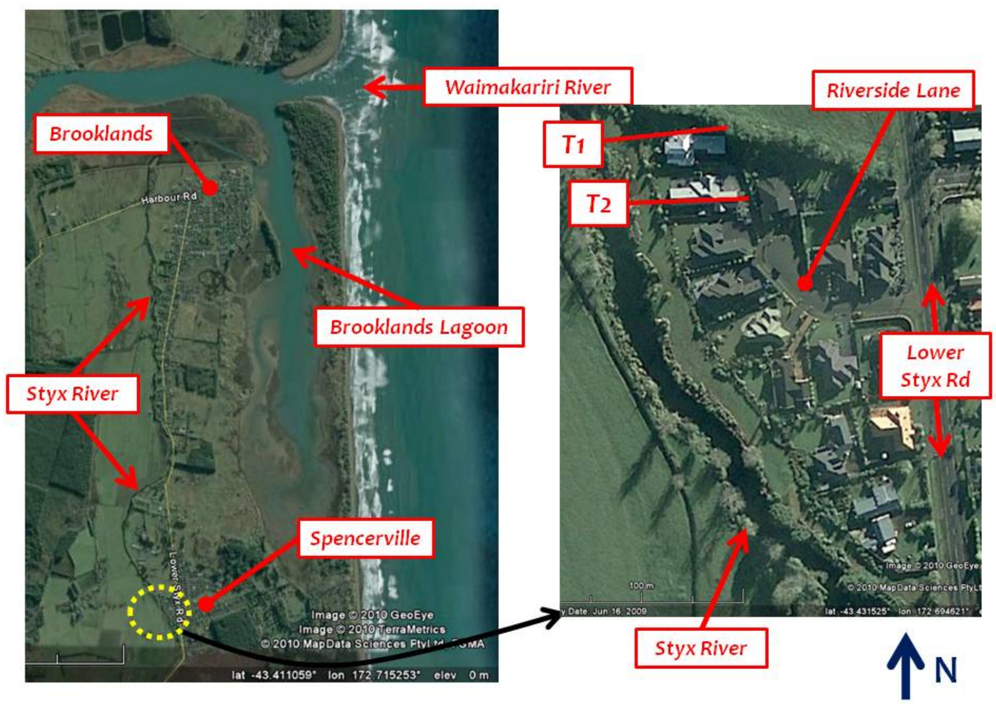

Figure 5.43 Spencerville and Brooklands communities (inset on right identifies surveys conducted by GEER-NZ Team on 14 September 2010 along Riverside Ln). The distances from the left to right edges of the left and right images are ~3.9 and ~ 0.21 km, respectively. (Annotated GoogleEarth image)

(a) (b)

Figure 5.44. Ruptured floor slab near the front entrance of Riverside Ln. Clearly visible is the gravel infill shown in Figure 5.41 (note that there appears to be no ejected sand present). (a) ground fissure separating front entry of the house and (b) same ground feature propagated through the house and departing on opposing side. (-43.43096°, 172.6931°; 1230hrs on 13 September 2010)

Figure 5.45 Interior view of residence at Riverside Ln. Note the two floor breaks visible in the photograph. (-43.4310°, 172.69319°; 1500hrs on 28 September 2010)

Figure 5.46. Lateral spread adjacent to residence at Riverside Ln. The location of this fissure is ~26 m from the nearby Styx River. (-43.4308°, 172.6930°; 1230 hrs on 13 September 2010)

Figure 5.47. House with fissured floor slab with damage carried through to the roof line, which is no longer weather proof. (Riverside Ln, Spencerville). (-43.4311°, 172.6935°; 1600hrs on 28 September 2010)

Figure 5.48 Separated fence line due to propagating ground fissure meandering between houses along Riverside Ln. (-43.43096°, 172.6931°; 1230hrs on 13 September 2010)

References

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