

Field Measurements of Lateral Spreading following the 2010 Darfield Earthquake

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ABSTRACT: A field investigation was launched following the 2010 Darfield Earthquake in order to measure permanent lateral ground displacements in areas significantly affected by liquefaction-induced lateral spreading. Ground surveying techniques were used to estimate total displacement along specific transects. Approximately 75 transects have been completed to date in the areas of Kaiapoi, Spencerville, and various suburbs within Christchurch City. Maximum lateral displacements measured in these areas ranged from about 0.5 m to up to 3.5 m, causing significant damage to nearby structures and lifelines. This paper presents the methods involved in our investigation, a summary of our results, and characteristics of the lateral spreading which occurred in South Kaiapoi.

1 INTRODUCTION

1.1 General

The September 4, 2010 Darfield Earthquake ($M_w = 7.1$) induced widespread liquefaction throughout the city of Christchurch and surrounding suburbs. The worst damage resulted from liquefaction-induced lateral spreading in residential suburbs located in close proximity to streams or rivers. The lateral spreading also resulted in significant loss to many lifelines in these areas. An on-going geotechnical reconnaissance effort led by the University of Canterbury aims to obtain data related to the liquefaction-induced ground deformations in these highly-damaged areas.

One of the reconnaissance efforts has been focused on field investigations of lateral spreading displacements through ground measurement techniques. We estimated the magnitude of permanent lateral ground displacement by summing up measured ground fissures (cracks) along a specific profile (transect) generally oriented perpendicular to the waterway and parallel to the direction of ground movement. This paper summarizes the lateral spreading data collected to date and some preliminary findings.

2 DATA COLLECTION

2.1 Areas Surveyed

Approximately 75 transects have been completed to date. The surveyed areas and mapped transects are shown in Figure 1.

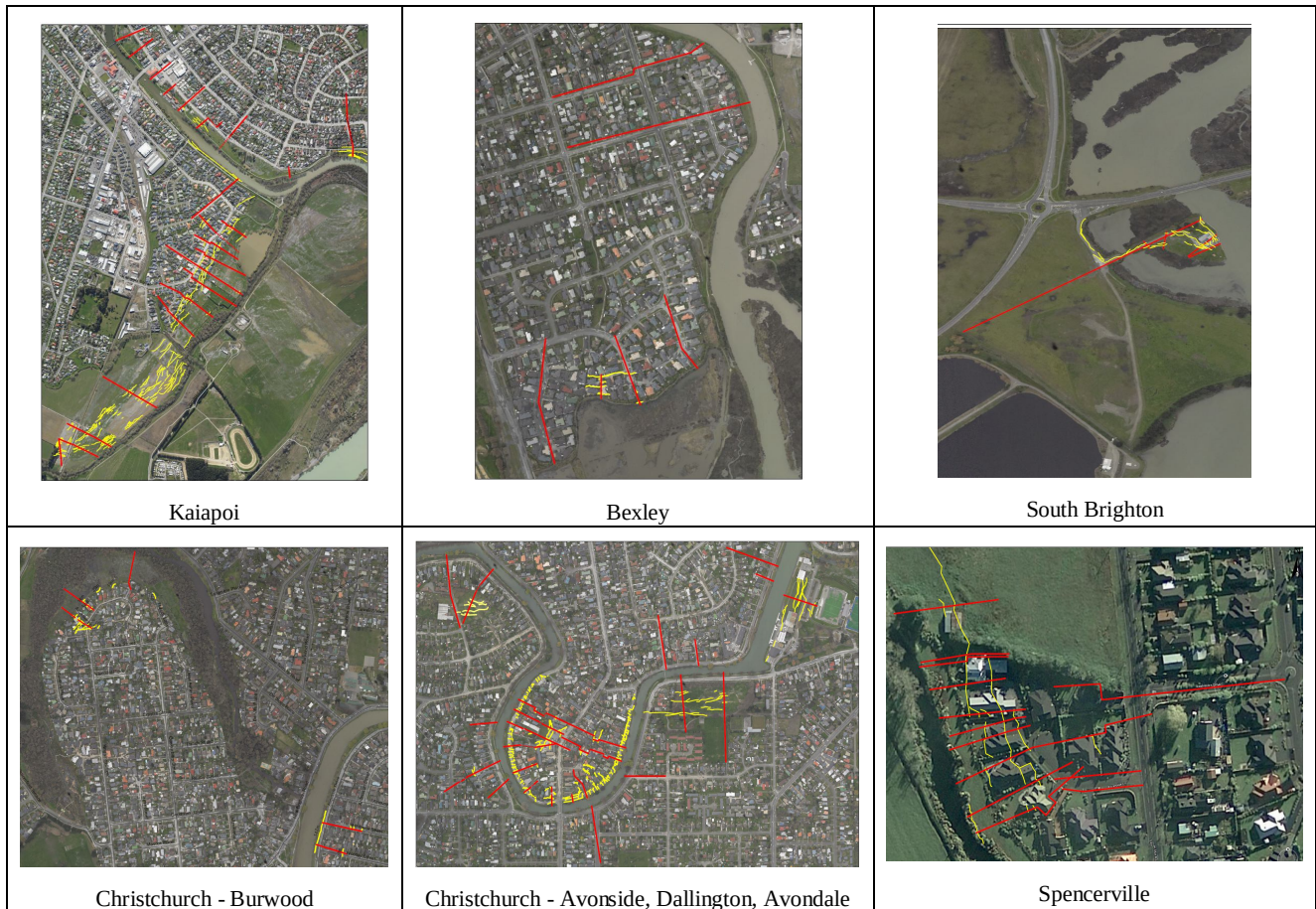


Figure 1. Aerial photographs or Google Earth images of surveyed areas indicating transect locations and major ground cracks/fissures in Kaiapoi, Bexley, South Brighton, Burwood, Avonside, Dallington, Avondale, and Spencerville

2.2 Ground Surveying Methodology

Prior to our field investigations, aerial photographs and Google Earth images of the area were reviewed to determine the approximate location of possible transects. These locations are typically defined by areas that are easily accessible, have a direct line-of-sight with the bank, and can be continued a long distance (e.g. a couple of hundred meters). Other factors that influence the transect location are areas where deformations can be easily measured (quantified), e.g. concrete driveways are typically a good place to measure displacements as the rigid concrete blocks show cracks that are easy to measure whereas cracks in the ground or turf are not always apparent and can be prone to weathering or water action.

Once the general area has been selected, the investigators surveyed the site to determine the best possible location for the transect. This was also dependent on property access, owner's permission, etc. The measurements were executed as follows: One team member stood at the beginning of the transect (typically at the bank) and recorded a waypoint using a handheld GPS and an estimated azimuth along the proposed transect line. The other team member located the first crack (or significant break in slope) along the alignment and sighted back to the other member at eye level using a laser rangefinder. The slope distance and slope angle were recorded and the crack width and vertical offset (where present) were measured using a tape measure. A waypoint at the crack measurement or break in slope location was taken for GPS records. If the crack appeared to extend for more than a few meters in either direction, the crack was traced using the "track" method on the GPS and walking along the crack with the GPS in hand. This process was continued along the transect alignment, generally extending a couple hundred meters where possible. The data was recorded in the field with rough sketches providing plan and profile views. Images of the field methodology are provided in Figure 2.



(a) Measuring crack width



(b) Tracing crack with GPS

Figure 2. Ground surveying and mapping of lateral spreading

2.3 Data Processing

The GPS data was input into a GIS (Geographic Information System) program, ArcMap, and plotted on post-earthquake aerial photographs (where possible) or Google Earth images. Using the GPS waypoints and tracking points, transect locations and crack traces drawn on the aerial photos provide a plan view for the final data presentation. A plan view of the transects located in the subject area of South Kaiapoi is provided in Figure 3.

The transect profiles were computer-drafted to scale using the program AutoCAD 2000, as shown in Figure 4. Dimensions showing distance from river, distance between cracks, and slopes are displayed above the profile, while crack dimensions are shown along the profile. A cross-section from South Kaiapoi (KS-10) is shown in Figure 4. The transect location is shown in Figure 3. A summary of the profile information was also input into excel for documentation and later analysis.

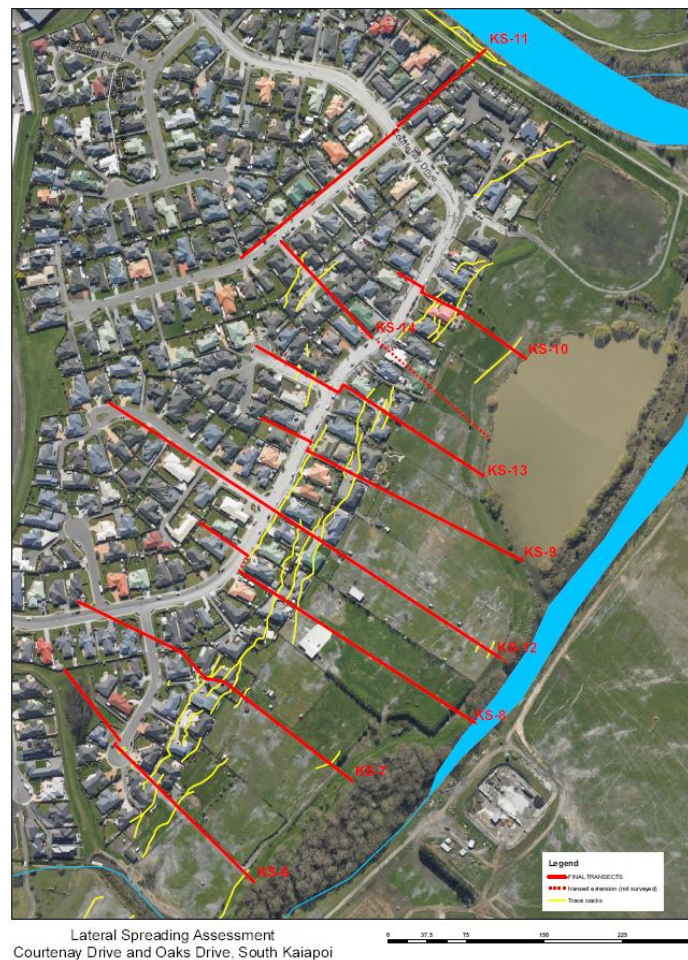


Figure 3. Aerial view of South Kaiapoi indicating lateral spreading transects and locations of major ground cracks/fissures

2.4 Limitations of the Ground Surveying Method

There are several potentially significant sources of error in the field method; error in maintaining the transect azimuth or inability to extend transect to water's edge, error in shooting the slopes and lengths, and error due to post-event modification of cracks. Care was taken to conduct the transect on the original azimuth; however, the actual transect likely strayed less than about a meter from the transect profiles shown on the aerial photographs. In addition, transects were “shifted” (perpendicular to the transect) when necessary to avoid obstacles and were continued as close as possible to the original azimuth. Locations of “shifting” can be seen in the aerial photographs. We note that cracks encountered along this “bend” in the transect were not recorded as only cracks in the direction of spreading contributed to the overall displacement. We note that crack widths often varied along the length of the crack; thus the “shift” in transects should be considered.

Cracks were often filled with sand ejecta or manually filled by the owner. In this case, the initial crack width was estimated as best as possible using engineering judgement. Care was also taken to record the “original” crack width, as often caving on the sides would lead to overestimation of the actual displacement.

The slope measurements may have been affected by either: human error in sighting to eye level on the other team member, local terrain effects, or the level of accuracy of the equipment. We estimate the cumulative error in the slope measurement to be within 0.5 degrees.

In Burwood as well as other locations, the transects were terminated at some distance from the water edge due to the dense bush surrounding the stream or some other obstacle. Where these distances could not be surveyed, we estimated the distance from aerial photos in ArcGIS. All distances estimated from aerial photos are noted as dashed lines on the drafted transect profile and on the plan view. While these sources of error undeniably introduce some scatter and variability into the data-set, we believe the magnitude of spreading was assessed as accurately as possible given the limitations of a rapid, ground-based field campaign.

3 TYPICAL RESULTS AT SOUTH KAIAPOI

The township of Kaiapoi is located approximately 20 km north of Christchurch and is divided into North Kaiapoi and South Kaiapoi by the Kaiapoi River. This paper presents the results on lateral spreading in the areas of extensive damage that occurred along the Courtenay Stream/Lake in South Kaiapoi. The majority of the damage associated with lateral spreading was limited to the houses located on the stream-side of Courtenay Drive and Oaks Drive. A map of the Courtenay Drive area relative to the local streams and rivers is provided in Figure 5.

3.1 Site Description

Courtenay Stream flows to the northeast of the area and joins the Kaiapoi River to the north. Courtenay Lake, located along the northern portion of Courtenay Stream, is an artificial lake created during the construction of the northern end of Courtenay Drive. The present-day lake area was used as a borrow



Figure 5. Aerial view of South Kaiapoi that was severely affected by lateral spreading

site for construction of a hydraulic fill for the northern branch of Courtenay Drive (WDC, 2010).

The houses are separated from the adjacent stream or lake by a large paddock area at distances of about 150 to 200 m from Courtenay Stream and 75 to 100 m from Courtenay Lake. The topography in the paddock areas is relatively flat with slopes generally less than 2 degrees. The houses are typically located on a fill slope which slopes up from the paddock area at gradients ranging from about 4 to 7 degrees. The residential driveways then slope away from the stream at gradients generally less than 3 degrees.

3.2 Geologic Conditions

Kaiapoi is situated in the north-eastern portion of the Canterbury Plains. The Canterbury Plains consist of coalescing fans deposited by the rivers extending eastward from the foothills of the Southern Alps (Brown and Weeber 1992). Berrill et al. (1994) reports of liquefaction in the Kaiapoi area during the 1901 Cheviot earthquake.

The geologic conditions in the area generally consist of Holocene deposits, approximately 100 m thick, underlain by about 300-400 m of late Pleistocene sands and gravels; rock and greywacke basement rock underlie the site at depths greater than 2 km (Berrill et al. 1994). The Holocene fluvial deposits typically consist of interbedded marine and terrestrial deposits resulting from sea level fluctuations (Brown and Weeber 1992).

As seen in Figure 5, the Waimakariri River is the dominant channel feature in the area. The historical meandering loops of this river are likely the cause of the extensive liquefaction observed after the earthquake. Prior to 1868, the river consisted of a northern branch which flowed into present-day Kaiapoi River and a southern branch which flowed into a now abandoned channel in the area of present-day Courtenay Drive area (Ward and Reeves, 1985). As a result of the two branches, the present town centre area was referred to as “Kaiapoi Island.” The old Waimakariri channel likely deposited loose silts and sand in its path (Berrill et al. 1994).

Review of bore logs performed as part of well logs provided by Environment Canterbury (ECan) in the vicinity of our transects indicate the soils in the area generally consist of sand, gravel, and shingle with occasional lenses of clay and peat, extending to termination of bore logs at a maximum depth of 94 m (ECan 2010). Review of preliminary results of Swedish Weight Sounding (SWS) testing (JSA 1995) performed in the area as part of the reconnaissance indicate very loose, granular sand and silty sand to depths of 5 to 6 m.

Groundwater table measurements were estimated during the post-earthquake SWS testing. In the Courtenay Drive area, the water table typically ranged between 1 and 2 m depth. This is consistent with peizocone data from the North Kaiapoi area presented in Berrill et al (1994) which reported water table measurements between 0.89 and 2.1 m.

3.3 Measured Permanent Ground Displacements

Figure 3 shows eight transects performed along Courtenay Stream/Lake as part of our reconnaissance work. Measured permanent lateral displacements at the banks in this area ranged from 1.3 to 2.7 m. A graph showing permanent ground displacement, U_g , versus distance from the waterway, L , for the transects shown in Figure 3 is presented in Figure 6 (a). In the graph, the “waterway” refers to Courtenay Stream or Courtenay Lake.

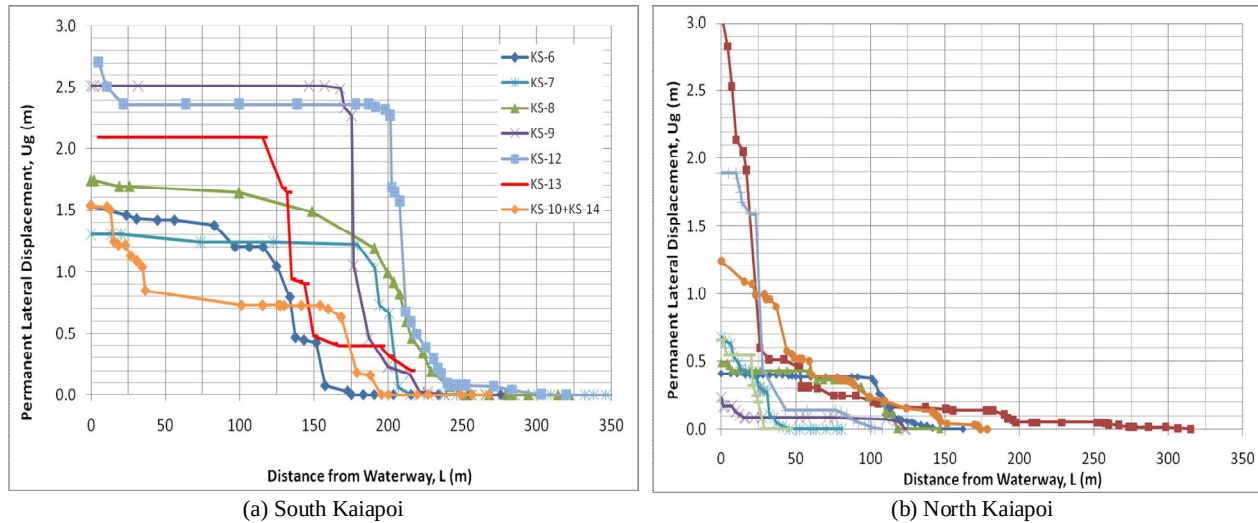


Figure 6. Distribution of permanent lateral ground displacement with distance from the waterway at: (a) South Kaiapoi and (b) North Kaiapoi

Cross-section KS-10 was combined with KS-14 given their proximity to one another as shown in Figure 3. The combined displacement fits well within the trend observed along other transects in the area. A block type of movement is apparent where large ground cracks/fissures are concentrated about 120 to 200 m from the banks with few/small cracks adjacent to the waterway. This is different from a typical distribution of ground displacement due to lateral spreading where the majority of displacements (largest cracks) occur near the banks and decrease with distance from the waterway. A similar plot of distribution of permanent lateral ground displacement with distance from the waterway for North Kaiapoi is shown in Figure 6 (b).

In North Kaiapoi much of the displacement occurred within 50 m of the bank. Similar findings were observed following the 1995 Hyogoken-Nambu (Kobe) earthquake, where permanent lateral displacements were reported to increase sharply within 50 m of the quay walls (Cubrinovski and Ishihara 2003). The block-type movement of South Kaiapoi is probably related to the fact that this area coincides with the location of an old Waimakariri River channel dating back to 1868 (Wotherspoon et al. 2010; Cubrinovski et al. 2010).

4 CONCLUSIONS

Field measurements of permanent lateral ground displacement were conducted along approximately 75 transects in urban areas affected by lateral spreading during the 2010 Darfield earthquake. Lateral displacements were measured as accurately as possible using the ground surveying method.

Maximum spreading displacements generally ranged between 0.5 to 3.5 m in the areas investigated. As a result, a significant amount of damage was induced to the residential properties/houses and lifelines in these areas. Table 1 summarizes the measured permanent lateral ground displacements in the investigated areas.

Table 1. Summary of measured permanent lateral ground displacements at the bank, U_g

Location	U_g (m)
Kaipoi	0.5 - 3.5
Spencerville	0.9 - 1.5
Bexley	0.3 - 0.9
Burwood	0.6 - 0.9
Dallington/Avonside/Avondale	0.5 - 1.8
South Brighton	0.8 - 1.0

In South Kaiapoi, block-type movement was observed with atypical distribution of ground displacements where no cracks occurred close to the river bank, but very large ground fissures/cracks split the ground at distances of 120 to 200 m from the waterway. This feature significantly contributed to the severe damage of residential properties/houses in this area.

The remainder of areas investigated displayed more ‘conventional’ patterns of lateral spreading, with the majority of displacement occurring closer to the free-face (or river bank). The Dallington/Avonside area displayed a very complex pattern of spreading as a result of the meandering features of the Avon River in the area.

The results of our field investigation provide a preliminary assessment of permanent lateral ground displacements in the areas investigated. Further analysis will include comparison of our findings with alternative methods such as aerial photographs and geodetic surveying.

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