2012 Caernarfon Award Submission
New Zealand

LAND DAMAGE ASSESSMENT

LIQUEFACTION & LATERAL SPREAD

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at the Annual QuarryNZ Conference
Wellington, New Zealand
July 2012

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Liquefaction & Lateral Spread

By Murray Discombe

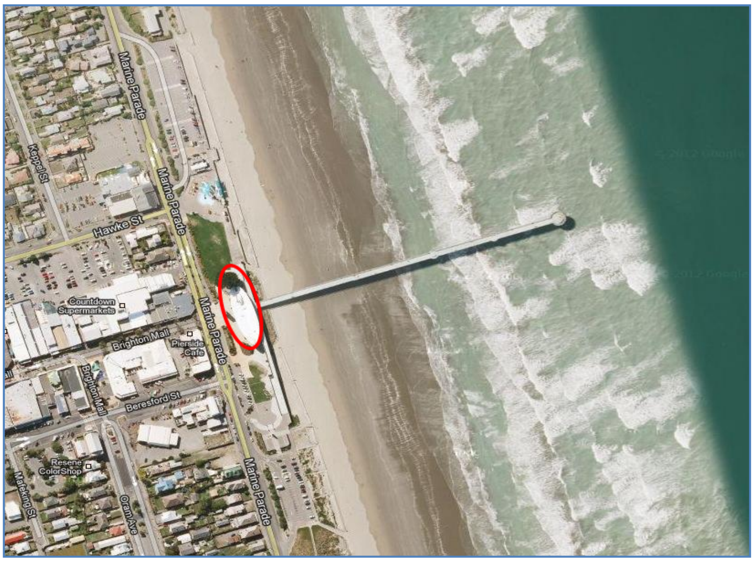
Introduction:

Earthquakes can be one of the most devastating natural disasters.

The sequences of four major earthquakes in the Canterbury / Christchurch area commencing in September 2010 has wreaked havoc in many areas and turned the lives of thousands of people into turmoil.

While extensive TV coverage on the evening news has highlighted the plight of the Central Business District (CBD), where falling multi-storey buildings claimed the lives of over 180 people, it is to the residential areas of Christchurch, home to more than 300,000 people that this paper is devoted.

The Brighton Pier at Brighton Beach is one of my favourite spots in Christchurch. It has a spectacular pier about 300m length and was opened in late 1997. The Brighton Library is an elliptical shaped building with commanding views over the sea, and is a wonderful spot to relax or to take in some great food at the restaurants nearby.



The aerial shot above gives some idea of the size of Brighton Pier. Access is via a concrete walkway constructed on the seaward side outside the library / restaurant complex (highlighted in red). The attached video was a segment of footage recorded by the CCTV camera fitted to the outside wall of the library. For those who have never seen what happens during an earthquake, this video demonstrates what just a six second event looks like and how a seismic gap functions under this duress.

Preamble:

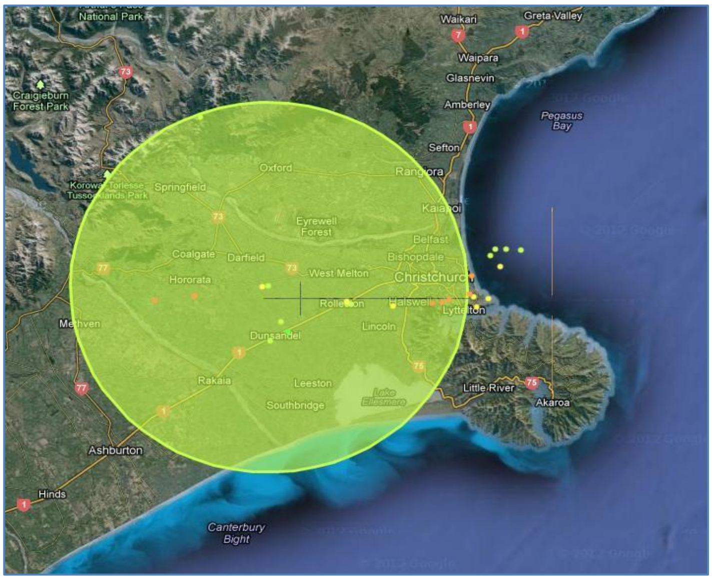
This paper shows the major earthquakes in Canterbury. A brief discussion on the geology of Christchurch will help explain why the damage has been so severe.

Land Damage Assessments were carried out by the Earthquake Commission (EQC)- these will be discussed including the damage associated with liquefaction & lateral spread.

In order to ascertain how to fix damaged dwellings, it's important to first understand the different dwelling foundation types as defined by the Department of Building and Housing Guidelines. There are several defined types of dwelling damage and many photos which aptly show each case. In addition to damage to residential land and dwellings, bridges have been significantly affected. Dwellings located on Christchurch's Port Hills also sustained significant damage and there a good examples of this.

Of course, we are a resilient lot – rebuilding a city requires construction. A few good examples of recent and future developments are presented.

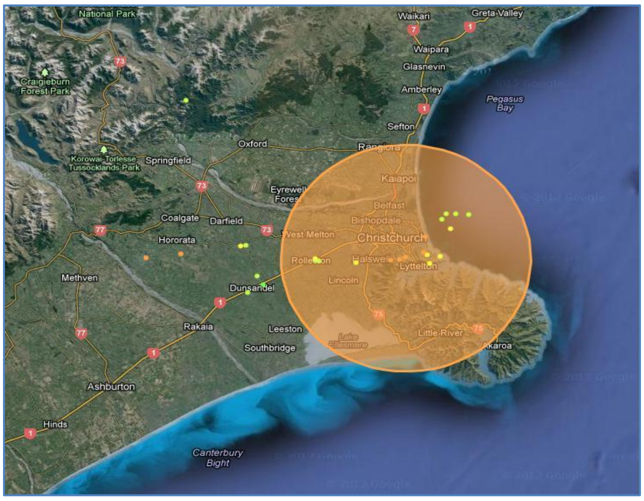
Recent Earthquakes:



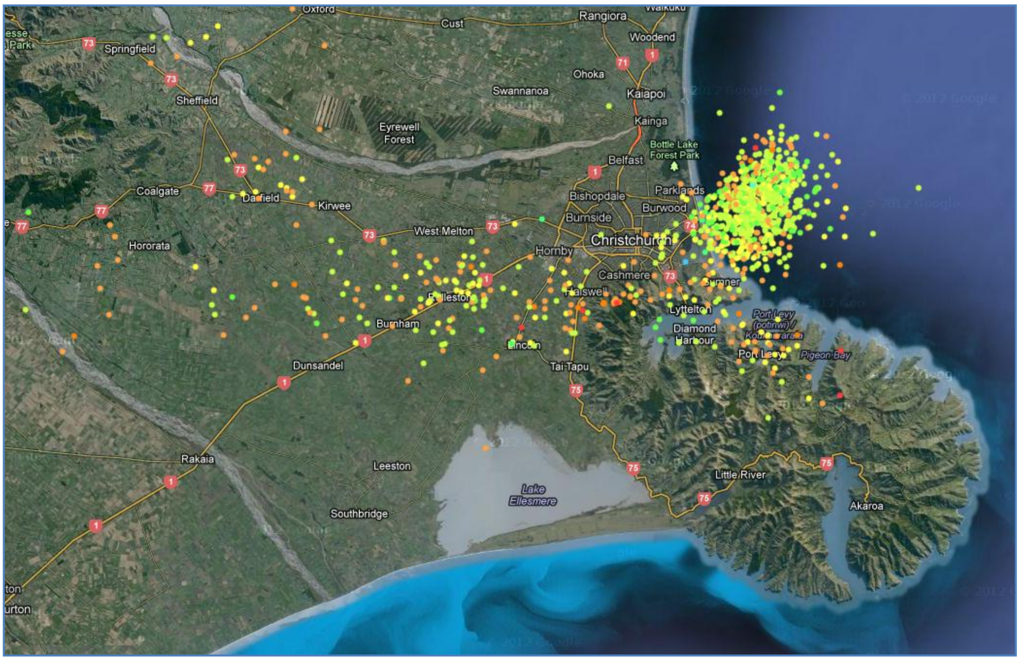
The first earthquake on 4th September 2010 centered near Darfield measured 7.1 on the Richter scale and caused unbelievable damage. The distorted railway line above is a good example of its power.

The earthquake on Feb 22nd 2011 registered 6.3 on the Richter scale and caused huge damage to land and buildings. It was located close Christchurch's CBD, was very shallow, and resulted in 181 deaths.

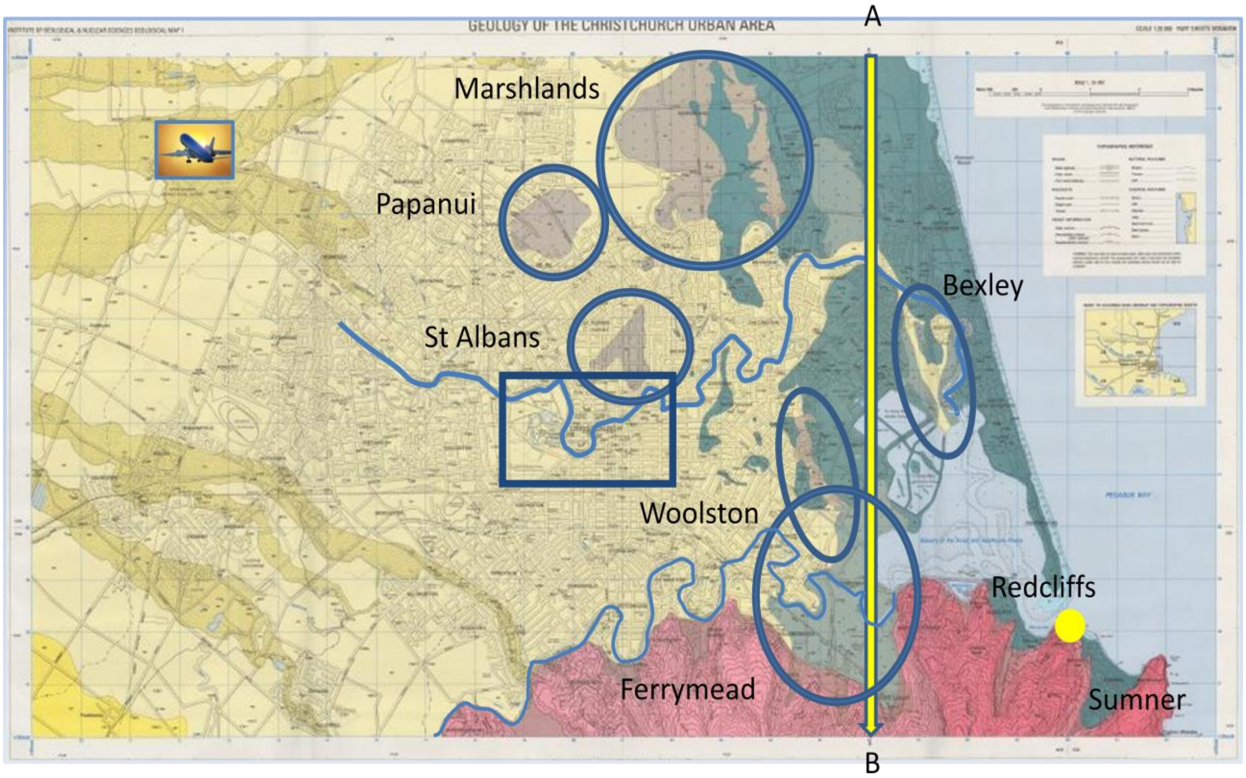
An earthquake in June of the same year of similar scale to the February one again created havoc and more damage. This one also being located just a few km east of the city



There have been more than 10,600 earthquakes since Sep 2010, with 1059 shown in the slide below (230 days since 23/12/2011). There is a distinct pattern, with the majority occurring in a line across the city extending out into Pegasus Bay in a north-easterly direction. Most are less than 10km depth (yellow dots).



Geology of Christchurch Urban Area:

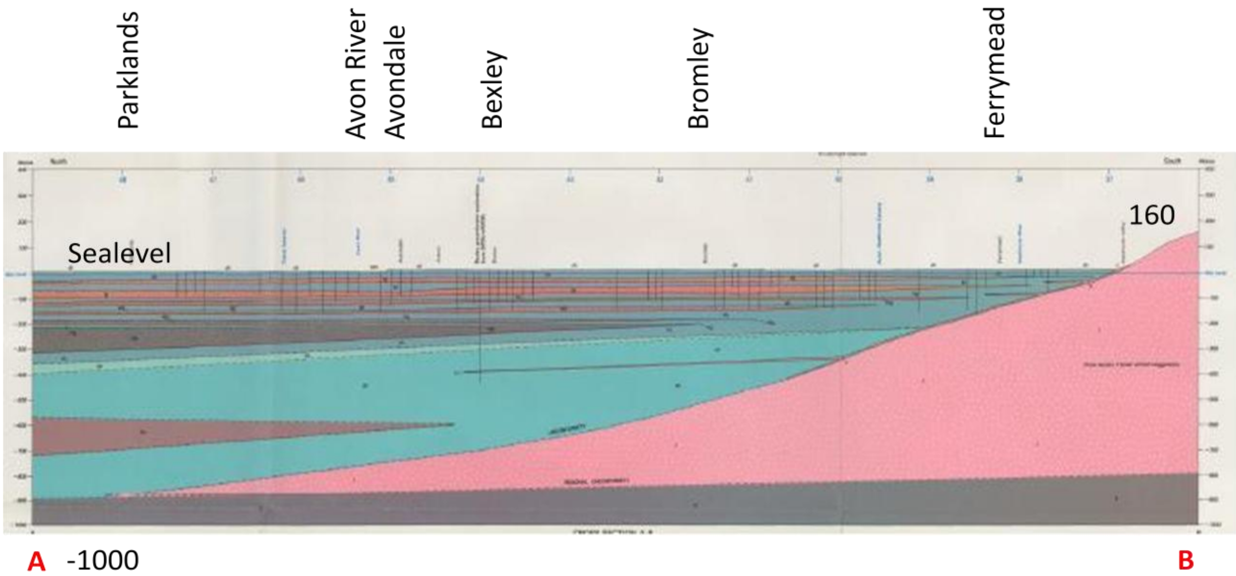


This map depicts the geology of the Christchurch urban area. There are a number of areas featured which will be addressed later in the paper.

To assist getting your bearings around Christchurch I have highlighted some key areas, as follows:

- The airport in the northwest
- the CBD in the rectangle
- the Avon River which discharges into the estuary near Bexley
- the Heathcote River which meanders around the base of the Port Hills and discharges to the same estuary near Ferrymead
- a wetlands swampy area known as Marshlands
- old peat swamps in Papanui and St Albans
- industrial / residential areas of Woolston and Ferrymead immediately adjacent to the current day estuary, as well as
- Bexley located immediately adjacent to the Avon River.

The slide below shows a cross-section through the city from A (in the north) to B in the south.



The cross section AB shows the Port Hills at approx 160m above sea-level. The geology is typically thin layers of deposited sands, gravels and silts, interspersed with some volcanic material comprising the following forms.

- Gravels and sands in present day river channels.
- Alluvial gravels, sand and silts from historic river flood channels.
- Peat swamps now drained.
- Higher elevation, older alluvial gravel sand, and silt.
- Valley fill and slope wash with loess-volcanic derived colluvium.
- Blue/brown alluvial gravel with some sand and silt.
- Brown alluvial gravel with some sand and silt.
- Sand of active dunes and present day beaches.
- Sand, silt and peat of drained lagoons and estuaries.
- Undifferentiated subsurface gravel, sand, shelly sand, silt, clay, peat and wood (marine, estuarine, swamp, dune).

In summary, where flat land is close to rivers, streams, coastline and marsh, the greater is the proportion of sands and silts present in the soil composition. The flat land usually has a high water table with an increased chance of liquefaction. Where flat land is further inland there are more gravels, less fine sand and silts present; a lower water table, and decreased chance of liquefaction.

Land near the Port Hills has sands with volcanic materials present but there are many other factors which give rise to damage in the hills.

Land Damage Assessment:

Part way through 2011, the Earthquake Commission (EQC) established a Land Damage Assessment Team led by Tonkin & Taylor as principal consultants to coordinate assessment work. They in turn invited support / assistance from other engineers to carry out the assessment for all residential properties. I consider myself privileged to be one of several in the Fraser Thomas team to be engaged for this key investigation work. Flat land took priority and land damage assessments in the Port Hills area followed quite quickly afterwards.

The earthquake land damage assessments were carried out predominantly by Geotechnical Engineers and Engineering Geologists to ascertain where the damage has occurred, how much, and what effects has the land damage has contributed to buildings, and to infrastructure.

The Department Building & Housing concurrently developed revised guidelines for residential construction based on the damages recorded.

There was a huge quantity of information gathered for each property including the presence of liquefaction or sand boils, lateral spread, as well as damage to any dwelling located on the property – factors such as foundations, walls, windows, internal piles, roof type (light or heavy), to name a few. Observations on the status of driveways and paths were also recorded, including settlement.

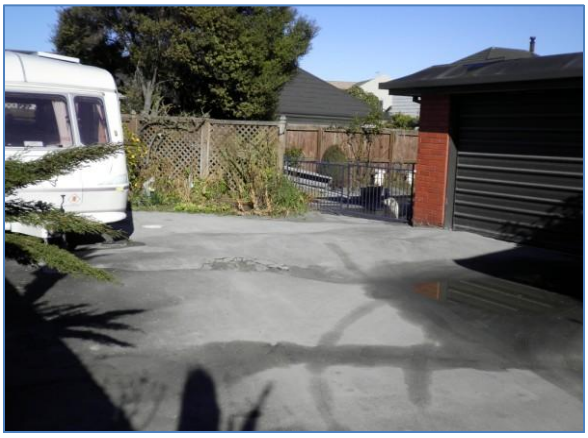
Liquefaction:

There are several definitions of liquefaction, but in essence it is *the process by which sediment that is very wet starts to behave like a liquid.* Liquefaction occurs because of the increased pore pressure and reduced effective stress between solid particles generated by the presence of liquid. It is often caused by severe shaking, especially that associated with earthquakes.

Liquefaction manifests itself in many ways – as sand boils where the sand ejects from the surface to look like mini volcanoes; as a deformed surface where the force is insufficient to cause sand ejection (e.g beneath a concrete slab or bitumen (asphalt) pavement; or as experienced in many areas in Christchurch, as a watery silt-laden fluid bursting through floor slabs, roads, generally creating havoc and large-scale devastation. The following photos show typical examples of liquefaction.

A row of sand boils look like mini volcanoes.

Sand boils created huge undulations in this lawn.



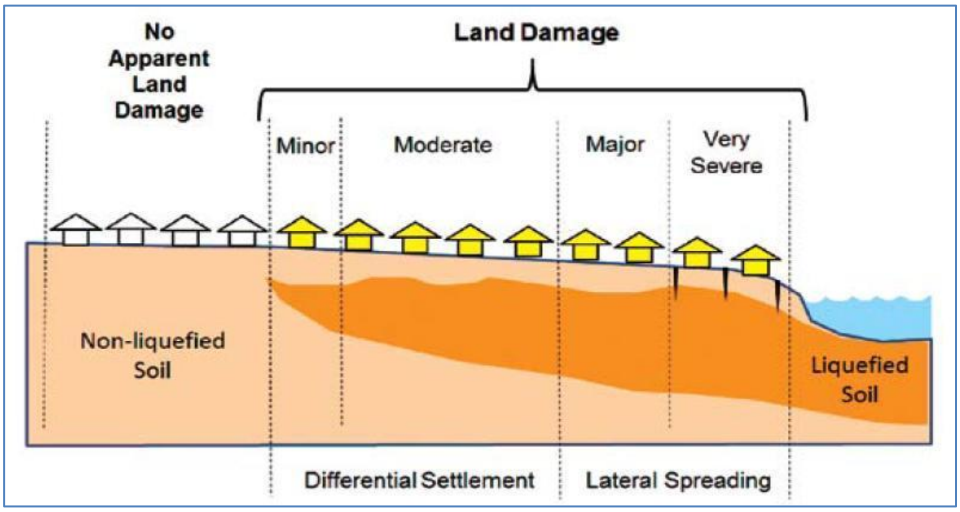
Sand boils – deformation of asphalt driveway.

Liquefaction, the aftermath is often a heavy densely-packed fine charcoal coloured silty sand.

Where liquefaction occurred in streets it created a serious motoring hazard - severe potholes and sink holes as well as horizontal and vertical distortions to the road surface.

Lateral Spread:

This diagram, courtesy of Department of Building & Housing indicates where lateral spreading and differential settlement is likely to occur. The extent of lateral spreading is greatest where the land is immediately adjacent to a waterway – creek, stream, river, estuary etc.



Earthquakes induce increased pore pressure in soils commencing the liquefaction process where soils containing fine silts especially silty sand trigger land to slide towards the water.

Lateral spreading is characterised by horizontal displacement creating cracks / fissures in ground generally parallel to a stream, river or estuary. They also form in areas adjacent to old river beds or edges of drained swamps. There is usually a vertical offset in ground level each side of the spread crack. The effects can be significant, often affecting foundations and inducing tilt settlements in dwellings and buildings.

The *Geology of Christchurch* section above provides examples of where lateral spread and liquefaction has occurred:

- Marshlands – a suburb comprising wetland / marshy areas together with drained peat swamp
- Papanui and St Albans – drained peat swamps
- Bromley, Woolston, Ferrymead – areas immediately adjacent to old and modern day estuarine sediments
- Bexley - a suburb constructed immediately adjacent to where the Avon river discharges to the estuary
- Areas immediately adjacent to the Avon and Heathcote Rivers

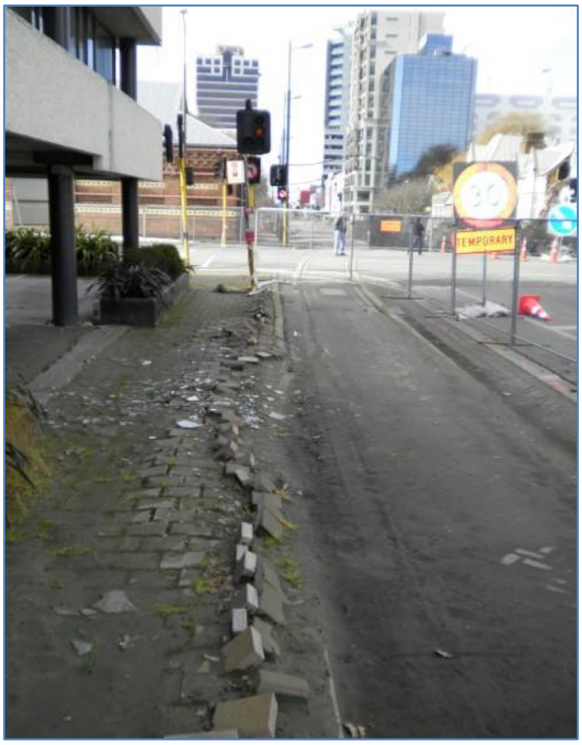
The net effect in suburbs adjacent to modern day rivers, previously drained swamps and waterways is so great that the infrastructure – in particular roads, and public wastewater systems have suffered major damage. Appraisal of the land damage has meant categorizing some of this land as "red zone", because it is not considered worthwhile to effect repairs only to have the work damaged again in another severe seismic event.

Lateral spreading fissures near the Avon River.

Deformed fences are good indicators of ground movement associated with lateral spread.

A 0.9m wide “river” of sand through this property shows the magnitude of lateral spread.

Land damage associated with lateral spread has caused severe tilt in this dwelling located just 20m from the Avon River.

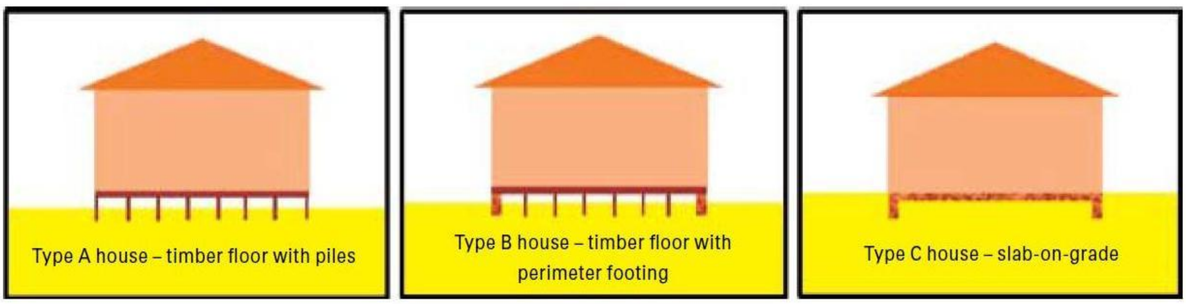


In the central city a distorted row of cobbles denotes lateral spread coupled with severe shaking damage.

Dwelling Foundation Types:

In order to assess how to fix damaged buildings, the Department of Building and Housing defined the types of foundations as in the diagram below:

Figure 2.1: Dwelling foundation Types A, B and C

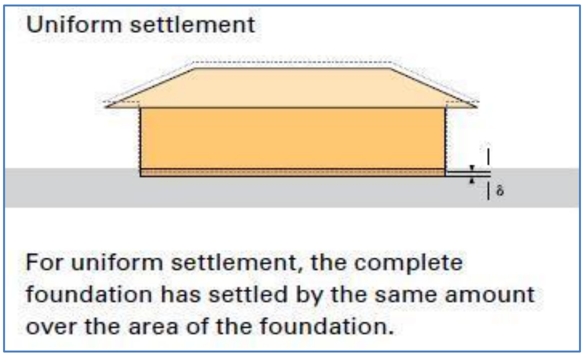


There are two categories of damage; damage that was caused solely by earthquake shaking and damage that resulted from ground deformation including liquefaction, lateral spreading or landslip.

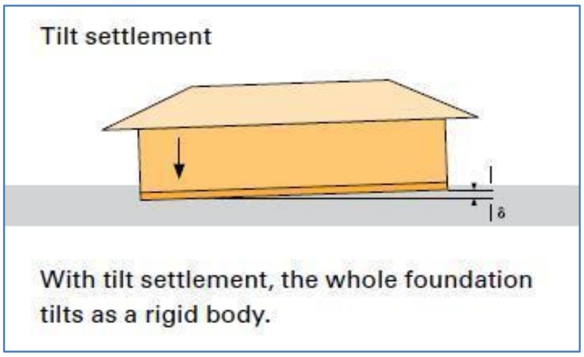
The severity of the damage is dependent on damage type, type of building, building geometry and the amount of foundation movement that has occurred.

Settlement Types:

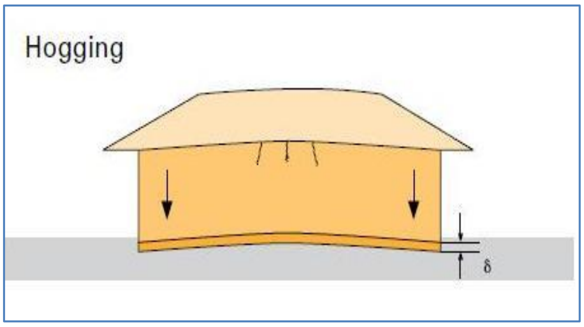
There are several types of settlement:



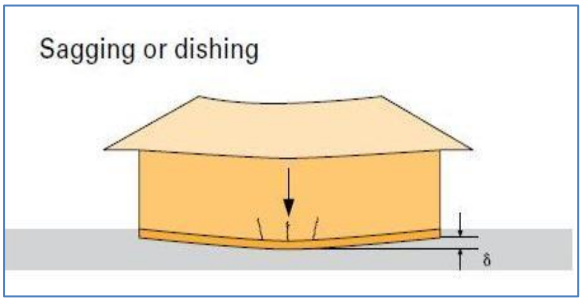
In this example, the house has settled approx 550mm.



I have seen many examples of tilt settlement but this one depicts it best.



Hogging - one end of this dwelling slumped more than 650mm.



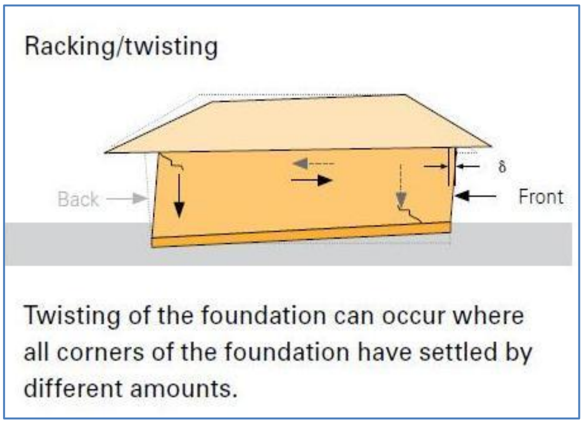
Here the foundations of this 'L-shaped' dwelling have collapsed causing it to sag.

Differential Settlement:

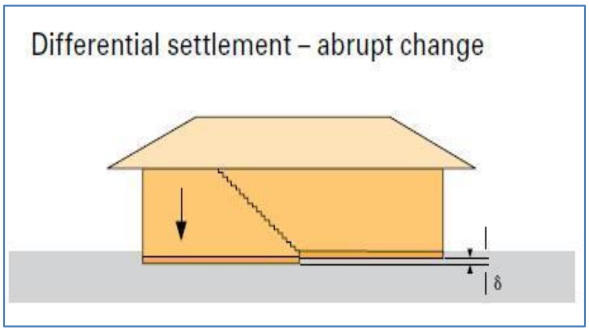
There are three types of differential settlement:

- Racking and twisting
- Abrupt change
- Lateral stretching

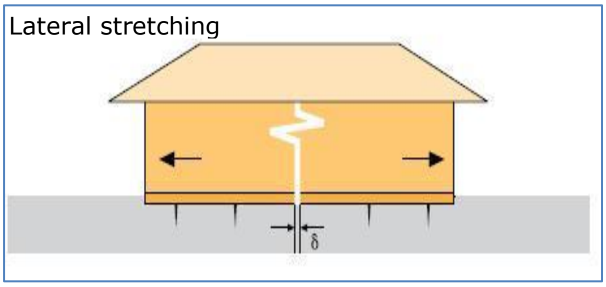
Examples are depicted below -



This dwelling was 'red stickered' due to significant racking and twisting.



In this type of differential settlement one portion of the foundation is lower than an adjacent section.



Lateral stretching is almost always associated with lateral spreading.

This stucco dwelling located just 30m from the Avon River has several rooms torn apart – induced by the lateral spread cracks directly through the surrounding ground.

Bridges:

During the course of our land damage assessments we observed that a number of bridges had been damaged as a result of the earthquakes. Of course the purpose of a bridge is to create a method of access between opposite sides of a river / stream. Abutments form a vital part of the bridge construction, with piles constructed in accordance with the loading and distance a bridge has to span.

In an earthquake, in areas prone to lateral spread, typically the base of abutments slide towards river / stream. Piles can be affected and in some instances the entire bridge has been relocated sideways or upwards or both.

The examples below demonstrate how some of the bridges fared.

Street lights located at each end of the bridge are attached to the abutments. The base of the abutments has slid towards the river as indicated by the angle of the lights - 4 to 5 degrees tilt.

This photo demonstrates the power of earthquake - significant misalignment of bridge and abutment.

The entire Medway pedestrian bridge has been severely distorted when the west bank moved approx 1.3m relative to east bank.

Lateral spread fissures parallel to the estuary edge (shown in the above photos) severely impacted on the bridge abutments to the bridge crossing the mouth of the Avon River. The bridge is now closed to all trafficwaiting on full engineering assessment and repair.

Port Hills Land Damage :

Suburbs located in the Port Hills area of Christchurch are currently subject to ongoing work by Christchurch City Council, Christchurch Earthquake Recovery Authority (CERA), EQC and GNS Science, investigating causes and implications of various forms of damage. They are also evaluating areas of rockfall, cliff collapse and boulder-roll to determine appropriate remediation options.

At the time of writing there have been 406 properties zoned red because the level of life risk in those areas is considered unacceptable and protective works to mitigate the life safety risk in those areas are not considered practicable.

Many dwellings in the Port Hills have suffered significant structural damage from earthquake shaking while others have severe damage, in many cases caused by increased ground accelerations on ridgelines, slope and cliff crests of up to minus 3G [approx minus 30 metres per second per second]. *Note the extra 'per second' is not an error - acceleration is a measure of velocity changes with time.*

The photos below depict typical examples of damage sustained.

Dislodged roof tiles.

This house has been severely damaged, the garage totally destroyed (a good example of unreinforced masonry!).

While the damage to houses depicted above has created misery for many home owners, it is the occurrence of tension cracks in many of the suburbs that has created the most concern. Collapsed road shoulders have created narrow roads, and have made private driveways impassable for many residents. Rockfalls are also an ever-present threat to residents from and visitors to the Port Hills.

This rock completely flattened a street light pole and came to rest on the footpath in front of this dwelling.

Tension cracks trigger road shoulder collapse and potential landslide.

Construction work:

Despite the damage, construction continues around Christchurch with replacement and reconstruction of the public wastewater system taking priority, with many thousands of tonnes of aggregate used for bedding and backfilling.

One of the consequences of the earthquakes is that the huge volumes sand / silt produced during liquefaction have caused the river beds to be elevated such that many areas of flat land adjacent to the Avon River were prone to flooding, especially at high tide. One project taking approximately three months to construct was stop banks for 9km length each side of Avon River. The base of the stop banks measured 7-8 m width, and 3-4 m at the top. Average height of 1.4m consumed about 140,000m^3 gravel - a significant boost to the local quarrying industry.

Some 36 projects are under way, many involving aggregate supply - bridge & road repairs, new roading projects, as well as stormwater culvert works.

A new 2000 home subdivision is planned which is expected to consume some 1.2 million cubic metres of aggregate over a 9 month period. On top of this will be the aggregate for concrete manufacture and asphalt production.

While infrastructure is unable to be repaired in the red zone, ongoing geotechnical assessment for stability is being assessed in the TC3 areas, as well as damage assessment in the Port Hills.

Another benefit is that the severe damage to structures has given the Department of Building & Housing an opportunity to provide revised guidelines for repair of damaged and construction of new safe dwellings, and instituted much needed changes to sections of the Building Code.

I trust this paper coupled with the photos has helped explain what the world already knows – that major earthquakes have caused serious damage across this Christchurch region and why many residents anxiously await the outcome of geotechnical investigation work. The geology of the Christchurch area has contributed to the damage of residential land, dwellings, and infrastructure caused by liquefaction and lateral spread. However repair and reconstruction has also provided a much needed boost to a previously “average” quarrying industry and this is best described by the old saying “every cloud has a silver lining”.