THE Q FILES

THE SOLID FACTS ON CHRISTCHURCH LIQUEFACTION

WHAT IS LIQUEFACTION?

Liquefaction (pronounced "lick-wi-fack-shin") happens during earthquakes.
The ground shaking that occurs during an earthquake can cause some soils to liquefy.
This means that during an earthquake these soils will behave
more like a liquid than a solid...

DOES LIQUEFACTION HAPPEN IN ALL EARTHQUAKES?

No. Strong ground shaking is required for liquefaction to occur. Liquefaction may occur at Modified Mercalli Intensity 7 (MM7). The MMI scale (1 to 10) is a measure of how strong ground shaking is at a specific location. At MM7 there is general alarm, it is difficult to remain standing, large bells will ring, furniture will move and un-reinforced masonry buildings w[...] Liquefaction is common in areas where there is MM8 a[...] shaking. At MM8 alarm may approach panic, steering o[...] is affected, substantial damage to buildings occurs, th[...] cracks and road cuttings collapse.

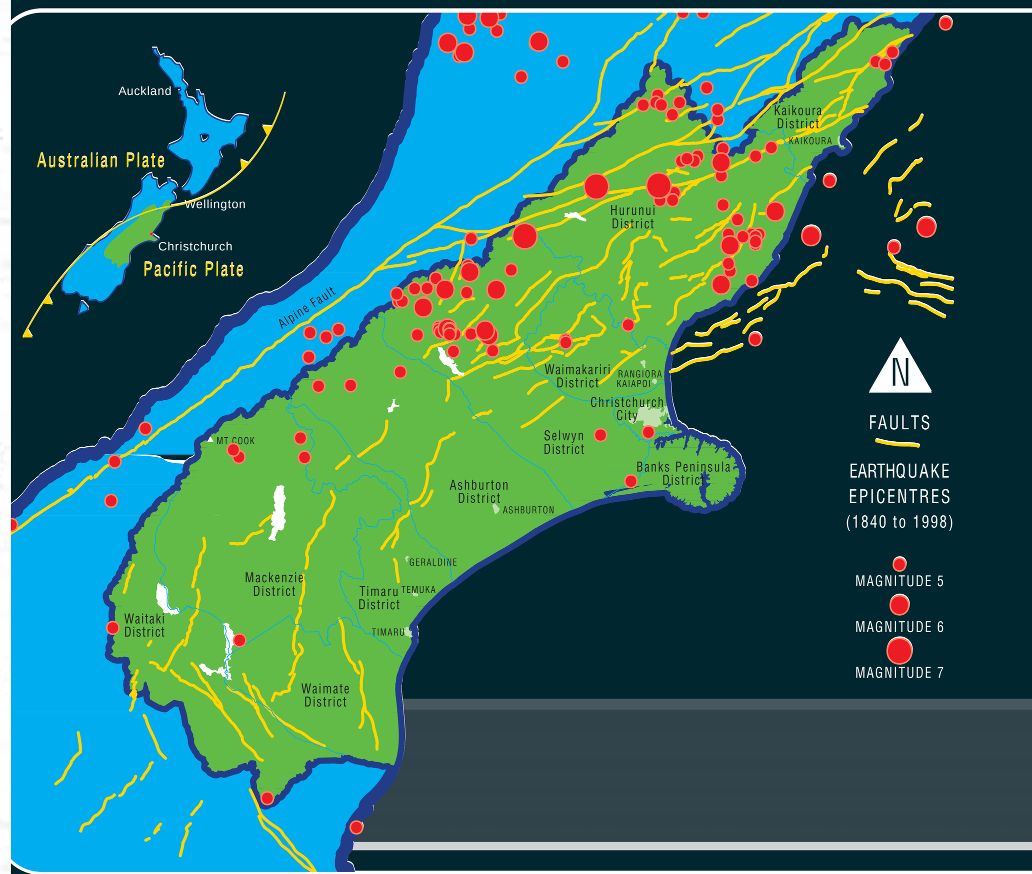
MODIFIED MERCALLI INTENSITY SCALE

The Modified Mercalli Intensity scale (MM scale) is not the same as magnitude. The MM scale is based on observations of the effects on people, objects (such as furniture and crockery), buildings and other structures, and the physical environment, including lakes, sea, and slopes. The effects vary with distance from the earthquake's epicentre, with the greatest damage usually occuring closest to the epicentre. A line called an isoseismal encloses areas of equal intensity of shaking, but actua[...] recorded at any particular location may vary dependi[...] topographic, geologic and soil conditions. On the [...] isoseismal maps for two historic earthquakes in Cante[...] one predicted earthquake scenario.

An abbreviated version of the MM scale is given belo[...]

5	Generally felt outside. Most sleepers awakened. Small unstable objects move, some glassware and crockery broken.
6	Felt by all. Difficulty in walking steadily. Objects fall from shelves. Slight damage to badly-constructed buildings.
7	General alarm. Difficulty in standing. Some damage to buildings not designed to withstand earthquakes. Furniture moves. Un-reinforced chimneys, roofing tiles and water tanks break.
8	Alarm may approach panic. Steering of motorcars greatly affected. Some damage to earthquake-resistant buildings. Serious damage to less well-designed building types. Monuments and elevated tanks brought down.
9	Heavy damage to buildings and bridges. Houses not secured to foundations shifted off. Landslides widespread on steep slopes. Cracking of ground conspicuous.
10	Severe damage to many buildings and bridges, even those of most recent design.

Source: Ansell, R. and Taber, J. (1999). Caught in the Crunch.



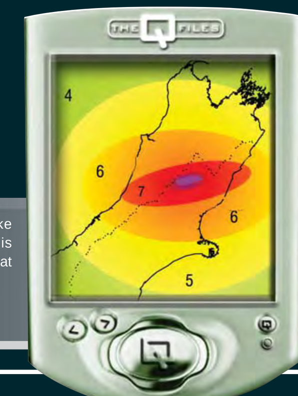
NEW ZEALAND'S TECTONIC SETTING

New Zealand is on the boundary of two of the earth's plates, the Australian Plate to the west and the Pacific Plate to the east. These plates are moving against each other and, because of this, New Zealand is a highly-active earthquake zone.

The earthquake hazard is even more extreme for Canterbury because of the Alpine Fault. It is the "on-land" boundary of the Australian and Pacific Plates, and is New Zealand's largest active fault, running under the Southern Alps for over 500km.

The Alpine Fault can produce magnitude 8 earthquakes and does so about every 300 to 350 years. The last earthquake on the Alpine Fault was in 1717. Ground shaking intensities in Christchurch during an Alpine Fault earthquake will be high enough to cause liquefaction. The Alpine Fault is not the only source of earthquakes for Canterbury, with about one hundred other sources having been identified. Some of these are also capable of producing strong ground shaking and liquefaction in Christchurch.

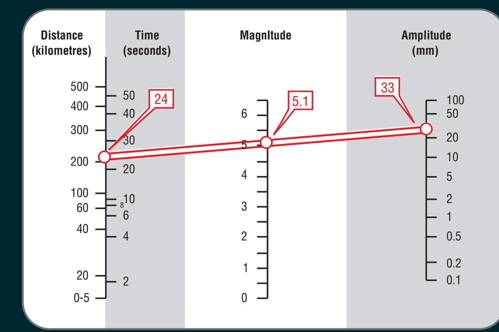
4 June 1869 Christchurch earthquake magnitude 5.0. This isoseismal pattern is typical of a magnitude 5 to 6 earthquake that could occur anywhere in Canterbury.



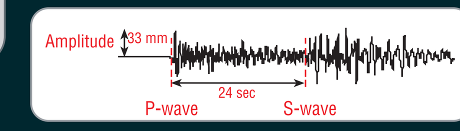
1 September 1888 North Canterbury earthquake magnitude 7.0-7.3. This isoseismal pattern is typical of a large shallow magnitude 6 to 7 earthquake that could occur on any of the known faults in north, west and southwest Canterbury.

The most probable ground shaking intensities for a magnitude 8 earthquake on the Alpine Fault, which is the largest earthquake likely to occur on faults close to Canterbury.

EARTHQUAKE MAGNITUDE



Earthquake magnitude is a measure of the actual energy released at the focus of the earthquake and was developed by Charles Richter for comparing the size of earthquakes in California, USA. The magnitude of an earthquake is determined by measuring the largest amplitude of either a primary (P) or secondary (S) wave recorded at a seismographic station, and the time lapse between each of these waves. A straight line is drawn between the time and amplitude scales on the chart to determine the magnitude and the distance of that particular seismographic station from the earthquake epicentre.



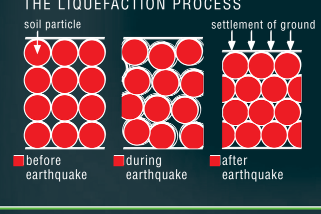
Because of the huge range in earthquake sizes, the magnitude scale, based on ground displacement, is logarithmic. For each step in magnitude, the energy released goes up 32 times. Therefore, a magnitude 7.5 is 2.8 times larger than a magnitude 7.2 earthquake, and a magnitude 8 earthquake releases almost one million times more energy than a magnitude 4 earthquake.

HOW DOES LIQUEFACTION HAPPEN?

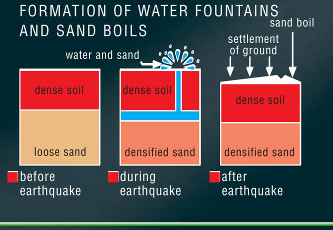
When the ground shakes during an earthquake the soil particles are rearranged and the soil mass compacts and decreases in volume. This decrease in volume causes water to be ejected to the ground surface.

Sand volcanoes or sand boils, water fountains and associated ground surface cracking are evidence that liquefaction has occurred.

THE LIQUEFACTION PROCESS



FORMATION OF WATER FOUNTAINS AND SAND BOILS

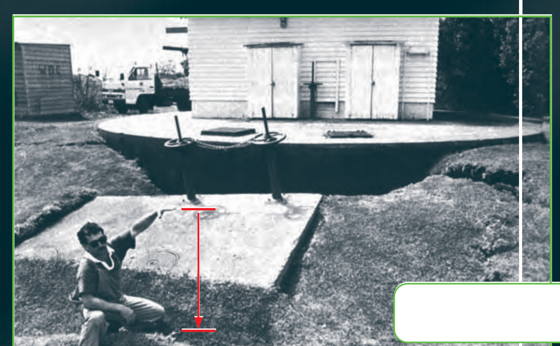


WHAT ARE THE EFFECTS OF LIQUEFACTION?

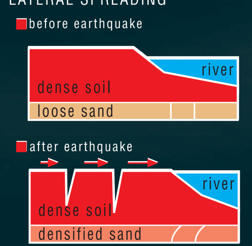
Liquefaction causes damage to the ground. Because the soil mass decreases in volume as a result of liquefaction, the ground surface may subside. Uniform subsidence over large areas may go unnoticed. Differential subsidence, particularly where there are buildings and other infrastructures, can be very obvious because of the variation in damage to those structures.

Lateral spread of the ground can also occur. Lateral spread is when blocks of land move sideways. This is most common near rivers, streams, lakes and coastal areas.

Flow failures (displacement of large masses of soil laterally for tens of metres and sometimes kilometres) and loss of soil strength are two other significant effects of liquefaction.



LATERAL SPREADING



WHAT TYPES OF SOILS ARE MOST LIKELY TO LIQUEFY?

Liquefaction does not occur at random, but is restricted to certain geologic and hydrologic environments. Young (less than 10,000 years old) marine sediments, estuary deposits, some river channel and floodplain deposits, and poorly compacted man-made fills are the most common soils to liquefy. The soils in these depositional environments are predominantly sandy and silty soils. For liquefaction to occur, the soils must be loose (unconsolidated) and saturated (be below the water table).

WHAT SORT OF DAMAGE MAY OCCUR TO STRUCTURES IN AREAS THAT LIQUEFY?

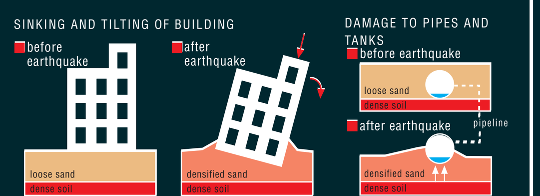
Loss of soil strength can cause large buildings and other structures to sink into the ground, tilt, topple over or partly collapse. Where there is differential subsidence, foundations of small buildings may crack and settle, causing deformation of the structure and cracking of walls.

Buried structures such as large pipes, tanks and manholes can become buoyant and float to the ground surface. Pipes are likely to be damaged. Other buried services are often damaged at the transition from a liquefied soil into a non-liquefied soil.

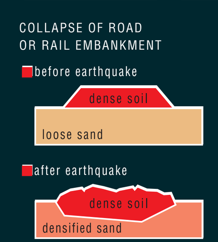
Deep foundations such as bridge piers can break where there are alternating layers of liquefied and non-liquefied soils. Approaches to bridges and stopbanks are particularly vulnerable. Roads, railway tracks and other structures built on fill can be damaged.

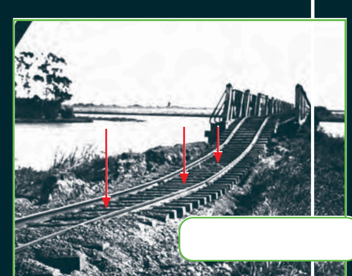
SINKING AND TILTING OF BUILDING

DAMAGE TO PIPES AND TANKS



COLLAPSE OF ROAD OR RAIL EMBANKMENT





REMARKABLE FISSURES IN THE EARTH

"At Kaiapoi, when the shock had passed…his land was apparently flooding from springs having been opened. It was then discovered that across his land…fissures from 1in to 3in [25 to 75mm] in width, and several chains [40m] in length had opened...From these earthquake openings the water was freely issuing…a liberal supply of sand from some grey quicksand layer below the level of the river, and this was deposited…in the shape of round and oval porridge pots and little hills.

"The fissures remained open, and could be probed to a depth of six feet [2m].

"On the opposite side of the Waimakariri…a crack is traceable out of the river 2ft [600mm] in width on to the river bed…where one of the fissures is 9in [230mm] wide, and has, like many smaller cracks of the earth, been filled with quicksand blowing up...A rod several feet long was inserted in the sand, but was not long enough to test the exact depth of the ooze, though it is surmised to have come up from 20ft to 25ft [6 to 7.5m]."

Evidence that liquefaction occurred in Kaiapoi during the Cheviot Earthquake in 1901. (The Press 18 November 1901).

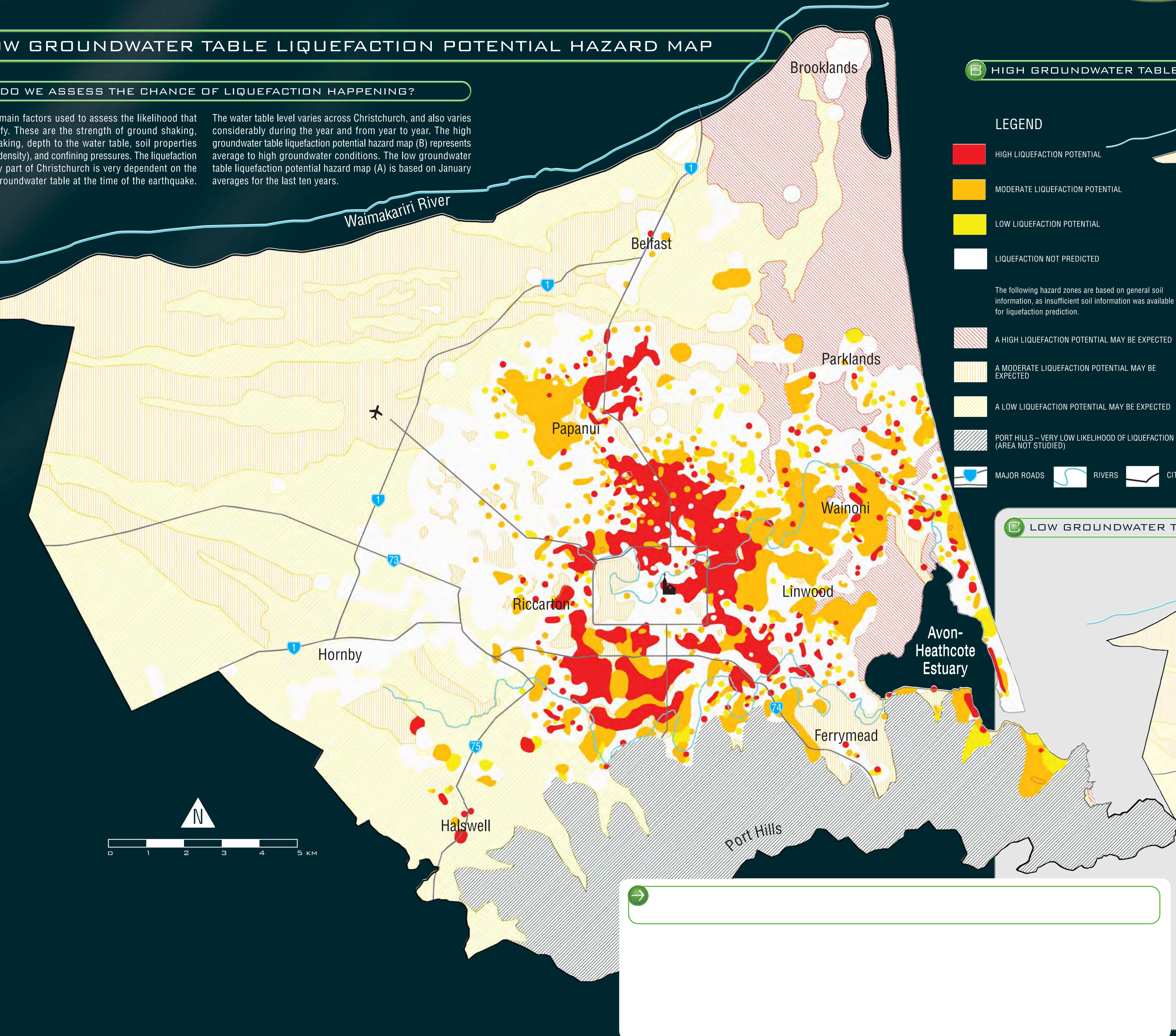
- Liquefaction itself may not be particularly damaging or hazardous. When accompanied by significant ground damage, it is potentially damaging or destructive to the built environment.
- Liquefaction is only one of the effects of an earthquake that may threaten life and property. Other effects of earthquakes such as ground shaking strength must be considered to obtain a complete picture of earthquake hazard.
- There is no certainty that liquefaction will occur at a particular site due to an earthquake of any magnitude.
- There is limited soils' information for parts of Christchurch. Therefore the potential for liquefaction and associated ground damage may be under or over estimated.
- The boundaries between the mapped liquefaction potential and damage zones are approximate and indicative only.
- The liquefaction potential and ground damage potential classifications are indicative only, and do not imply any level of damage to any particular structure, service or other infrastructure.
- The liquefaction hazard information is regional in scope and cannot be substituted for a site-specific investigation. Further advice on the liquefaction hazard at a specific site, the effects on existing or proposed development, and options for mitigating risk may be sought from specialist geotechnical engineers.

A LOW GROUNDWATER TABLE LIQUEFACTION POTENTIAL HAZARD MAP

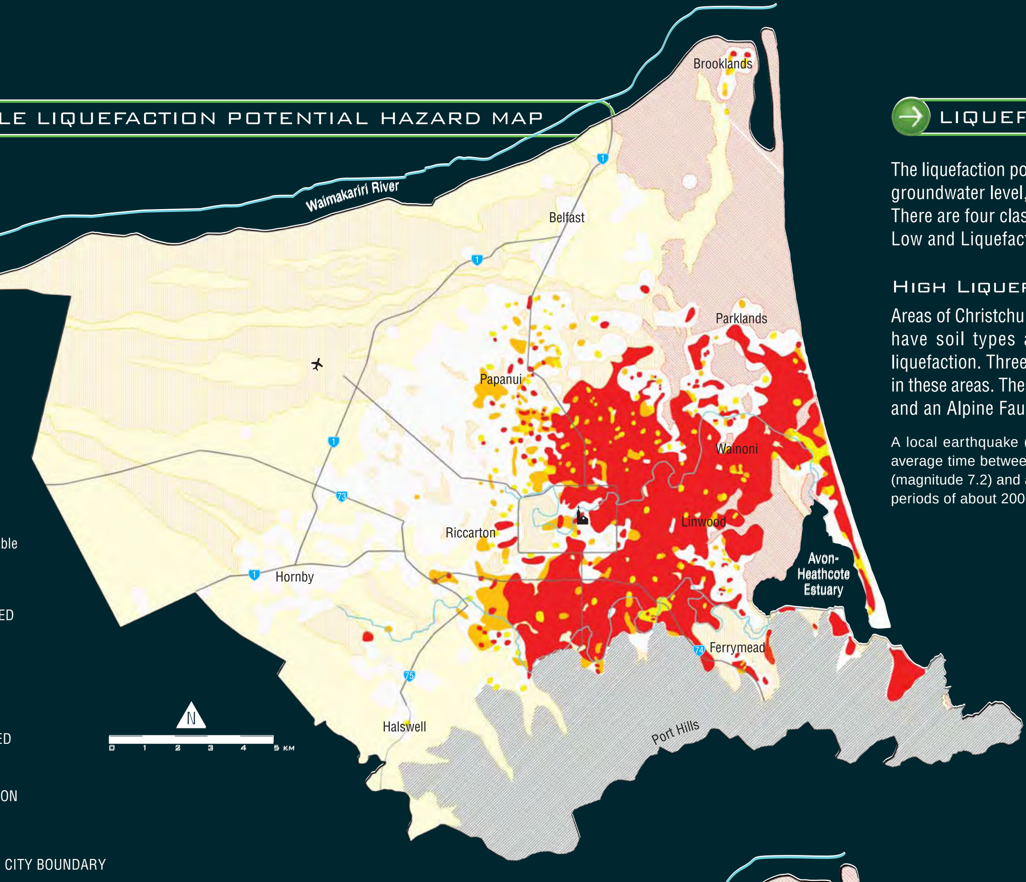
HOW DO WE ASSESS THE CHANCE OF LIQUEFACTION HAPPENING?

There are five main factors used to assess the likelihood that soils will liquefy. These are the strength of ground shaking, duration of shaking, depth to the water table, soil properties (grain size and density), and confining pressures. The liquefaction potential in any part of Christchurch is very dependent on the height of the groundwater table at the time of the earthquake.

The water table level varies across Christchurch, and also varies considerably during the year and from year to year. The high groundwater table liquefaction potential hazard map (B) represents average to high groundwater conditions. The low groundwater table liquefaction potential hazard map (A) is based on January averages for the last ten years.



B HIGH GROUNDWATER TABLE LIQUEFACTION POTENTIAL HAZARD MAP



LIQUEFACTION POTENTIAL

The liquefaction potential rating is based on soil type and strength, groundwater level, and the location and strength of earthquakes. There are four classes of liquefaction potential – High, Moderate, Low and Liquefaction Not Predicted.

High Liquefaction Potential

Areas of Christchurch rated as having "high liquefaction potential" have soil types and strengths that are the most prone to liquefaction. Three types of earthquakes could cause liquefaction in these areas. These are a local earthquake, a foothills' earthquake and an Alpine Fault earthquake.

A local earthquake (magnitude 6) is likely to have a return period (the average time between events) of about 200 years. A foothills' earthquake (magnitude 7.2) and an Alpine Fault earthquake (magnitude 8) have return periods of about 2000 years and 400 years respectively.

Moderate Liquefaction Potential

Areas of Christchurch rated as having "moderate liquefaction potential" have soil types and strengths in between the High and Low classes. Two earthquake types could cause liquefaction in these areas – a foothills' earthquake and an Alpine Fault earthquake.

A foothills' earthquake (magnitude 7.2) and an Alpine Fault earthquake (magnitude 8) have return periods (the average time between events) of about 2000 years and 400 years respectively.

Low Liquefaction Potential

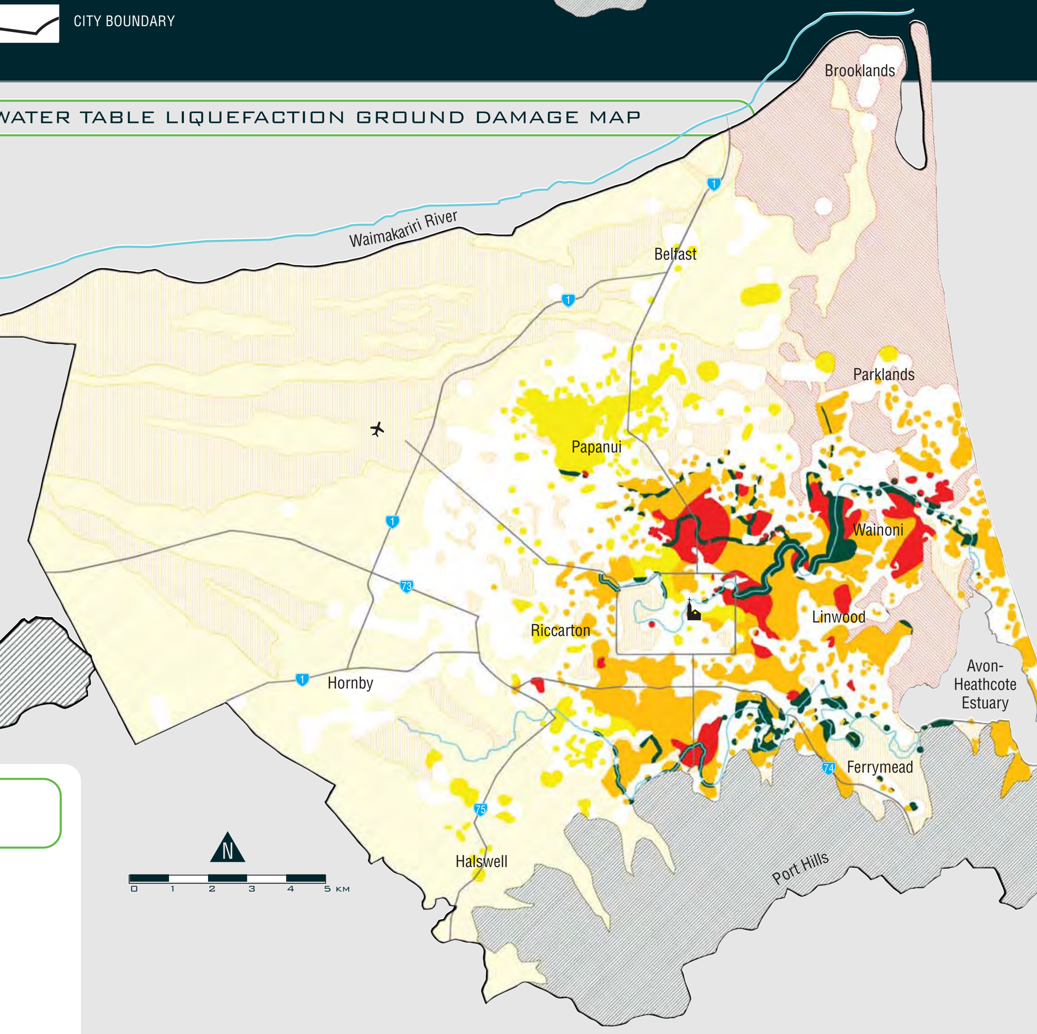
Areas of Christchurch rated as having "low liquefaction potential" have soil types and strengths that are the least prone to liquefaction. Only an Alpine Fault earthquake could cause liquefaction in these areas.

An Alpine Fault earthquake (magnitude 8) has a return period (the average time between events) of about 400 years.

Liquefaction Not Predicted

Areas of Christchurch rated as "liquefaction not predicted" are areas where expected ground shaking intensities are unlikely to cause liquefaction. These areas may contain liquefiable soils or could be subject to settlement or ground fissuring as a result of ground shaking itself, and not liquefaction.

C LOW GROUNDWATER TABLE LIQUEFACTION GROUND DAMAGE MAP



LIQUEFACTION GROUND DAMAGE POTENTIAL

Five classes of liquefaction ground damage potential have been defined for Christchurch – Very High, High, Moderate, Low and No Liquefaction.

Very High Liquefaction Ground Damage Potential

Areas of Christchurch rated as having "very high liquefaction ground damage potential" may be affected by lateral spreading and significant ground subsidence. Subsidence is likely to be greater than 300mm.

High Liquefaction Ground Damage Potential

Areas of Christchurch rated as having "high liquefaction ground damage potential" may be affected by significant ground subsidence. Subsidence is likely to be greater than 300mm.

Moderate Liquefaction Ground Damage Potential

Areas of Christchurch rated as having "moderate liquefaction ground damage potential" may be affected by 100-300mm of subsidence.

Low Liquefaction Ground Damage Potential

Areas of Christchurch rated as having "low liquefaction ground damage potential" may be affected by up to 100mm of ground subsidence.

No Liquefaction Ground Damage Potential

Areas of Christchurch rated as having "no liquefaction ground damage potential" are those areas where liquefaction is not expected to occur.

LEGEND

- VERY HIGH LIQUEFACTION GROUND DAMAGE POTENTIAL
- HIGH LIQUEFACTION GROUND DAMAGE POTENTIAL
- MODERATE LIQUEFACTION GROUND DAMAGE POTENTIAL
- LOW LIQUEFACTION GROUND DAMAGE POTENTIAL
- NO LIQUEFACTION GROUND DAMAGE POTENTIAL

The following hazard zones are based on general soil information, as insufficient soil information was available for liquefaction prediction.

- A HIGH LIQUEFACTION GROUND DAMAGE POTENTIAL MAY BE EXPECTED
- A MODERATE LIQUEFACTION GROUND DAMAGE POTENTIAL MAY BE EXPECTED
- A LOW LIQUEFACTION GROUND DAMAGE POTENTIAL MAY BE EXPECTED
- PORT HILLS – VERY LOW LIKELIHOOD OF LIQUEFACTION (AREA NOT STUDIED)
- MAJOR ROADS
- RIVERS
- CITY BOUNDARY

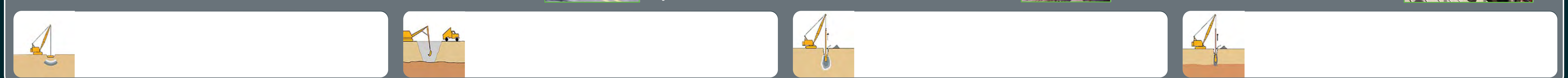
WHAT CAN BE DONE TO REDUCE THE IMPACT OF LIQUEFACTION?

There are three main ways to reduce the effects of liquefaction – by stabilising the ground, by specific foundation design or by strengthening structures to resist predicted ground movements.

There are various methods available to stabilise a soil. These methods generally increase the density of the soil thereby increasing the resistance of the soil to liquefaction. Most of the methods are expensive and would be uneconomic for residential structures.

De-watering (drainage) and buttressing of lateral spread zones are other ground stabilisation techniques.

Specific foundation designs reduce the likelihood of damage to the foundation and deformation of the structure. Stronger foundations, deep piles and piling to non-liquefiable soil layers are the more common methods used to reduce the effect of liquefaction on structures.



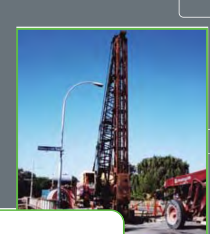
MITIGATION WORK CARRIED OUT IN CHRISTCHURCH

CHRISTCHURCH WASTEWATER PLANT

Vibro-compaction of the soil. The vibrations are liquefying the soil forming a denser soil structure that will be more resistant to liquefaction. Note how water has been ejected to the surface as the soil mass compacts and decreases in volume.

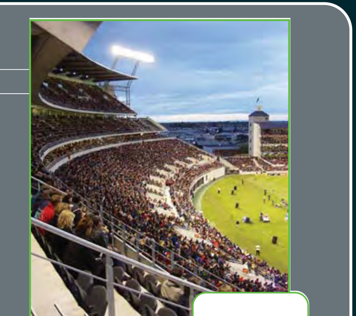
OPAWA ROAD BRIDGE

Installation of concrete piles through liquefiable layers. The piles will resist liquefaction-induced lateral spread (sideways movement of blocks of land toward the river) and reduce damage to the bridge substructure.



JADE STADIUM

To reduce the potential for liquefaction-induced ground damage, an extensive network of stone columns was placed beneath the Paul Kelly Motor Company Stand at Jade Stadium. The stone columns are 600mm in diameter and about 1.4 to 1.7m apart. The stone columns, extending to a depth of 8 to 10m and covering an area of 12,500m , improve the strength and stiffness of the soil, as well as providing a path for the excess pore water during liquefaction.



Beca undertook the research, analysis and mapping for this liquefaction study and is proud to be associated with Environment Canterbury. New Zealand owned, Beca is one of the leading professional services consultancies in the Southern Hemisphere with offices in Auckland, Hamilton, Tauranga, New Plymouth, Wellington, Christchurch, Dunedin, throughout the rest of the Asia-Pacific Region, and further afield. Beca delivers professional services in engineering, planning, project management and valuations. Other Beca projects include: Northlands Mall expansion; safety improvement studies for pedestrians and cyclists; rating valuations for district councils; treatment optimisation modelling of oxidation ponds at Bromley; Otira viaduct design; power systems consulting for Transpower and Orion; and the design of Auckland's Sky Tower.

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