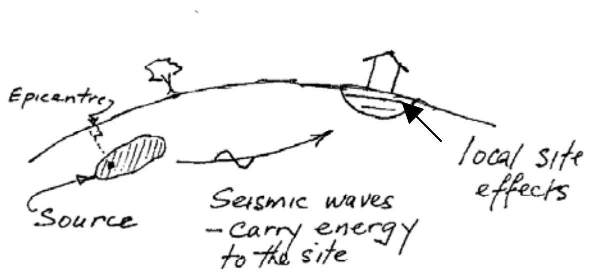
Some Aspects of the M6.3 February 22nd Earthquake

John Berrill[1],

The M6.3 February 22nd Earthquake caused exceptionally violent shaking in Christchurch. The motions recorded within the city are amongst the strongest ever recorded anywhere: over twice the acceleration of gravity at the CanNet/GeoNet instrument at Heathcote Valley School and close to 1g downtown. Several factors combined to make the shaking especially severe in the eastern hill suburbs, the eastern suburbs of Christchurch and the central city area. We will look at these below, but first some general remarks.

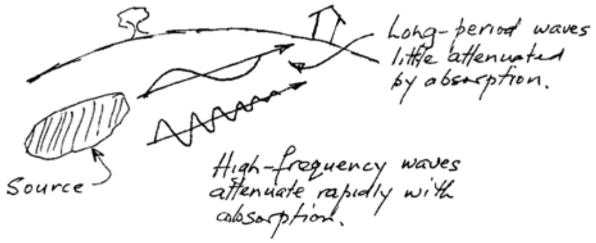
In the large, rupture occurs on a *fault* in the Earth's crust and energy is radiated outwards in the form of seismic waves. The *source* sends out waves over a broad range of frequencies, from very low up to several tens of Hertz (or cycles per second. Seismic waves decay with distance as the energy spreads out and also as energy is absorbed along the *transmission path*. The waves are also modified by reflection and refraction. Since high-frequency waves go through more cycles per kilometre, they decay more rapidly than the low-frequency, long-period waves. Finally, incoming waves are often further modified by the local *site effects* due to resonance and amplification in soft, near-surface soils and by topographic effects.



Of the factors that combined on February 22nd, the following are particularly important.

1. The proximity and shallowness of the rupture. Since the source was close to the City and especially to the hill suburbs, there was little chance for attenuation.

   It is the high-frequency components of the shaking that are most damaging to houses and low structures and in provoking liquefaction. Since a constant proportion of wave energy is lost per cycle, and high-frequency waves go through several cycles per kilometre, they attenuate more rapidly with distance than the low-frequency, long-period waves. As the February 22nd source was very close, there was little attenuation of the high-frequency components, and hence there was much damage to houses, especially on the hills right above the rupture, and in the eastern suburbs.

   The rupture started at depth and propagated upwards and towards the City, focusing energy in that direction. This effect is due to the closeness of the speed of travel of seismic shear waves and of the speed at which the rupture propagated upwards from the hypocentre (the point of first rupture) and along the fault, towards the city. Because of this, pulses sent out by the rupture of successive segments along the fault arrive almost simultaneously at sites to the north and add up to very strong shaking.

   Conversely, at sites to the south, such as Akaroa, arrival of the successive pulses would be separated in time, and the shaking would have been weaker but would have gone on longer.

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2. The mechanism of rupture was an oblique thrust one and occurred on a steeply-dipping fault, both factors in making it particularly energetic. The unusually steep (for a thrust mechanism) dip of the fault, at 65 degrees, made the rupture especially energetic and gave rise to exceptionally strong vertical components of shaking, which lifted roof tiles and reduced the strength of masonry so that brick veneers were displaced more easily.

   Normally, thrust sources dip at about 30 degrees, and vertical components of motion are caused principally by the weaker P-waves rather than the more energetic S-waves (on average, about five times stronger than the P-waves). But the thrust rupture on such a steeply dipping surface generated shear waves with a strong vertical, SV, component.

3. For the City, the soft sediments beneath it amplify earthquake motions. There are two principal causes of amplification. Firstly, as seismic waves pass from stiff rock into soft sediments, the balance of energy demands that the sediments deform more than the rock to transmit the same quantity of energy.

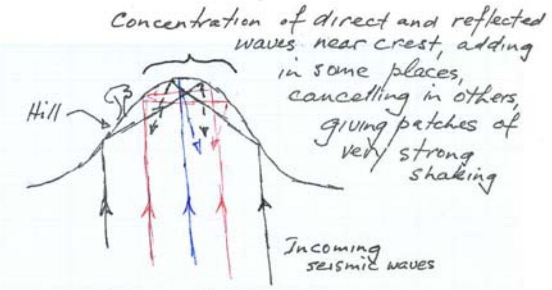
   Secondly, resonance occurs in well-defined layers. The main layers are:
   a) The full depth of 700-1000m, which has a period of resonance of about 2.5-3 seconds.
   b) The upper 10-30m of very soft soil, layed down loosely in the rapid sea-level rise following the last glaciation, about 10,000 years ago. The resonant period of this layer varies markedly depending on its thickness and density, but is in the range of 0.5-1 seconds.

   When the resonant period of the ground is close to that of a structure, the response of the structure will be increased, sometimes substantially. As a rough rule of thumb, the natural period of a multi-storey building is n/10, where n is the number of stories. The Grand Chancellor has 26 stories; thus a fundamental natural period of about 2.6 seconds, placing it in the band of amplified motion.

   Also, there is the *trampoline effect*, a term coined by GNS seismologists to describe the separation of soft, near-surface soil layers under high downward accelerations and their subsequent impact when motion reverses. This may well have been a factor contributing to the pervasiveness of liquefaction.

4. For the hill suburbs, additional factors come into play.

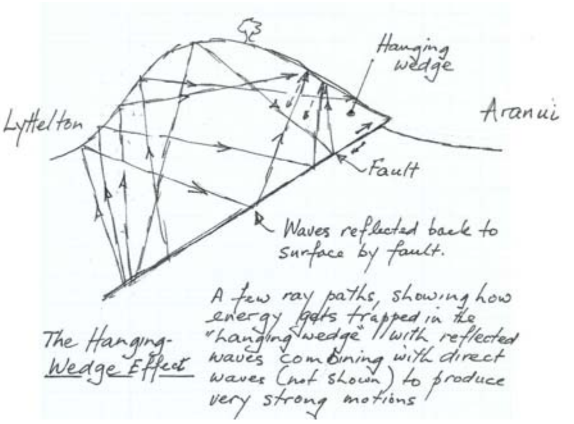
   - Firstly, the shape of the ridges served to concentrate energy at some places and diminish it at others, contributing to the strength and patchiness of the damage. To see this more clearly, think of the hill as a car headlight, but running in reverse. Seismic waves come in as a beam of more or less parallel rays and focus around the surface of the curved ridge crest.



Hill Crest Effect.

   - Secondly, because hard rock is close to the surface, the waves were transmitted with little loss of energy. The high frequency components, responsible for the very sharp, rapid motion, decay quickly with distance, and with passage through soft sediments, such as those found beneath the central city. In the hills, there is little depth of soft, absorbing soil and the source was very close, so the high-frequency motions came through largely unattenuated.

- Hanging wall effect. The mass of rock above the rupture surface is roughly wedge shaped, and seismic waves travelling towards the point of the wedge get reflected back into the narrowing rock mass, concentrating shaking in the grimly-named “hanging wall” region. On Feb 22nd, this would have increased the strength of shaking along the foot of the hills and on the lower slopes.



Summary

A number of factors combined to on February 22nd to produce exceptionally strong shaking and pervasive liquefaction. They were:

- The closeness and shallowness of the source.
- Its unusually energetic nature.
- The steep dip of the source, which caused unusually strong vertical motions to be generated.
- The focusing of energy towards the city.
- The amplifying effects of the sediments beneath the city.
- On the hills, topographic amplification and the hanging-wall effect made things worse.

Records

Another unusual feature of the Canterbury earthquakes is the large number of recordings obtained of them. About 80 percent of these records have been made on CUSP strong-motion accelerographs, which were designed and built in the City for the Canterbury Network, CanNet. CanNet and CUSP (**C**anterbury **U**niversity **S**eismograph **P**roject) started out in 1996 as a Univesity project, with the aim of getting about 80 instruments out in the Canterbury Plains and across the City in anticipation of an Alpine Fault earthquake. The original CUSP-3A instrument was designed by Hamish Avery as part of his doctoral project and the first instruments were built in the Geomechanics Lab at the University. In 2003, CanNet was taken over by GeoNet, for their operational expertise and easier access to funding. At the time, GeoNet insisted that a separate company be set up to manufacture the instruments, and Canterbury Seismic Instruments (the real CSI) was formed, with Dr Avery as its main spring. Since then, the range of instrunents has been extended and as well as supplying GeoNet, they are now sold all over the world.

The three components of the record from the Heathcote Vally School, close to the February 22nd epicenetre, are shown below. All three components are exceptionally strong, but the vertical component is particularly so, with two acceleration peaks of more than twice the acceleration due to gravity, both about 2.2g, and five other peaks over 1.0g.

Note that the downward, negative, acceleration peaks are all less than 1.0g, whereas seven positive peaks are well in excess of 1.0g. This suggests that the building housing the instrument, and possibly some underlying soil, was left behind in the air as the ground accelerated more rapidly downwards beneath it, with the building then falling under its own weight at near, but less than, 1.0 g until it impacted on the ground, giving the high positive (upwards) accelerations. Then, after impact, the building and instrument moves at the acceleration of the underlying ground, with peaks still greater than 1g, This illustrates the “trampoline” effect, mentioned above.

The two horizontal components have peak acceleration values of 1.68 and 1.27g. These are unusually high. For about 20 years, the strongest horizontal peak acceleration recorded was the 1.25g from Pacoima Dam, in the epicentral region of the 1971, M6.4 San Fernando, California Earthquake, on the northern outskirts of Los Angeles. While this is partly a question of luck in having instruments in the right place, it does show that the shaking from our earthquake was indeed very strong.

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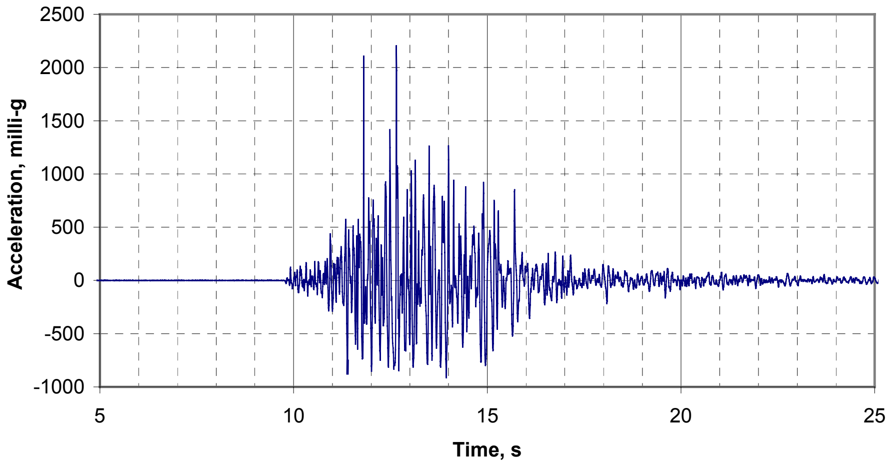
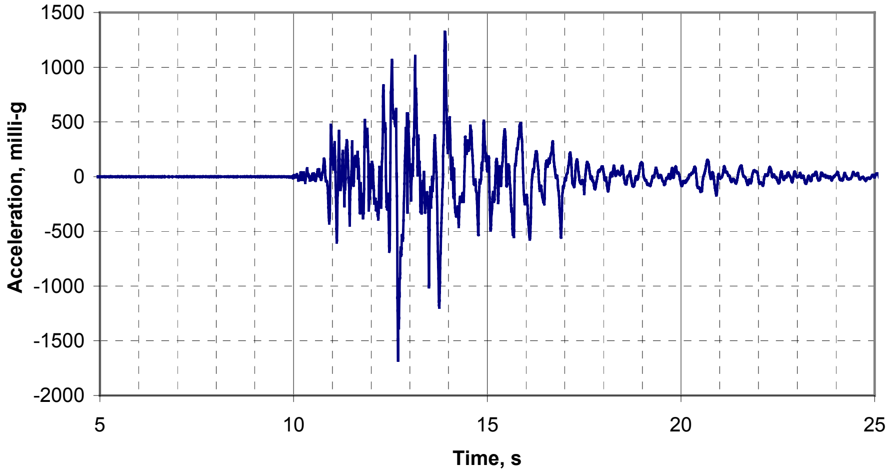
HVSC- Heathcote Valley School, M6.3, Feb 22, 2011, Vertical Component



HVSC- Heathcote Valley School, M6.3, Feb 22, 2011, N26E (x-comp.)



HVSC- Heathcote Valley School, M6.3, Feb 22, 2011, S64E (y-comp.)