(f) A second deep borehole should be drilled, this time in the Central City area preferably to the north of the City Centre where the severest amplifications are predicted. This will refine the assumed subsurface sequence used in this study which has been based largely on the Bexley drillhole for depths from 120 m - 500 m.

(g) In conjunction with this drillhole a gravity geophysics survey should be undertaken to define the topography on the bedrock contact beneath the alluvium.

(h) Carry out cyclic triaxial testing of loess and other Christchurch sediments (e.g. reclamation silts, estuarine silts etc.) to confirm assumptions regarding susceptibility to liquefaction.
CHAPTER 13: Conclusions

13.1 Hazard Model for Christchurch

Christchurch is located close to several active faults with potential to generate earthquakes which could cause damage to the city. Analysis of the possible earthquake magnitudes and epicentral distance suggests the most critical faults are the Pegasus Bay Fault, fault strands in the Porters Pass Tectonic Zone (which includes the Porters Pass and Ashley Faults) and the central section of the Alpine Fault. Significant damage could also result from very close earthquakes of moderate magnitudes associated with the relatively shallow active seismicity below the Pleistocene and recent sediments close to Christchurch. The highest intensity earthquake which Christchurch has experienced historically, the 1869 New Brighton earthquake which reached MM Intensity VII - VIII, appears to have been of this type. Other damaging historical earthquakes have reached Intensity VII in the city and include the 1888 Amuri earthquake (associated with rupture on the Hope Fault) and the 1901 and 1922 Cheviot and Motunau earthquakes. No historical earthquakes have been attributed to the most critical capable faults i.e. the Porters Pass Tectonic Zone, Pegasus Bay Fault, or the central section of the Alpine Fault.

To assess the probability of future earthquake shaking in Christchurch, the available records of seismicity have been analysed using the traditional occurrence model (log N = a - bM). The model is generally based on that developed by Smith & Berryman (1983). To improve accuracy seven new, small regions have been employed in northern and offshore Canterbury and the $M_{\text{max}}$ values have been reduced in some areas based on the geologic evidence. Low b values found for these tightly-defined zones are consistent with those reported elsewhere for specific fault zones.

The intensity attenuation model of Smith (1978) has been adapted using a functional relationship which avoids the need for discretisation of the intensity - magnitude - distance correlation.

The attenuation model for seismic acceleration has been considered in detail. It has been demonstrated that the modifications made to the Katayama attenuation model for New Zealand conditions may not be justified, at least on the basis of published data. This is a major area requiring further work.

The return periods for various intensities of bedrock shaking in Christchurch have been calculated in this study as:

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Return Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM VI</td>
<td>12 years</td>
</tr>
<tr>
<td>MM VII</td>
<td>25 years</td>
</tr>
<tr>
<td>MM VIII</td>
<td>100 years</td>
</tr>
<tr>
<td>MM IX</td>
<td>1,200 years</td>
</tr>
<tr>
<td>MM X</td>
<td>6,000 years</td>
</tr>
</tbody>
</table>
When compared with the predictions of the earlier study by Smith & Berryman (1983) the frequency of small and large events are decreased, but there is an increase in the predicted frequency of medium earthquakes (MM VII - MM VIII) (refer to Figure 5.8). The effect of local amplification through the deep alluvium beneath Christchurch will increase felt intensities by 0 to +2 MM units (Figure 7.5a). This increases the frequency of shaking at the ground surface in Christchurch to the following average return periods:

<table>
<thead>
<tr>
<th>Intensity</th>
<th>MM VI</th>
<th>7 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM VII</td>
<td>20 years</td>
<td></td>
</tr>
<tr>
<td>MM VIII</td>
<td>55 years</td>
<td></td>
</tr>
<tr>
<td>MM IX</td>
<td>300 years</td>
<td></td>
</tr>
<tr>
<td>MM X</td>
<td>in excess of 6,000 years</td>
<td></td>
</tr>
</tbody>
</table>

The effect on the structural response spectra at Christchurch of propagation of incoming seismic waves through the underlying deep alluvium is dramatic. The effect varies laterally, principally reflecting variations in the top 30 metres of sediment.

Over 10,000 borelogs have been synthesised to obtain information on the extent of this lateral variation. Areas of St Albans, Papanui and Redwood, Sydenham, Addington and Halswell have near surface soil profiles that produce particularly strong ground shaking.

The modifications to the response spectra by underlying alluvium are greater than those which would be predicted by the current New Zealand Loadings Code. The effects are generally threefold:

- A total removal of very short period (less than 0.2 sec) acceleration from the response spectrum by hysteretic damping through the deep, relatively soft soil.

- A general amplification of the peak spectral accelerations by up to twice the peak bedrock acceleration.

- A shift in all the spectral values towards the longer period region of the spectrum.

When these effects are compared with the response spectra from the current code for a fully elastic structure on flexible soils in Zone B, the average amplification in Christchurch produces a typical response spectra nearly 30% in excess of the code spectra (for periods between 1 and 2.5 seconds). For the maximum amplification in Christchurch, the code spectra could be exceeded by 50% at 0.7 sec period, and 160% at 1.2 sec period (for 150-year return period accelerations - refer Figure 7.21).
13.2 Potential Consequences and Hazards

The prediction of likely impacts resulting from a moderate to large earthquake affecting the City is hampered by a lack of site specific information. However a number of general conclusions can be reached:

- There is a substantial portion of Christchurch City that is underlain by layers of sand which would be susceptible to liquefaction if the sand is loose. The main sand area extends generally east of Marshland Road, Fitzgerald Avenue and Opawa Road and includes Brighton, Heathcote and Sumner. Other smaller areas exist scattered through the city. In a number of sites where specific test data is available, loose sand has been identified and analysis shows that liquefaction is likely to occur during a large earthquake. How far these areas extend, and the extent of earthquake shaking required to initiate liquefaction, are important questions requiring extensive further research.

- Comparison with overseas studies suggests slope failure could be triggered by large earthquakes on the central segment of the Alpine Fault, the Kaikoura Fault and the Porters Pass Tectonic Zone. Moderate earthquakes within the Pegasus Bay, Banks Peninsula and Christchurch seismicity zones could also generate slope instability.

- Pseudostatic slope stability analysis suggests that in addition to the degree of shaking, pre-existing soil moisture levels will be critical in controlling the extent of damage in hill suburbs. Widespread foundation damage could result if a large earthquake (say intensity VIII - IX, with return period 300 years) coincided with virtual soil saturation, but fortunately these saturated conditions exist for a relatively small proportion of the year. In general the most at risk period is from July to October, and the most vulnerable housing areas are those of the fringes of existing development located below steep hill slopes. Houses in these locations may also be damaged by debris inundation and boulder roll.

- Rock slides, topple failures and falls are likely during a substantial earthquake in the eastern suburbs where high cliffs have been produced by coastal erosion and local quarrying. Damage to houses from these processes may be limited in extent but roading may be more widely affected.

- Liquefaction induced landsliding in loessial soils during earthquakes has been reported overseas but initial consideration suggests this process is unlikely to affect Christchurch hill soils. Lateral spreading in alluvial materials subject to liquefaction is more likely to occur. Potential for this process appears to exist in some areas, in particular, along the lower
reaches of the Avon and Heathcote Rivers and around the margins of the Estuary.

13.3 Potential Damage

Severe seismic shaking comparable to the historical recorded maximum (Intensity VII - VIII) will produce widespread damage to the city during a future event. The effect of the deep alluvium below the city on the spectral response is likely to subject mid to high rise structures to severe resonant shaking, but may reduce the damage to housing to mainly inertial effects. Services are likely to be seriously affected from a combination of settlement, ground lurching and liquefaction. If liquefaction is widespread, extensive damage is likely to key components of the sewerage system and electrical supply located in the eastern city. Major damage with potentially serious environmental consequences may occur at the oil tank farm in Lyttelton, which is built on loose fill overlying soft marine sediments.

Substantial further work is required to assess the type and extent of potential damage. A Lifeline study similar to that recently completed in Wellington will be an important part of this work.
Acknowledgements

This study was funded by the EQC, without whose support this work would not have been possible. We have been very much assisted by early results and discussion relating to a concurrent EQC funded project entitled "Structural Evolution and Seismotectonic Hazard Assessment of the Active Porters Pass Tectonic Zone" undertaken by Mr Hugh Cowan, Dr Jarg Pettinga and Mrs Jocelyn Campbell of the Geology Department, University of Canterbury. Their assistance in this and many other geological aspects of the work is gratefully acknowledged.

In addition, Dr J.B. Berrill and Dr R.O. Davis of the Civil Engineering Department, University of Canterbury, assisted us in reviewing and discussing the seismicity, liquefaction and slope stability aspects of the study. The computer modelling of wave propagation was done under the supervision of Dr R.O. Davis using programmes developed at the University.

DSIR assisted with provision of Seismological Observatory information and Dr Euan Smith was helpful in commenting on various aspects of this material.

Borelogs for Christchurch were provided by a number of organisations and consultants whose help is gratefully acknowledged:

Christchurch Drainage Board  Christchurch City Council
Canterbury Regional Council  Works Corp
P.J. Alley  Heathcote County Council
G.L. Evans  Paparua County Council
Waimairi County Council

The major job of borelog compilation and map work was done by M.D. Adamson of Soils & Foundations. Figure preparation was by M.A. Smith and C.D. McCormick. Typing the many drafts and revisions was patiently carried out by Julie Howard. David Brathwaite and Jim Park undertook final reading and comment.

Special thanks go to our various wives and offspring whose lives at times became seriously disrupted by our overwork, in particular, Therese, Jamie, Dorle, William, Lisa and Ben.
References


Johnston, M.R. (1979) "Geology of the Nelson Urban Area" (1: 25 000), New Zealand Geological Survey Urban Series Map 1. Map (1 sheet) and notes (52 p), New Zealand Department of Scientific and Industrial Research, Wellington.


Lloyd, K. "Earthquake Effect Upon Services and Roading", Local Authority Engineering in New Zealand, Vol. 5, No. 3.


Wise, D.U., Pettinga, J.R., Campbell, J.K. and Nicol, A. (In Prep.) "A Surface Slab Model for the Transfer Zone of New Zealand’s Alpine Fault".


APPENDIX A: Modified Mercalli Scale of Intensity of Earthquake Shaking (N.Z. Version, 1965)
APPENDIX A

MODIFIED MERCALLI SCALE OF INTENSITY OF EARTHQUAKE SHAKING
(N.Z. VERSION, 1965)

MM I
Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floors of buildings more than 10 storeys high.
Dizziness or nausea may be experienced.
Branches of trees, chandeliers, doors, and other suspended systems of long natural period may be seen to move slowly.
Water in ponds, lakes, reservoirs, etc., may be set into seiche oscillation.

MM II
Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed.
The long-period effects listed under MMI may be more noticeable.

MM III
Felt indoors, but not identified as an earthquake by everyone. Vibration may be likened to the passing of light traffic.
It may be possible to estimate the duration, but not the direction. Hanging objects may swing slightly.
Standing motorcars may rock slightly.

MM IV
Generally noticed indoors, but not outside.
Very light sleepers may be wakened.
Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building.
Walls and frame of buildings are heard to creak.
Doors and windows rattle.
Glassware and crockery rattles.
Liquids in open vessels may be slightly disturbed.
Standing motorcars may rock, and the shock can be felt by their occupants.

MM V
Generally felt outside, and by almost everyone indoors.
Most sleepers awakened.
A few people frightened.
Direction of motion can be estimated.
Small unstable objects are displaced or upset.
Some glassware and crockery may be broken.
Some windows cracked.
A few earthenware toilet fixtures cracked.
Hanging pictures move.
Doors and shutters may swing.
Pendulum clocks stop, start, or change rate.
Felt by all.
People and animals alarmed.
Many run outside.
Difficulty experienced in walking steadily.

Slight damage to Masonry D.
Some plaster cracks or falls.
Isolated cases of chimney damage.

Windows, glassware, and crockery broken.
Objects fall from shelves, and pictures from walls.
Heavy furniture moved. Unstable furniture overturned.

Small church and school bells ring.
Trees and bushes shake, or are heard to rustle.
Loose material may be dislodged from existing slips,
talus slopes, or shingle slides.

General alarm.
Difficulty experienced in standing.
Noticed by drivers of motorcars.
Trees and bushes strongly shaken.
Large bells ring.

Masonry D cracked and damaged.
A few instances of damage to Masonry C.

Loose brickwork and tiles dislodged.
Unbraced parapets and architectural ornaments may fall.
Stone walls cracked.
Weak chimneys broken, usually at the roof-line.
Domestic water tanks burst.
Concrete irrigation ditches damaged.

Waves seen on ponds and lakes.
Water made turbid by stirred-up mud.
Small slips, and caving-in of sand and gravel banks.

Alarm may approach panic.
Steering of motorcars affected.

Masonry C damaged, with partial collapse.
Masonry B damaged in some cases.
Masonry A undamaged.

Chimneys, factory stacks, monuments, towers, and elevated
tanks twisted or brought down.
Panel walls thrown out of frame structures.
Some brick veneers damaged.
Decayed wooden piles broken.
Frame houses not secured to the foundation may move.
Cracks appear on steep slopes and in wet ground.
Landslips in roadside cuttings and unsupported excavations.
Some tree branches may be broken off.

Changes in the flow or temperature of springs and wells
may occur.
Small earthquake fountains.

MM IX
General panic.

Masonry D destroyed.
Masonry C heavily damaged, sometimes collapsing completely.
Masonry B seriously damaged.
Frame structures racked and distorted.

Damage to foundations general.
Frame houses not secured to the foundations shifted off.
Brick veneers fall and expose frames.

Cracking of the ground conspicuous.
Minor damage to paths and roadways.
Sand and mud ejected in alluviated areas, with the
formation of earthquake fountains and sand craters.
Underground pipes broken.
Serious damage to reservoirs.

MM X
Most masonry structures destroyed, together with their
foundations.
Some well built wooden buildings and bridges seriously
damaged.
Dams, dykes, and embankments seriously damaged.
Railway lines slightly bent.
Cement and asphalt roads and pavements badly cracked or
thrown into waves.

Large landslides on river banks and steep coasts.

Sand and mud on beaches and flat land moved horizontally.
Large and spectacular sand and mud fountains.
Water from rivers, lakes, and canals thrown up on the bank.

MM XI
Wooden frame structures destroyed.
Great damage to railway lines.
Great damage to underground pipes.

MM XII
Damage virtually total. Practically all works of
construction destroyed or greatly damaged.

Large rock masses displaced.
Lines of sight and level distorted.
Visible wave-motion of the ground surface reported.
Objects thrown upwards into the air.
Categories of Non-wooden Construction

Masonry A. Structures designed to resist lateral forces of about 0.1 g, such as those satisfying the New Zealand Model Building Bylaws, 1955. Typical buildings of this kind are well reinforced by means of steel or ferro-concrete bands, or are wholly of ferro-concrete construction. All mortar is of good quality and the design and workmanship is good. Few buildings erected prior to 1935 can be regarded as in category A.

Masonry B. Reinforced buildings of good workmanship and with sound mortar, but not designed in detail to resist lateral forces.

Masonry C. Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces.

Masonry D. Buildings with low standards of workmanship, poor mortar, or constructed of weak materials like mud brick and rammed earth. Weak horizontally.

Windows

Window breakage depends greatly upon the nature of the frame and its orientation with respect to the earthquake source. Windows cracked at MM V are usually either large display windows, or windows tightly fitted to metal frames.

Chimneys

The "weak chimneys" listed under MM VII are unreinforced domestic chimneys of brick, concrete block, or poured concrete.

Water tanks

The "domestic water tanks" listed under MM VII are of the cylindrical corrugated-iron type common in New Zealand rural areas. If these are only partly full, movement of the water may burst soldered and riveted seams.

Hot-water cylinders constrained only by supply and delivery pipes may move sufficiently to break the pipes at about the same intensity.
APPENDIX B: Log of the Bexley Borehole
Location: Pages Road, M35869440
Depth: 433 m
**FEATURE:** NCCB DRILLHOLE  
**LOCATION:** BEXLEY, CHRISTCHURCH  
**ATTITUDE/DIRECTION:** VERTICAL  
**R.L. GROUND(m):** 1.0 a.m.s.l  
**MACHINE:** [Diagram of drilling equipment]

<table>
<thead>
<tr>
<th>GEOLOGICAL UNIT</th>
<th>DESCRIPTION</th>
<th>GROUND LOG</th>
<th>DRILL METHOD</th>
<th>PENETRATION (SPT)</th>
<th>MOISTURE CONTENT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Grey SILTY fine to medium SAND with a trace of shells</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| SM              | Grey SILT  
- minor organics from 29.9m to 31.8m  
- worm holes from 29.9m to 31.8m  
- traces of very fine sand from 31.8m to 37.15m  
- some stratified organics from 37.15m to 38.3m |  |  |  |  |
| 30              | Grey GRAVELLY fine to coarse SAND  
- gravel, fine to medium, subangular to subrounded greywacke  
- minor shells |  |  |  |  |
| ML              | Grey SANDY fine to medium GRAVEL  
- sand, fine to coarse  
- gravel, subangular to subrounded greywacke |  |  |  |  |
| 35              | Grey fine to coarse SAND with some layers of grey SILT and traces of medium gravel  
Grey SANDY fine to coarse GRAVEL  
- sand, fine to coarse  
- gravel, subangular to subrounded greywacke |  |  |  |  |
| 40              | Grey SILT |  |  |  |  |
| 45              | Grey SILT |  |  |  |  |
| 50              | Grey SILT |  |  |  |  |

**COMMENTS:**  
- SAND PUMP SAMPLE POSITION  
- SHELL SAMPLE POSITION  
- LOGGED MDA   
- DATE 8/8/89   
- LENGTH  
- DRILLER McCLEAN   
- STARTED   
- FINISHED
FEATURE: MCB DRILLHOLE
LOCATION: BEXLEY, CHRISTCHURCH
ATTITUDE/DIRECTION: VERTICAL

R.L. GROUND(m): 1.0 a.m.s.l
MACHINE:

<table>
<thead>
<tr>
<th>GEOLGICAL UNIT DESCRIPTION</th>
<th>DEPTH (m)</th>
<th>DRILL METHOD</th>
<th>PENETRATION (SPT) (uncorrected for overburden)</th>
<th>MOISTURE CONTENT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey SILT</td>
<td>50</td>
<td>Cable Tool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey SAND with minor shells and traces of fine gravel</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey fine SAND with traces of silt</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey SILT with minor fine sand</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey fine SILT -soft</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greyish yellow SILT with minor fine sand</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey SANDY fine to medium GRAVEL with minor yellow silt -sand, fine to coarse -gravel, subrounded to subangular greywacke</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greyish yellow SANDY SILT -sand, fine to coarse -sand</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey SILT with some organics and traces of medium gravel</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown GRAVELS and SAND?</td>
<td>85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey SILT with layers of well compressed black and brown peat</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

COMMENTS: SAND PUMP SAMPLE POSITION
LOGGED MGA: 11/8/89
DRILLER MCILLAN STARTED 4/1/89
LENGTH: 90m
FINISHED
FEATURE: NCC3 DRILLHOLE,
LOCATION: BEXLEY, CHRISTCHURCH
ATTITUDE/DIRECTION: VERTICAL

DESCRIPTION OF MATERIAL RECOVERED:

- Grey SILT with layers of well compressed black and brown peat
- Grey SANDY fine to coarse GRAVEL with minor silt
  - stained brownish
  - sand, fine to coarse
  - gravel, subrounded to subangular
- Greyish brown soft SILT with lenses of greyish brown firm silt and minor fine sand
- Brownish grey soft SILT with lenses of firm silt
  - minor organics
  - traces of fine sand
- Greyish yellow SILT with minor fine sand and traces of organics
- Grey, brown stained SANDY fine to coarse GRAVEL with minor silt
  - sand, fine to coarse
  - gravel, subrounded to subrounded greywacke
- Brown fine SAND with traces of fine gravel and small lumps of clay

COMMENTS - SAND PUMP SAMPLE POSITION

LOGGED MDA
DATE 11/8/89
LENGTH
DRILLER: McILLAN
STARTED 4/1/89
FINISHED
<table>
<thead>
<tr>
<th>GEOLOGICAL UNIT</th>
<th>DESCRIPTION OF MATERIAL RECOVERED.</th>
<th>DRILL METHOD</th>
<th>PENETRATION (SPF)</th>
<th>MOISTURE CONTENT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>Light brown SILTY CLAY to CLAYEY SILT with a trace of very fine sand. Brown fine SAND with traces of fine gravel and small lumps of clay. -gravel, angular greywacke</td>
<td>Cable Tool</td>
<td>406mm</td>
<td></td>
</tr>
<tr>
<td>CL</td>
<td>Brownish grey SANDY fine to medium GRAVEL with some silt. -sand, fine to coarse. -gravel, subrounded to subangular greywacke. -stained brown. Brownish grey fine to medium GRAVEL with some fine to coarse sand and a trace of silt. -gravel, subrounded to subangular greywacke.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GW</td>
<td>Brownish grey fine to medium dense SAND with minor silt. -stained brown. Grey SILT with a trace of fine sand and fine organics.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ML</td>
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</table>
FEATURE: NCCB DRILLHOLE
LOCATION: BEXLEY, CHRISTCHURCH
ATTITUDE/DIRECTION: VERTICAL

GEOLLOGICAL
UNIT
DESCRIPTION

DESCRIPTION OF MATERIAL
RECOVERED.

DRILL METHOD
DATE/FORMAT
SAMPLES AND
TESTS

PENETRATION (SPT)
(uncorrected for
overburden)

MOISTURE
CONTENT (%)

COMMENTS - SAND PUMP SAMPLE POSITION

LOGGED MD
DRILLER McILLAHAN
DATE 11/8/89
STARTED 4/1/89
LENGTH
FINISHED

Grey SILT with a trace of fine sand and fine organics

Yellowish grey SILT

Grey stained yellow fine to medium gravelly with some clay and minor fine to medium sand -gravel, subangular to subrounded greywacke
<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>Light brown SILT with minor fine to medium sand</td>
</tr>
<tr>
<td>155</td>
<td>Grey fine to coarse GRAVEL with minor coarse sand and traces of light brown silt, subrounded to subangular greywacke</td>
</tr>
<tr>
<td>160</td>
<td>Light brownish grey SANDY fine to coarse GRAVEL with minor silt -sand, fine to medium -gravel, subrounded to subangular greywacke</td>
</tr>
<tr>
<td>165</td>
<td>Grey SANDY fine GRAVEL with minor medium gravel and traces of light brown clayey silt -sand, fine to coarse</td>
</tr>
<tr>
<td>170</td>
<td>Light brownish grey SILT with some fine to medium sand and gravel</td>
</tr>
<tr>
<td>175</td>
<td>Yellowish light brown SILTY fine SAND -very stiff</td>
</tr>
<tr>
<td></td>
<td>Grey SANDY SILT -fine sand</td>
</tr>
</tbody>
</table>

**Comments:** SAND PUMP SAMPLE POSITION

**Logged MOA:** 10/10/89

**Driller:** McILLAN

**Started:** 4/1/89

**Finished:** 4/1/89
<table>
<thead>
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<th>DESCRIPTION OF MATERIAL RECOVERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>Grey SANDY SILT - sand, fine</td>
</tr>
<tr>
<td>180</td>
<td>Grey SANDY fine to medium GRAVEL with minor lumps of silt bound fine to medium gravel with traces of fine sand - sand, fine to coarse - gravel, subrounded to subangular greywacke</td>
</tr>
<tr>
<td>185</td>
<td>Blueish grey SILT with minor fine to medium gravel and traces of fine sand - gravel, subrounded to subangular greywacke - stiff</td>
</tr>
<tr>
<td>190</td>
<td>Grey fine to medium GRAVEL with some fine to medium sand - gravel, subrounded to subangular greywacke</td>
</tr>
<tr>
<td>195</td>
<td>Grey SILT with minor clay and traces of fine sand - stiff</td>
</tr>
<tr>
<td>200</td>
<td>Grey SANDY fine to coarse GRAVEL with traces of silt - sand, fine to coarse - gravel, subrounded to subangular greywacke - grey fine to medium SAND with wood and traces of silt</td>
</tr>
</tbody>
</table>

COMMENTS:  - SAND PUMP SAMPLE POSITION

LOGGED MDA: 12/10/89
DRILLER: McILLAN
STARTED: 4/1/89
FINISHED: 8/28/89
FEATURE: NCCB DRILLHOLE
LOCATION: BEXLEY, CHRISTCHURCH
ATTITUDE/DIRECTION: VERTICAL

<table>
<thead>
<tr>
<th>GEOLOGICAL UNIT</th>
<th>DESCRIPTION</th>
<th>CONE LOSS %</th>
<th>DRILL METHOD</th>
<th>PENETRATION (SPT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>Grey fine to medium SAND with wood and traces of silt</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>205</td>
<td>Grey SANDY SILT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>210</td>
<td>- firm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>- sand, fine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>220</td>
<td>Grey SANDY fine to coarse GRAVEL with traces of silt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>225</td>
<td>- sand, fine to medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- gravel, subrounded to subangular greywacke</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grey SILT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

COMMENTS: SAND PUMP SAMPLE POSITION

LOGGED MDA: 11/10/89
DRILLER: MCILLAN
DATE: 11/10/89
STARTED: 4/1/89
FINISHED:
**SOILS & FOUNDATIONS**

**GEODETICAL CONSULTING ENGINEERS**

**FEATURE:** NCCB Drillhole

**LOCATION:** Bexley, Christchurch

**ATTITUDE/DIRECTION:** Vertical

**MACHINE:** 1.C.a.m.s.l.

<table>
<thead>
<tr>
<th>GEOLOGICAL UNIT</th>
<th>DESCRIPTION</th>
<th>PENETRATION (SPT)</th>
<th>MOISTURE CONTENT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CORE LOSS/L spill</strong></td>
<td><strong>DEPTH (m) below GL</strong></td>
<td><strong>DATE/DEPT.' (m)</strong></td>
<td><strong>DATE</strong></td>
</tr>
<tr>
<td>ML</td>
<td>Grey SILT</td>
<td>230</td>
<td>225</td>
</tr>
<tr>
<td>ML</td>
<td>Blueish grey SILT</td>
<td>235</td>
<td>225</td>
</tr>
<tr>
<td>ML</td>
<td>Blueish grey medium to coarse SANDY SILT with some fine gravel</td>
<td>240</td>
<td>225</td>
</tr>
<tr>
<td>SP</td>
<td>Grey SANDY fine to medium GRAVEL with minor silt</td>
<td>245</td>
<td>225</td>
</tr>
<tr>
<td>SP</td>
<td>Grey SANDY SILT</td>
<td>250</td>
<td>225</td>
</tr>
</tbody>
</table>

- **Comments:** Sand Pump Sample Position

**Logged MDA:** 11/10/89

**Started by McMillan:** 4/1/89

**Length:** 9128/10

**R.L. Ground:** 1.0 m.s.l.
**DESCRIPTION OF MATERIAL RECOVERED.**

- **Blueish grey SILT**
  - firm
  - trace of organics from 253.1m to 266.0m

- **Blueish grey SANDY SILT with some clay and minor shell fragments**
  - sand, fine to coarse
  - soft

- **Grey SILT**
  - some fine sand from 266.4m to 275.6m
  - minor clay from 275.6m to 282.4m
  - minor fine sand from 283.4m to 282.9m
<table>
<thead>
<tr>
<th>GEOLOGICAL UNIT</th>
<th>DESCRIPTION</th>
<th>DEPTH (m)</th>
<th>CORE LOSS</th>
<th>LOG</th>
<th>GRAPHIC LOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>275</td>
<td>Grey SILT</td>
<td>266.4 to 275.6m</td>
<td>some fine sand</td>
<td></td>
<td>275</td>
</tr>
<tr>
<td></td>
<td></td>
<td>275.6 to 282.4m</td>
<td>minor clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>282.4 to 282.9m</td>
<td>minor fine sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>280</td>
<td>Grey GRAVEL</td>
<td>285</td>
<td>with some sand and minor silt, trace of shells</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>285</td>
<td>-gravel, fine to medium, sub-rounded to rounded</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>285</td>
<td>-sand, fine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>Grey BLUE SILT</td>
<td>290</td>
<td>with minor clay and trace of shells</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>290</td>
<td>-soft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>295</td>
<td>Grey blue mottled reddish brown SILT</td>
<td>295</td>
<td>with minor sand and trace of shells</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>295</td>
<td>-sand, fine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>295</td>
<td>-firm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>Grey SILT</td>
<td>300</td>
<td>with some sand and trace of gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300</td>
<td>-sand, fine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300</td>
<td>-gravel, fine to medium, sub-rounded to rounded</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300</td>
<td>-firm</td>
<td></td>
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<tr>
<td>GEOLOGICAL UNIT</td>
<td>DESCRIPTION</td>
<td>PENETRATION (SPT)</td>
<td>MOISTURE CONTENT (%)</td>
<td></td>
<td></td>
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<tr>
<td>-----------------</td>
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<td>------------------</td>
<td>----------------------</td>
<td></td>
<td></td>
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<tr>
<td>300 ML</td>
<td>Grey Silt with minor sand - sand, fine</td>
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<tr>
<td>305 ML</td>
<td>Grey Silt with minor shells - very soft</td>
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<tr>
<td>310 ML</td>
<td>Grey blue Silt with some sand and trace of shells - sand fine - very soft</td>
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<tr>
<td>315 ML</td>
<td>Grey blue Silt with minor sand and trace of shells - sand fine - silt soft</td>
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<tr>
<td>320 ML</td>
<td>Grey blue Silt with minor clay and trace of shells - firm</td>
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<tr>
<td>325 ML</td>
<td>Grey blue mottled orange Silt with minor clay and trace of shells - soft</td>
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<td></td>
</tr>
<tr>
<td>GEOLOGICAL UNIT</td>
<td>DESCRIPTION</td>
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<td></td>
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<tr>
<td>-----------------</td>
<td>-------------</td>
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<tr>
<td>350</td>
<td>Grey black SILT with some sand and trace of shells - sand, fine - firm - grey mottled orange and no shells from 351.5m</td>
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<td></td>
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<tr>
<td>360</td>
<td>Grey SILT with some sand, trace of clay and marine organics</td>
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<tr>
<td>365</td>
<td>Grey SILT with trace of sand - sand, fine - 25-30% shells</td>
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<tr>
<td>370</td>
<td>Grey SILT with minor sand and clay and trace of shells - sand fine to medium - soft</td>
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</tbody>
</table>

**COMMENTS**

LOGGED DATE: 6/4/90
LOGGED LENGTH: PJR
DRILLER: McILLAN
STARTED: 4/1/89
FINISHED: 4/1/89
<table>
<thead>
<tr>
<th>GEOLOGICAL UNIT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>Grey blue SILT with minor sand and trace of shells</td>
</tr>
<tr>
<td></td>
<td>- sand, fine</td>
</tr>
<tr>
<td></td>
<td>- soft</td>
</tr>
<tr>
<td></td>
<td>- organics from 391.7m</td>
</tr>
<tr>
<td></td>
<td>- soft to firm from 391.7m</td>
</tr>
<tr>
<td>ML</td>
<td>Grey black SILT</td>
</tr>
<tr>
<td>ML</td>
<td>Light green, iron stained SILT with minor clay and trace of organics</td>
</tr>
</tbody>
</table>

COMMENTS:
- No samples taken from 391.7 to 433m
- Logged using drillers log

HOLE: NCCB DRILLHOLE
LOCATION: BEXLEY, CHRISTCHURCH
ATTITUDE/DIRECTION: VERTICAL

R.L. GROUND(m): 1.0 a.m.s.

MACHINE:

LOGGED PJR DRILLER McILLAN
DATE 6/4/90 STARTED 4/1/89
LENGTH FINISHED
**GEOLOGICAL UNIT DESCRIPTION**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Soil Loss (M)</th>
<th>Soil Loss (C)</th>
<th>Soil Loss (S)</th>
<th>Soil Loss (%)</th>
<th>Soil Loss (F)</th>
<th>Soil Loss (F)</th>
<th>Soil Loss (F)</th>
<th>Soil Loss (F)</th>
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</thead>
<tbody>
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</tr>
</tbody>
</table>

**DESCRIPTION OF MATERIAL RECOVERED.**

- No log

**COMMENTS**

- Grey SAND
- Sand, fine

**LOGGED BY**

- DRILLER MCILLAN
- DATE: 15/5/90
- LENGTH: finished

**MACHINE:**

- Rotary Drill
FEATURE. NCCB DRILLHOLE
LOCATION. BEXLEY, CHRISTCHURCH
ATTITUDE/DIRECTION: VERTICAL

R.L. GROUND (m). 1.0 a.m.s.l
MACHINE:

<table>
<thead>
<tr>
<th>GEOLOGICAL UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>CORE LOSS/ LOSS</td>
</tr>
<tr>
<td>BOREHOLE (m)</td>
</tr>
<tr>
<td>RECORDED (m)</td>
</tr>
<tr>
<td>PENETRATION (m)</td>
</tr>
<tr>
<td>DATE</td>
</tr>
<tr>
<td>WATER LEVEL (m)</td>
</tr>
<tr>
<td>PENETRATION (SPF) (uncorrected for overburden)</td>
</tr>
<tr>
<td>MOISTURE CONTENT (%)</td>
</tr>
</tbody>
</table>

Grey SAND with trace of organics
-Sand, fine

COMMENTS

LOGGED RJR
DATE 15/5/90
LENGTH

DRILLER McILLAH
STARTED 4/1/89
FINISHED