

# **GROUND SHAKING HAZARD KAPITI**

**NOTES TO ACCOMPANY**

**SEISMIC HAZARD MAP SERIES: GROUND SHAKING HAZARD  
MAP SHEET 5 KAPITI (FIRST EDITION) 1:40000**

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## 1. INTRODUCTION

### 1.1 BACKGROUND

The occurrence of earthquakes in the Wellington Region is inevitable due to its location at the boundary of two crustal plates. Earthquakes have the potential to cause significant adverse effects within the Region, including loss of life, injury, and social and economic disruption. In recognition of these potential effects, the Wellington Regional Council initiated a project in 1988 to:

- \* Assess the risks posed by earthquakes.
- \* Identify mitigation options.
- \* Implement measures to ensure that the level of risk is acceptable.

The first step in the project is to define the characteristics of the hazard. Information on the type and magnitude of possible effects, the probability of these occurring and the location of the effects within the Region is required. For the purposes of the project, *earthquake hazard* has been divided into a number of separate but interrelated components, including:

- \* Ground shaking.
- \* Surface fault rupture.
- \* Liquefaction and ground damage.
- \* Landsliding.
- \* Tsunami.

Although not all the effects will occur during every earthquake and many will be localised all components must be considered to obtain a complete picture of earthquake hazard.

### 1.2 PURPOSE OF MAP AND BOOKLET

A series of six map sheets, with accompanying booklets, has been compiled to describe the *ground shaking hazard* for the main metropolitan areas in the Region (refer to Index Map on accompanying map sheet):

- \* Sheet 1 - Wellington.
- \* Sheet 2 - Porirua and Tawa.
- \* Sheet 3 - Lower Hutt.
- \* Sheet 4 - Upper Hutt.
- \* Sheet 5 - Paekakariki, Paraparaumu, Waikanae and Otaki.
- \* Sheet 6 - Featherston, Greytown, Carterton and Masterton.

The purpose of the maps is to show the geographic variation in ground shaking hazard that could be expected during certain earthquake events. **The map sheets and booklets have been compiled from Wellington Regional Council reports and detailed reports prepared for the Wellington Regional Council by DSIR Geology and Geophysics, Land Resources and Physical Sciences, and Victoria University of Wellington. A list of the reports is given in Appendix 1.**

The intention of the map and booklet series is to raise public awareness of ground shaking hazard in the Wellington Region. The information will be useful to a range of potential users, including land use planners, civil defence organisations, land developers, engineers, utility operators, scientists and the general public.

Information on active faults in the western part of the Region has been published in a map series by the Wellington Regional Council - *Major Active Faults of the Wellington Region* (Map sheets 1, 2 and 3: 1991). Tsunami hazard information for Wellington Harbour is also available.

### 1.3 BOOKLET STRUCTURE

This booklet is divided into four main parts. Part 1 provides background information on the study. Part 2 outlines the hazard assessment approach and details the mapping methodology. Parameters used to quantify the hazard zones are also discussed. Part 3 states the assumptions and limitations that determine the certainty with which the hazard zones can either be mapped or quantified. A brief summary is given in Part 4.

Technical terms are defined in Appendix 2.

## 2. HAZARD ASSESSMENT

### 2.1 DATA SOURCES

The geographic variation in earthquake ground shaking was defined using geological and geotechnical information from microearthquake records, penetrometer logs, aerial photograph interpretation and field mapping. The shaking response of a representative suite of geological materials was assessed at 10 sites using records from 16 microearthquakes. The properties of the younger *flexible* materials were quantified using ten cone and two seismic-cone penetrometer probings.

## 2.2 EARTHQUAKE SCENARIOS

The Wellington Region is located across the boundary of the Pacific and Australian plates (Figure 1). As a consequence, the Region is cut by four major active faults and is frequently shaken by moderate to large earthquakes (Figures 2 and 3).

Because no single earthquake event adequately describes the potential ground shaking hazard in the Region two earthquake scenarios were used to define the hazard.

Scenario 1 is for a large, distant, shallow earthquake that produces Modified Mercalli intensity (MM) V-VI on bedrock (Appendix 3). It is expected that this type of earthquake will produce the largest variation in ground response. Scenario 1 implies minor damage to structures founded on the *best* sites and significant damage to certain structures on the *worst* sites. An example of such an event would be a Magnitude (M) 7 earthquake centred about 100 kilometres from the study area at a depth of less than 30 kilometres. Twenty years is a minimum estimate for the return time of a Scenario 1 event. This return time is derived from the historical occurrence of both large earthquakes and moderate sized local events. A maximum estimate is 80 years, which is the return time of MM VII or greater

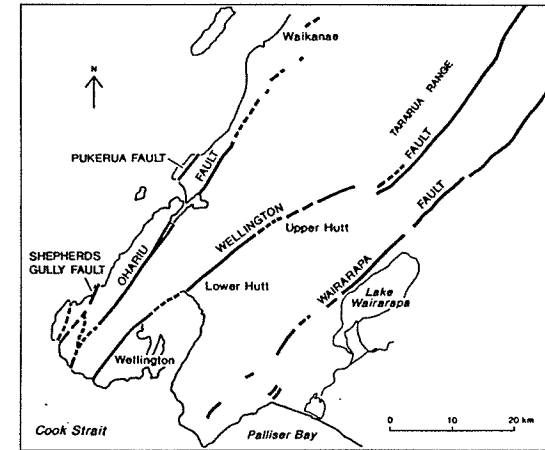


Figure 2: Active faults in the western part of the Wellington Region.

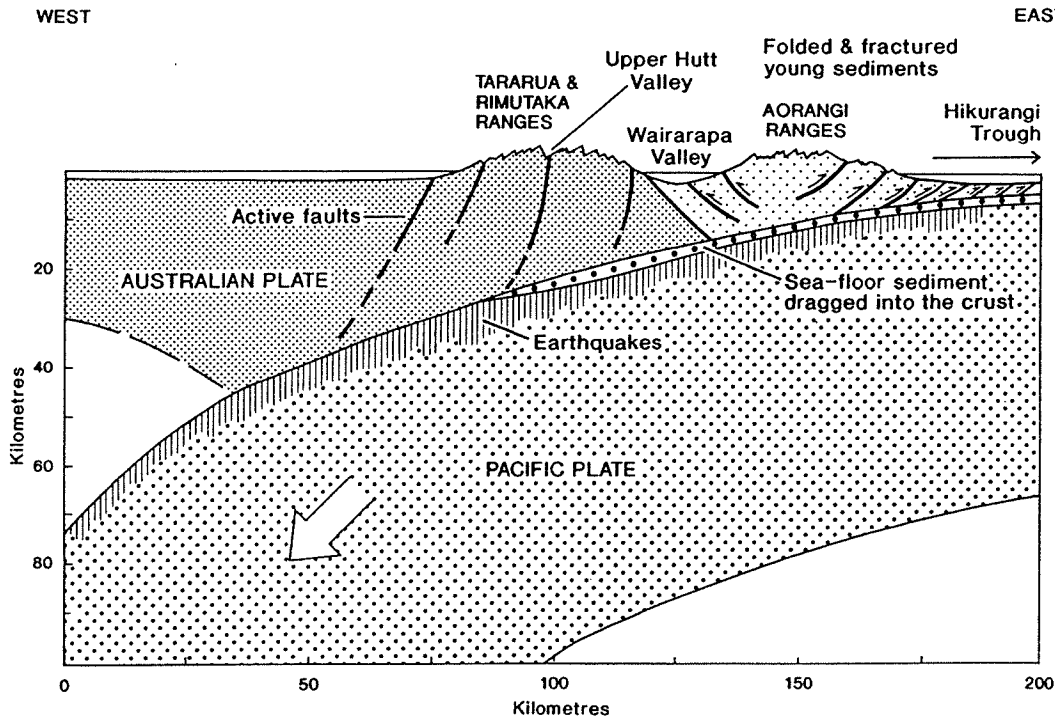


Figure 1: Source of earthquakes at plate boundary and along active faults. (After Stevens, 1991).

shaking at bedrock sites in the Wellington Region.

Scenario 2 is for a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault. Rupture of this segment is expected to be associated with a Magnitude 7.5 earthquake at a depth less than 30 kilometres, and up to 5 metres of horizontal and 1 metre vertical displacement at the ground surface. The return time for such an event is about 600 years and the probability of this event occurring in the next 30 years is estimated to be 10 percent. The values for near-source shaking resulting from a Scenario 2 earthquake are given with less certainty (refer to Section 2.5). This is because there are so few near-source ground motion data from large earthquakes, and factors such as proximity to local asperities along the rupture plane and random cancellation and reinforcement of seismic waves can locally suppress the effects caused by near-surface geological deposits. Furthermore, amplification of some local geological deposits will not occur at particular ground shaking frequencies and strengths.



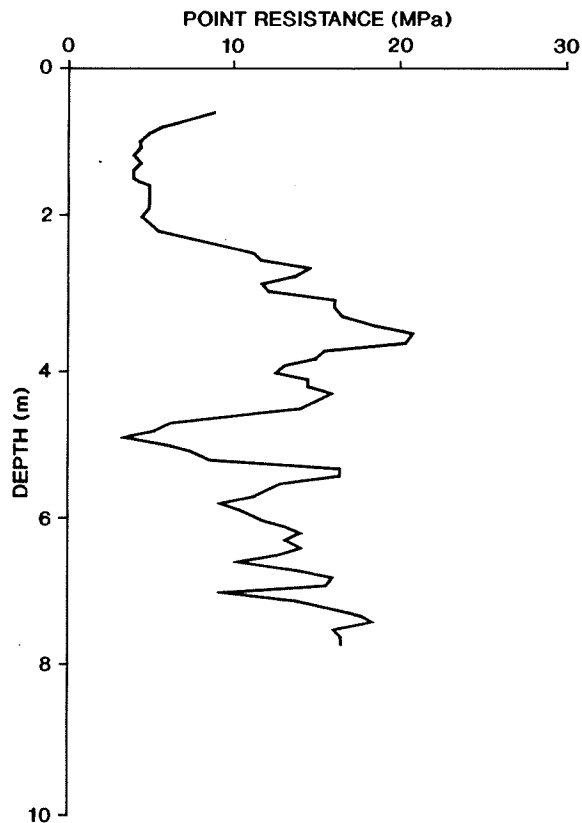


Figure 5: Cone penetrometer test results at Campbell Park, Paekakariki. (After Stephenson and Barker, 1992).

than 10 metres depth due to the inability of the cone to advance. The materials were generally loose to medium dense sand, and some peat and loose gravel. Shear wave velocities in the order of 130 to 200 metres/second were measured at two sites for the upper 5 to 10 metres. It is significant to note that during probing no reflected seismic energy was observed. This suggests that shear wave velocity gradually increases with depth, at least to a depth below which a reflected signal could not be detected, in the order of 15 metres.

### 2.3.4 Ground shaking hazard zones

Based on the distribution of geological materials and the measured response of these materials to seismic waves the Kapiti study area was mapped into three ground shaking hazard zones; Zone 1, Zone 2, and Zone 3-4 (refer to accompanying map sheet).

Zone 1, the least hazardous zone, is characteristically underlain by bedrock, and typically shows very low to low amplification of seismic waves.

Zone 2 areas are underlain by the *stiff* Pleistocene material, including compact gravel and sand interbedded with weaker silt and peat. Relative to Zone 1 low to moderate ground motion amplifications are expected in Zone 2.

Zone 3-4 areas are typically underlain by loose Postglacial material including geologically young beach and dune sand, river and fan alluvium, and peat. Moderate to high ground motion amplifications are anticipated in Zone 3-4 relative to Zone 1.

Figures 6 and 7 illustrate diagrammatically some of the relationships between the ground shaking hazard zones and the geology.

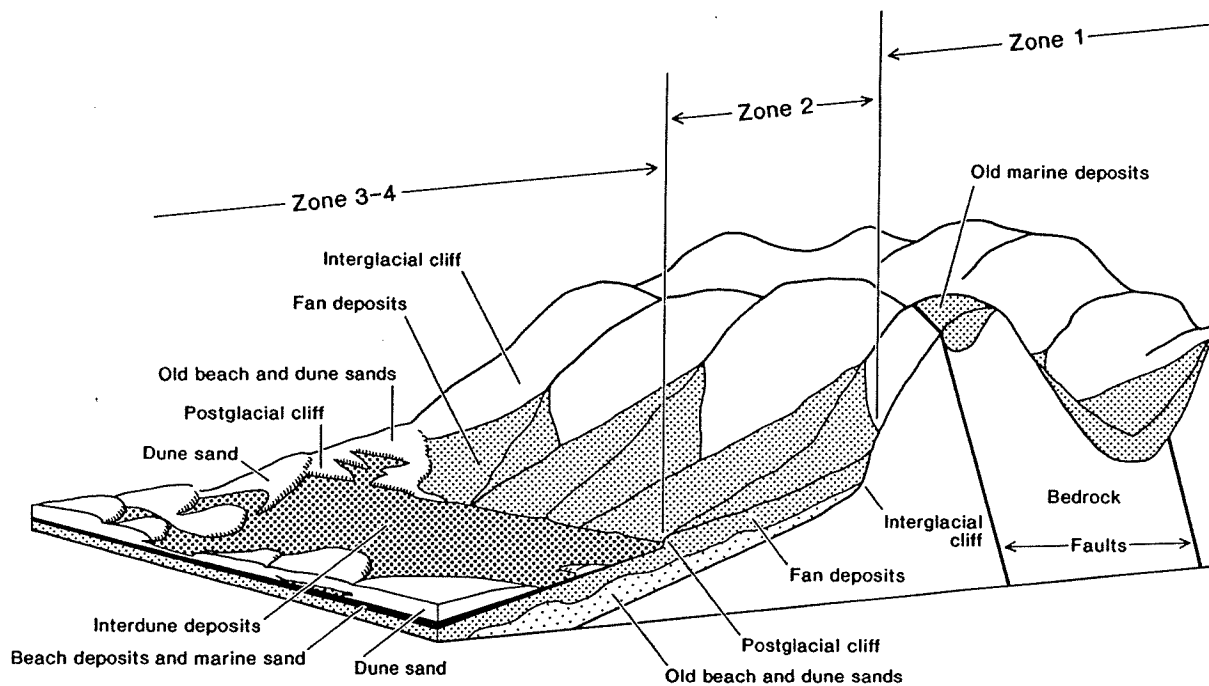


Figure 6: Block diagram showing the distribution of the main deposits on the Kapiti Coast. (After Heron and Van Dissen, 1992).

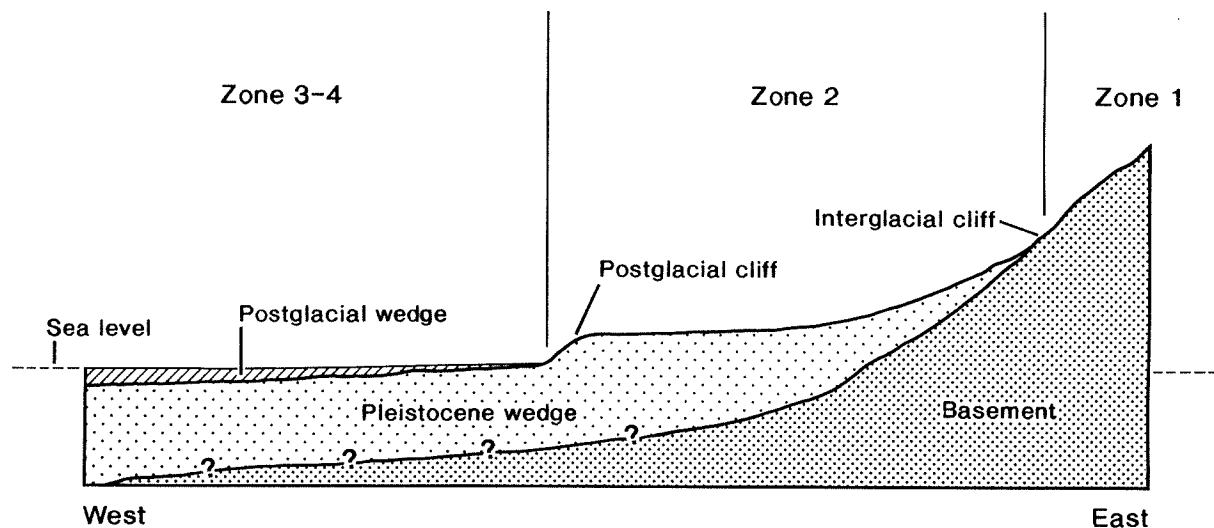


Figure 7: Diagrammatic cross section near Paraparaumu. (After Heron and Van Dissen, 1992).

Recent studies in both New Zealand and in California have found that the most *hazardous* site condition is typified by a greater than 10 metre thickness of geologically young (usually less than about 10000 years old), unconsolidated, often water saturated, fine-grained sediment with shear wave velocities in the order of 200 metres/second or less. These materials, often referred to as *soft soil* or *flexible sediment*, have the potential to greatly amplify earthquake ground shaking. Zone 3-4 materials in the Kapiti study area have near-surface shear wave velocities in the order of 200 metres/second or less. However, there does not appear to be any appreciable mappable extent of such materials with thicknesses greater than 10 metres. This contrasts with other parts of the Wellington Region, such as the low-relief coastal areas in Wellington, Lower Hutt, and Porirua that are typically underlain by thick *soft soil* or *flexible sediment*.

## 2.4 GEOLOGICAL DESCRIPTION OF HAZARD ZONES

Descriptions of the geological materials that typify each hazard zone are given in Appendix 4.

## 2.5 QUANTIFICATION OF HAZARD ZONES

The shaking response of the ground shaking hazard zones was assessed for the two earthquake scenarios (as described in Part 2.2). The response of each zone was expressed as a set of ground motion parameters, comprising:

- \* Expected Modified Mercalli intensity.
- \* Peak horizontal ground acceleration.
- \* Duration of strong shaking.
- \* Amplification of ground motion with respect to bedrock - expressed as a Fourier spectral ratio.

Some of these parameters were measured directly, others were estimated using comparisons found in the published scientific and engineering literature.

The Loma Prieta earthquake (1989, San Francisco) is significant to this study because of the recorded variations in ground motion related to local geological conditions and because the magnitude is similar to that expected for the Scenario 1 earthquake. Therefore, the values calculated for the ground motion parameters used in this study were compared with those measured for the Loma Prieta event.

### 2.5.1 Modified Mercalli intensity

Scenario 1: The Scenario 1 earthquake (a large, distant, shallow earthquake resulting in MM V-VI shaking on bedrock) will be of sufficient duration and contain sufficient long period energy to allow strong long period response to develop at sediment sites. The shallow focal depth will allow strong surface wave effects. The result will be a marked difference between the shaking of the *worst* sediment site and the *best* firm site. It is not uncommon during an earthquake to have a spread of three to four units of MM intensity separating the response of the *best* site from the response of a nearby *worst* site. However, it is again important to note that there does not appear to be an appreciable, mappable extent of thick (10 metres or more) near-surface *soft soil* or *flexible sediment* in the study area. Therefore a spread of three to four MM units, resulting from geographic variation in near-surface geology, is not anticipated for earthquakes impacting on the Kapiti Coast. The response of Zone 3-4 is expected to be in the order of one to two MM intensity units stronger than Zone 1. The Zone 2 response is expected to be one MM intensity unit stronger than Zone 1.

In terms of MM intensity the response of Zone 1 is expected to be MM V with some VI, Zone 2 is MM VI and Zone 3-4 is MM VI-VII (Table 1).

Scenario 2: The effects of a Scenario 2 event (a large, local Wellington Fault earthquake) will be a marked increase in the shaking throughout the Region relative to Scenario 1 and an increase in the variability of shaking within each zone, owing in part to differing source to site distances between

the southern and northern part of the study area. In general, shaking decreases with increased distance from the source. Pukerua Bay is about 15 kilometres from the Wellington-Hutt Valley segment, Otaki is about 35 kilometres from the northern-most portion of the segment. Therefore sites near Otaki are expected to shake less than similar sites near Pukerua Bay. Ground shaking in Paraparaumu and Waikanae is expected to be intermediate between that of Pukerua Bay and Otaki.

Epicentral intensities for the 1989 Loma Prieta earthquake were MM VIII. However, the Loma Prieta earthquake was smaller than the Scenario 2 event (M 7.1 compared to M 7.5). Epicentral intensities for similarly sized New Zealand earthquakes have been MM IX (1848 Marlborough), MM IX-X (1931 Hawkes Bay) and MM VIII-IX (1968 Inangahua).

On the basis of these relationships, MM VIII is expected in Zone 1 in the southern part of the study area (Table 1). Further from the Fault, near Otaki, MM VII is expected. In Zone 2, MM VIII to IX is expected near Pukerua Bay, and MM VII to VIII near Otaki. In Zone 3-4, MM IX to X is anticipated in the southern part of the study area, and MM VIII to IX in the northern part.

#### 2.5.2 Peak horizontal ground acceleration

Scenario 1: Peak ground acceleration for Zone 1 is expected to be in the order of 0.02 to 0.06g. This compares to the 0.06g recorded during the Loma Prieta earthquake at a hard rock site 95 kilometres from the epicentre. Accelerations of 0.02 to 0.1g are expected in Zone 2 and Zone 3-4 (Table 1).

Scenario 2: The average peak ground accelerations expected for Scenario 2, based on a variety of attenuation relations and geological site considerations are Zone 1, Zone 2 and Zone 3-4, 0.3 to 0.6g near Pukerua Bay, and 0.1 to 0.3g near Otaki (Table 1).

#### 2.5.3 Duration of strong shaking

*Duration* provides a qualitative estimate of the effects that local geological deposits can have in increasing the length of time a site will experience strong shaking. In general, amplitudes and durations

SCENARIO 1				
Zones	MM Intensity	Peak ground acceleration (g)	Duration	Amplification of ground motion (FSR)
1	V-VI	0.02-0.06	<5 sec	c. 1
2	VI	0.02-0.1	2-3x	<5x
3-4	VI-VII	0.02-0.1	2-3x	>5x, generally 8-15x
SCENARIO 2				
Zones	MM Intensity	Peak ground acceleration (g)	Duration	
1	Pukerua Bay	VIII	15-40 sec	
	Otaki	VII	10-30 sec	
2	Pukerua Bay	VIII-IX	1-2x	
	Otaki	VII-VIII	1-2x	
3-4	Pukerua Bay	IX-X	2x	
	Otaki	VIII-IX	2x	

Table 1: Ground motion parameters for the ground shaking hazard zones in the Kapiti area.

of shaking increase with decreasing firmness of the underlying sediment. This has been observed in the Kapiti area for non-damaging earthquakes and elsewhere for larger damaging earthquakes. In this study, *duration* refers to the time between the first and last accelerations that exceed 0.05g.

Scenario 1: The expected duration of strong shaking in Zone 1 during a Scenario 1 event is less than 5 seconds (Table 1). The expected increase in duration, relative to bedrock, is 2 to 3 times in Zone 2 and Zone 3-4.

Scenario 2: Length of fault rupture is a controlling factor regarding the duration of near-source ground shaking. The Loma Prieta earthquake produced about 10 seconds of strong shaking, resulting from a 40 kilometres bilateral rupture (rupture propagation from the centre of the fault to the ends). Had the rupture been unilateral (rupture propagation from one end of the fault) the shaking would have lasted much longer, perhaps up to 20 seconds. Rupture of the Wellington Fault in Scenario 2 is expected to be about twice as long as the rupture that produced the Loma Prieta earthquake. The duration of shaking for Zone 1, close to Pukerua Bay, during Scenario 2 is expected to be 15 to 40 seconds, by comparison with the Loma Prieta event and depending on whether the rupture propagates bilaterally or unilaterally. Zone 1 shaking near Otaki is expected to be about 10 to 30 seconds. The anticipated increase in duration, relative to Zone 1, is 1 to 2 times for Zone 2 and 2 times for Zone 3-4 (Table 1).

#### 2.5.4 Amplification of ground motion spectrum

Characteristic peak Fourier spectral ratios, within the frequency band of 0.5 to 4 Hz, are summarised in Table 1. Peak ratios vary from less than 5 for *stiff* sediment sites to greater than 20 for thick, loose sediment sites. The results are useful for determining relative shaking and for identifying the frequencies over which this shaking will be most strongly amplified during certain earthquakes, specifically Scenario 1 type events.

Ground motion amplification at most sites in the Kapiti study area occurred over a broad frequency band. Some Zone 3-4 sites exhibited a notable high frequency response. Two sites showed a narrow (resonant) frequency response at about 9 Hz. Resonant response appears most common when relatively thin (less than about 30 metres), *flexible*, low velocity sediment overlies much firmer material. The resonant frequency is a function of the thickness and velocity of the *flexible* layer. Site resonance is of most concern where built structures exist with natural periods that coincide with the resonant period band(s) of strong ground shaking. The resonant response in the above two cases was attributed to a thin (4 metres or less) layer of peat and silty sand. The lack of resonance at the other Kapiti sites probably indicates that the increase with depth of shear wave velocity and stiffness is gradual rather than occurring at an abrupt layer boundary.

Even though the ground motion amplifications measured in the Kapiti area were recorded during non-damaging earthquakes it is significant to note that intensity maps, prepared in the 1970's for the San Francisco Bay area, anticipated all of the areas that experienced high intensity shaking during the 1989 Loma Prieta earthquake. The level of

amplification during even larger ground motions at near-source sites is unresolved. An amplification of near 20 at Paraparaumu is unlikely to persist to extreme motions because at high strain levels weak sediments begin to behave in a non-linear fashion - they begin to lose strength and increase wave attenuation or damping. This is particularly the case for the relatively non-cohesive Postglacial sediments. Nevertheless, variations in the nature of seismic response can still be expected from one zone to another. High amplification of small bedrock ground motions, such as the Scenario 1 bedrock motions, means that significant local damage at the *worst* sites in Zone 3-4 could result from an earthquake that would cause little or no damage in Zone 1. It is amplification of small bedrock ground motions that the measured spectral ratios best characterise, therefore they are given only for Scenario 1.

### 3. ASSUMPTIONS AND LIMITATIONS

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified are discussed below.

- (1) Within each hazard zone there are isolated occurrences of materials that may cause ground motions that are not typical of the zone as a whole.

Along most of the Kapiti Coast the Postglacial cliff marks the boundary between Zone 2 and Zone 3-4. However, near Waikanae and north of Otaki sand derived from the Postglacial wedge has been blown up and over the Postglacial cliff and formed dunes on top of the Pleistocene wedge (Figure 7). The tallest

dunes are 20 metres above the surrounding surface of the Pleistocene wedge. In places peat has formed between the dunes. Even though these geologically young deposits are east of the Postglacial cliff they are mapped as Zone 3-4. The position of the cliff in these cases is marked by a *dashed* line on the accompanying map. However, where these deposits are thin (less than 5 to 10 metres thick) their shaking response may be more typical of Zone 2.

The Waikanae and Otaki Rivers flow west across the Postglacial wedge. Coarse-grained channel deposits (gravel and sandy gravel) and finer-grained flood deposits (sand and silt) close to these rivers commonly form lenses within or a thin veneer (less than 5 metres thick) of alluvial sediment on top of the Postglacial wedge. The Postglacial wedge is primarily composed of beach and dune sand, and interdune peat, and the presence of thin alluvial deposits is not expected to alter the Zone 3-4 designation given to the Postglacial wedge. However, it is possible that in places the coarse-grained alluvial deposits are thick in the order of the thickness of the Postglacial wedge. In these cases the response to earthquake shaking may be more characteristic of Zone 2.

Potential significant variations in amplified resonant response over relatively short distances in some areas emphasise the importance of site specific studies to determine the nature and response of the materials at a site.

- (2) High amplifications (greater than or equal to 20) have been recorded at Paraparaumu Beach. However, the spatial and subsurface distribution of the materials causing these amplifications is not well defined. This area has been mapped as Zone 3-4 because the presumed non-cohesive nature of the near-surface sediment at this site implies that high amplifications will not persist at high levels of shaking. If the sediment properties are not as presumed then high amplifications could occur at high levels of shaking and the area would be better mapped as a more hazardous zone, Zone 5.
- (3) Near-surface shear wave velocities, including velocity profiles, for the geological materials in the Kapiti study area are not well known. Shear wave velocity is the parameter that best correlates with site amplification. Velocity profiles provide information regarding possible site resonance.
- (4) Amplification of ground motion due to topographic effects has not been addressed for this study. Though probably localised, these effects can be pronounced.
- (5) Near-surface geology is a primary factor influencing the relative level of earthquake shaking at a site. Earthquake source and path effects, including size of and distance from an earthquake, complexity of rupture, direction of rupture propagation, and possible crustal reflections can also play an important role. However, most of these factors are unique for every earthquake impacting on a site and are therefore difficult to characterise on a regional scale.

The subsurface distribution of sediment, including the shape, depth and type of sediment fill, can influence both the direction and frequency content of shaking at a site. It is not uncommon for sites within a sedimentary basin to show a marked directionality of response during earthquakes. Also, total sediment thickness, not just the physical properties of the near-surface sediments, can strongly influence the frequency band over which shaking is amplified. Deeper sediment sites tend to show broader band amplifications and stronger long period response. If the sediment of the coastal plain or part of the plain consistently responds strongly in certain directions then this information can be incorporated into the design and siting of built structures.

- (6) Scenario 2 ground motion parameters are defined with less certainty. There is a worldwide lack of near-source ground motion data recorded during large earthquakes. During a large local earthquake, near-source seismic wave propagation will be complex and non-uniform, and ground strains will be large enough to cause some sediments to exhibit non-linear response. These effects will tend to increase the variability of shaking within a zone, decrease the average difference in shaking between zones and decrease the certainty with which expected ground motions can be characterised. Also, near-source ground motions for an earthquake associated with a long fault rupture, such as Scenario 2, may be correlated with proximity to local asperities along the fault rupture, rather than proximity to the fault itself.

(7) The information given in this booklet and on the accompanying map is the result of a regional scale multi-disciplinary study of ground shaking hazard. The booklet and map provide useful information for the mitigation of ground shaking hazard in the Kapiti study area but should not be used to replace site specific studies.

Detailed geological mapping, additional penetrometer probing, seismograph instrumentation, and topographic and mathematical modelling would resolve some of these issues.

#### 4. SUMMARY

The geographic variation in ground shaking was defined using information from microearthquake records, penetrometer logs and aerial photograph interpretation. Three ground shaking hazard zones were established. These are Zone 1, Zone 2 and Zone 3-4. The geographic distribution of the zones is shown on the accompanying map.

Zone 1 areas are the least hazardous and are underlain by bedrock. Zone 2 areas show low to moderate amplification of earthquake shaking and are underlain by compact gravel and sand, interbedded with weaker silt and peat. These materials comprise the Pleistocene wedge. Zone 3-4 areas show moderate to high amplification of earthquake motions and are typically underlain by loose beach and dune sand, river and fan alluvium, and peat. These sediments comprise the Postglacial wedge.

The expected response of each ground shaking hazard zone to two earthquake scenarios is given by Modified Mercalli intensity, peak ground acceleration, duration and amplification of ground motion parameters. The two parameters most easily understood are MM intensity and duration. For a large distant earthquake (Scenario 1), MM values range from V-VI in Zone 1, to VI-VII in Zone 3-4. The response will range from *some alarm and damage* in Zone 1 areas to *general alarm and moderate damage* in Zone 3-4 areas. Strong shaking will last for less than 5 seconds in Zone 1 areas but continue for 10 to 15 seconds in Zone 3-4 areas. For a large earthquake centred on the Wellington Fault (Scenario 2) there is less difference between the zones, with strong shaking experienced everywhere.

In the Kapiti study area there does not appear to be extensive areas underlain by thick deposits of *soft soil* or *flexible sediment*. These materials, characteristic of the low relief, coastal areas of Wellington, Lower Hutt, and Porirua, are expected to most strongly amplify earthquake ground motions. Areas underlain by such materials are therefore subject to the greatest earthquake ground shaking hazard in the Wellington Region. The absence of these sorts of materials in the Kapiti study area implies that earthquake effects in the Kapiti area, particularly for Scenario 1 type events, may be less pronounced than in, for example, Wellington or Porirua.

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified exist and must be considered when interpreting the hazard information.

## APPENDICES

### APPENDIX 1: CONTRIBUTING REPORTS AND REFERENCES

Hastie W J (1992). Seismic hazard: Summary report on work carried out in 1991/92. Publication No. WRC/PP-T-92/23, Policy and Planning Department, Wellington Regional Council.

Heron D W and Van Dissen R J (1992). Geology of the Kapiti Coast (Pukerua Bay to Otaki), Wellington. DSIR Geology and Geophysics Contract Report 1992/19 (prepared for Wellington Regional Council).

Stephenson W R and Barker P R (1992). Report on cone penetrometer and seismic cone penetrometer probing in Wellington City, Kapiti Coast and Upper Hutt valley. DSIR Land Resources Contract Report 92/14 (prepared for Wellington Regional Council).

Stevens G (1991). On shaky ground: A geological guide to the Wellington metropolitan region. DSIR Geology and Geophysics and the Geological Society of New Zealand, Lower Hutt.

Taber J J and Richardson W (1992). Frequency dependent amplification of weak ground motions in Wellington City and the Kapiti Coast. Institute of Geophysics, Victoria University of Wellington (prepared for Wellington Regional Council).

Van Dissen R J *et al* (1992). Earthquake ground shaking hazard assessment for the Kapiti Coast, New Zealand. DSIR Geology and Geophysics Contract Report 1992/23 (prepared for Wellington Regional Council).

## APPENDIX 2: GLOSSARY OF TECHNICAL TERMS

**Active fault** A fault with evidence of surface movement in the last 50000 years or repeated surface movement in the last 500000 years.

**g Gravity.** For an earthquake which produces a ground acceleration of 0.4g, the actual acceleration is 40 percent of gravity.

**Hazard** A potentially damaging physical event.

**Liquefaction** Process by which water-saturated sediment temporarily loses strength, usually because of strong shaking and behaves as a fluid.

**Pleistocene** The *Ice Age*. The period of time that lasted from about 2 million years ago to 10000 years ago.

**Quaternary** Geological time period spanning the last 2 million years.

**Risk** The combination of a natural hazard event and our vulnerability to it. Risk can be specified in terms of expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural hazard.

**Seiche** Oscillation of the surface of an enclosed body of water owing to earthquake shaking.

**Seismicity** Ground shaking due to release of energy by earthquake.

**Tsunami** An impulsively generated sea wave of local or distant origin that results from seafloor fault movement, large scale seafloor slides or volcanic eruption on the seafloor.

## APPENDIX 3: MODIFIED MERCALLI INTENSITY SCALE

**MM I** Not felt by humans except in especially favourable circumstances but birds and animals may be disturbed. Reported mainly from the upper floor 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 and reservoirs may be set into seiche oscillation.

**MM II** Felt by few a persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long period effects listed under MM I 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 awakened. 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 frames of buildings are heard to creak. Doors and windows rattle. Glassware and crockery rattle. 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.

**MM VI** 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 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.

**MM VII** 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 roofline. 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.

**MM VIII** 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 foundations 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 may form.

**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 alleviated 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 banks.

**MM XI** Wooden frame structures destroyed. Great damage to railway lines and 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.

#### **APPENDIX 4: GEOLOGICAL DESCRIPTIONS OF HAZARD ZONES**

Zone 1: **BEDROCK**. Moderately strong to very strong quartzite, and sandstone and argillite (collectively referred to as *greywacke*). Also included are weak to moderately strong siltstone, sandstone, and greensand. These rocks are typically moderately weathered but in places are highly weathered. Rock defects are common and most closely spaced adjacent to major faults. Areas within Zone 1 are often overlain by less than 3 metres of scree, slopewash and loess.

Zone 2: **STIFF SEDIMENT**. Compact to very compact granular material composed primarily of Pleistocene gravel and sand. These materials are interbedded with weaker layers of silt and peat, and are collectively referred to as the Pleistocene wedge (Figure 7). The maximum sediment thickness beneath this zone is unknown but probably exceeds 100 metres in places.

Zone 3-4: **LOOSE SEDIMENT**. Loose to moderately dense granular material composed of geologically young (less than 6500 years old) beach and dune sand, and river and fan alluvium. Interdune peat, up to about 5 metres thick, is also present. Collectively these sediments comprise the Postglacial wedge (Figure 7) and have near-surface shear wave velocities in the order of 200 metres/second or less. From the Postglacial cliff these sediments almost certainly thicken to the west, towards the present-day coast. At Te Horo they are 40 metres thick.