GROUND SHAKING HAZARD WAIRARAPA

NOTES TO ACCOMPANY

SEISMIC HAZARD MAP SERIES: GROUND SHAKING HAZARD
MAP SHEET 6 WAIRARAPA (FIRST EDITION) 1:50000

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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 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 for the Wairarapa study area was based on previously established correlations between near-surface geological materials and their capability for amplifying earthquake ground motions.

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 a large, distant, shallow earthquake that produces Modified Mercalli intensity (MM) V-VI in bedrock over the Wairarapa area (Appendix 3). 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 15 to 60 kilometres.

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 2.4). This is because there are so few near-source ground motion data from large

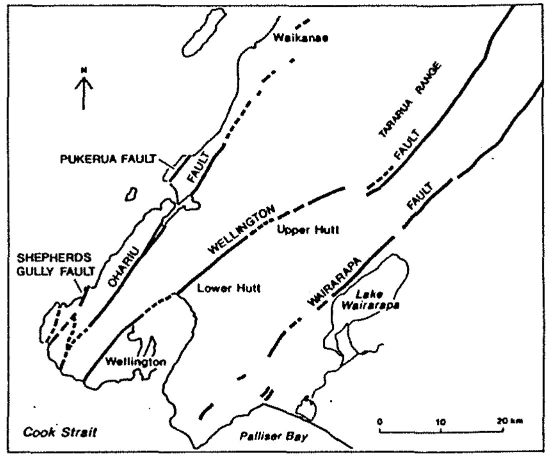

Figure 2: Active faults in the western part of the Wellington Region.

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.

2.3 GROUND SHAKING HAZARD ZONES

Based on the distribution of geological materials the Wairarapa study area was mapped into two ground shaking hazard zones; Zone 1 and Zone 2-4 (refer to accompanying map sheet). Areas in the Wellington Region underlain by significant thicknesses (greater than 10 metres) of *soft soil* or *flexible sediment* are mapped as Zone 5 and are expected to have a high to very high amplification capability. No Zone 5 areas were mapped in the Wairarapa study area.

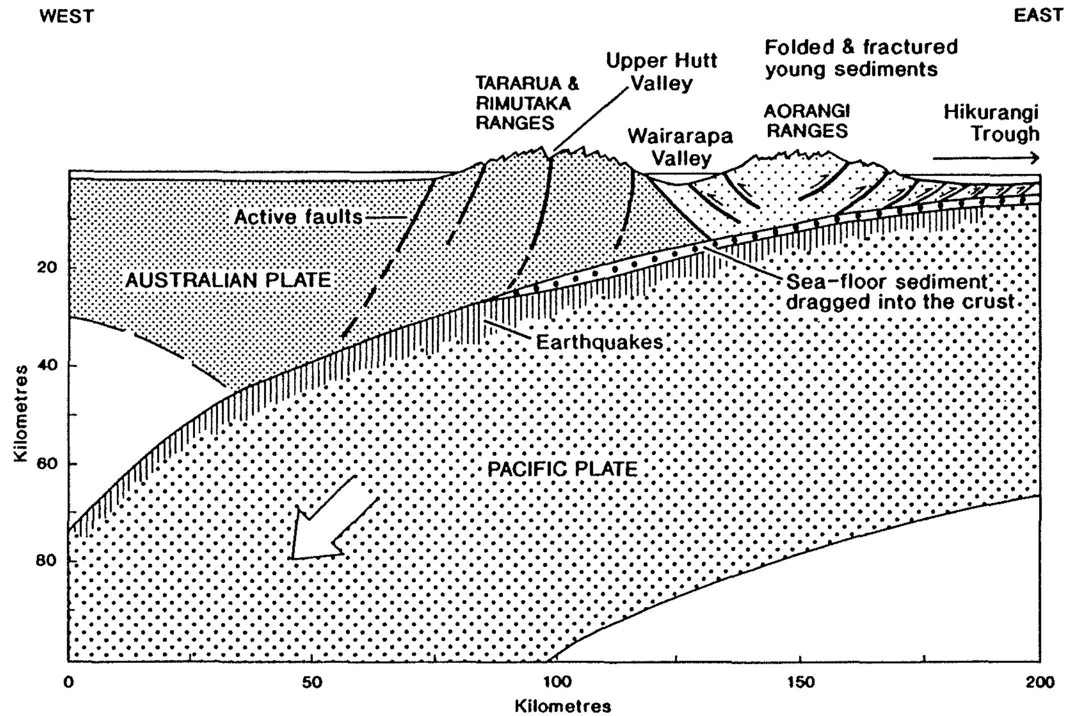

Figure 1: Source of earthquakes at plate boundary and along active faults. (After Stevens, 1991).

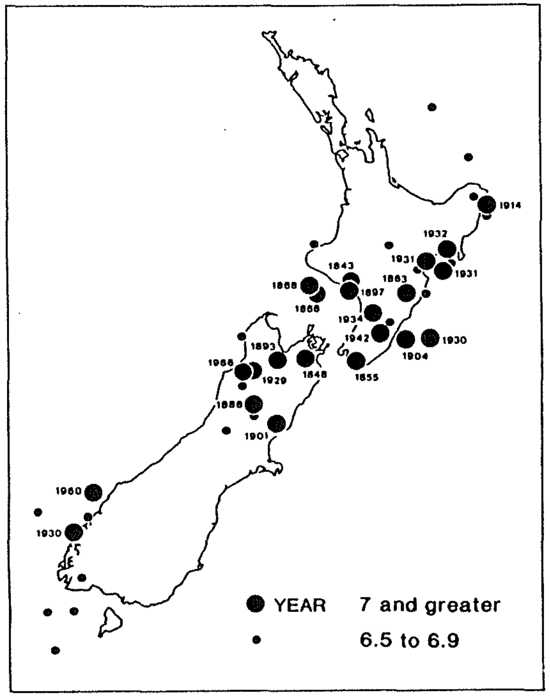

Figure 3: Epicentres of shallow earthquakes of magnitude 6.5 and greater since 1840 (after Van Dissen, 1992).

Areas directly underlain by weak to strong rock, with little or no cover, are mapped as Zone 1. This includes areas underlain by weathered greywacke. Zone 1 areas are expected to have an intermediate to very low amplification capability.

Areas underlain by greater than about 10 metres of Holocene and Pleistocene gravel and sand, and very weak rock are expected to have an intermediate ground shaking response compared to Zones 1 and 5. These areas are mapped as Zone 2-4 and are expected to have an intermediate to high amplification capability. The geological deposits mapped as Zone 2-4 in the Wairarapa study area encompass a wide range of grain sizes and sediment thicknesses. Zone 2-4 includes much of the Wairarapa valley floor and the gentle hill country.

2.4 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.

These parameters were estimated using comparisons found in the published scientific and engineering literature, and from other work in the Wellington Region.

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.

2.4.1 **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* rock 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 near-surface *soft soils* or *flexible sediments* in the Wairarapa. The response of Zone 2-4 is expected to be in the order of one MM intensity unit stronger than Zone 1.

Therefore, in terms of MM intensity the response of Zone 1 is expected to be MM V with some VI and Zone 2-4 is MM VI with some 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 study area, 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 parts of the study area. In general, shaking decreases with increasing distance from the source. Featherston is about 10 kilometres from the Wellington-Hutt Valley segment of the Wellington Fault, Masterton is about 40 kilometres from the northernmost portion of the segment. Therefore, sites near Masterton are expected to shake less than similar sites near Featherston. The shaking in Martinborough, Greytown and Carterton is expected to be intermediate between that of Featherston and Masterton.

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

Scenario 1				
Zones	MM Intensity	Peak ground acceleration (g)	Duration	Amplification of ground motion (FSR)
1	V-VI	0.02-0.06	<5 sec	1-3x
2-4	VI-VII	0.02-0.1	2-3x	2-10x

Scenario 2				
Zones		MM Intensity	Peak ground acceleration (g)	Duration
1	Featherston	VIII	0.3-0.6	15-40 sec
	Masterton	VII	0.1-0.3	10-30 sec
2-4	Featherston	VIII-IX	0.3-0.6	1-2x
	Masterton	VII-VIII	0.1-0.3	1-2x

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

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 western part of the study area (Table 1). Further from the Fault, near Masterton, MM VII is expected. MM VIII-IX is expected in Zone 2-4 near Featherston, and MM VII-VIII further away, near Masterton.

2.4.2 **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 2-4 (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, 0.3 to 0.6g near Featherston, and 0.1 to 0.3g near Masterton; Zone 2-4, 0.3 to 0.6g near Featherston, and 0.1 to 0.3g near Masterton (Table 1).

2.4.3 **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 of shaking increase with decreasing firmness of the underlying sediment. This has been observed in the Wellington Region 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 2-4.

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 Featherston, 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 Masterton is expected to be in the order of 10 to 30 seconds. The anticipated increase in duration for Zone 2-4, relative to Zone 1, is 1 to 2 times (Table 1).

2.4.4 **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. 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.

Based on a comparison between the geological materials (and their amplification characteristics) present elsewhere in the Region with those in the Wairarapa study area, the following inferences are made regarding amplification of ground motions in the Wairarapa. During a Scenario 1 type event, Zone 1 areas are expected to experience amplifications of less than 3 (excluding locally significant topography related amplifications) and Zone 2-4 areas are expected to experience amplifications of 2 to 10.

Even though the ground motion amplifications measured elsewhere in the Wellington Region 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 FSR greater than 5 is unlikely to persist to extreme motions. This is because at high strain levels weak sediments begin to behave in a nonlinear fashion - they begin to lose strength and increase wave attenuation or damping. 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 in Zone 5 could result from an earthquake that would cause little or no damage in Zone 1. Amplification of small bedrock ground motions are best characterised by measured spectral ratios and are therefore 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) The single most noticeable factor limiting the certainty of the zonation presented in this report is that no earthquake ground motions have been measured in the Wairarapa study area. The ground motion response of the near-surface geological materials in the Wairarapa is inferred based on the measured response of similar materials in New Zealand and overseas. The high degree of compatibility between the ground motion amplifications reported in other parts of the Wellington Region with those from overseas, for similar geological materials, gives confidence that the Wairarapa ground shaking zonation is realistic.

(2) 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. The hill country in the Wairarapa is composed of several different rock types that are expected to have a range of shear-wave velocities. In the hill areas it is expected that there will be a complex interaction between amplifications caused by topography and those caused by variations in local geology, including weathering profile. Parts of what is mapped as Zone 2-4 in the Wairarapa study area are underlain by near-surface layers of peat and alluvial silt. Usually these layers are thin, two metres or less. However, if they are about 10 metres thickness or more a response less favourable than that anticipated for Zone 2-4 is expected. Areas where an appreciable thickness of these fine-grained materials may exist include the ponded region immediately northwest from the Waingawa freezing works site and the abandoned meander channels along the course of the Ruamahanga River. Also, the former extent of Lake Wairarapa presents an unresolved question regarding the possible occurrence of near-surface fine-grained lake sediments in the southwestern-most part of the study area (the Murphys Line/South Featherston Road area).

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.

(3) Near-surface shear wave velocities for the geological materials in the Wairarapa study area are not known. Therefore, direct comparisons between shear wave velocity and ground motion amplification is not possible. The ability to correlate geological material with amplification capability is therefore limited. This is specifically the case regarding the ground shaking hazard classification of the mid-Quaternary compact gravels and sands that directly underlie Bidwell hill, the southeastern border of the

study area and the hill northeast from Masterton marked by Owaka South trig. At present, areas underlain by these materials are mapped as Zone 2-4. Additional studies could find that they are better classified as Zone 1.

(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) 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.

(6) 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 play an important role. However, these factors are rather unique for every earthquake impacting on a site and are therefore difficult to characterise on a regional scale.
Basin geometry, including the depth and type of basin fill, can influence both the direction and frequency content of shaking within the basin. It is not uncommon for sites within a sedimentary basin, such as the Wairarapa depression, to show a marked directionality of response during earthquakes. Also, total sediment thickness, not just the physical properties of the near-surface sediments, can influence the frequency band over which shaking is amplified. Deeper sediment sites tend to show broader band amplifications and stronger long period response compared to sites underlain by a relatively simple, thin (about 10 to 30 metres thick) layer of soft, unconsolidated, fine-grained sediment. If the basin, or an area within a basin consistently responds strongly in certain directions or consistently amplifies ground motions within a certain frequency band, then this information can be incorporated into the design and siting of built structures.

(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 Wairarapa study area but should not be used to replace site specific studies.

Detailed geological mapping including compilation of existing drillhole data, penetrometer probing, seismograph instrumentation, and topographic and mathematical modelling would resolve some of these issues.

4. SUMMARY

The geographic variation in ground shaking was based on previously established correlations between near-surface geological materials and their capability for amplifying earthquake ground motions. Two ground shaking hazard zones were identified in the Wairarapa study area. These are Zone 1 and Zone 2-4. During damaging earthquakes Zone 2-4 is expected to experience, on average, greater levels of shaking than Zone 1. The geographic distribution of the zones is shown on the accompanying map.

The expected response of the two ground shaking hazard zones to two earthquake scenarios is given by Modified Mercalli intensity, peak ground acceleration, duration, and amplification of ground motion parameters.

In the Wairarapa study area there do not appear to be extensive areas of *soft soils* or *flexible sediments*. These materials, characteristic of the low-relief coastal areas of Wellington, Lower Hutt and Porirua, are expected to strongly amplify earthquake ground motions. Therefore, areas underlain by such materials are subject to the greatest earthquake ground shaking in the Wellington Region and are mapped as Zone 5. The absence of these materials in the Wairarapa study area suggests that earthquake effects in the study area will 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.

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.

Van Dissen R J (1992). Earthquake ground shaking hazard assessment of the Wairarapa, New Zealand. DSIR Geology and Geophysics Contract Report 1992/10 (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.

Holocene The last 10000 years.

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 1 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 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 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.