Client report 40652B

CONFIDENTIAL

Hawke's Bay Regional Council Earthquake Hazard Analysis Program:

Stage III - Evaluation of Ground Shaking Amplification Potential

Volume 1

J V Hengesh
G D Dellow
D W Heron
G H McVerry
W R Stephenson

HBRC Report No.AM15-05
HBRC Plan No. 4727

June 1998

Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

Hawke's Bay Regional Council Earthquake Hazard Analysis Program: Stage III - Evaluation of Ground Shaking Amplification Potential

Volume 1

by

J V Hengesh, G D Dellow, D W Heron
G H McVerry, W R Stephenson,

Prepared for

HAWKES BAY REGIONAL COUNCIL

CONFIDENTIAL

Client Report 40652B

HBRC Report No. AM15-05
HBRC Plan No. 4727

CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY

Local geological deposits, or ground conditions, are well known for their ability to influence the nature of shaking a site experiences during an earthquake. Wood (1908) reporting on the San Francisco earthquake of 1906, noted that damage in the city

> " ... depended chiefly on the geologic character of the ground. Where the surface was of solid rock, the shock produced little damage; whereas upon made ground [man-made fill] great violence was manifested ...".

Strong ground shaking is the most pervasive earthquake hazard, and accounts, either directly or indirectly, for most of the damage, and consequent loss of life, resulting from an earthquake. When areas of enhanced shaking hazard are identified, then the potential exists to reduce the vulnerability, and consequent risk, to the community from strong earthquake ground shaking.

Sites underlain by soft, flexible, material often experience greater shaking than nearby sites underlain by firmer, stiffer material. This relationship has been documented during extensive studies of (for example):

- weak and moderate ground motions in the Wellington region;
- weak ground motions in the Palmerston North and Wanganui areas; and
- damaging and non-damaging levels of earthquake shaking in the San Francisco Bay area.

Areas of enhanced shaking hazard can be identified in three ways. Firstly they can be identified from instrumental records and ground conditions for instrumented areas that have experienced large earthquakes. The Hawke's Bay region was not instrumented at the time of the 1931 Napier earthquake or 1932 Wairoa earthquake. Secondly, areas of enhanced ground shaking can be identified from historical accounts of past large earthquakes, and thirdly, in other places by comparing and grouping together areas of similar near-surface geological conditions and similar geotechnical properties such as shear wave velocity and ratios of weak and strong ground motion response.

This report is the third prepared for the Hawke's Bay Regional Council by the Institute of Geological and Nuclear Sciences on earthquake hazards in the Hawke's Bay region. It assesses the potential for earthquake ground shaking amplification throughout the region using the methodology of Borcherdt (1994) and an update of the recommended United States National Earthquake Hazard Reduction Programme (NEHRP) provisions for earthquake resistant design codes (Building Seismic Safety Council, 1991).

The methodology used in this report integrates information on geological conditions with geotechnical parameters, such as mean shear wave velocity, and standard penetration test results to develop amplification response classifications. The seismic response of each class has been evaluated using Nakamura analyses (Nakamura, 1989), weak ground motion studies and accelerograph data and resulted in the calculation of amplification factors (at short, intermediate and long periods) for each site response class.

The methodology has been used to extrapolate the amplification factors across broad geographical areas and thus permits the spatial variation of ground motions to be estimated across the region.

Analytical techniques that compare geological and geotechnical data with seismic response characteristics have been used to prepare hazard maps (Figures 1-4) depicting site responses for the Hawke's Bay region at a scale of 1:250,000, and for the Heretaunga Plains, Waipawa/Waipukurau and Wairoa at a scale of 1:50,000. These maps depict the distribution of soil and rock types which are expected to behave in a similar fashion during earthquake shaking.

A further set of maps (Figures 5-8) depict the amplification hazard expected for a scenario earthquake on the Mohaka Fault. The maps have been produced by using the amplification factors calculated for each soil class to predict ground motions.

In general, the soils in the Heretaunga Plains are considered to represent average (Class 3) soil conditions with respect to the New Zealand soil peak ground acceleration (PGA) earthquake attenuation equation (Zhao *et al*, 1997). Soils in the vicinity of the Ahuriri lagoon and other local swamp, lagoonal and estuarine deposits along the coast (Class 4), are weaker than the alluvium on the Heretaunga Plains.

- At low levels of shaking both the soils of the Heretaunga Plains and the soils of the former Ahuriri lagoon and other lagoonal, estuarine and swamp deposits will amplify ground shaking with respect to rock sites. The weaker (Class 4) soils will show greater amplifications.

- During strong shaking the soils of the former Ahuriri lagoon and other local lagoonal, estuarine and swamp deposits will begin to liquefy, thus loosing shear strength and loosing their ability to amplify ground shaking. However, these areas are likely to suffer ground deformation and consequent damage to buried services and structures founded in them.

- The soils of the Heretaunga Plains (Class 3) are considered unlikely to liquefy west of Hastings, judged from ground damage accounts from the 1931 Napier earthquake which report liquefaction-induced ground damage from sites that lie to the east, south-east and north-east of Hastings.

A localised area (in Flaxmere) has been observed to show a site response that doubles the amplification factor of the mean values used to develop the hazard maps (Figures 1-4). It should be noted that this type of local site response might also occur elsewhere, and special studies are required for sensitive facilities, or facilities that would be critical in the event of an earthquake.

The implications of this with respect to Hawke's Bay are that strong distant earthquakes will have the greatest impact with regards to the hazard of ground shaking amplification. The level of shaking required to generate this level of site response is most likely to be sourced on faults at moderate to large distances from the "site" in question. We cannot be more specific, as the levels of shaking likely to be generated are both magnitude and distance dependant.

1.0 INTRODUCTION

This report presents the results of the Hawke's Bay Regional Council's "Earthquake Hazard Analysis Programme: *Stage III - Evaluation of Ground Shaking Amplification Potential*." The work is presented in two volumes. Volume 1 presents the evaluation of ground shaking amplification potential, with the second volume containing the appendices to the report. The appendices describe the detailed methodology used in the acquisition of the data sets that have been used in the derivation of the ground shaking amplification hazard.

1.1 Background

During the period 1994/1995 the Institute completed Stage I of the Earthquake Hazard Analysis Programme, which involved estimating the recurrence of large damaging earthquakes from geologic and seismologic data in the Hawke's Bay region. As a result of the Stage I study at least four seismic source zones which could cause future moderate to large magnitude earthquakes were identified. Such earthquake events are likely to cause damage due to primary surface fault rupture and strong ground shaking, as well as secondary effects such as liquefaction, amplified strong ground shaking, and seismically induced slope failure.

In 1995/1996 the Stage II portion of this Programme was completed to estimate and map the distribution of strong ground shaking for a range of time periods (Part 1), and to assess the extent and distribution of areas susceptible to seismic liquefaction in the Hawke's Bay region (Part 2). During 1996/1997 the Institute conducted the Stage III investigation. The specific objectives and scope of work completed during the Stage III study are presented below.

1.2 Stage III Study Objectives

The objectives of this study were to:

- Compile existing data to develop maps of soil profile types which may cause amplification of strong ground motions; and
- Develop ground shaking amplification factors for soil-type map units in the region.

1.3 Work Undertaken

The scope of work completed during this Stage III study includes:

I. Collecting available information on the occurrence of felt intensities, peak horizontal ground motions and other ground shaking amplification indicators necessary to delineate ground shaking hazard zones based upon geology, soil descriptions and geotechnical properties;

II. Conducting a series of seismic CPT probes to characterise subsurface materials at selected locations in the region;

III. Deploying a field array of seismographs to quantify earthquake ground shaking amplification with respect to (peak) ground accelerations on bedrock;

IV. Collecting ground motion data for Nakamura analyses using portable EARSS (Equipment for Automatic Recording of Seismic Signals) instruments;

V. Carrying out the field experiments developed above and analyzing and interpreting the field results;

VI. Preparing a map, at a scale of 1:250,000, that shows the ground shaking hazard in the Hawke's Bay region during a high probability earthquake shaking event;

VII. Preparing detailed maps at 1:50,000 scale showing the ground shaking hazard in the Heretaunga Plains and Waipukurau/Waipawa areas during a high probability shaking event; and

VIII. Preparing this overview report to accompany the ground shaking hazard maps.

1.4 Acknowledgements

The Institute would like to acknowledge the support and assistance of Mr. Robert Van Voorthuysen of Hawke's Bay Regional Council during this study. Mr. Peter Barker was contracted to provide seismic CPT data for several areas of the Hawke's Bay region. The authors would also like to thank Mr Kelvin Berryman, Mr Jim Cousins, Mr Peter Wood and Mr Dick Beetham for their helpful review comments.

2.0 GROUND SHAKING AMPLIFICATION HAZARDS

Local geological deposits, or ground conditions, are well known for their ability to influence the nature of shaking a site experiences during an earthquake. Wood (1908) noted, following the great San Francisco earthquake of 1906, that damage in the city

> "... depended chiefly on the geologic character of the ground. Where the surface was of solid rock, the shock produced little damage; whereas upon made ground [man-made fill] great violence was manifested....".

Sites underlain by soft, "flexible", material often experience greater shaking than nearby sites underlain by firmer, stiffer material. This relationship has been recently documented during extensive studies of weak and moderate ground motion studies in the Wellington region (Taber & Smith, 1992; Van Dissen et al., 1992, 1993), in the Palmerston North and Wanganui areas with weak ground motion (Taber & Rollo, 1994), and in the San Francisco Bay area during both damaging and non-damaging levels of earthquake shaking (Borcherdt 1991). Recent major earthquakes affecting Leninakan (Armenia), Newcastle (Australia), and San Francisco (United States), also serve to illustrate this point, and underscore the important role that local geological conditions can have in influencing property damage and life loss during earthquakes (e.g. Seed et al., 1988; Borcherdt et al., 1989; Holzer, 1994; Rynn, 1991).

Strong ground shaking is the most pervasive earthquake hazard, and accounts, either directly or indirectly, for most of the damage, and consequent life loss, resulting from an earthquake (e.g. Holzer, 1994). If areas of enhanced shaking hazard can be identified, then the potential exists to reduce the vulnerability, and consequent risk to the community due to strong earthquake shaking. For example, the cost of repairs to certain lifelines, such as (brittle) cast iron pipeline systems, increases by a factor of ten for each MM unit increase (O'Rourke et al., 1991), so that determination of the likely future level of earthquake shaking has important implications with respect to earthquake damage evaluation and prediction. This is an approach that has been adopted in several regions of New Zealand and around the world, as part of the process of earthquake hazard quantification and mitigation.

Areas of enhanced shaking hazard can be identified for specific locations from historical accounts of past large earthquakes (Appendix C, Volume 2), and in other places by extrapolations based on near-surface geological conditions and measurement of some characteristics of the geological materials such as shear wave velocity, or ratios of soil to rock ground motion in weak and strong earthquakes. The hazard of enhanced shaking can be quantified in terms of variations in Modified Mercalli intensity (MM) units, relative to bedrock, expected during an earthquake (the MM intensity scale is described in Appendix A, Volume 2).

While MM intensity has been and is widely used for the evaluation and prediction of earthquake damage (e.g. Evernden & Thomson, 1988), it does not answer all the questions for all possible users of information about earthquake ground shaking response. For example, MM intensity is not always well correlated with peak ground acceleration. In extreme cases, peak ground accelerations attributed to the same intensity can differ by close to an order of magnitude (e.g. Murphy & O'Brien, 1977). Nor does MM intensity always provide information regarding the frequencies over which site-related shaking amplification (or attenuation) occurs. Peak ground accelerations and frequency content, as well as parameters such as duration of shaking, are required if the variation in shaking hazard within a region is to be fully defined. Hence there is a modern trend towards greater use of accelerographs to measure strong earthquake motions, and the gradual phasing out of the more "subjective" intensity reports.

Two distinct types of ground shaking amplification have been observed, site resonance and broadband amplification. Site resonance, i.e. strong amplification either at single frequency or over a well-defined narrow band of frequencies, is usually associated with the presence of near-surface weak materials such as recent, fine-grained marine, estuarine or lake sediments, overlying distinctly firmer materials. Locations in New Zealand that have shown signs of resonance include soft sediment sites at Wairoa, Gisborne, Hanmer Springs, Hutt City and Wellington. The evidence consists of the repeated occurrence of well-defined peaks in Fourier spectra calculated from accelerograph records, and for Hutt City and Wellington it is supported by comparisons of matched records from rock, firm soil, and soft soil sites. For resonant sites in the Hutt Valley amplification factors exceeding ten in the 5% damped acceleration spectra were recorded for input rock motions of small to moderate intensity (McVerry and Sritharan, 1991).

Broadband amplification has been observed at sites above deep soils. Instead of there being a dominant and repeated resonant peak in the Fourier spectrum of the acceleration, the amplification is generally spread over a period band that can be up to several seconds wide. Examples of such sites in New Zealand are located in Te Anau, Wanaka, Murchison, Hutt City, Palmerston North and Massey University (McVerry and Sritharan, 1991). Their characteristic feature seems to be the presence of some hundreds of metres of sediment, which may include soft layers, but which do not have a distinct hard-soft boundary within a few tens of metres of the surface. For the sites of broadband amplification, maximum amplifications of five were recorded for several events, and in one event the maximum amplification exceeded ten in the 5% damped acceleration response spectra for input rock motions of small to moderate intensity (McVerry and Sritharan, 1991). In Hawke's Bay such sites with deep (soft) soils are not common and a hard-soft boundary is generally present within several tens of metres of the ground surface.

The characterisation of soft soil response to strong shaking requires special attention, because shear failures of soils, common under strong loading, may result in attenuation of shaking, but raise the possibility of liquefaction induced ground failure. This phenomenum was demonstrated during the 1931 Napier earthquake when the damage that occurred on the Bluff Hill (Scinde Island) was compared with the damage that occurred in Napier South. On Bluff Hill the greatest damage was to structures and services above ground (ie buildings) while in Napier South the main damage was to buried structures and services. This can be attributed to the soils of Napier South attenuating ground shaking because they had failed in shear (that is they liquefied and fissured). Thus, quantification of both enhanced ground shaking and liquefaction potential is vital if seismic hazard maps are to offer the widest applicability and greatest use to both planners and engineers.

3.0 METHODOLOGY

The potential for ground shaking amplification was assessed throughout the Hawkes Bay region using the methodology of Borcherdt (1994). This can be treated as an update of the recommended procedures outlined in the United States National Earthquake Hazard Reduction Programme (NEHRP) - Provisions for Earthquake Resistant Design Codes (United States Building Seismic Safety Council, 1991; Section 4.2.1).

The methodology used integrates information on geological conditions (e.g. geological mapping) with geotechnical parameters (e.g. mean shear wave velocity, and Standard Penetration Test (SPT-N60) blow counts) to determine site response (i.e relative amplification) for both short and long period frequencies.

The amplification factors can then be applied to theoretically derived ground motions for a scenario earthquake event to estimate the ground motions at a particular site. In some cases the result is the amplification of ground motion and in other cases the result is a dampening, or deamplification of the ground motion. Where liquefaction occurs, the loss of shear strength within the liquefied material prevents amplification from occurring, but may cause other (severe) damage.

The Borcherdt and NEHRP methodology was augmented by techniques under development at the Institute. These included:

- analysis of ambient (background) ground vibration data recorded on portable seismographs deployed at a number of sites across the region (Nakamura analysis, Appendix D);

- comparison of weak motion earthquake recordings at selected sites in the Heretaunga plains with a "bedrock" reference site in the adjacent uplands (weak ground motion studies, Appendix E); and

- verification of the results of these analyses with strong-motion earthquake records obtained from previous earthquakes in the region (accelerograph site records, Appendix F).

The delineation of the zones of similar amplification potential is based on geological mapping. The assessed extent of geological units allows individual site response results to be extrapolated across broad geographical areas, thus giving by correlation the variation in ground motion response across the region.

The compilation and analysis of the data-sets used to calculate the ground shaking amplification potential for the Hawkes Bay region and the results of these analyses are described in detail in Appendices A-G in Volume 2 and are summarised here:-

3.1 MM Intensity (Appendix A)

The Modified Mercalli Intensity Scale presented in Appendix A is the version developed by Dowrick (1996).

3.2 Geological Database (Appendix B)

Appendix B (Volume 2) describes the methodology used in the acquisition of geological data. In general, this involved:

- the creation of maps showing Quaternary geology, (these maps delineate deposits using relative age, depositional environment, and grainsize); and

- the evaluation of the thickness of Quaternary deposits in the Hawke's Bay region.

The geological maps are presented as Figures B-1 and B-2 covering the Hawke's Bay region (at a scale of 1:250,000) and the Heretaunga Plains (at a scale of 1:50,000) in the map pocket at the back of Volume 2 and Figures B-3 and B-4 covering the Waipawa/Waipukurau and Wairoa areas (at a scale of 1:50,000) in Appendix B (Volume 2).

3.3 Historical Database (Appendix C)

Analysis of the historical earthquake record (Appendix C) has thrown up some interesting observations.

- In the Waipawa-Waipukurau area, higher intensities are more often reported from Waipawa when compared to Waipukurau (e.g. 1931 Napier earthquake).
- The same phenomena is observed on the Heretaunga Plains with Napier generally experiencing higher shaking intensities than Hastings, although there are exceptions where the difference is the other way round.
- At Wairoa, only one event (1904, Cape Turnagain) provided information on variations in intensity, with the intensity being one unit higher at Frasertown than at Wairoa.

Generally the historical record shows that some areas (e.g. Napier, Waipawa) experience amplified ground shaking during moderate to strong shaking. Closer analysis of the damage data may enable refinement of this observation. For example, at Napier amplification of ground shaking may occur both because of weak ground and because of topographic enhancement.

3.4 Nakamura Database (Appendix D)

Appendix D describes the methodology used in the acquisition of microtremor data and the results of processing the microtremor data using the Nakamura method (Nakamura, 1989). Ambient, or background ground vibrations are recorded on a portable seismograph. This data is then processed using the Nakamura method. This enables the potential resonance at a site to be evaluated.

The value of the Nakamura technique is that data on site response (microtremor data) can be quickly gathered in the field, and analyzed to assess the resonant characteristics of a number of sites. The flexibility of the technique allows it to be used as a screening technique to identify which areas may or may not be susceptible to the amplification of strong ground shaking.

The Nakamura method provides a reasonable estimate of the natural frequency of a resonant site, and a rough estimate of the amplification, provided that the local geology is simple. The Nakamura method will confidently locate highly resonant areas where a widespread uniform soft layer has an abrupt interface with firmer material.

Microtremors were recorded at 31 locations in the Hawke's Bay region. The analysis of the recorded data from the Hawkes Bay region using the Nakamura method has identified some strongly resonant sites. Areas which exhibit resonant behaviour include the former Ahuriri lagoon, coastal areas on the north side of Scinde Island, St Lukes School in Havelock North, Flaxmere and Hastings. Areas where no clear indication of resonance is seen include areas of the former Ahuriri lagoon south of Scinde Island. Sites at Waipukurau, Waipawa, Flaxmere, the Napier CBD and Napier Hospital do not amplify ground shaking according to the Nakamura method.

3.5 Weak Motion Database (Appendix E)

Appendix E describes the methodology used in the acquisition of weak ground motion data. These are measurements of motions generated from small to moderate earthquakes located at moderate to large distances. Data has also been utilised from a previous study (Benites and Haines, 1996).

Strong amplification of small ground motions at some alluvial sites means that significant local damage could be caused at such sites by a moderate earthquake that would cause no damage at a firm site. If the comparison of strong and weak motions in other areas can be applied to Hawke's Bay, the moderate amplification factors recorded at most sites may remain the same for strong ground motion, while the large amplifications at short period measured for weak motion on the softest sites are likely to be decreased for larger earthquakes, but with the increased risk of liquefaction-induced ground damage.

Both the observed and synthetic ground motions modelled by Benites and Haines (1996) in the Bluff Hill area are consistent with the damage distribution due to the 1931 Hawke's Bay M=7.8 earthquake.

In general, the test sites in the Heretaunga Plains alluvium show amplifications at frequencies between 1 and 3 Hertz. In the lagoonal deposits, the mean soil/rock ratios indicate that amplification occurs at somewhat lower frequencies, 0.1 to 2.0 Hz.

3.6 Strong Motion Database (Appendix F)

The Institute of Geological and Nuclear Sciences operates an accelerograph network throughout New Zealand (Cousins and McVerry, 1997). Several of the instruments are permanently deployed in the Hawke's Bay area. By analyzing the data sets obtained from these instruments it is possible to further refine the ground shaking hazard and identify areas where the amplification of ground shaking has occurred during historical (post-1968) earthquakes (Appendix F, Volume 2).

Topographic sites (i.e. sites that are elevated above the surrounding area) have statistically significant, larger ratios in all but the 0.1-0.5s band. In other words topographic sites will amplify strong ground shaking in the intermediate and longer period bands of the response spectra.

Rock sites with more than 3.0 metres of layered soils have statistically significantly higher values than rock sites with more than 3.0 metres of uniform soil, in the three longer period bands.

Soft sites usually have statistically significant lower values for their Nakamura ratios than others in their class in the 0.1-0.5s band, and statistically significant higher values in the other period bands.

The accelerograph data available from these past earthquakes confirms the resonant frequencies of sites identified through the Nakamura and weak motion studies. The strong motion data has also provided better constraints on the value of the soil/rock ratios for the site response units.

3.7 Geotechnical Database (Appendix G)

Appendix G describes the sources of geotechnical data used in this report. Geotechnical data has been collected from a variety of sources, including Hawke's Bay Regional Council records, IGNS files, and Barker (1994) as well as being collected specifically for this project (Barker, 1997). This data includes:

- Standard Penetrometer Test (SPT N_{60}) results where available;
- Cone Penetrometer Test (CPT) results; and
- Seismic Cone Penetrometer Test (SCPT) results.

The low shear wave velocity estimates obtained from the SCPT testing indicate the generally weak nature of materials in both the fluvial, lagoonal and estuarine systems in the region.

4.0 EVALUATION OF SITE RESPONSE (AMPLIFICATION) CLASSES

4.1 Background

Over recent years, there has been much research in the United States on the development of site response factors for various site conditions. We have made use of two of those models to verify the findings of this study. Borcherdt (1991, 1994) has developed a model based on a combination of relative site responses in the Loma Prieta earthquake, and weak-motion responses in the San Francisco and Los Angeles regions from nuclear test blasts in Nevada. The results of Borcherdt's work, and others, have been used by a National Earthquake Hazards Reduction Program (NEHRP) to develop new site classifications and associated response factors for the next generation of United States earthquake design codes. For reference, the site response classes from Borcherdt (1994) are summarised in Table 4.1 below, and the site response classes from the NEHRP programme are summarised in Table 4.2.

Table 4.1: Borcherdt Site Classification Scheme

Geological Setting	Mean Shear Wave Velocity V_{30} (m/s)		
	min	ave	max
SC-Ia HARD ROCKS e.g. metamorphic rocks with very widely spaced fractures	1400	1620	4000
SC-Ib FIRM to HARD ROCKS e.g. granites, igneous rocks, conglomerates, sandstones, and shales with close to widely spaced fractures	700	1050	1400
SC-II GRAVELLY SOILS and SOFT to FIRM ROCKS e.g. soft igneous sedimentary rocks, sandstones, and shales, and soils with >20% gravel	375	540	700
SC-III STIFF CLAYS and SANDY SOILS e.g. loose to very dense sands, silt loams and sandy clays, and medium stiff to hard clays and silty clays (N>5)	200	290	375
SC-IVa NON SPECIAL-STUDY SOFT SOILS e.g. loose submerged fills and very soft to soft (N<5) clays and silty clays 5-37 m thick	100	150	200
SC-IVb SPECIAL-STUDY SOFT SOILS e.g. liquefiable soils, quick and sensitive clays, peats, highly organic clays, very high plasticity clays (PI>75%), and soft soils more than 37 m thick	-	-	-

Borcherdt's site response factors were developed as a function of mean shear wave velocity to 30 m depth, V30, defined as 30 m divided by the shear-wave travel time to that depth. In recognition that this parameter is often not available, Borcherdt used an extensive correlation between geotechnical descriptions of sites and measured V30 values to develop descriptive site classes when the shear-wave velocity is unknown.

The NEHRP study produced a site classification (Table 4.2, below) with very similar shear-wave velocity bounds to those of Borcherdt. In assessing the results from our studies against the NEHRP and Borcherdt site response classes, the NEHRP site classes A, B, C, D, E and F have been taken as equivalent to the Borcherdt classes Ia, Ib, II, III, IVa and IVb, respectively.

Table 4.2: NEHRP Site Classification Scheme

Site Class	Site Class Name / Generic Description	Site Class Definition - Mean shear-wave velocity (V_{30} m/s)
A	Hard rock	$V_{30} > 1500$ m/s
B	Rock	760 m/s < V_{30} < 1500 m/s
C	Very Dense Soil and Soft Rock	360 m/s < V_{30} < 760 m/s, or N > 50, or $S_u > 100$ kPa
D	Stiff Soil	180 m/s < V_{30} < 360 m/s, or 15 < N < 50, or 50 kPa < S_u < 100 kPa
E	Soft Soil Soft clay with soil profile	$V_{30} < 180$ m/s PI > 20; w > 40%; & $S_u < 25$ kPa
F	Site specific geotechnical investigations and dynamic site response analyses. 1. Soils vulnerable to potential failure or collapse under seismic loading: (liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils). 2. Peats and/or highly organic clays : (H > 3 m of peat and/or highly organic clay). 3. Very high plasticity clays: (H > 8 m with PI > 75). 4. Very thick "soft/medium stiff clays" (H > 36 m).	

4.2 Proposed Site Classifications for Hawkes Bay Region

The computation of ground motions for seismic hazard assessments involves the use of ground motion attenuation equations to estimate the decay of ground motion amplitudes with respect to distance from source. These equations implicitly treat various types of site classifications. However, the New Zealand PGA (peak ground acceleration) attenuation studies differentiate only between "rock" and "soil" site classes to address site amplification effects, and as such, there are not sufficient divisions within these broad categories to treat all of the likely site conditions that may arise from various geological environments.

In the current New Zealand attenuation model, "Rock" is a subgroup of those sites satisfying site subsoil category (a) (Rock or very stiff soil sites) of the New Zealand Loadings Standard NZS4203:1992, namely rock outcrop sites, or sites with no more than 3 metres of soil overlying rock. All other subsoil category (a), (b) and (c) sites of NZS4203:1992 are treated as "soil sites" in the PGA attenuation expression. When the current attenuation expression was developed, a variety of other site classes were considered, but there was found to be no statistically significant difference between the "soil" classes used. This does not necessarily mean that all "soil" sites will produce the same PGAs, but rather that there were insufficient data in developing the New Zealand attenuation equation to determine statistically significant differences. For this reason it was necessary to develop the more detailed site classification units, shown on Figures 1 to 4, to augment the site classifications of the attenuation equation for input to the calculation of PGA for the Hawkes Bay region (see Section 5.0).

Based on the data developed for this study, and comparisons with the Borcherdt and NEHRP site classification schemes, we have defined four site classifications for the Hawkes Bay region. The geological descriptions for each site classification, and their associated geotechnical properties, do not always fall completely within one site classification. Accordingly, the approach taken has been to identify the predominant conditions, and map the corresponding site responses. The site classifications defined for this study are listed below, and the correlations to the NEHRP and Borcherdt schemes are summarised in Table 4.3.

Site Response Class 1: Soft rock and soil overlying rock (very dense soil)
Site Response Class 1 comprises the bedrock and shallow soil areas of the region. Bedrock in the region is comprised of Tertiary age marine sandstones, siltstones, mudstones, and limestones. The shear wave velocity for this reference unit is assumed to be approximately 650 m/s (Melhuish and Bannister, 1995). This unit is defined as the reference class for the comparison between weak motions for soil and rock sites.

Site Response Class 2: Firm to stiff sediment of Pleistocene age (stiff soil)
Site Class 2 comprises the older alluvial and fluvial sediments (map units lg, f1 and f2, Figure B-2 - in map pocket, volume 2) along the margins of the Heretaunga plains. These deposits include interlayered clayey sands and gravels. Some of these deposits may have a high degree of cementation. Shear wave measurements were not available for these materials, however, their texture and age suggests that they would fall into NEHRP Class D (or Borcherdt Class SC-III) as shown in Table 4.3.

Data from our investigations were compared with the response factors of Borcherdt and NEHRP to develop the final factors for the Hawkes Bay Site Response Maps, Figures 1 to 4. However, in reviewing the Borcherdt model, which accounts for non-linear soil response through amplitude-dependent response factors, it became apparent that the amount of non-linearity for one of the Borcherdt classes (SC-III, that corresponds to site response Class 2 of this study) was greater than suggested by site responses in the Northridge earthquake, a point that has been acknowledged by Borcherdt (1994) in an evaluation of his model against Northridge earthquake data. The NEHRP study uses similar site classifications to Borcherdt, and gives similar site response factors in low to moderate amplitude shaking, but predicts less nonlinearity at high amplitudes. In other words liquefaction is less likely in this class than is suggested by the Borchedt model.

Figure 3: Earthquake Ground Shaking Amplification Hazard, Waipukurau - Waipawa area

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

LEGEND

RELATIVE EARTHQUAKE AMPLIFICATION

HIGH

- 4 — Unconsolidated swamp, estuarine and lagoonal deposits and reclaimed land
- 3 — Alluvial sand, silt, and gravel
- 2 — Compact alluvial sand, silt, and gravel.
- 1 — Bedrock/Regolith

LOW

Site class	Site Amplification Factor at various Peak Ground Accelerations (relative to Class 3 sites)					
	0.00g to 0.16g	0.16g	0.28g	0.36g	0.44g	> 0.50g
4	1.25	1.25	1.15	1.00	0.62	N/A
3	1.00	1.00	1.00	1.00	1.00	1.00
2	0.88	0.88	0.85	0.90	0.90	1.00
1	0.75	0.75	0.80	0.88	0.90	1.00

See accompanying report for a full explanation of this table.

TOPOGRAPHIC REFERENCE

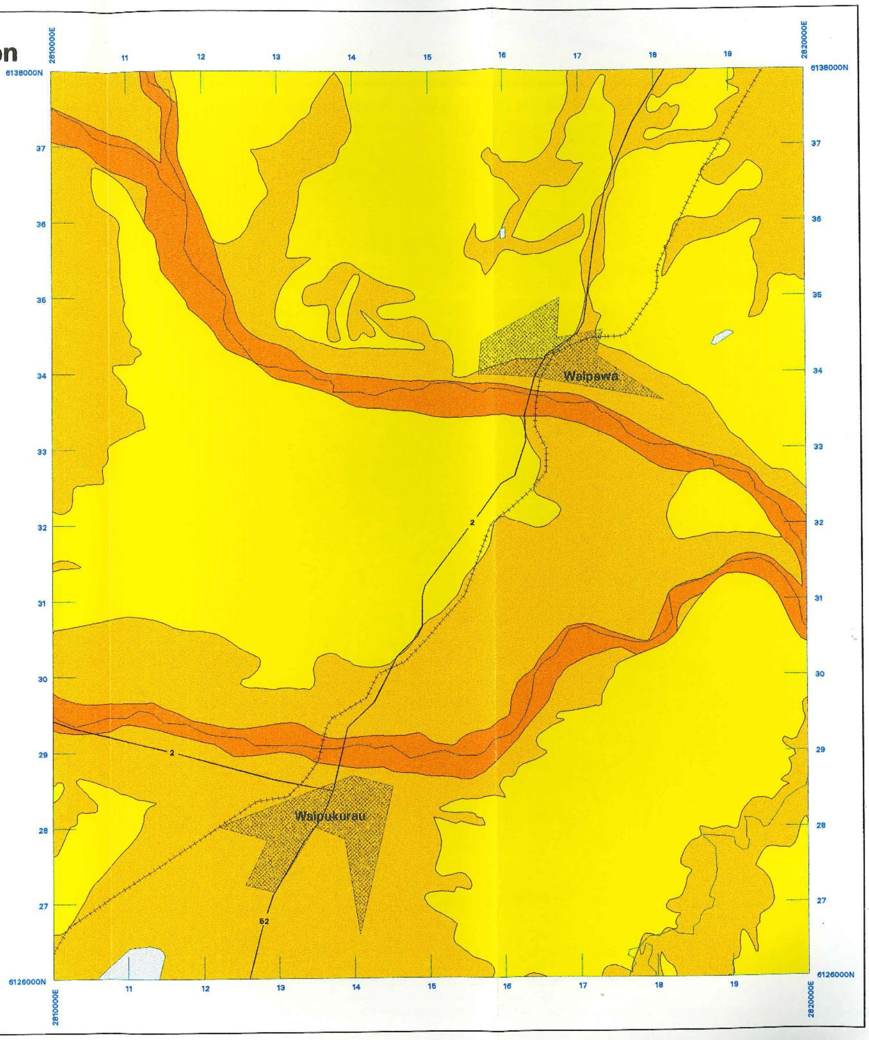
- Urban area
- Road
- Railway
- River
- Water

The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.

Institute of GEOLOGICAL & NUCLEAR SCIENCES Limited

SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres



ound Shaking Amplification

AKE

FICATION

uarine and
med land

N

and gravel.

derations
> 0.50g
NA
1.00
1.00
1.00

See accompanying report for a full explanation of this table.

CE

stence of
xistence
mine

ek. The
the
ge,
ulting
lawkes Bay Region.

d Land Information.
ED.

0 000

3 4 5 6 kilometres

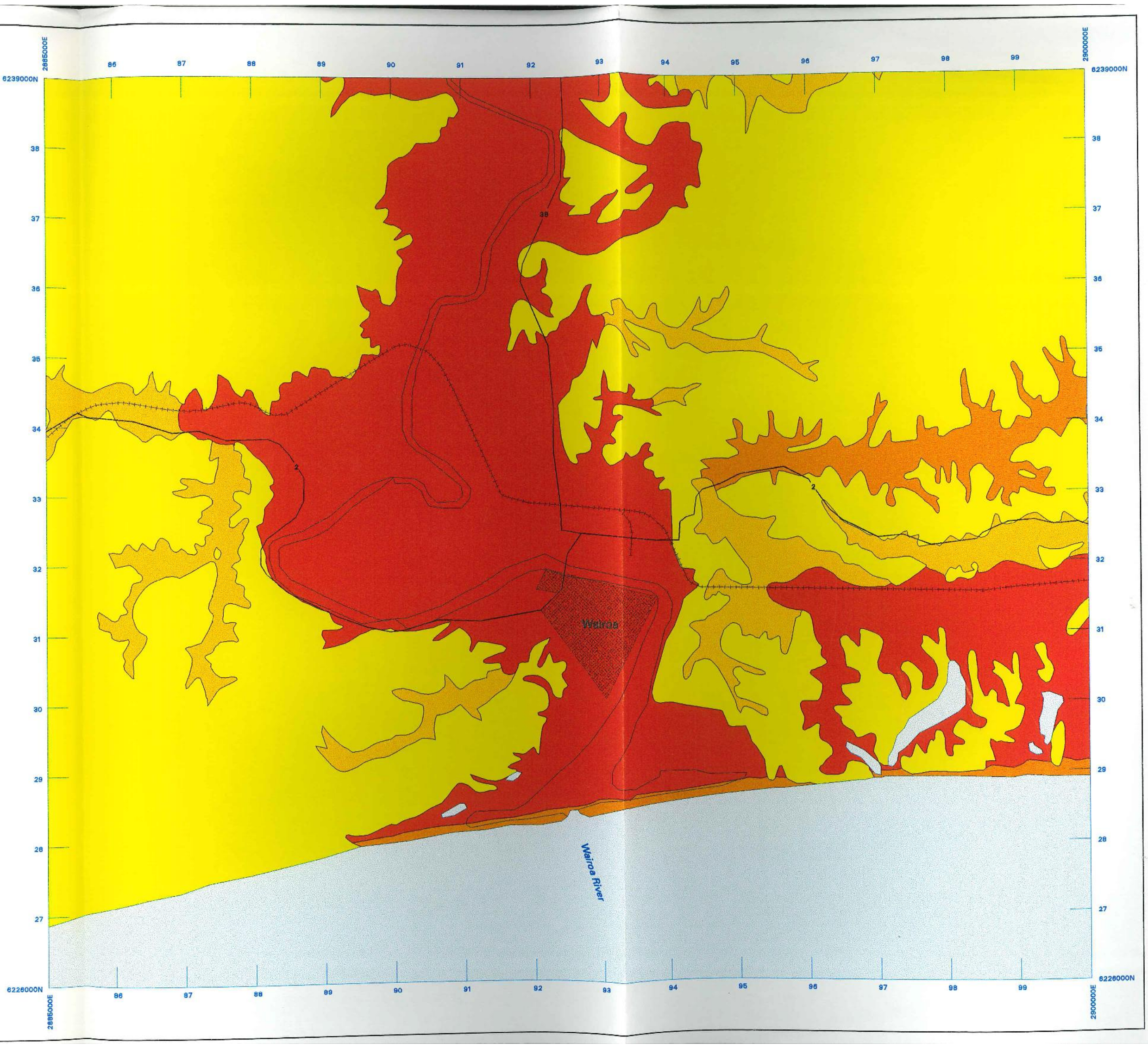
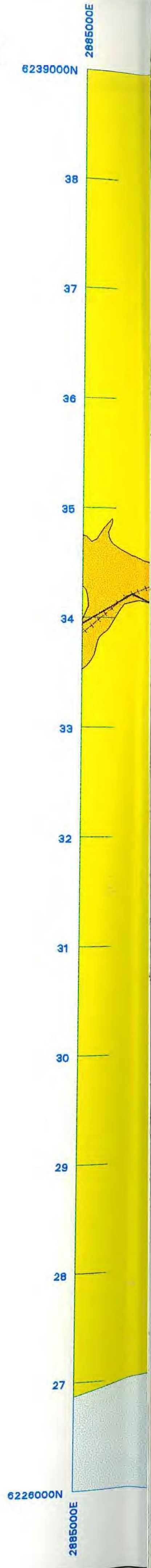


Figure 4: Earthquake Ground Shaking Amplification Hazard, Wairoa area

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III



LEGEND

RELATIVE EARTHQUAKE AMPLIFICATION

HIGH

- 4 — Unconsolidated swamp, estuarine and lagoonal deposits and reclaimed land
- 3 — Alluvial sand, silt, and gravel
- 2 — Compact alluvial sand, silt, and gravel.
- 1 — Bedrock/Regolith

LOW

Site class	Site Amplification Factor at various Peak Ground Accelerations (relative to Class 3 sites) 0.00g to 0.16g	0.16g	0.28g	0.36g	0.44g	> 0.50g
4	1.25	1.25	1.15	1.00	0.82	N/A
3	1.00	1.00	1.00	1.00	1.00	1.00
2	0.88	0.88	0.85	0.90	0.90	1.00
1	0.75	0.75	0.80	0.88	0.90	1.00

See accompanying report for a full explanation of this table.

TOPOGRAPHIC REFERENCE

- Urban area
- Road
- Railway
- River
- Water

The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.

Digital Terrain Information obtained from the Department of Survey and Land Information. Digital Licence Number TD098617/94. CROWN COPYRIGHT RESERVED.

Institute of GEOLOGICAL & NUCLEAR SCIENCES Limited

SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres

Site Response Class 3: Alluvial plain deposits (soft soil, soft clay with soil profile)

Site Class 3 comprises the soft interlayered fluvial sands and loose gravels (b, f3, f4, f5, and f6, Figure B-2 - in map pocket, volume 2) which make up the majority of deposits in the Heretaunga Plains, as well as many of the inland valleys, stream channels, and some coastal areas near Wairoa. These deposits have low shear wave velocities, generally between 120 and 170 m/s. Site Class 3 corresponds to NEHRP site Class E and Borcherdt Site Class SC-IVa.

These areas have previously been mapped (Hengesh *et al*, 1996) as having a high liquefaction hazard, which is likely to be an over-estimate. Amplification would be expected to occur until the onset of liquefaction. However, liquefaction is not likely to extend uniformly across this unit, and so it is appropriate to determine amplification factors for this class.

Site Response Class 4: Estuarine Deposits of Holocene Age

Site Class 4 comprises the late Holocene lagoonal, estuarine and swamp deposits of the former and present swamps, lagoons and intertidal areas along the coast. These are predominantly fine grained saturated deposits of sometimes organic silt and sand, with gravel layers (l1 and l2). These deposits have low shear wave velocities. This class corresponds to NEHRP Site Class F and the Borcherdt Site Class SC-IVb. As with Class 3, amplification would be limited by the onset of liquefaction.

Table 4.3: Summary of Site Classes

This study - Site response class	**NEHRP Class**		**Borchedt Class**	
	Class	**Shear wave m/s**	**Class**	**Shear wave m/s**
1	C	360-760	SC-II	375-700
2	D	180-360	SC-III	200-375
3	E	< 180	SC-IVa	100-200
4	F	< 180	SC-IVb	< 200

Site response (or ground amplification) **classes**, are here defined as map units which have similar geological characteristics, and hence by correlation, similar characteristics with respect to the resonance and amplification of earthquake ground motions. Figure 1 (map pocket, this volume) shows an amplification hazard map prepared for the Hawkes Bay region at a scale of 1:250,000. Figure 2 (map pocket, this volume) shows a similar amplification hazard map for the Heretaunga Plains at a scale of 1:50,000. Figures 3 and 4 (following pages) show the amplification hazard maps for the Wairoa and Waipukurau- Waipawa areas respectively at a scale of 1:50,000. These maps were derived from:

(1) Quaternary geological mapping to help define the distribution of surface and subsurface deposits (Appendix B, Volume 2);
(2) The historical earthquake record (Appendix C, Volume 2);
(3) Nakamura measurements to locate areas with potential resonant characteristics (Appendix D, Volume 2);

(4) Weak earthquake ground motions recorded at both soil and rock sites (Appendix E, Volume 2);
(5) Accelerograph site records (Appendix F, Volume 2); and
(6) CPT and Seismic CPT probes at selected sites to develop information on the subsurface materials and their shear wave velocity profiles (Appendix G, Volume 2);

4.3 Site Response (Amplification) Factors

In order to develop amplification **factors** for each site response (or ground amplification) **class** in the Hawkes Bay Region, data from a wide variety of sources was used. This data included geological mapping; geotechnical investigations; Nakamura analyses; weak motion ground shaking data and accelerograph site data.

Amplification data from the weak motion study carried out for this report is presented in Table 4.4, where the amplification factor is defined as the soil/rock Fourier spectral ratio. The data from the IGNS weak motion study shows that the amplification of ground shaking is dependant on both the strength of the material (Class 1 is the strongest and Class 4 the weakest) and the frequency of shaking. High frequency shaking (2-10 Hz) is transmitted more easily in stronger materials, while weaker materials are less able to transmit shaking of this frequency. Hence, high frequency shaking tends to be attenuated in weaker materials. Conversely low frequency shaking appears to be attenuated in stronger materials (for example rock) and amplified in weaker materials (for example soil).

Table 4.4: Soil/rock Fourier spectral ratios for site response classes 1, 2, 3, and 4, in various frequency bands. The amplification factors are calculated from weak motion data with the relevant rock reference site (Class 1) located at St Peter's Mission, Greenmeadows.

Reference Class	**1 Hz (1 sec)**	**1-2 Hz (0.5-1.0 sec)**	**2-4 Hz (0.25-0.5 sec)**	**2-10 Hz (0.1-0.5 sec)**
Class 1	1.00	1.00	1.00	1.00
Class 2	1.50	1.50	1.33	0.78
Class 3 (minus Flaxmere high resonance site)	2.50	1.94	1.34	0.93
Class 4	3.08	2.27	1.10	0.83

When the amplification factors derived from weak motion data for this study (Table 4.4) were compared with the amplification factors used by the Borcherdt and NEHRP models (Table 4.5) discrepancies were apparent. The Borcherdt and NEHRP models develop amplification factors based on short period spectra, but a comparison of the amplification factors used by these models with data obtained from the IGNS weak motion studies reveal that for short period spectra (high frequency shaking) the motion is attenuated in weak materials (for example soft soils). So for weak materials peak ground accelerations tend to be derived from longer period (low frequency) motions than is the case for stronger materials.

The discrepancy most probably arises because the Borcherdt factors rely heavily on strong-motion data derived from moderate to large earthquakes (such as the magnitude 7.1 Loma-Prieta earthquake of 1989). The IGNS weak-motion data in contrast is dependant largely on small, local earthquakes. When compared with the large earthquake data the IGNS weak-motion data is deficient in long-period content, and the amplitude at both short (< 0.2s) and long (> 1.0s) periods are relatively low, hence there is a relatively high level of uncertainty in the spectral ratios at short and long periods. For these reasons we prefer to use the short period amplification factors given by Borcherdt and NEHRP (Table 4.5) for the Hawke's Bay study, rather than those derived from weak motion studies.

Table 4.5: Short period amplification factors from the NEHRP and Borcherdt models with respect to classes B and SC-Ib.

PGA (g)	B	SC-Ib	C	SC-II	D	SC-III	E	SC-IVa
0.1	1.0	1.0	**1.2**	1.3	**1.6**	1.6	2.5	**2.0**
0.2	1.0	1.0	**1.2**	1.2	**1.4**	1.4	1.7	**1.6**
0.3	1.0	1.0	**1.0**	1.0	**1.1**	0.9	0.9	**0.9**
0.4	1.0	1.0	**1.0**	1.0	**1.1**	0.9	0.9	**0.9**
0.5	1.0	ns[1]	**1.0**	ns	**1.0**	ns	-[2]	**ns**

Notes:

1.0 Factors in bold are those that have been selected for mapping in this study.

1 ns = "not specified". Borcherdt does not give amplification factors for 0.5g rock motion.

2 Site-specific geotechnical investigations and dynamic site response analyses required for site class E at this level of motion.

The amplification factors used for the Hawkes Bay Region are listed in Table 4.5. These factors are those that are used by both the NEHRP and Borcherdt models. The amplification factors are based on the response for the reference class, which is defined for this study as Site Response Class 3. Class 3 was selected because it corresponds to the soil term used in the previous seismic hazard analysis completed for Hawkes Bay Regional Council (Hengesh et al., 1996). As shown in Table 4.6 below, and on Figures 1 to 4, the factor for Class 3 is 1.0. Therefore, no modification to the PGA values from the previous ground motion study would be required. The factors presented for Classes 1 and 2 reduce the PGA values with respect to Class 3, and the factors for Class 4 amplify the values up to approximately 0.44g with respect to Class 3.

It should be noted that for ground accelerations above 0.15 g, liquefaction may begin to occur in susceptible soils (i.e. Class 4 materials). With the onset of liquefaction, the ground shaking amplification effects will diminish due to the loss of shear strength of the materials. Class 4 will be particularly susceptible to liquefaction, and therefore, the amplification factors presented here should be viewed as high. If liquefaction does not occur in a particular area, then these values provide reasonable estimates of the amplification effects for short period, or alternatively, high frequency ground shaking.

Table 4.6: PGA Amplification Factors[1] (based on short period spectra[2])

PGA	Class 1 Bedrock	Class 2 Older Alluvium	Class 3 Younger Alluvium	Class 4 Young Lagoon/ Estuarine
0.00 - 0.16	0.75	0.88	1.00	1.25
0.16 - 0.28	0.75	0.88	1.00	1.25
0.28 - 0.36	0.80	0.85	1.00	1.15
0.36 - 0.44	0.88	0.90	1.00	1.00
0.44 - 0.50	0.90	0.90	1.00	0.82
> 0.50	1.00	1.00	1.00	-

Notes
1 Reference soil type for the PGA values is equivalent to Class 3 in this Table.
2 Amplification factors in this table correspond to short period spectral amplitudes between 0.1 and 0.5 second period. Long period amplification effects were noted for Class 3 between 0.5 and 1.5 second periods.

Amplification factors for Class 3 (younger alluvium) correspond to the factors for NEHRP classes D to E (stiff to soft soils). These are the standard soils to which the results of the PGA (and MM Intensity) attenuation models are taken to apply directly. The Borcherdt SC-III to SC-IVa classification (stiff clays and sandy soils) is equally appropriate. However, the NEHRP amplification factors agree better with recent data from strong shaking during the Northridge earthquake. In low amplitude motions (up to rock motions of 0.2g) the factors for SC-III and NEHRP D are identical.

For Class 4, Estuarine Deposits of Holocene Age, we have selected the Borcherdt SC- IVb factors. Recommendations for the NEHRP code subdivided class E into subcategories E1 and E2, depending on the thickness of soft to medium stiff clay in the profile, but simplified this to a single class in the final code. The site factors of the final code correspond to the E1 values, while the E2 values were the same as for SC-IVb. Our reason for adopting the NEHRP factors in preference to the Borcherdt values for other hazard zones is because of their more linear behaviour with increasing amplitude. The equivalence of the SC-IVa and NEHRP E2 values indicate that the SC-IVa values do not exhibit too much nonlinearity at large amplitudes. The Borcherdt values have been well verified in low levels of motion. Therefore, for Site Class 4, we have retained the Borcherdt SC-IVa values, rather than those of the final NEHRP code that produce stronger amplifications for rock motions less than 0.3g.

It would seem appropriate then to evaluate the New Zealand PGA expression for rock, and then apply the amplification factors selected from Table 4.5 for other site conditions. However, the factors of Table 4.6 are amplitude dependent, while the site factor in the New Zealand PGA relation is a constant for all amplitudes. The soil PGAs in the dataset used to develop the attenuation relation ranged from 0.0005g to 0.58g from New Zealand data, and up to 0.98g in the overseas data used. Most of the rock PGAs were for lower amplitude motions in the PGA attenuation model, with the maximum New Zealand value of 0.21g.

The New Zealand PGA site amplification factors are relevant for low- to moderate- amplitude motions, up to about 0.2g rock accelerations, for which it is consistent with the values from the Borcherdt and NEHRP studies. At higher amplitudes of motion, the New Zealand attenuation expression is likely to be more correct for soil rather than rock conditions, given that the soil data extend up to high amplitudes. For this reason it was decided to take the soil PGA expression as the reference, corresponding to site classes SC-IVa or NEHRP E. Other PGAs are evaluated from their ratio to the SC-IVa/E values.

This is achieved by constructing in Table 4.7 equivalent PGAs for the various site classes and hazard zones from the amplifications given in Table 4.6. Piece wise linear interpolationis then used toconvert PGAs from the attenuation expression for site classes SC-III/NEHRP D to equivalent values for other site conditions.

Table 4.7: Peak ground accelerations for different site classes at a variety of ground shaking strengths.

NEHRP Class	A	B	C	D	E	F
Borcherdt Class	Ia	Ib	II	III	IVa	IVb
Hawke's Bay Class	-	-	1	2	3	4
PGA values with respect to site classes and strength of shaking.	0.00	0.00	0.00	0.00	0.00	0.00
	-	0.10	0.12	0.16	0.20	-
	-	0.20	0.24	0.28	0.32	-
	-	0.30	0.33	0.36	0.36	-
	-	0.40	0.40	0.44	0.36	-
	-	0.50	0.50	0.50	ns[1]	-

Note
1. ns = not specified.

4.4 Comparison of PGA with MM Intensity

Up until about the 1960's, intensity information (felt observations) were used as the main method for assessing near field (strong motion) effects of earthquakes. Since the 1960's, strong motion records have increasingly been used as they provide more reliable and useful data for analyses. Accelerograph instruments are now widely deployed in some countries. There have been fewer recent studies on site response modifications for Modified Mercalli intensities than for instrumental measures of earthquake ground motions. The NEHRP study was performed for revision of United States loadings codes, where MM intensities are no longer used as a parameter.

Borcherdt (1991) gave some results for intensities at an early stage of his study. He gave a single expression for intensity modifications, with no amplitude dependence. The difference dI from standard intensities for a deposit with an average shear-wave velocity V30 was given by Borcherdt (1991) as:

$$dI = 0.27 + 2.70 \log AHSA$$

AHSA is the average spectral amplification over the period band 0.4–2.0s. Borcherdt expressed AHSA as a function of V30, measured in m/s:

$$AHSA = 701/ V30$$

This leads to the difference in intensities between two soil deposits with average shear-wave velocities V30 of vs1 and vs2 as:

$$dI\,(vs1) - dI\,(vs2) = 2.70 \log (vs2/vs1)$$

The appropriate V30 values for the hazard zones have been taken as those given by Borcherdt for his corresponding classes. The differences in amplifications with respect to Borcherdt class SC-III, assumed to be the reference class for the New Zealand MM Intensities attenuation model, are given in Table 4.7, rounded to the closest 0.05 unit.

Dowrick (pers comm) has developed an expression relating MM intensity to PGA for New Zealand data. This expression is given below:

$\log a = 0.347 I_{MM} - 0.384$, where "a" is acceleration in cm/s/s.

So for a given MM intensity the mean PGA from New Zealand data is (Table 4.8):

Table 4.8: Relationship between MM intensity and PGA.

MM Intensity	VI	VII	VIII	IX
Mean PGA (g)	0.05	0.11	0.25	0.54
PGA (g) range	0.030-0.100	0.065-0.220	0.15-0.52	0.3-1.1

When these mean PGA values are compared with the values in Table 4.7 it can be seen that the difference in ground shaking is about one unit of intensity at moderate levels of shaking. As the PGA increases to moderate to high levels and again to high levels the difference in the strength of ground shaking becomes negligible, until at levels around 0.4g there is effectively no discernable difference in the levels of shaking experienced due to poor quality foundation conditions. However it should be noted that at these levels of shaking the poor quality ground will have begun to fail in shear (and liquefaction may be occurring producing sand boils, fissures and in extreme cases lateral spreading).

The implications of this with respect to the Hawkes Bay are that strong distant earthquakes will have the greatest impact with regards to the hazard of ground shaking amplification. The level of shaking required to generate this level of site response is most likely to be sourced on faults at moderate to large distances from the "site" in question. We cannot be more specific, as the levels of shaking likely to be generated are both magnitude and distance dependant.

5.0 THE MOHAKA FAULT SCENARIO EARTHQUAKE

5.1 Background

The Mohaka Fault forms part of the North Island Shear Belt, a major fault system that extends along the length of the North Island, and is composed of a number of large active fault segments. This fault system includes major structures such as the Waiohau, Whakatane, Waimana, and Waikaremoana Faults in the Bay of Plenty region, the Mohaka and Ruahine Faults in the Hawkes Bay region, and the Wellington and Wairarapa Faults in the Wellington Region. The structures are predominantly right-lateral strike-slip faults with a normal (vertical extensional) component of motion. Single event displacements on these faults typically appear to range up to 4-5 metres.

Although a large earthquake has not occurred on the Mohaka Fault in historical times, geological evidence indicates a continued history of late Cenozoic and Quaternary deformation. Raub *et al* (1987) conclude that large earthquakes on the Mohaka Fault have a recurrence of *c.* 1000 years. The average right lateral slip rate of the Mohaka Fault is about 3mm/year. Radiocarbon dating of wood fragments from a trench across the fault in the Wakarara area indicates that the last surface rupture is less than 1200 years old (Raub *et al* (1987).

A magnitude 7.25 earthquake on this fault has been selected as a realistic scenario. As shown on Figures 5 to 8, this earthquake would generate the strongest ground motions in the western part of the region. Ground shaking is amplified in some places and not in others.

Some lines on the map (boundaries) are the product of the way our model has been designed and do not necessarily reflect actual conditions likely to be experienced on the ground. For example, on the recent river terraces around Wairoa the important thing to note is that the flats amplify ground shaking, while the Tertiary bedrock hills do not. The apparent change in amplification potential on the river flats is directly due to the attenuation equation used and distance from the source (i.e. the boundary within the river flats should be considered as a diffuse zone rather than a discrete boundary).

This `apparent' amplification can also be observed on other maps. That is changes within hazard zones are theoretical constructs derived from our model used and do not reflect real conditions. The discrete boundaries between adjacent hazard zones in the same geological material should be thought of as broad zones that may be some kilometres wide.

Figure 7: Earthquake Ground Shaking, Waipukurau - Waipawa area, Mohaka Scenario

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

PEAK GROUND ACCELERATION FROM MOHAKA SCENARIO EVENT

> 0.50
0.50
0.40
0.30
0.20
0.10

Areas with white crosses (right column) are areas where liquefaction is likely. Liquefaction may affect up to 30 percent of the depicted area. Peak Ground Accelerations in these areas will therefore be lower than depicted here for those areas where liquefaction occurs.

TOPOGRAPHIC REFERENCE

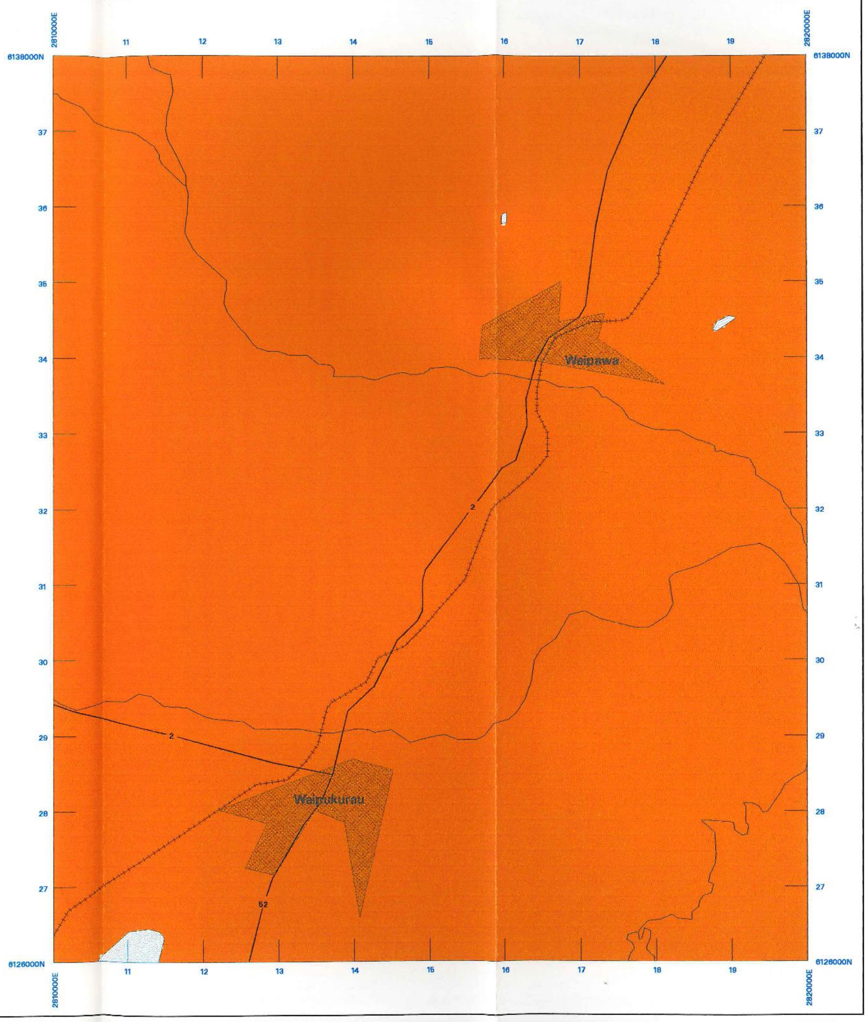
- Urban area
- Road
- Railway
- River
- Water

The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.

Institute of Geological & Nuclear Sciences Limited

SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres



und Shaking,
enario

KE

with white crosses (right column) are areas where
action is likely. Liquefaction may affect up
percent of the depicted area. Peak Ground
erations in these areas will therefore be lower
epicted here for those areas where liquefaction
s.

00

3 4 5 6 kilometres

the existence of
de the existence
o determine
al. The
s own risk. The
viding the
s, damage,
wise resulting
in the Hawkes Bay Region.

Institute of GEOLOGICAL & NUCLEAR SCIENCES Limited

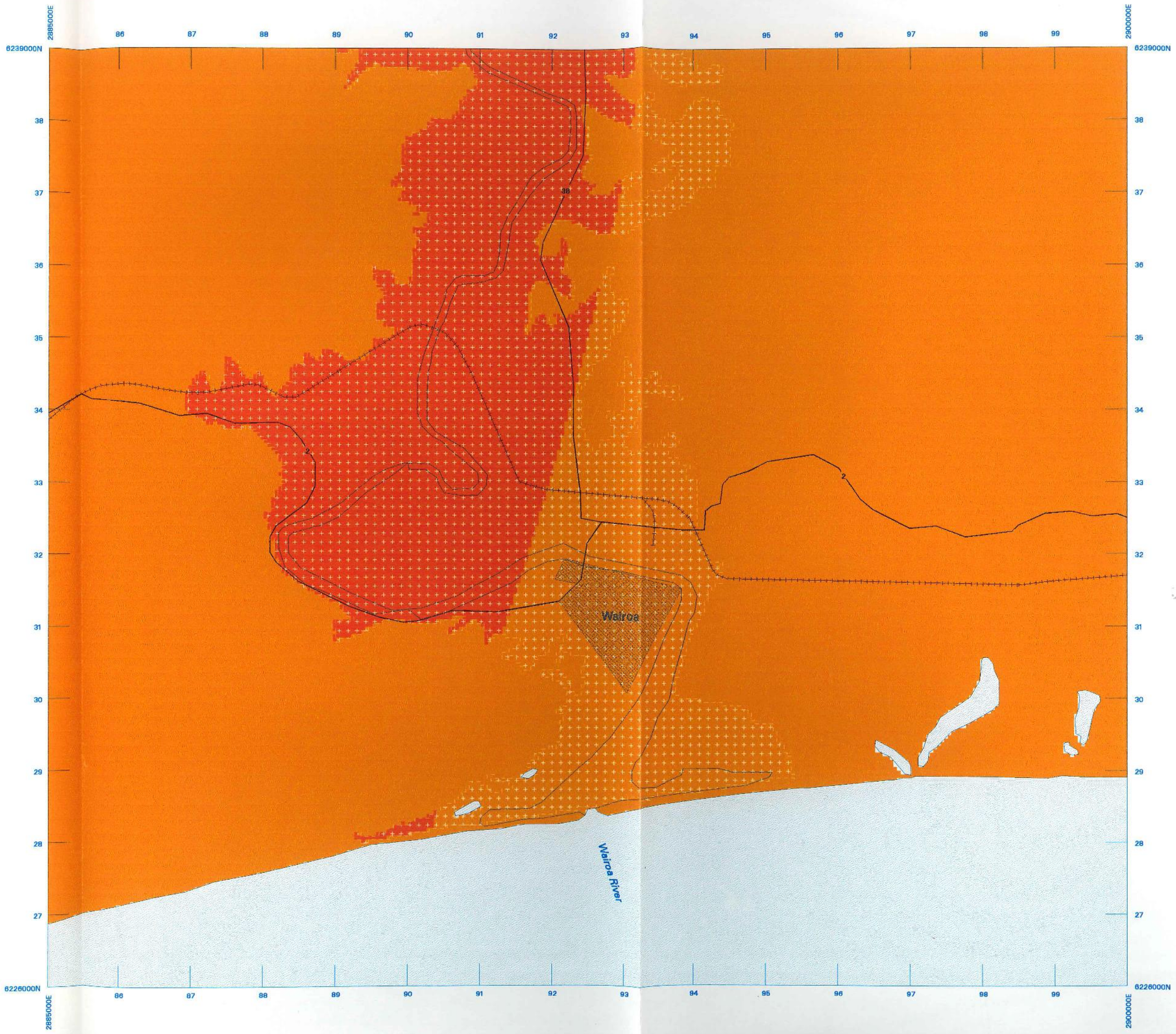


Figure 8: Earthquake Ground Shaking, Wairoa area, Mohaka Scenario

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

PEAK GROUND ACCELERATION FROM MOHAKA SCENARIO EVENT

> 0.50

0.50

0.40

0.30

0.20

0.10

Areas with white crosses (right column) are areas where liquefaction is likely. Liquefaction may affect up to 30 percent of the depicted area. Peak Ground Accelerations in these areas will therefore be lower than depicted here for those areas where liquefaction occurs.

TOPOGRAPHIC REFERENCE

Urban area

Road

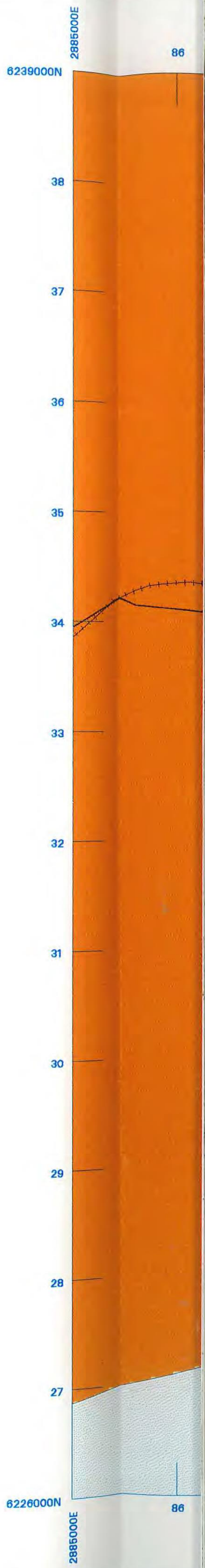
Railway

River

Water

SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres



The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.

Institute of GEOLOGICAL & NUCLEAR SCIENCES Limited

5.2 Predicted Shaking for Scenario Earthquake

The scenario earthquake maps have been developed in GIS (Geographic Information Systems) using the following procedures. The classification of soil type was derived from underlying geology captured from regional geological maps produced at varying scales. For the Hawke's Bay region, the data capture scale was 1:50,000. Geological boundaries from the geological maps were captured with an average interval of about 30 m between vertices, and we estimate that 80% of well known points are within ±50 m of their actual position. Once the geological units were classified, adjacent polygons of the same soil class were amalgamated. The soil class data was converted from vector to raster (grid) format to enable it to be used in grid modelling of ground shaking intensity.

Attenuation of earthquake shaking (PGA) was determined for a source on the Mohaka Fault (M 7.25) to the northwest of the Hastings-Napier area. Attenuation was modelled for the entire region based on the formulae described previously (Zhao *et al*, 1997). The resulting PGA values were stored in raster format.

Predicted shaking (as defined by PGA) was modelled using grid, a cell-based technique. The input grids of soil class and attentuated PGA were overlayed and compared on a cell by cell basis. Using the appropriate amplification factor (Table 4.6), a shaking value for each cell was determined based on the input PGA and the soil class. The resulting ground motions, shown on Figures 5-8 reflect the amplification effects of soils in the region. These maps are based on the same earthquake scenario used in the Stage II Liquefaction study, and the basis for that event is described in the Stage II report.

The resulting ground motions highlight the high amplification effects of soft young soils in Class 4. These include the Ahuriri Lagoon and the reclaimed swamp land around Napier. Other resonant areas would include the estuaries and lagoons around the coast.

It should be noted that for ground accelerations above 0.15g, liquefaction may begin to occur in susceptible soils. With the onset of liquefaction, the ground shaking amplification effects will diminish due to the loss of shear strength of the materials. Class 4 will be particularly susceptible to liquefaction, and therefore, the amplification factors presented should be viewed as conservative. If liquefaction does not occur in a particular area, then the values given provide reasonable estimates of the amplification effects for short period, or alternatively, high frequency ground shaking.

Classes 3 and 4 appear to have somewhat distinct resonance patterns. Class 3 begins amplification about 0.25 seconds period and begins reducing at about 1.0 seconds period, while Class 4 begins at 0.3 seconds period and increases through 1.5 seconds period. This indicates that longer period (larger structures) would be affected more when located on Class 4 than on Class 3.

Additionally, at lower spectral periods, Classes 2 and 3 may show similar response. However, our hazard maps do not depict this effect.

The site response classes and response factors described in this report are based on data which have been extrapolated across large areas. Variances within our data were observed which indicate that locally, some areas may differ (be higher or lower) from the mean values described in this report. An example of such variance from the mean is seen in the weak motion soil/rock ratio for Flaxmere. At this location the amplification factor is up to a factor of 4.5 greater than the rock record. These types of localised effects cannot be fully assessed during a regional investigation of this nature and emphasise the requirement for specific investigations prior to the development of important sites.

6.0 THE IMPLICATIONS OF AMPLIFIED GROUND SHAKING IN THE HAWKE'S BAY REGION

The ground amplification response to earthquakes in Hawke's Bay will depend on the predominant type of ground material and the strength of the earthquake shaking. The ground response can be summarised by considering two strength categories of earthquake shaking, a "weak" and a "strong" earthquake acting on the four classes of ground.

Firstly a "weak" earthquake is defined as either a small magnitude local earthquake, or a large magnitude distant earthquake, each of which would cause lower levels of shaking up to MM Intensity 7 (see Appendix 1 for MM Intensity descriptions). The small local earthquake might have a duration of felt shaking that is typically less than ten seconds, while a large distant earthquake might have a duration of up to 30 seconds or more. MM Intensity 7 is the level of shaking at which property and ground damage start to become significant.

By contrast a "strong" earthquake is defined as one that generates shaking of MM Intensity 7 or more, typically with a duration of shaking of more than 10 seconds, and causes significant property and ground damage, with damage levels increasing with increased shaking intensity (as measured by the MM Intensity Scale). The ground damage would include liquefaction related effects such as sand boils, lateral flows and spreads, and differential settlements, as well as landslides of various types.

TABLE 6.1: A "weak" earthquake

Weak earthquake parameters are:-
MM Intensity <7; PGA <0.15g; building and ground damage slight or not significant.

Ground Class	Amplification
1 - bedrock	none
2 - stiff soils/compact alluvium	weak attenuation of high frequency shaking and low amplification of longer period shaking
3 - recent alluvium	moderate attenuation of high frequency shaking and moderate amplification of longer period shaking
4 - recent swamp, lagoon, and estuarine deposits	strong attenuation of high frequency shaking and strong amplification of longer period shaking

TABLE 6.2: A "strong" earthquake

The strong earthquake parameters are:-
MM Intensity > 7 and up to 10; PGA > 0.15g and up to 1.0g; significant to major/severe (building and ground) damage.

Ground Class	Amplification
1	none - slight attenuation of high frequency shaking and slight amplification of longer period shaking compared to a hard rock site. Rockfalls and (regolith) landslides on steep slopes.
2	moderate to strong attenuation of high frequency shaking, and moderate to strong amplification of longer period shaking.
3	strong attenuation of high frequency shaking and strong amplification of longer period shaking. At higher intensities (> MM 8) soils are likely to be failing in shear, possibly leading to some deformation of the ground surface, and there may be some (few) occurrences of liquefaction.
4	very strong attenuation of high frequency shaking and strong amplification of longer period shaking. Soil failing in shear and widespread liquefaction likely, with subsequent large surface failures or displacements leading to severe damage to buried services.

A weak earthquake will be more strongly felt on weaker, more responsive ground, but significant damage is not expected.

Weak soils will tend to attenuate strong earthquake shaking, but ground damage could be severe, particularly when liquefaction occurs, leading to severe damage to buried services. Such damage might take weeks to months to repair.

Low-rise buildings typically have a short natural period and are thus most affected by high frequency ground shaking. Thus a well founded and constructed building of this type located on the Heretaunga Plains faces a lower risk than a tall structure with a long natural period.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary and Conclusions

Ground shaking amplification hazard maps (Figures 1-4) have been prepared for the Hawkes Bay region at a scale of 1:250,00 and for the Heretaunga Plains, Wairoa and Waipawa/Waipukurau at a scale of 1:50,000. These maps depict the distribution of soil and rock types which are expected to behave in a similar fashion with respect to ground shaking, during moderate to large earthquakes.

Amplification factors have been developed for rock and soil classes which group materials that are expected to have a similar response to ground shaking. When the amplification factors are applied to peak ground accelerations (PGA) derived from the recent New Zealand specific attenuation relationship for soil sites (Zhao *et al,* 1997), they yield ground responses which mirror the expected local soil conditions.

A suite of maps (Figures 5-8) depicting the seismic hazard expected for a specific event has been produced by applying the amplification factors to predicted ground motions from a scenario earthquake on the Mohaka Fault.

In general, the soils in the Heretaunga Plains are considered to represent average soil conditions with respect to the soil PGA attenuation equation. Some, relatively small areas of soils in the vicinity of the Ahuriri lagoon and other local lagoonal and estuarine deposits along the coast, are weaker than the alluvium on the Heretaunga Plains.

- At low levels of shaking both the soils of the Heretaunga Plains and the soils of the former Ahuriri lagoon and other lagoonal, estuarine and swamp deposits will amplify ground shaking with respect to rock sites. The weaker (Class 4) soils will show greater amplifications.

- At levels of strong shaking the soils of the former Ahuriri lagoon and other local lagoonal, estuarine and swamp deposits will begin to liquefy, thus loosing shear strength, which limits their ability to amplify ground shaking.

- The soils of the Heretaunga Plains (Class 3) are unlikely to experience widespread liquefaction. This statement is made because ground damage accounts from the 1931 Napier earthquake report minor liquefaction-induced ground damage from sites that lie to the northeast, east and south-east of Hastings.

A localised area (in Flaxmere) has been observed to show a site response that doubles the amplification factor of the mean values used to develop the hazard maps (Figures 1-4). It should be noted that this type of local site response can occur, and special studies may be required for sensitive facilities, or facilities that would be critical in the event of an earthquake.

The implications of this with respect the Hawkes Bay are that strong distant earthquakes will have the greatest impact with regards to the hazard of ground shaking amplification. The level of shaking required to generate this level of site response is most likely to be sourced on faults at moderate to large distances from the "site" in question. We cannot be more specific, as the levels of shaking likely to be generated are both magnitude and distance dependant.

7.2 Recommendations

The results of this study will be valuable for input into a regional lifelines project. The maps give a regional depiction of the type of ground motions to be expected during a major event in the region.

Application of the Nakamura technique at widely spaced locations in the Hawke's Bay has identified a number of strongly resonant sites. The definition of the areas that are strongly resonant can be further refined by designing site specific studies using the Nakamura method.

Further work that could be undertaken with respect to seismic hazard characterisation in the Hawke's Bay region could include the development of a landslide inventory map (as a component of a hazard register), and a dynamic landslide hazard model which depicts the potential for seismically induced landslides.

8.0 REFERENCES

Barker, P.R., 1994: A report on cone penetrometer and seismic cone penetrometer testing at selected sites in the lower North Island. *Engineering Seismology Section, Institute of Geological and Nuclear Sciences, Gracefield.*

Barker, P.R., 1997: A report on cone penetrometer and seismic cone penetrometer testing in the Napier and Hastings areas. *Engineering Seismology Section, Institute of Geological and Nuclear Sciences, Gracefield.*

Benites, R.A., and Haines, A.J., 1996: Weak motion experiment and modelling in the Bluff-hill area of Napier, New Zealand. *Bulletin of the Seismological Society of America. Vol 86: 333-345.*

Borcherdt, R.D., 1991: On the observation, characterisation, and predictive GIS mapping of strong ground shaking for seismic zonation. *Proceedings of the Pacific Conference on Earthquake Engineering, Auckland, New Zealand, 20-23 November, Vol. 1, pp 1-24.*

Borcherdt, R.D., 1994: Estimates of site-dependant response for design (methodology and justification); *Earthquake Spectra, Vol 10: pp 617-653*

Borcherdt, R.D., Glassmoyer, G.M., Der, K.A., and Cranswick, E., 1989: Effect of site conditions on ground motions in Leninakan, Armenia SSR. *In* Results and data from seismologic and geologic studies following earthquakes of December 7, 1988, near Spitak, Armenia SSR. *United States Geological Survey Open-file report; pp 86-108.*

Cousins, W.J., and McVerry, G.H., 1997: Peak accelerations, velocities and displacements for New Zealand earthquake accelerogram. *Institute of Geological and Nuclear Sciences, Science Report 97/10. 62 pp.*

Dowrick, D.J., 1996: The Modified Mercalli Intensity scale - revisions arising from recent studies of New Zealand earthquakes. *Bulletin of the New Zealand National Society for Earthquake Engineering, Vol 29(2): 92-106 pp.*

Everden, J.F., and Thomson, J.M., 1988: Predictive model for important ground motion parameters associated with large and great earthquakes. *United States Geological Survey Bulletin 1838.*

Hengesh, J.V., Heron, D., Brown, L., and Hull, A.G., 1996: Stage II - Earthquake Hazard Analysis: Part II - Evaluation of liquefaction potential in the Hawke's Bay region. *Institute of Geological and Nuclear Sciences Contract Client Report 33591D.*

Holzer, T.L., 1994: Loma Prieta damage largely attributed to enhanced ground shaking. *Eos Vol. 75(26): 299-301 pp.*

McVerry, G.H., and Sritharan, S., 1991: Earthquake site response effects demonstrated by New Zealand strong-motion records. *Proceedings 3rd Pacific Conference on Earthquake Engineering, Auckland, New Zealand. Volume 3: 205-216.*

Melhuish, A., and Bannister, S., 1995: Shallow P-wave and S-wave reflection and refraction data from Bluff Hill and surrounding flats, Napier. *Institute of Geological and Nuclear Sciences Science Report 95/19, 11p.*

Murphy, J.R., and O'Brien, L.J., 1977: The correlation of peak ground acceleration amplitude with seismic intensity and other parameters. *Bulletin of the Seismological Society of America 67: 877-915 pp.*

Nakamura, Y., 1989: A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Quarterly Report of Railways Technical Research Institute*; 30(1) February 1989.

National Earthquake Hazards Reduction Program (NEHRP), 1994: Recommended provisions for seismic regulations of new buildings: Part 1, Provisions. *Issued by Federal Emergency Management Agency, FEMA 222A, 290 pp.*

O'Rourke, T.D., Growdy, T.E., Stewart, H.E., Pease, J.W., 1991: Lifeline and geotechnical aspects of the Loma Prieta earthquake. *In* Proceedings, Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, St Louis: Paper LP04.

Raub, M.L., Cutten, H.N., and Hull, A.G., 1987: Seismotectonic hazard analysis of the Mohaka Fault, North Island, New Zealand. *Proceedings of Pacific Conference on Earthquake Engineering, Wairakei, New Zealand. Vol. 3. NZ National Society for Earthquake Engineering. Pp 219-230.*

Rynn, J.M.W., 1991: Potential for earthquake mitigation in Australia: the needs as stimulated by the 1981 Newcastle earthquake. *In* Proceedings, Pacific Conference on Earthquake Engineering, Auckland, N.Z. Vol 2: 327-338.

Seed, H.B., Romo, M.P., Sun, J.I., Jaime, A., Lysmer, J., 1988: Relationship between soil conditions and earthquake ground motions. *Earthquake Spectra 4: 687-730 pp.*

Taber, J.J., and Rollo, J.L., 1994: Manawatu-Wanganui region earthquake hazard analysis: Stage 4C - Measurement of earthquake ground shaking in Palmerston North and Wanganui. *Institute of Geological and Nuclear Sciences Client Report 333902/4C.*

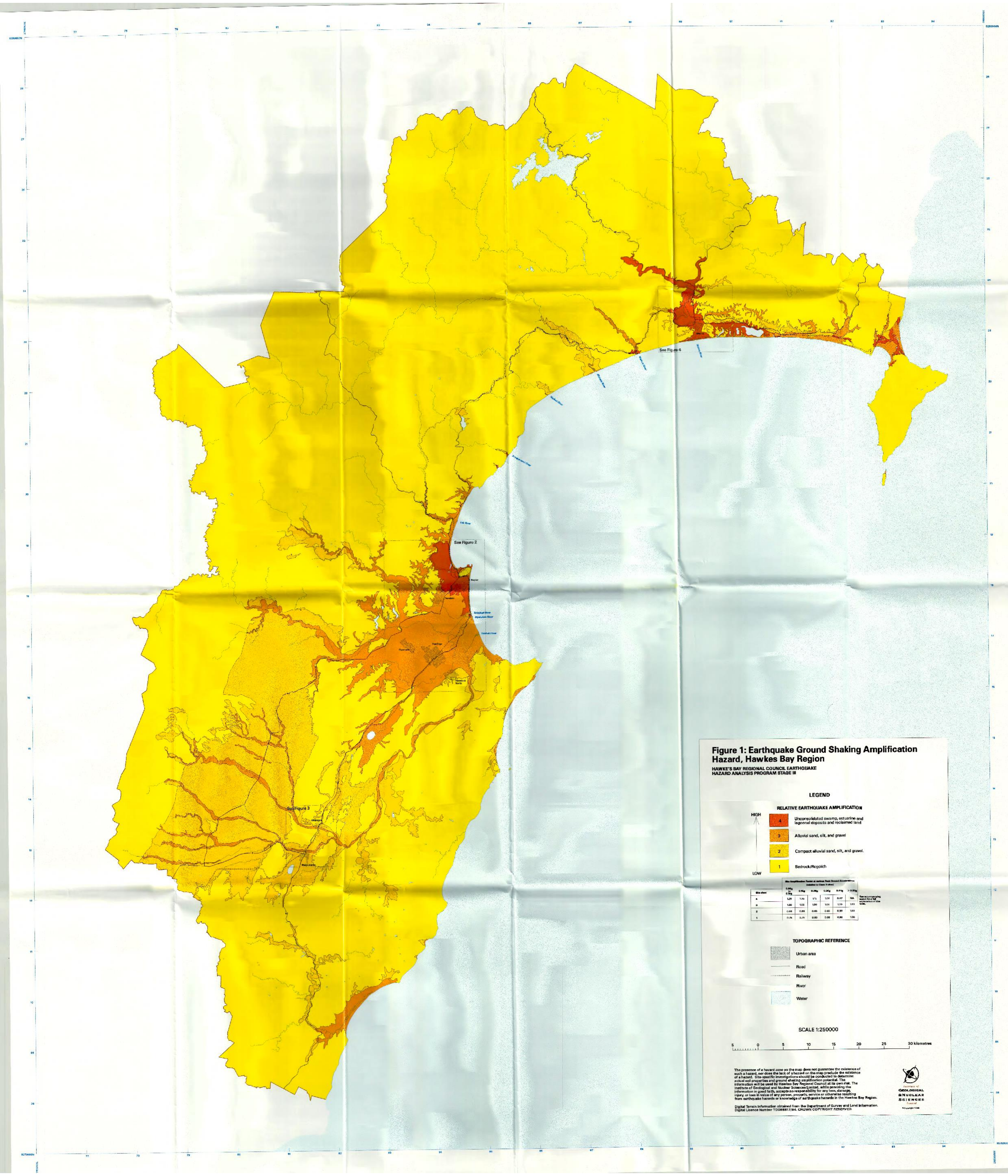
Taber, J.J., and Smith, E.G.C., 1992: Frequency dependant amplification of weak ground motions in Porirua and Lower Hutt, New Zealand. *Bulletin of the New Zealand National Society for Earthquake Engineering, Vol 25(4): 303-331 pp.*

Van Dissen, R.J., Taber, J.J., Stephenson, W.R., Sritharan, S., Read, S.A.L., McVerry, G.H., Dellow, G.D., and Barker, P.R., 1992: Earthquake ground shaking hazard assessment for the Lower Hutt and Porirua areas, New Zealand. *Bulletin of the New Zealand National Society for Earthquake Engineering, Vol 25(4): 286-302 pp.*

Van Dissen, R.J., Taber, J.J., Stephenson, W.R., Sritharan, S., Perrin, N.D., McVerry, G.H., Campbell, H.J., and Barker, P.R., 1993: Ground shaking hazard zonation for Wellington city and suburbs, New Zealand. *New Zealand National Society for Earthquake Engineering Technical Conference 26-28 March, Taupo.*

Wood, H.O., 1908: Distribution of apparent intensity of San Francisco in the California earthquake of April 18, 1906. *Report of the State Earthquake Investigation Commission, Washington D.C., Carnegie Institute Publication 87: 220-245 pp.*

Zhao, J.X., Dowrick, D.J., and McVerry, G.H., 1997: Attenuation of peak ground accelerations in New Zealand earthquakes. *Bulletin of the New Zealand National Society for Earthquake Engineering,* Vol 30(2):133-158.


See Figure 4
See Figure 2
See Figure 3
Figure 1: Earthquake Ground Shaking Amplification Hazard, Hawkes Bay Region
HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III
LEGEND
RELATIVE EARTHQUAKE AMPLIFICATION
HIGH
LOW
4 Unconsolidated swamp, estuarine and lagoonal deposits and reclaimed land
3 Alluvial sand, silt, and gravel
2 Compact alluvial sand, silt, and gravel.
1 Bedrock/Regolith
TOPOGRAPHIC REFERENCE
Urban area
Road
Railway
River
Water
SCALE 1:250000
5 0 5 10 15 20 25 30 kilometres
The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.
Digital Terrain Information obtained from the Department of Survey and Land Information. Digital Licence Number TD098817/94. CROWN COPYRIGHT RESERVED.
GEOLOGICAL & NUCLEAR SCIENCES

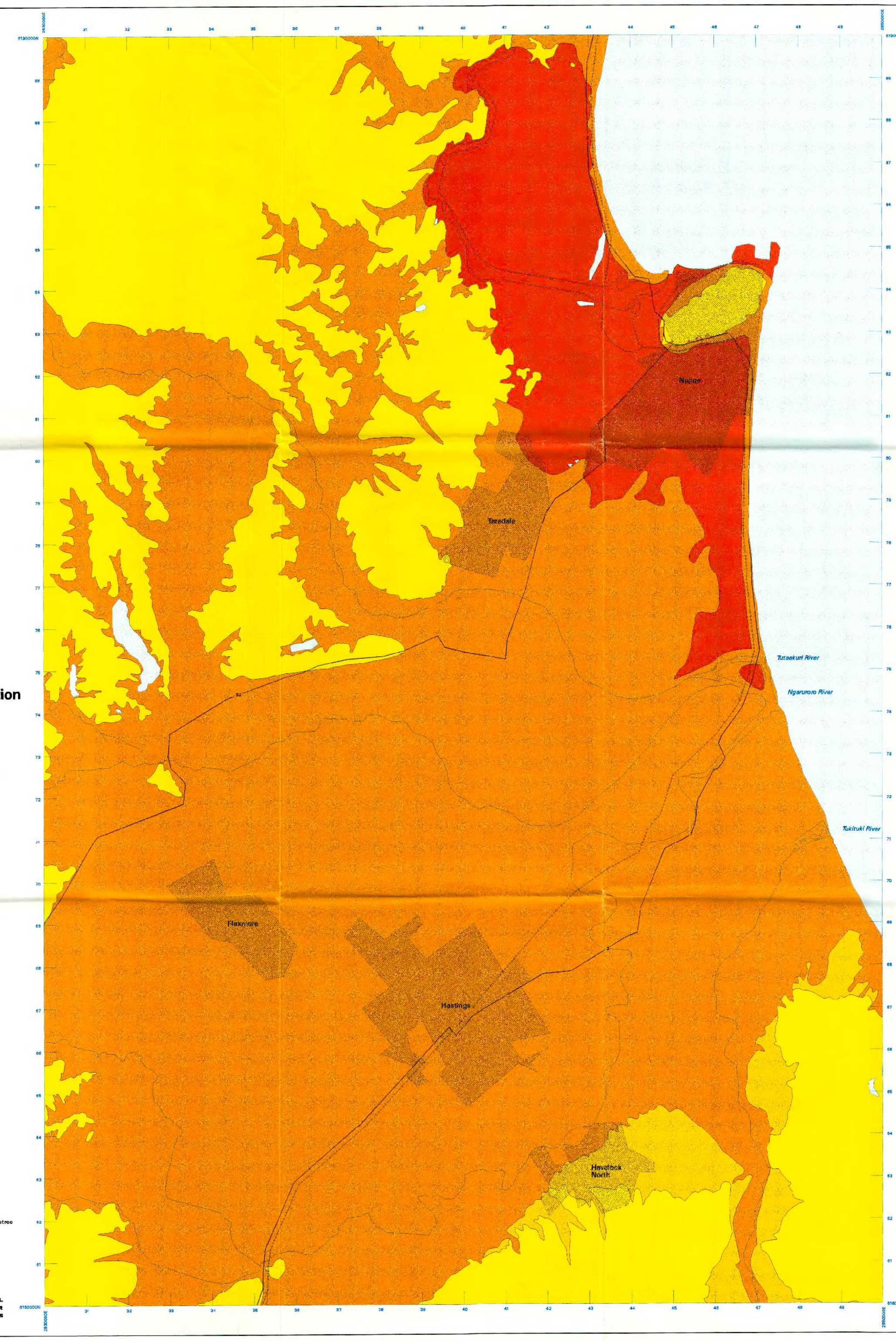


Figure 2: Earthquake Ground Shaking Amplification Hazard, Heretaunga Plains

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

LEGEND

RELATIVE EARTHQUAKE AMPLIFICATION

HIGH

- 4 — Unconsolidated swamp, estuarine and lagoonal deposits and reclaimed land
- 3 — Alluvial sand, silt, and gravel
- 2 — Compact alluvial sand, silt, and gravel.
- 1 — Bedrock/Regolith

LOW

Site class	Site Amplification Factor at various Peak Ground Accelerations (relative to Class 3 sites)					
	0.00g to 0.16g	0.16g	0.28g	0.36g	0.44g	> 0.50g
4	1.25	1.25	1.15	1.00	0.92	N/A
3	1.00	1.00	1.00	1.00	1.00	1.00
2	0.88	0.88	0.85	0.90	0.90	1.00
1	0.75	0.75	0.80	0.86	0.90	1.00

See accompanying report for a full explanation of this table.

TOPOGRAPHIC REFERENCE

- Urban area
- Road
- Railway
- River
- Water

SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres

The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existance of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.

Institute of GEOLOGICAL & NUCLEAR SCIENCES Limited

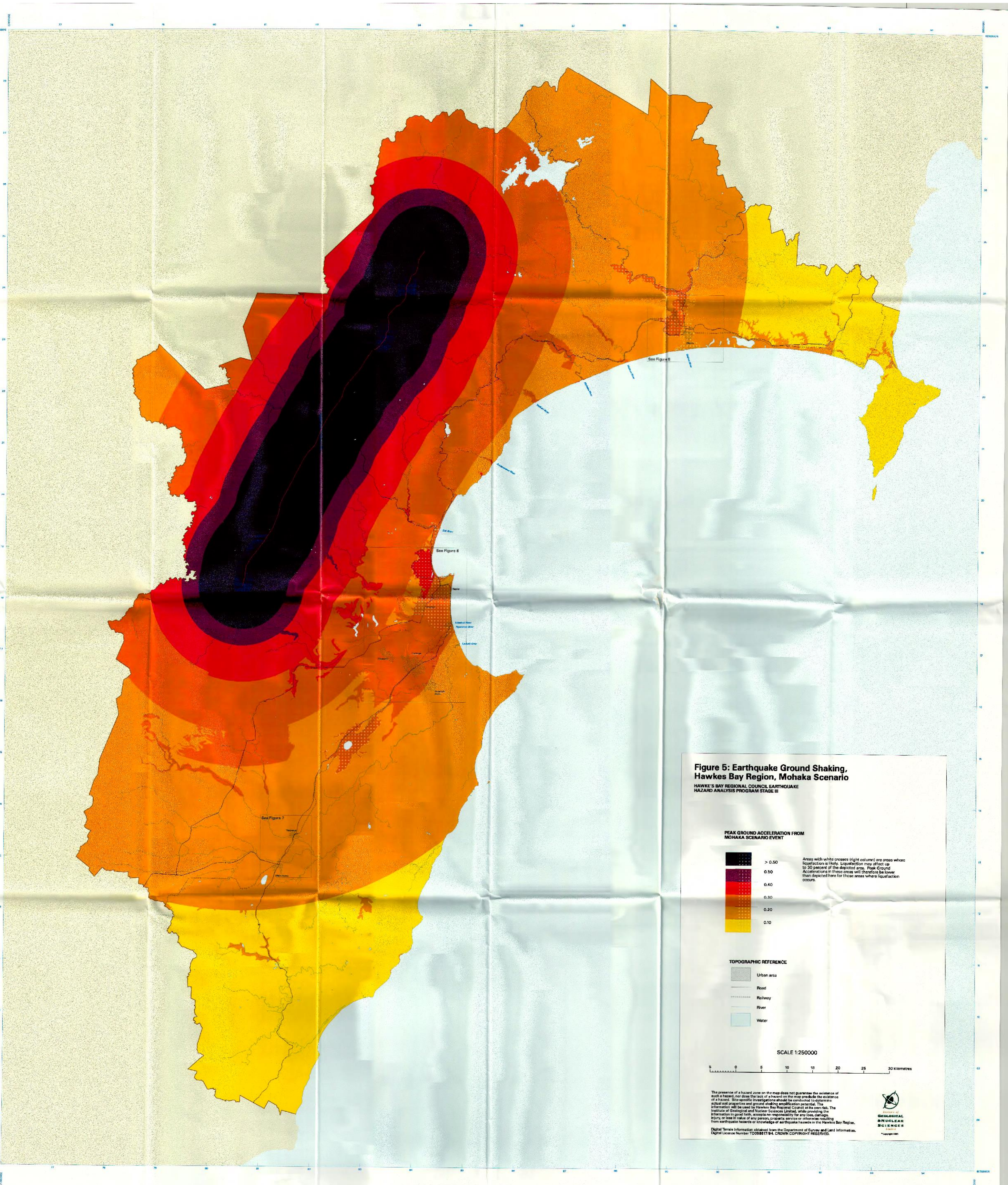


Figure 5: Earthquake Ground Shaking, Hawkes Bay Region, Mohaka Scenario
HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III
PEAK GROUND ACCELERATION FROM MOHAKA SCENARIO EVENT
> 0.50
0.50
0.40
0.30
0.20
0.10
Areas with white crosses (right column) are areas where liquefaction is likely. Liquefaction may affect up to 30 percent of the depicted area. Peak Ground Accelerations in these areas will therefore be lower than depicted here for those areas where liquefaction occurs.
TOPOGRAPHIC REFERENCE
Urban area
Road
Railway
River
Water
SCALE 1:250000
5
0
5
10
15
20
25
30 kilometres
The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.
Digital Terrain Information obtained from the Department of Survey and Land Information. Digital Licence Number TD098617/94. CROWN COPYRIGHT RESERVED.
GEOLOGICAL &NUCLEAR SCIENCES
See Figure 6
See Figure 7

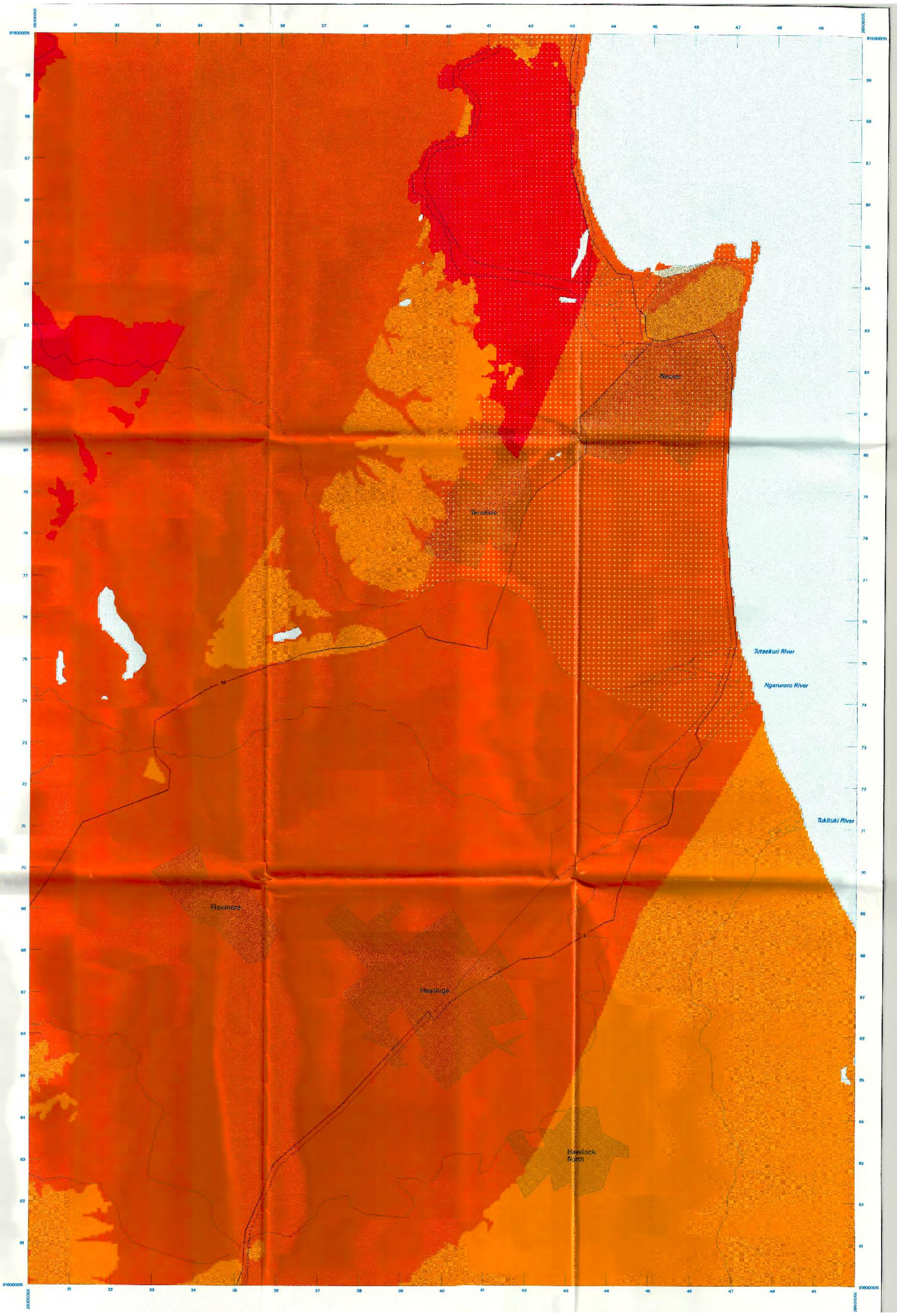


Figure 6: Earthquake Ground Shaking, Heretaunga Plains, Mohaka Scenario

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

PEAK GROUND ACCELERATION FROM MOHAKA SCENARIO EVENT

> 0.50
0.50
0.40
0.30
0.20
0.10

Areas with white crosses (right column) are areas where liquefaction is likely. Liquefaction may affect up to 30 percent of the depicted area. Peak Ground Accelerations in these areas will therefore be lower than depicted here for those areas where liquefaction occurs.

TOPOGRAPHIC REFERENCE

Urban area
Road
Railway
River
Water

SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres

The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.

Institute of Geological & Nuclear Sciences Limited