WELLINGTON REGIONAL COUNCIL

EARTHQUAKE RISK ASSESSMENT STUDY

STUDY AREA 1 - WELLINGTON CITY

WRC/PP-T-95/22

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Project C5327

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May 1995

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1 INTRODUCTION

The Wellington Regional Council is developing a strategy aimed at achieving an acceptable level of risk from earthquake and geological hazards in the Wellington Region. As part of the strategy, the Regional Council has undertaken a series of earthquake hazard assessment studies. Detailed technical studies have been completed for:

- active faulting
- ground shaking
- liquefaction and associated ground damage
- slope failure

As part of its hazard mitigation and emergency management functions, the Regional Council needs to know the likely impact of a major earthquake on the buildings and the population in the Region. The Regional Council has therefore commissioned Works Consultancy Services to undertake an earthquake risk assessment study of the Wellington Region. The aim of the study is to identify and quantify the geographic variation of risk to buildings and structures, critical facilities and the population from earthquake hazards for the main urban parts of the Wellington Region. The study is based on a moderate and a severe earthquake scenario.

For the purpose of this study, the region has been divided into the following five study areas, the locations of which are shown on Figure 1 :

Study Area 1	Wellington City
Study Area 2	Hutt Valley
Study Area 3	Porirua Basin
Study Area 4	Kapiti Coast
Study Area 5	Wairarapa

Part 1 of the study was a brief review of the available literature on specific earthquake risk assessments carried out in the Wellington Region, and methodologies/approaches developed in New Zealand and internationally for assessing earthquake risk (Davey, 1994). This review indicated that previous risk assessments for Wellington have either been confined to limited areas (eg Darwin, 1980; Shephard, 1993) or have not included risk to population (eg Birss, 1985; Dowrick, 1990a,b,c, 1991b,c). With the exception of Shephard's 1993 study for Porirua City, previous risk assessments have not had the benefit of the comprehensive earthquake hazard data now available as a result of the Regional Council's hazard studies completed in 1993.

The review of methodologies carried out in Part 1 confirmed that the methodologies, risk models and data proposed for this study are consistent with current international practice.

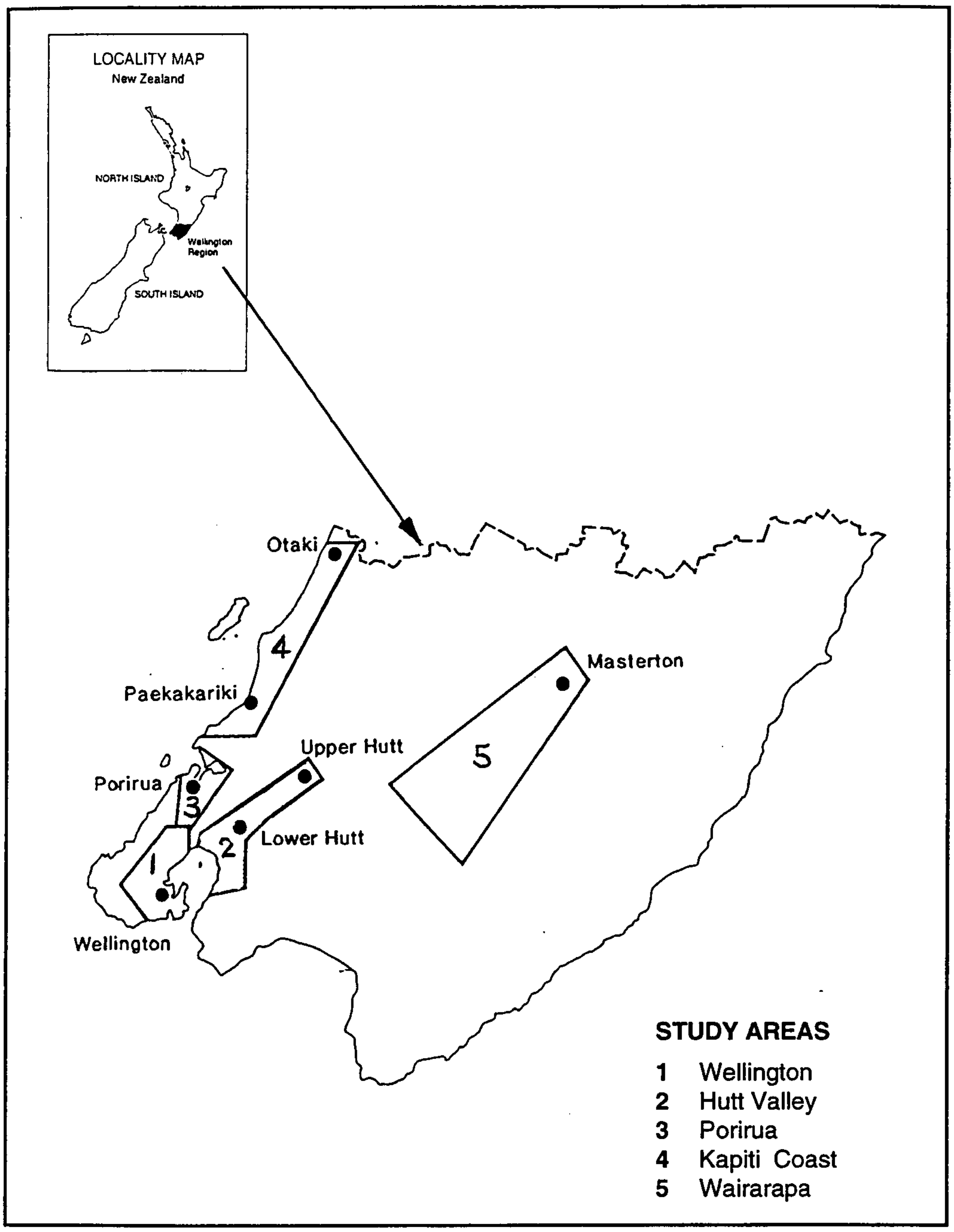

Figure 1.1: Wellington Regional Council Earthquake Risk Assessment Study Areas

This report presents the assessed earthquake risk to buildings, critical facilities and population in Study Area 1, Wellington City. The geographic, building vulnerability and casualty models used in the assessments are described, and the seismic hazard, building inventory and population data are summarised. The risk analysis methodology is described and results are presented as tables and maps of assessed building damage vulnerability, building damage states, building repair costs, numbers of injuries and numbers of fatalities.

2 TERMINOLOGY

The following definitions have been adopted for this study.

- *Damage Model:* A mathematical relationship between the earthquake hazard (ground shaking, ground deformation) and the amount of damage (damage cost, repair rate).

- *Damage Ratio:* Total cost of repairs divided by the replacement cost.

- *Earthquake Intensity (MM):* Earthquake shaking intensity at a particular site. Measured by the Modified Mercalli (MM) scale.

- *Earthquake Magnitude (M):* Often referred to as Richter or local magnitude (M_L). A measure of the total energy released in the earthquake.

- *Loss:* For this study, earthquake loss or damage loss, is the economic loss resulting from the cost of repairing earthquake damaged buildings.

- *Probable Maximum Loss:* Is the maximum loss assessed for a return period or annual probability of exceedance. For most general purposes the return period is taken in the range of 200 to 500 years or 5% to 2% annual probability of exceedance.

- *Repair Cost:* Cost of restoring an earthquake damaged building to its condition before the earthquake.

- *Replacement Cost:* Cost of replacing the existing building with a new building having the same floor area, function, standard of finishes, and services using modern materials and construction methods.

- *Risk Assessment:* The methodical assessment of seismic risk across an area using seismic hazard, building vulnerability and population distribution data.

- *Seismic Hazard:* Refers to the intensity and frequency of ground shaking, and other potentially damaging phenomena (landslip, slumping, etc) resulting from earthquakes.

- *Seismic Risk:* Refers to the amount and extent of potential losses resulting from earthquakes; a function of the seismic hazard and the vulnerability of the exposed structures.

- *Vulnerability:* The susceptibility of a structure, or a class of structure, to earthquake damage.

3 THE STUDY AREA 1 - WELLINGTON CITY

3.1 Location

The Study Area 1, Wellington City, is located to the west of Port Nicholson and extends from Miramar Peninsula to Glenside, see Figure 1.1 It includes the Miramar Peninsula, Rongotai, Kilbirnie, Lyall Bay, Newtown, Hataitai, Te Aro, City, Thorndon, Karori, Ngaio, Khandallah, Johnsonville and Newlands. The NZMS 260 Map Grid Reference of the southern and northern ends of the area are R27 625 835 and R27 625 985 respectively.

3.2 Topography

The topography of the Wellington City Study Area is dominated by the Wellington Harbour (Port Nicholson), the various bays, Miramar Peninsula and the hills surrounding the harbour and city. A number of stream valleys lie within these hills.

Large areas of land have been reclaimed from the harbour and bays, particularly in the City, Kilbirnie/Lyall Bay and between Thorndon and Ngauranga. These reclaimed areas have been developed with commercial, port and transport facilities.

3.3 Land Use

The 1991 Justice Department census statistics give the daytime and nighttime populations of the study area as 157,346 and 134,940 persons respectively.

The building inventory, given by current Valuation New Zealand's data, comprises:

- Residential: 45,678 buildings, 6,733,627 square metres area
- Commercial and Industrial: 2,602 buildings, 3,290,500 square metres commercial and 885,180 square metres industrial.

4 RISK ASSESSMENT METHODOLOGY

The process of earthquake risk assessment of a region may be visualised as a series of overlayed maps representing the various types of data involved. The overlayed maps are representative of a model which is then analysed up through the layers of data variations for sub-areas, to arrive at a damage assessment, sub-area by sub-area, which may again be presented in map form showing the levels of damage. The total damage or loss may then be summed over the various areas to give totals for the particular study area or the whole region.

The data layers used in this study include:

- base map to establish location is made up of coastlines, main roads, rivers, and Valuation Roll Number area (Roll areas) boundaries and identifiers,

- ground shaking hazard data comprising the shaking intensity for the particular earthquake scenario being analysed. Ground shaking includes the amplifying affects of soft ground areas,

- liquefaction hazard data comprising permanent ground deformations resulting from liquefaction induced by the scenario earthquake ground shaking,

- areas subject to land slope in stability under the earthquake scenario,

- fault displacements resulting in permanent ground deformation,

- building inventory data comprising the numbers, floor areas and replacement costs of the buildings,

- building construction attribute data obtained from surveys and existing databases,

- population data.

The hazard, inventory, and population data is summarised for sub-areas of land with generally consistent attributes. The sub-areas are of a size such that significant errors from approximating their generally non-uniform distribution across the sub-areas as a uniform distribution are minimised. This representation of the study area by sub-areas, having generally homogeneous uniformly distributed attributes is referred to as the geographical model of the study area, and enables analysis of the combined effects of the various attributes, to be amalgamated.

Mathematical models assessing building damage from the hazard and building attributes are used to calculate a building damage data layer, and a model relating casualties to building damage and population is used to calculate a casualty data layer. By aggregating across these layers, total building damage losses and casualties may be obtained for the study areas and the whole region.

5 EARTHQUAKE HAZARDS

5.1 Earthquake Scenario

Seismic activity in the Wellington Region results from crustal strain induced by movement on the tectonic plate boundary, 20-30 km beneath the region where the Pacific Plate is subducting beneath the Australian plate. As a consequence the region is traversed by a number of active faults with potential for moderate to large earthquakes.

The Wellington Region is underlain by Greywacke rock with alluvial gravel, sand and silt deposits in river valleys, estuaries and coastal zones, and with large reclamations in harbour waterfront areas. Some of these soils have the potential to liquefy. There is also a significant risk of earthquake induced slope failure in hilly terrain within the Region.

The Regional Council has identified two earthquake scenarios for this study:

Scenario 1 is a large, distant, shallow (<60 km) earthquake that produces Modified Mercalli (MM) intensity of V-VI in bedrock over the Wellington Region. An example of such an event would be a magnitude 7 earthquake centred 100 km from the study area at a depth of 15-60 km, perhaps similar to the 1848 Marlborough earthquake. The return period of a Scenario 1 event is 20-80 years. The probability of this event occurring in the next 50 years is very high (90% or greater).

Scenario 2 is a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault. Rupture of this segment is expected to be associated with an earthquake having a Magnitude in the range 7.2 to 7.8 with an assumed mean of 7.5, centred at a depth less than 30 kilometres, and with up to 5 metres of horizontal and 1 metre of vertical displacement at the ground surface. The return period for such an event is about 600 years and the probability of this event occurring in the next 50 years is estimated to be 10 percent. Earthquake damage losses calculated for this scenario are generally considered to be the "Probable Maximum Losses" for the Region and for New Zealand as a whole, when building damage is considered, eg. the balance of the seismic hazard and the quantity of buildings exposed to the hazard dominates other potential scenarios.

5.2 Ground Shaking Hazard

The geographic variation in ground shaking due to attenuation with distance from the earthquake source, and amplification characteristics of the various soil types was taken from the ground shaking hazard map for Wellington City published by the Regional Council (Kingsbury, 1992b). The ground shaking intensities in the study area as measured on the Modified Mercalli (MM) intensity scale are expected to range from MM V-VI in rock and stiff alluvial soils, to MM VIII-IX in soft sediments for scenario 1 and from MM XI in rock to MMX-XI in soft sediments for scenario 2.

5.3 Liquefaction Hazard

Some alluvial soils and reclamation areas in Wellington City are susceptible to ground subsidence or lateral spreading induced by liquefaction. Zones of potential liquefaction induced ground damage were taken from liquefaction hazard maps published by the Regional Council (Kingsbury, 1993).

For this study ground subsidence was estimated for each zone based on the available soil information, and from the soil profile indicated by a key borehole for each sub-area. The approximate subsidence deformation has been estimated using the method proposed by Tokimatsu and Seed (1987) for sands, for a magnitude 7.5 earthquake. The method is considered to be appropriate for the Wellington Fault event (scenario 2), but may overestimate settlements for scenario 1. While the method is for sands (as with most liquefaction methods), it has been applied for silty sands and in some instances silts. The method may overestimate settlements in soils containing significant proportions of silts. The thickness of the liquefiable layer has been estimated from the key boreholes which, in some instances, contain very sketchy information.

The subsidence estimates include an assessment of the likely earthquake shaking induced densification of loose sediments in addition to those areas subject to liquefaction.

Ground subsidence in the range 25 mm to 250 mm has been estimated for scenario 2 and 25 mm to 150 mm for scenario 1.

The ground lateral spreading estimates are based on the extent of movement reported during past earthquakes and estimates that have been made for previous specific projects. Such estimates involve approximations. Lateral spreading displacements are estimated for coastal areas, for zones 0 to 200 m from the water front, where liquefaction potential is moderate to high, and are estimated to be of the order of 500 mm and more.

Obviously the estimated subsidence and lateral spreading will not affect the whole of each zone. For this study it has been assumed that the estimated upper bound liquefaction affects 20% of the zone area, the lower bound estimate affects 40% of the area, and no subsidence occurs in 40% of the area.

For the risk analysis, the ground deformation bands shown in Table 5.1 were adopted.

Table 5.1: Ground Deformation Bands

Ground Deformation Band	Type of Deformation	Deformation Range
1	Subsidence	0 - 50 mm
2	Subsidence	50 - 100 mm
3	Subsidence	100 - 200 mm
4	Subsidence	>200 mm
5	Lateral spreading	500 - 1000 mm
6	Lateral spreading	>1000 mm

5.4 Slope Failure Hazard

Reports on the earthquake induced slope failure hazard in the Wellington Region have been prepared by Brabhaharan and others (1994).

The Wellington Region's slopes are predominantly composed of Greywacke sandstones and argillites which are generally resistant to slope failure during earthquake except where they are steep. The main areas of hazard are steep areas in the Northern and Western suburbs, in the Miramar peninsular and elsewhere in the city. Slope failures in these areas can be expected to contribute to building damage and casualties.

For this study it has been assumed that there is a 25% probability that areas assessed as having "severe" or "very severe" potential for slope failure in the scenario earthquake, will undergo significant permanent ground deformation.

5.5 Fault Rupture Hazard

Earthquake scenario 1 is based on fault rupture outside of the Wellington Region and consequently, fault rupture will not contribute to building damage or casualties in the study area for this scenario.

Scenario 2 is based on rupture of the Wellington Fault which passes through Wellington City and hence fault rupture can be expected to contribute to building damage and casualties for this scenario.

5.6 Tsunami Hazard

Studies of the tsunami hazard in the Wellington Region (Gilmore, 1989, 1990, Barnett 1991) identify a replication of the 1855 West Wairarapa Fault earthquake as the critical scenario.

For the Wellington Fault scenario (Gilmore, 1990) gives tsunami or seiche wave inundation height maximums for Wellington Harbour and the south coast of:

Somes Island	0.50 m
Evans Bay	0.35 m
Harbour Channel	0.30 m
Makara	0.30 m
Seatoun	0.30 m
Petone	0.30 m
Outer Harbour	0.30 m
Breaker Bay	0.30 m
Lyall Bay	0.30 m
Ngauranga Gorge	0.25 m
South Coast	0.20 m
Inner Harbour areas	0.20 m

These water level heights, by wave or slow inundation, are not expected to result in initiating or increasing damage levels from earthquake effects.

6 GEOGRAPHIC MODEL

In order to allow for variation of building and population attributes, and variation of hazard within the study area, and in order to determine the distribution of risk, the study area has been divided into a number of sub-areas. The risk has then been assessed for each of these.

It was decided to adopt the Valuation New Zealand (VNZ) roll areas for the sub-areas as building inventory is available for each of these areas from the VNZ database. The VNZ roll areas are small enough to allow the construction attributes of buildings in the area to be described in simple proportions with sufficient accuracy for the purposes of this study. Map 1 shows the VNZ roll areas for Study Area 1, Wellington City.

Even with the comparatively small size of the majority of the roll areas, the seismic hazard was still found to vary significantly within some of them. In these cases the proportion of the roll area in each hazard zone was assessed and allowed for in the analysis. For a number of these areas the buildings are not uniformly distributed so that the hazard zone proportions were assessed for the developed part of the roll area rather than the total area. This process was repeated separately for residential and commercial/industrial development.

7 BUILDING INVENTORY

7.1 Building Classification System

The purpose of the building inventory classification system is to group buildings with similar damage/loss characteristics into a set of pre-defined building classes. Damage vulnerability models can then be developed for these building classes which represent the average characteristics of the total population of buildings within each class.

The building inventory classification system used in this study has been developed to provide an ability to differentiate between buildings with substantially different damage and loss characteristics. The following primary parameters affecting building damage and loss characteristics were given consideration in developing the building inventory classification system :

- Occupancy
- Structural parameters affecting structural capacity, namely :-
  basic structural system (steel moment frame, etc)
  building height (low-rise, mid-rise)
- Nonstructural elements affecting nonstructural damage
- Age (affecting seismic design standards)
- Variability of building characteristics within the classification

The following classes were adopted to represent the building stock in the Wellington Region :

- Occupancy classes :

  Residential
  Commercial
  Industrial

- Structural classes :

  Timber frame
  Steel portal frame
  Tilt up concrete
  Steel moment resisting frame
  Concrete moment resisting frame
  Concrete Shear walls
  Unreinforced masonry

- Height classes :

  Low rise (generally 1-4 storey for commercial and industrial, 1-2 for residential)
  High rise

- Age classes for residential property :

  <1940
  1940-1970
  >1970

- Age classes for commercial and industrial property :

  <1930
  1930-1970
  >1970

- Non structural classes :

  Lightweight cladding (eg metal)
  Heavy cladding (eg brick)

In addition to the primary parameters affecting building damage listed above, the within class variability of residential property was also measured by foundation type, roof types (ie tile roof or light roof) and numbers of brick chimneys.

A significant number of residential and commercial/industrial building properties were not identified with construction types and or identified by age in the Valuation NZ data. These groups of properties were assumed to have the same construction type and age distribution as the properties which were fully identified.

Descriptions of the structural classes are included in Appendix E.

For the purpose of casualty estimation all buildings were placed in one of three construction groups based on their vulnerability. These groups are also used for summarising building damage assessments.

A brief description of these building construction groups is shown in Table 7.1

Table 7.1 Building Construction Groups

Construction Group	Relative Vulnerability to Damage	Structural Classes
1	Low vulnerability, ductile	Timber frame Light steel frame
2	Medium vulnerability, ductile	Concrete & steel, frame and wall buildings
3	High vulnerability, non ductile	Unreinforced masonry

7.2 Valuation New Zealand Data

The number of buildings and total floor areas in each roll area were supplied by the Wellington Regional Council from its Valuation New Zealand database.

The following definitions were used for sorting the VNZ data:

- single properties were counted as one property and multiple units by each individual unit,
- residential was defined as being all assessments classified Residential Dwelling or Residential Flats,
- industrial was defined as being all assessments classified Farm-Animal Production, Farm-Group/Specialist, Lifestyle, Forestry/Mining, Industrial or Vacant-Commercial/Industrial,
- commercial was defined as being all assessments classified Commercial,
- the area of a building is defined as being the total floor area,
- the number of floors for commercial buildings was calculated by dividing the floor area by the scope area and rounding up to the next integer,
- assessments with no classification (residential, industrial or commercial) were classified on a prorata basis,
- assessments with undefined construction were classified as a prorata basis,

- "high-rise" residential property for use in casualty estimates was defined as those residential buildings with floor areas greater than 400 square metres.

The data was supplied for each occupancy class and each age class. The database also records a construction type. This was found to be useful for classifying residential property into those having heavy brittle cladding (brick, stucco) and those having light cladding (timber, fibreboard). However the valuation roll construction data was not suitable for classifying commercial and industrial buildings by structural type. It was therefore necessary to identify structural type and other parameters not included in the VNZ database by sample on site survey.

A summary of VNZ inventory data is presented in Appendix A.

7.3 Survey Data

"Drive through" surveys of roll areas estimated the proportions of residential properties in each age group having particular characteristics. These included number of storeys, sloping sites, pile or strip foundations of different heights, partial basements, tile roofs and masonry chimneys.

For Commercial and Industrial areas the proportions in each of the three most predominant structural classes was estimated for the two building height classes in each age class.

Sample survey inputs are included as Appendix D.

A review of previous building surveys and studies carried out by Consultancy Services in the study area was used to check the survey data.

Aerial photographs were used to identify properties exposed to slope failure and fault rupture hazards.

7.4 Replacement Costs

Building replacement costs were obtained from Rawlinson's New Zealand Construction Handbook (1993) Edition. This publication gives average costs per square metre for typical buildings with a range of occupancies, for the four main centres. The costs given in Rawlinson exclude demolition and removal of debris and professional fees. These latter costs are included in the cost of repair.

For residential occupancy class buildings the floor area for each roll area was scaled by a factor that allowed for the effect of quality of construction and finishes on replacement cost. This factor was estimated during the survey phase of the project and varied between 0.75 for smaller properties of basic construction and 1.1 for larger properties with higher quality finishes and materials. These factors were used in conjunction with a basic floor replacement cost of $1000 which was expected to give an average value for the Wellington region of approximately $900 per sq metre.

The replacement costs of commercial and industrial buildings was estimated on a Study Area basis taking account of the mix of building uses that were dominant for the area. For Wellington City study area, the replacement cost of commercial floor area was assumed to be $1503 per square metre and for industrial properties was assumed to be $350 per square metre.

7.5 Post-earthquake Inflation

In the post-earthquake reconstruction period, diminished local resources and increased demand for construction material, labour and machinery, and other factors are expected to result in inflated prices, at least for a short period following the event. The amount of inflation will vary with different items according to supply and source.

To the extent that Damage Ratios used in this study are largely based on insurance claims costs and historical repair costs, some component of post earthquake inflation is already included.

The effects of a major earthquake may also influence foreign exchange rates, adding inflationary pressures. The relative size and isolation of New Zealand may be expected to result in higher inflation rates than included in the referenced United States data.

The use of insurance for reconstruction and business interruption costs, and the likelihood of Government intervention to curb excessive profiteering or other unjustifiable price increases, will tend to limit the extent of post-earthquake inflation levels.

Reviews of local economies of earthquake sites in the United States have generally indicated that after some sharp increase in costs the general inflationary trend soon becomes established again, (Steinbrugge personal communication to Shephard), with the economy depressed in some areas of activity and gaining in others but generally retaining overall balance.

Consultancy Services has previously undertaken an economic evaluation of post earthquake inflation for earthquake scenario 2, making appropriate assumptions for damage levels, demands for services in reconstruction, insurance levels, occupancy rates, relocations, shift in dominant activities, and foreign exchange fluctuations. (A short term drop in currency value was forecast with medium term recovery to about pre-earthquake level as overseas reinsurance balances foreign content of reconstruction costs). Allowing for a rebuilding duration of 5 years, analysis indicates that reconstruction activity would peak at about 1.6 times the average, (a little more than the boom era pre-October 1987) and that likely post-earthquake inflation was about 10% to 15%.

In this study the earthquake damage repair costs for scenario 2 were increased by 10% to allow for post-earthquake inflation costs over and above those already incorporated in the damage ratios.

8 BUILDING VULNERABILITY MODELS

8.1 Introduction

Vulnerability matrices form the basis of the model used to make the earthquake damage risk assessment. These matrices describe how the damage ratio for a particular structural class is expected to vary with Modified Mercalli ground shaking intensity, liquefaction induced ground deformation and construction attributes.

8.2 Damage Ratios

For this study a damage ratio is defined as the cost of repairing an earthquake damaged building divided by the replacement cost of the building. The repair cost is the cost of restoring the building to the condition it was in before the earthquake. It includes demolition and removal of debris costs and professional fees.

The replacement cost is the cost of replacing the building with a new building having the same floor area, function, standard of finishes and services, using modern materials and construction methods. It includes the foundations, structural frame, floors, roof, internal and external walls, windows, doors, ceiling, wall and floor finishes, fittings, fixtures, plumbing, electrical and mechanical services, lifts and escalators. It excludes the building contents, furniture and demountable partitions. It also excludes demolition, siteworks and professional fees. Damage ratios can exceed 100% because repair costs include demolition costs and professional fees.

For example, suppose a house with a replacement cost of $100,000 sustained damage in an earthquake which cost $20,000 to repair including restoring all finishes to the same condition as they were before the earthquake. The damage ratio for that house would then be 20,000/100,000 = 0.20.

Damage ratio data derived for the various structural classes are used in this study to estimate post earthquake repair costs to buildings.

8.3 Level of Confidence in Loss Estimates

For the purposes of this project the use of MEAN DAMAGE RATIOS has been specified by the Wellington Regional Council. This implies that in an actual event there is equal probability of the damage or casualty values being greater or less than those resulting from this assessment. More conservative considerations may be appropriate for specific uses of the results presented, eg. for emergency response planning or assessment of insurance losses.

The limited amount of historic earthquake damage data available makes a formal probabilistic evaluation impossible.

An approximate estimate of the inter-event coefficient of variation is 55 to 60 percent. This is based largely on expert judgement supported by the limited historical data available.

Alternatively, doubling of the loss values may be considered to approximate the 90 percentile values ie in nine out of ten of the scenario events, the actual loss will be less than double the mean losses presented in this report.

8.4 Vulnerability to Ground Shaking

Residential Property

A number of New Zealand and overseas sources (Dowrick 1990d, 1990e, 1991a, 1991e, 1994, Hamblett 1969, Lowry 1989, Rojahn 1985, Steinbrugge 1973, 1982, 1990, 1994) were evaluated to determine mean damage ratios (MDR) that could be expected for domestic construction when subjected to a range of earthquake shaking intensities as measured by the Modified Mercalli scale..

Although the basic MDRs used for the analysis recognised the value of the New Zealand data and were weighted towards these, the values adopted were generally higher. Higher values were adopted because overseas data from previous earthquakes suggests that the New Zealand MDRs, which were largely derived by Dowrick from the 1987 Edgecumbe and 1931 Napier earthquakes are relatively low. Because the Wellington region presents a great diversity of building forms and to allow for inter earthquake event diversity it was considered prudent to use them only in a modified form for this study.

The model also included a number of modifiers that were applied to the basic damage ratios described above to allow for attributes which are known to, or are expected to, affect the seismic vulnerability, and which are known to vary from one area within the region to another. Modifiers were used for building age, foundation type, sloping sites and the adverse effects of heavy cladding on walls and/or roofs. The model also allowed for the additional damage expected where heavy masonry chimneys are present.

Commercial and Industrial Property

Vulnerability matrices were developed for the seven structural classes described in Section 7, Building Inventory.

Mean damage ratios were developed from material published by the Applied Technology Council for Californian construction (Rojahn, 1985). Adjustments have been made for New Zealand conditions and in light of other published information on earthquake vulnerability (Porro, 1989. Cochrane, 1992). Building damage data on which to base the vulnerability matrices is limited and considerable engineering judgement was required to derive the values used, especially at the higher earthquake intensity levels where there is almost no reliable and/or applicable data that can be used.

Damage ratio modifying factors are also included in the model that adjust the basic ratios for building height, cladding type and for the lower damage expected to industrial properties because these tend to have finishes of lower value and less sensitivity to damage.

The MDRs were also modified according to the age classes.

Typical damage ratios are shown in Figure 8.1 for a range of general building types, illustrating the relationship between ground shaking intensity and the extent of damage as a ratio of replacement cost. Note that the MM Intensity contour value is the level of ground shaking in terms of a continuous function representing the normal Modified Mercalli intensity areas, ie

Conventional Mercalli Intensity	VI	VII	VIII	IX	
Continuous Function	6.0	7.0	8.0	9.0	10.0

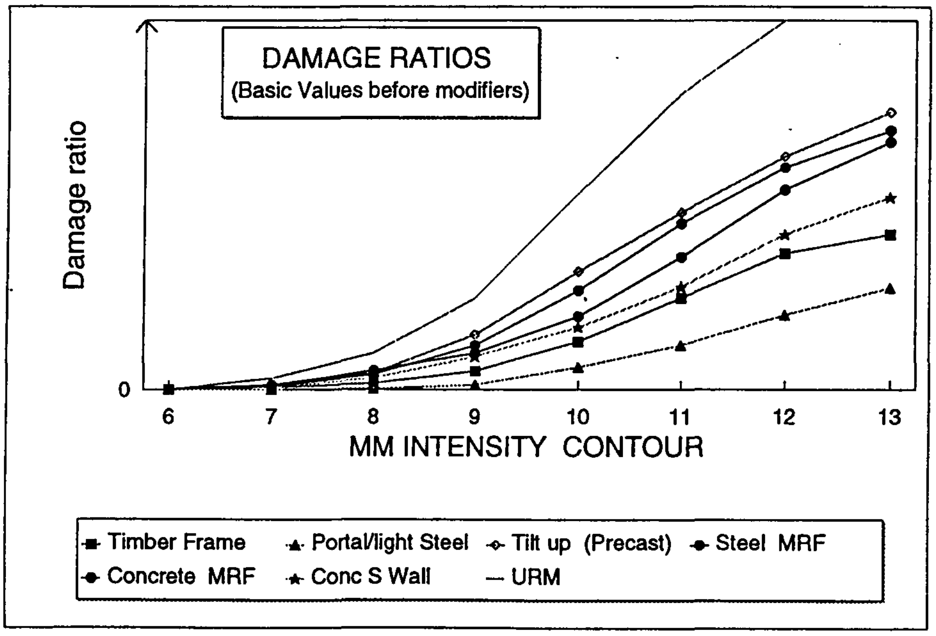

Figure 8.1: Damage Ratios

Note: MMI contour values greater than MM10 enable analysis including permanent ground deformation effects and are an extension of convenience beyond the formal definitions of Modified Mercalli ground shaking intensities.

8.5 Vulnerability to Permanent Ground Deformation

A study by King (King, 1994) gives an overview of quantitative models available for the secondary seismic effects of liquefaction and landslide, sources of permanent ground deformation. The common method of increasing the level of estimated ground surface shaking is used in absence of adequate probabilistic models.

Using Modified Mercalli Intensity as the measure of ground surface shaking, the following relationships are presented as heuristic rules:

Final combined hazard, MMI_F has a maximum value equal to or less than 12.

For ground shaking alone:

$$MMI_{F}, = MMI_{GS},$$

where MMI_{GS} is the intensity of ground shaking.

For ground shaking and liquefaction:

$$MMI_F = 0.55\ MMI_{GS} + 0.45\ MMI_{LIQ} + 0.5$$

where MMI_{LIQ} is the increased effect of liquefaction, which is given as approximately $MMI_{LIQ} = MMI_{GS}+2$ for areas with liquefiable soils.

Thus $MMI_F = 1.95\ MMI_{GS}$ by substitution.

The Applied Technology Council's publication ATC-13 (Rojahn, 1985) provides the following procedure for calculating liquefaction induced damage :

$$MDR\ (PG) = MDR(s) \times P(GFI)x5$$

where MDR(PG) = Mean damage ratio caused by liquefaction

MDR(s) = Mean damage ratio caused by ground shaking

P(GFI) = Probability of a given ground failure intensity for a given shaking intensity

This procedure is based on observations from the 1906 San Fransico earthquake that damage on poor ground was 5 to 10 times greater than on firm ground.

The total MDR is conservatively the sum of the MDR for ground shaking and the MDR for liquefaction.

The NIBS study (NIBS, 1994) gives a relationship between damage state and permanent ground deformation (PGD) based on engineering judgement as shown in Table 8.1.

Table 8.1: Building Damage Relationship to PGD (NIBS)

Probability of Being in Extensive or Complete Damage State	Settlement PGD (mm)	Lateral Spread PGD (mm)
0.1	50	300
0.5	250	1800

The above assumptions are based on the expectation that about 10 out of 100 buildings would be severely damaged for 50 mm of settlement PGD or 300 mm of lateral spread PGD, and that about 50 out of 100 buildings would be severely damaged for 250 mm of settlement PGD or 1800 mm of lateral spread PGD. Lateral spread is judged to require significantly more PGD to effect severe damage than ground settlement. Many buildings in lateral spread areas are expected to move with the spread, but not be severely damaged until the spread becomes quite significant.

Based on assumed MMI/PGD relationships, there is reasonably close correlation between the ATC-13 and the NIBS procedures.

The NIBS relationship was assumed to be applicable to Group 2 construction class buildings for the Regional Council risk assessment study. Relationships were also developed by engineering judgement for Group 1 and Group 3 construction class buildings.

Total MDRs are the sum of MDR from ground shaking and MDR from permanent ground deformation.

8.6 Damage States

When subjected to a particular level of ground shaking intensity a population of buildings of similar construction and age will not all exhibit damage equal to the MDR but will have a damage distribution about this mean.

The variation in the damage to individual buildings is the result of the variation in the characteristics of the buildings such as height, orientation, shape (irregularities) etc and its particular response to the ground shaking experienced. In order to quantify the levels of damage that may occur five damage states, each corresponding to a range of damage ratios, have been developed and are presented in Table 8.2.

Table 8.2: Building Damage States

Damage State	Damage Ratio (%)
None	0
Light	>0 < 10
Moderate	10 < 30
Extensive	30 < 100
Complete	100

The distributions of damage ratios for particular MDRs obtained from past earthquakes (Rojahn, 1985, NIBS, 1994) were used to determine the individual damage states from the computed MDRs. Figure 8.2 shows typical distributions of damage for a range of MDRs, presented in terms of cumulative probability against the given Damage Ratio.

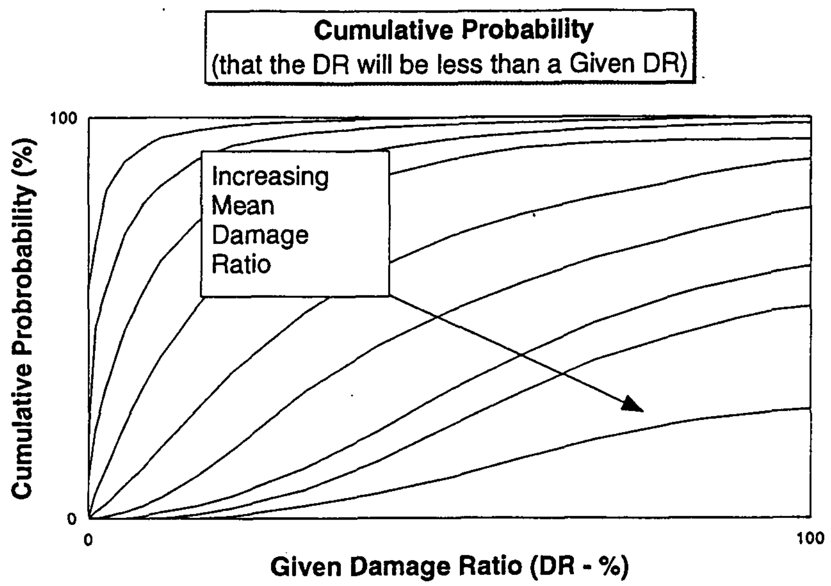

Figure 8.2 Damage Distribution Given Mean Damage Ratio

The following are generalised descriptions of the type of damage which is likely to exist in each of the damage states:

> **Light Damage State** includes internal disruption caused by planters, furniture, bookshelves, or other items that are free to shift around during shaking and some slight damage to permanent building elements such as ceilings, lighting fixtures, or partitions. Damage may require clean-up and minor repair to the extent that the building cannot be used immediately, but would require a maximum of a few days to complete clean up. Although essentially no injuries are expected in these buildings, there is always a remote possibility that shaking objects could shift or topple in such a way as to cause an "incidental" hazard.
>
> Buildings in **Moderate Damage State** would suffer more extensive damage to internal elements than those in light damage state, and may also have minor structural damage such as cracks in concrete or masonry walls. The building is not to be considered in any danger of structural failure, but a slight risk of injury could result from falling light fixtures, or equipment. The damage would be sufficient to require repair, and the building could be partially or completely closed, pending analysis and/or repairs. Partial closure is expected in any case while repairs and clean-up are completed.
>
> The **Extensive Damage State** will include damage to structural elements such as walls, columns, and beams. Buildings may be leaning or certain floor levels or walls may be out-of-plumb. Internal elements may be damaged beyond repair. These buildings would definitely be closed by Civil Defence until structural repairs are completed. Occupants or passersby may have been injured by falling debris. Owners of buildings that have been damaged this severely often must wait for engineering and economic studies to be completed to determine if it is economically justifiable to repair the building or whether to simply demolish it.
>
> The **Complete Damage State** includes both collapsed buildings and those that are so severely damaged that repair is clearly uneconomical. There would be life threatening situations caused by fall internal elements or collapsing floors in every building in this category. Because of the many structural requirements placed in modern codes specifically for the purposes of preventing collapse, this damage state should be rare in new buildings.

More detailed, technical descriptions of damage at each damage state for the various structural classes, and for non-structural elements of buildings are given in Appendix F.

9 POPULATION DATA

Population data used as a basis of the casualty estimates was obtained from the Department of Statistics 1991 census based "Supermap 2" computer database. The data was analysed using building floor areas and occupancy rates to divide the population into industrial, commercial and residential components.

Census data contained within the database is available for two basic units of area, census area units and mesh blocks. Each census area unit is made up from a collection of mesh blocks which are the smallest units of area for which population data are available.

The boundaries of the census area units do not coincide with those of the VNZ roll areas, the census areas being considerably larger. It was therefore necessary to use the mesh block population data and allocate this to the appropriate roll areas. Where mesh blocks straddled roll boundaries the population was allocated to the roll area where the bulk of the population was expected to lie.

The database revealed that the population of a census area was often higher than the sum of the mesh block populations it contained sometimes by up to 2 percent. This results from the census process being able to locate people within the census area, but not the exact mesh block. Since the census area figures are the more accurate it was necessary to allocate the difference across the mesh blocks. The approach taken was to scale up the roll area populations to give the same total as given by the census area data.

The census data provided total nighttime, and daytime over 15 years population data. The under 15 year old daytime population, which includes pre-school and school age children, was estimated from consideration of the primary school and total regional populations.

The under 15 year old population for the whole Wellington region was assumed to be equal to the difference between the total regional day and nighttime populations, it being assumed that the net regional daytime commuter gain would have negligible effect. This missing population component was then distributed between the study areas in proportion to the primary school population in each Study Area and then distributed to the roll areas in proportion to the census daytime over 15 year old residential population. This only approximately allocates 12 to 15 year old high school students to correct roll areas.

In the absence of more detailed demographic information, which is beyond the scope of this study, the latter assumptions are considered reasonable.

Building occupancy rates for use in the casualty model were obtained from the day and nighttime roll populations by dividing these amongst the range of construction groups on a weighted floor area basis.

To make the division, day and nighttime average floor areas per person for residential, commercial and industrial properties were assumed for the study area. A projected population for the domestic and commercial/industrial occupancy classes within each roll area based on estimated occupancy rates were calculated and summed. To match the projected total roll population to the actual study area population, revised estimates of the floor areas per person were made. For the residential class this was based only on the total residential population and floor area in roll areas with more than 90% - 99% (depending upon the study area) of the population in residential accommodation. For the commercial/industrial component the revised estimate was based only on the data for roll areas with at least 0.5% - 10% (depending upon the study area) of the population in commercial/industrial properties. This iterative process was repeated until satisfactory convergence was reached to give a match between the projected and actual population.

Within the industrial and commercial building occupancy classes the roll populations were divided between the construction groups on a floor area basis.

"High-rise" residential property was assumed to be all residential buildings with floor areas greater than 400 square metres. The population in high rise residential was computed from the Roll area average population per unit floor area. All "high-rise" residential population was assumed to be in properties with the same casualty rates as construction group 2 properties. The remaining residential population was assumed to be in light timber frame construction.

10 CASUALTY MODEL

10.1 Introduction

Deaths and injuries resulting from the two scenario earthquakes will be principally attributable to the failure of man-made structures and facilities. Of these the largest proportion of casualties will be due to building damage and is the focus of this study. Other causes will include collapse of road or rail bridges and tunnel portals, which might cause significant casualties especially if the event occurs during the peak commuting times, and also such associated causes as medical conditions and reactions, panic actions, falls and strike by falling objects and other miscellaneous causes such as traffic accidents. Freak occurrences of damage also have a significant effect on causalities. Casualties from the two most recent Californian earthquakes (Loma Prieta, 1989 and Northridge 1994) have been dominated by a particular bridge and building collapse respectively.

The literature contains less information on earthquake casualties than on building and other damage despite earthquakes this century having caused a total loss of life exceeding 1.5 million people worldwide. The data may or may not include associated deaths and the categorisation of injuries can vary. Often the type of structure in which the casualties occur is not clear and care is needed when applying generalised data to specific situations.

Most available methods for assessing casualties assume a link with building damage, both structural and non-structural. In major earthquakes causing a significant number of total or partial collapses, the casualty rates will rise and are likely to be dominated by this group of structures.

A proportion of the occupants of collapsed buildings will survive the initial collapse but remain entrapped with various degrees of injury. Some, with life threatening injuries, may die before rescue. This will depend on the capabilities of search and rescue organisations in the emergency period. For timber framed buildings rescue is likely to be speedy but in other cases, where heavy lifting equipment may be needed, rescue could come too late for some.

10.2 Available Casualty Models

Several methods available for the estimation of casualties have been examined.

<u>Applied Technology Council of California, ATC-13</u>

The Applied Technology Council of California document "Earthquake Damage Evaluation Data for California" (Rojahn, 1985) gives casualty rates for various levels of building damage.

The building damage states are ranked from 1, no damage (and nil casualties), to 7 for destroyed. Casualty rates are given for fatalities and minor and serious injuries.

The estimates are based on past earthquake statistics, especially in the United States of America, and consensus of opinion of earthquake engineering experts. The approach is independent of building construction type except for light steel and light timber construction where it is recommended that the basic rates be divided by 10 in recognition of the lower vulnerability.

National Institute of Building Sciences (NIBS)

A report on Development of a Standardised Earthquake Loss Estimation Methodology prepared for the National Institute of Building Sciences of America (NIBS, 1994) extends and develops the ATC approach.

Four casualty levels are used namely light (requiring basic medical aid), moderate (requiring hospitalisation), serious (life threatening and requiring immediate attention), and fatal. The casualties are related to given damage states between no damage and destroyed.

While currently in 95% complete draft form, the NIBS approach has relevance to New Zealand because of the similarities of construction types between the two countries and because it recognises the vulnerabilities of different construction types.

University of Cambridge, UK

The Martin Centre for Architectural and Urban Studies, University of Cambridge has researched earthquake damage and casualty data worldwide and developed a methodology based on building collapse.

It has been found that for the major earthquakes studied which caused more than 5000 buildings to be heavily damaged, casualties due to building collapse dominated the total. For less destructive earthquakes, deaths and injuries from non-structural causes, accidents and medical conditions can contribute a large part of the total and are much more variable.

Modifiers are applied to the estimated proportion of collapsed buildings of a particular construction type for building occupancy, entrapment, injury level and mortality. A further modifier estimates mortality post-collapse, ie those that die before rescue. This reflects the search and rescue capability of the community and varies with construction type and likely time to rescue.

A casualty estimation for the Wellington area has recently been prepared for the New Zealand Accident Rehabilitation and Compensation (ACC) using the University of Cambridge methodology (Spence, 1994).

10.3 Wellington Regional Risk Assessment Casualty Model

The methodology adopted for this study generally follows the NIBS approach described above because it provides recognition of the different building construction types and utilises the same building damage states as used elsewhere in this report. For timber framed residential construction however NIBs predicts nil casualties. As this was seen as being unrealistic the University of Cambridge approach has been used for this construction and occupancy class.

Building Groups

For the purposes of casualty estimation all buildings are placed in one of three construction groups based on their vulnerability and potential to generate casualties as shown previously in Table 7.1

Injury Classification

The injury level classification scale is shown in Table 10.1.

Table 10.1: Injury Classification Scale

Injury Severity Level	Injury Description
Level 1	Injuries requiring basic medical aid without requiring hospitalization.
Level 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life threatening status.
Level 3	Injuries which pose an immediate life threatening condition if not treated adequately and expeditiously. The majority of these injuries are a result of structural collapse and subsequent entrapment or impairment of the occupants.
Level 4	Instantaneously killed or mortally injured.

Entrapments

As noted previously the number of casualties related to building damage are likely to be dependent on the number of partial or totally collapsed buildings in a major earthquake.

The proportion of occupants of buildings in the "complete" building damage state (complete in terms of 100 percent loss and probably in at least a partially collapsed state) who are trapped is given in Table 10.2. The risk analysis model allows for the assessment of entrapments, and results are presented to indicate expected rescue requirements.

The casualty rates for each level of injury presented in Table 10.2 includes an allowance for injuries sustained by entrapped people.

Casualty Rates

The casualty rates adopted for this study are shown in Table 10.3.

Table 10.2: Casualty Rates for Construction Groups and Damage States
(Refer to Table 8.2 for Damage State)

Building Construction Group	Building Damage State	% Casualty in Each Injury Level				Entrapment %
		Level 1	Level 2	Level 3	Level 4	
1	Light	0.0003	0.00004	0.000005	0	
	Moderate	0.006	0.001	0.0001	0.0001	
	Extensive	0.06	0.01	0.005	0.005	
	Complete	2	0.27	0.065	0.15	0.65
2	Light	0.003	0.0004	0.000033	0	
	Moderate	0.06	0.01	0.0002	0.0002	
	Extensive	0.6	0.07	0.002	0.002	
	Complete	7.5	6.8	1.5	6.0	15
3	Light	0.06	0.01	0.0007	0	
	Moderate	0.3	0.04	0.005	0.005	
	Extensive	3	0.4	0.05	0.05	
	Complete	28	10	6.0	4.0	20

The comparison carried out between the entrapment rates forecast by NIBS (NIBS, 1994) and the ACC report (Spence, 1994) for the Wellington area gave reasonable agreement for building construction groups 2 and 3 if a large proportion (approximately 40%) of the buildings at the "complete" Damage State are assumed to have collapsed. However for group 1 buildings the NIBS data predicts nil entrapment. This is considered to be unrealistically low, giving very low casualties for this construction type. Consequently the casualty rates proposed for the ACC report have been adopted here.

Casualty Estimation

For each building construction group the number of casualties at each level can be calculated from :

$$Casualties\ (Level) = \left(\sum_{i=1}^{5} C_i\ DS_i \right) \times Pop(group)$$

where	C_i	=	casualty rate for buildings at Damage State i
	DS_i	=	fraction of buildings of the particular category at Damage State i
	Pop(group)	=	population within area being considered (valuation role area) occupying buildings of the particular construction group

To obtain the total casualty figures for the area of interest and time of day the calculation is repeated for each building category and population figure and summed appropriately.

11 FIRE FOLLOWING EARTHQUAKE

The threat of fire following earthquake always exists as shown by historic events, where major conflagrations have occurred:

1906 San Francisco, USA
1923 Kanto, Japan
1931 Napier, New Zealand
1995 Kobe, Japan

There were also significant fire ignitions and in some cases fire spread to other properties following earthquakes in Loma Prieta (San Francisco) USA 1989 and Northridge, USA 1994.

Many other events have resulted in post earthquake fires affecting individual properties where ignition occurred.

It is interesting to note that no significant fires have occurred in recent small to moderate New Zealand earthquakes. While perhaps 3 or 4 fire ignitions may have been forecast for the 1987 Edgecumbe earthquake, none occurred, This is attributed to there being warm weather and no fires for heating, no piped gas supplies, and an earthquake foreshock stopping electricity supplies and hence removing a major source of ignition.

To date there has not been an earthquake induced fire involving modern multistorey construction. In fact the very recent post-earthquake fire conflagration occurring in Kobe was largely restricted in spread by areas of modern construction and wide roads. Preliminary reviews of the 17 January 1995 Kobe earthquake indicate that in the areas of significant shake damage and conflagration:

12% of the damaged area suffered 3-5% burnt area
30% of the damaged area suffered 0.5-3% burnt area
58% of the damaged area suffered 0.05-0.5% burnt area

Note that the areas subject to conflagration comprised tightly packed, old, light weight timber frame residential buildings, with high shake damage vulnerabilities, that were mixed with flammable contents of light industries, in areas of very narrow streets.

Parts of the Wellington region are generally considered susceptible to fire following earthquake for reasons of:

reduced mains water supply
perception of frequent high winds
reduced access in narrow streets
dense construction in flammable materials
fire spread up hillsides

all coupled with anticipation of high levels of ground shaking and ground deformation damage.

At the same time in-built construction fire safety measures in the form of fire barriers, particularly in city centre construction, substantially reduce the fire spread risk in some parts of the region.

Data on post earthquake fire ignitions are available for United States cities that have experienced earthquakes (Scawthorn, 1987). In this case the term ignition is defined as a fire starting that requires firefighting response to extinguish. The graphical presentation of ignition rates is shown in Figure 11.1. From these data the following rates of fire ignition are determined:

Earthquake MMI	VI	VII	VIII	IX	X
Approximate number of fire ignitions per million square metres of building exposed	0	1	2	3	4

Once fire ignition occurs the spread of fire is subject to a wide range of variables:

- form of ignition,
- building density,
- local occupant response,
- fire fighting response,
- inbuilt fire protection measures,
- fuel availability,
- wind velocities,
- topography, and
- vegetation.

Models of fire spread have not reliably replicated actual situations due mainly to the variability of parameters of the considerable database and difficulty of analysis.

A comprehensive study of potential losses due to fire following earthquake for the greater Wellington region (Dowrick, 1990b) has been adopted as the basis of this Wellington Regional Council earthquake risk study.

The Dowrick study considers (in part) the scenario 2 event, taking into account all earthquake effects and modelling the fire effects. The study does not include an assessment of casualties resulting from fire. The authors believe that their assessment is conservative, particularly given that prior losses due to earthquake shaking have not been deducted.

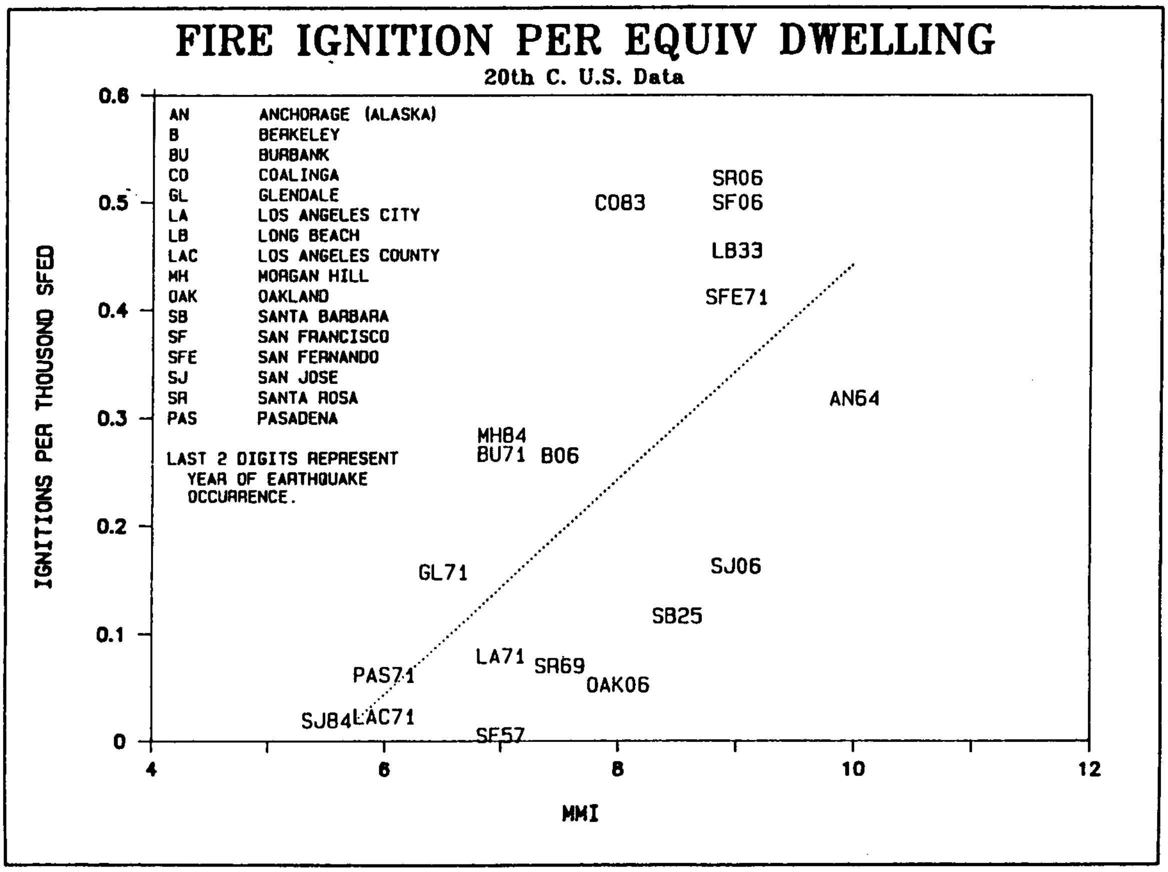

Figure 11.1 Fire Ignitions as a function of Earthquake Modified Mercalli Intensity (Scawthorn 1987)

Because the rate of fire losses is dominated by the number of ignitions, the fire losses for scenario 1 are proportioned from those of scenario 2 according to the relative rate of ignitions, using the Scawthorn ignition rates (as does Dowrick).

The number of ignitions determined by Dowrick for each study area was verified using the current Valuation New Zealand data for residential properties and commercial/industrial areas, factored by the ignition rates derived by Scawthorn. Where there were significant differences then the property destroyed was adjusted in proportion. This is expected to account for changes in development and growth subsequent to Dowrick's study.

Following are results extracted from Dowrick's study:

Table 11.1 Estimated numbers of post-earthquake fire ignitions (requiring Fire Service attention) for Scenario 2

Locality	Number of Ignitions	
	Domestic	Commercial
Kapiti	3	1
Porirua City	5	2
Tawa	2	0
Eastbourne	1	0
Lower Hutt	12	7
Petone	1	2
Upper Hutt	6	2
Wellington	21	17
Wainuiomata	3	0
Wairarapa	1	3

Table 11.2 Property Destroyed by Fire Following Scenario 2, Determined from Ignitions and Site Assessed Fire Spread

Locality	Property Destroyed	
	Number of Houses	Commercial Floor Area (m^2)
Kapiti	5	300
Porirua City	11	16,200
Tawa	5	0
Eastbourne	4	0
Lower Hutt	62	70,400
Petone	22	11,300
Upper Hutt	23	18,900
Wellington	185	205,000
Wainuiomata	21	4,300
Wairarapa	1	4,300

12 RISK ANALYSIS PROCESS

A separate analysis model was developed for each of the 5 study areas that were considered for the earthquake risk assessment of the Wellington region.

Each of these analysis models has 2 similar but largely independent components. One of the components is for residential properties and the other is for commercial and industrial properties.

There are five stages to the earthquake risk analysis process.

Stage 1: Calculation of Representative Roll Area Vulnerabilities

Inputs: Inventory data (refer to Section 7)
Building ground shaking vulnerability models (refer to Section 8.2).

Process: The mean damage ratio (MDR) for residential property and for the three commercial and industrial property construction groups (refer to Section 7.2) in each roll areas is calculated assuming that all buildings are exposed to the same earthquake shaking intensity (MMI).

This process is repeated for each earthquake shaking intensity level from MM6 to MM13.

Outputs: Representative roll area ground shaking vulnerability models comprising tables of MDRs vs MMI, for residential property and the three commercial/industrial construction groups, for all roll areas.

Stage 2: Calculation of Representative Roll Area MDRs

Inputs: Ground shaking hazard data (Section 5.2)
Liquefaction hazard data (Section 5)
Slope failure hazard data (Section 5)
Fault rupture hazard data (Section 5)
Construction group permanent ground deformation (PGD) vulnerability model (Section 8.3)
Roll area ground shaking vulnerability models (Stage 1 output)

Process: The earthquake scenario 1 ground shaking, liquefaction slope failure and fault rupture hazard levels for each roll area are estimated from the hazard maps.

The MDRs due to ground shaking and PGD are then determined from the vulnerability models and summed to give total MDRs.

The process is repeated for earthquake scenario 2.

Outputs: Representative roll area MDRs for residential property and the three commercial/industrial construction groups for all roll areas, and for both earthquake scenarios.

Stage 3: Assessment of Building Damage States

Inputs: Inventory data (Section 7)
Damage distribution model (Section 8.4)
Roll area MDRs (Stage 2 Output)

Process: The roll area MDRs are used to compute the proportion of buildings expected in each of the damage states (none, light, moderate, extensive and complete) in each earthquake scenario, using the damage distribution models. The floor area and numbers of buildings in each damage state are then calculated from the inventory data.

Outputs: The floor areas and numbers of properties for the residential construction group and the three commercial/industrial construction groups which are in each of five damage states, for all roll areas and for earthquake scenarios 1 and 2.

Stage 4: Calculation of Repair Costs

Inputs: Inventory data (Section 7)
Replacement cost data (Section 7.4)
Roll area MDR's (Stage 2 output)

Process: The cost of repair of damaged buildings is calculated from the MDR's, the building floor areas, and the replacement cost per unit area of the various building classes.

The process is applied for both scenarios.

Output: Cost of repair of earthquake damage to buildings for all roll areas and for earthquake scenarios 1 and 2.

Stage 5: Casualty Assessment

Inputs: Population data (Section 6)
Casualty model (Section 10)
Building damage states (Stage 3 output)

Process: The casualty model uses the scenario 1 building damage states and the daytime population data to calculate the numbers of casualties in each of the four injury severity levels in each roll area if the earthquake occurs during the day.

This process is repeated for an earthquake occurring during the night using nighttime population data.

These two steps are then repeated using the earthquake scenario 2 damage states.

Outputs: Numbers of daytime and nighttime casualties in each roll area in each of 4 injury severity levels running from minor to fatality, for earthquake scenarios 1 and 2. Entrapment numbers are also calculated.

Note that the risk analysis model includes a weighting factor that allows for the relative value of industrial floor area compared with the value of commercial floor area. This factor is used to scale the Industrial floor area so that its relative importance is reflected in the combined mean damage ratio computed for each Roll area. It also ensures that the relatively low value of industrial floor area is correctly accounted for when repair costs are calculated for a Roll area.

A different weighting factor is used for Industrial floor area when calculating the proportion of the population in each roll area that is assumed to be located in Commercial/Industrial properties.

13 RISK ANALYSIS RESULTS

13.1 Introduction

The results of the risk analysis process described in Section 12 are presented in detail by roll area and by construction type grouping, in Tables B-1 to B-8 in Appendix B.

Results are also plotted on the following maps in Appendix C:

Map 2: Residential Property Mean Damage Ratios: Scenario 2

Map 3: Property Repair Cost Estimates: Scenario 2

Map 4: Numbers of Residential Properties in the Extensive or Complete Damage State: Scenario 2

Results for Study Area 1 - Wellington City are summarised in the following sections.

13.2 Residential Property Damage Ratios (Table B-1)

For the moderate regional earthquake (Scenario 1) the residential property mean damage ratio weighted by floor area is 0.5% with individual Roll area MDRs ranging from less than 0.1% to over 5.0%. The Study Area Scenario 2 weighted MDR is 12.0% with the Roll area MDRs ranging from less than 7.0% to over 25.0%.

The variation in MDR can be attributed mainly to variations in the ground shaking and liquefaction hazard between roll areas. Variations in residential property vulnerability due to age, and vertical and horizontal irregularities do have a significant effect however. For example, if it is assumed that all areas have the same ground shaking intensity and zero permanent ground deformation, then analysis shows those Roll areas containing a high percentage of the more vulnerable buildings as having MDRs approximately twice as high as those with a high percentage of the less vulnerable buildings.

13.3 Commercial and Industrial Property Damage Ratios (Table B-2)

The Scenario 1 weighted MDR for the Study Area is 2.9% with a range over the Roll areas of less than 0.1% to over 10.0%.

The scenario 2 MDR is 28.3% and ranges from less than 5.0% to over 50.0%.

The variation in MDR between roll areas is once again largely due to variation in hazard. However relative to residential property, commercial/industrial property has a much wider range of construction type and vulnerability as can be seen in the construction group Scenario 2 MDRs (Table B-2) which vary from 13% for light timber frame and light steel frame buildings to 70% for the unreinforced masonry buildings.

13.4 Residential Property Damage States (Table B-1)

The assessed numbers of properties in each of the damage states are shown in Table 13.1.

Table 13.1: Residential Property Damage States Following Earthquake

Earthquake Scenario	Damage State									
	None		Light		Moderate		Extensive		Complete	
	No.	%	No.	%	No.	%	No.	%	No.	%
1	41504	90.9	3480	7.6	538	1.2	154	0.3	3	0.0
2	5582	12.2	25265	55.1	9729	21.2	4386	9.5	900	2.0

Buildings shown in the "complete" damage state include those destroyed by ground shaking, ground deformation and fire.

Most properties with extensive or complete damage are likely to be vacated for a significant period following the earthquake. Buildings with slight or moderate damage should be habitable immediately or shortly after the earthquake in cases where only minor repair or securing work is required.

13.5 Commercial and Industrial Property Damage States (Table B-2)

The assessed numbers of commercial and industrial buildings in each of the damage states including buildings damaged by fire are shown in Table 13.2.

Table 13.2: Commercial/Industrial Property Damage States Following Earthquake

Earthquake Scenario	Damage State									
	None		Light		Moderate		Extensive		Complete	
	No.	%	No.	%	No.	%	No.	%	No.	%
1	1809	69.5	618	23.8	122	4.7	46	1.8	7	0.2
2	168	6.5	1038	39.9	631	24.2	439	16.9	327	12.5

Properties in the extensive or complete damage state are likely to be "red tagged" (ie classified as unsafe) and vacated for a significant period following the earthquake.

13.6 Repair Costs for Residential Properties (Table B-3)

The cost of repair of earthquake damage to residential property is estimated to be $29.4 million for Scenario 1 and $765.6 million for Scenario 2.

13.7 Repair Costs for Commercial and Industrial Properties (Table B-4)

The cost of repair of earthquake damage to commercial and industrial property is estimated to be $149 million for Scenario 1 and $1,486 million for Scenario 2.

13.8 Casualties (Tables B-5 and B-6)

Estimated casualties in Wellington City from building damage only (ie excluding casualties from damage to other structures, associated causes and freak events) are shown in Table 13.3.

Table 13.3 Casualties

Casualty Severity	Earthquake Scenario			
	1		2	
	Daytime	Nighttime	Daytime	Nighttime
Minor	123	4	1897	123
Moderate	30	1	651	38
Severe	15	1	300	13
Fatal	11	1	346	24
Trapped in collapsed buildings	48	1	1283	75

Note: The casualty levels include those casualties resulting from entrapment, assuming rescue capabilities and response time. Entrapment numbers are presented to enable rescue planning.

A large proportion (40%) of the nighttime casualties are expected to be caused by damage to multi-unit and apartment type of residential buildings (refer to Table B-7). These buildings are commonly multistorey and are of heavy construction and expected to have higher damage and higher casualty rates for given damage states, than typical houses which will usually be single storey and of light timber frame construction.

14 CRITICAL FACILITIES

The critical facilities included in this study are:

Civil Defence Headquarters buildings
Hospitals which have operating/critical care facilities
Police stations (not including community police offices)
Fire Stations
Ambulance buildings

The New Zealand loadings code (NZS 4203) requires buildings which are dedicated to the preservation of human life, which include the critical facilities listed above, to be designed for higher than normal earthquake loads. Buildings for critical facilities which have been designed to NZS 4203 are therefore expected on average to have significantly less structural damage in an earthquake than ordinary commercial buildings. In addition to this, in recognition of their importance following an earthquake, many of the older buildings have had their earthquake resistance assessed and in some instances upgraded so that earthquake damage to these older buildings will on average be less than the general stock of buildings of similar age.

Because it was outside the scope of this study to inspect individual buildings, damage assessments have been based on building reports from the owner or Works Consultancy Services records where they were available. Where buildings construction data are not available conservative default values are used. It must be emphasised that the damage assessments are indicative only and may be substantially modified if detailed surveys and assessments of the buildings were to be made.

The ground shaking and liquefaction hazards for the facility locations were assessed from the Regional Council hazard maps. The building structural type data and the hazard data were then input in to the risk analysis model described in Section 12 of this report. The probabilities of the buildings being in one of the five damage states described in Section 8 were then evaluated for earthquake scenario 2.

The results of the analyses are shown in Table 14.1

Table 14.1: Estimated Damage to Critical Facilities in the Study Area for Earthquake Scenario 2

Facility	Estimated Probability of the buildings being in the following damage states (%)				
	None	Light	Moderate	Extensive	Complete
Wellington Central Police Stn	18	61	16	5	0
Wellington Hospital	0-10	7-55	20-35	10-45	0-25
Wellington Ambulance	10	55	25	10	0
Regional CD HQ	25.7	59.2	11.6	3.5	0
Wellington City CD HQ	0	18.7	34.1	37.0	10.2
City Fire Stn	3	44	32	17	4
Brooklyn Fire Stn	17	61	16	6	0
Kilbirnie Fire Stn	0	18	34	38	10
Newtown Fire Stn	5	48	29	15	3
Thorndon Fire Stn	8	51	26	13	2
Johnsonville Fire Stn	6	50	28	13	3
Khandallah Fire Stn	4	41	30	20	5
Newlands Fire Stn	6	50	28	13	3
Northland Fire Stn	0	23	34	33	9

15 CONCLUSIONS

15.1 Scope of Study

An assessment has been made of the risk to buildings, critical facilities and the population in Wellington City. Two earthquake scenarios were considered. Scenario 1 is a large distant shallow earthquake that would produce moderate levels of shaking in the Wellington Region. Scenario 2 is a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault that would produce severe levels of shaking and associated liquefaction and slope failure ground damage in Wellington.

The risk to buildings has been quantified by two methods. The first method was to assess the probability of the buildings being in one of five damage states ranging from no damage to collapsed. The second method was to estimate the cost of repair of the earthquake damage. The risk to critical facilities has been quantified by the first of the two methods.

The risk to the population has been quantified by estimating the numbers of deaths and injuries resulting from earthquake damage to buildings.

To quantify the geographic variation of risk, the study area has been divided into a number of sub-areas corresponding to the Valuation New Zealand roll areas.

While this study is based on the most up-to-date risk assessment methodologies and data available, the data is neither precise nor complete in some cases. In particular, comprehensive data is lacking for building structure types, building damage vulnerability and casualty rates. As a consequence the assessments made in this study are approximations only and will need to be reviewed and updated as new data become available from studies of the effects of past and future earthquakes.

15.2 Building Damage

The costs of repairing earthquake damaged buildings in the study area are estimated to be $178 million in Scenario 1 and $2252 million in Scenario 2. These costs represent respectively 1.6% and 20.4% of the total replacement cost of buildings in the study area.

The cost of repairing lifelines (eg roads, bridges, pipelines, etc) is not included in these estimates.

Damage to buildings is highest where the ground comprises soft alluvial soils or reclaimed ground. This type of ground will experience increased ground shaking intensity and greater susceptibility to settlement or slumping from soil liquefaction, all of which will increase building damage.

Analyses carried out for this study indicate that the probability of residential property located in soft soil zones having extensive or greater damage in Scenario 2 could be higher than 30% whereas the probability of extensive or greater damage to residential property located on firm ground is expected to be less than 10%. (For this study, extensive damage is defined as damage having a repair cost greater than 30% of the replacement cost of the building).

Compared to commercial/industrial properties, the mainly timber frame construction residential buildings have lower vulnerability to damage and a higher proportion are located on firm ground having relatively lower ground shaking intensity and low or zero susceptibility to liquefaction. Consequently the total cost of repair of residential property in the study area as a proportion of replacement cost at 0.5% for Scenario 1 and 12.0% for Scenarios 2 are lower than the equivalent costs for commercial/industrial property at 2.9% and 28.3%.

Similarly the relative risk to commercial/industrial and residential buildings is reflected in the probabilities of the different type of properties having extensive or greater damage. The probabilities for commercial/industrial buildings are 2% for scenario 1 and 26% for scenario 2, whereas the equivalent probabilities for residential buildings are 0.3% and 11.5%.

15.3 Casualties

Casualties caused by building collapses and other building damage if the earthquake occurs during daytime while people are at work, are estimated to be 11 dead and 168 injured for Scenario 1, and 346 dead and 2850 injured for scenario 2. Casualties if the earthquake occurs at nighttime while most people are at home are estimated to be less than 10% of the daytime casualties. Daytime and nighttime populations in the study area are estimated to be 157,346 and 134,940 respectively.

Casualties at night are low compared with daytime casualties for two reasons. Firstly, on average, residential buildings have lower damage than commercial and industrial buildings. Secondly, severely damaged houses, which are likely to be single storey timber frame construction, are less likely to cause injuries or fatalities than severely damaged commercial or industrial buildings which may be several storeys high and of heavy concrete or masonry construction.

Over 80% of the estimated nighttime fatalities result from damage to either commercial/industrial buildings or multi-unit and apartment type of residential buildings which are commonly multistorey and of heavy construction.

Casualties caused by damage to non-building structures and freak events similar to the San Francisco freeway structure collapse are excluded from the casualty estimates.

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APPENDIX A

Valuation New Zealand Building Inventory Data

and Department of Statistics Population Data

Table A1	Study Area 1 - Wellington City Residential Property in Each Age Group
Table A2	Study Area 1 - Wellington City Commercial and Industrial Property in each Construction Category
Table A3	Study Area 1 - Wellington City Day and Nighttime Populations

TABLE A-1 STUDY AREA 1 -WELLINGTON CITY
RESIDENTIAL PROPERTY IN EACH AGE GROUP

(Note: area given corresponds to floor area in square metres)

Val NZ ROLL No.	Pre 1940		1940 - 1970		Post 1970		Undefined Age		TOTALS	
	No.	Area	No	Area	No	Area	No	Area	No	Area
16690	24	2618	50	5121	15	1857	7	1197	96	10793
16700	0	0	0	0	0	0	0	0	0	0
16701	7	843	35	4567	283	61523	5	802	330	67735
16702	0	0	129	22479	643	91359	2	437	774	114276
16719	0	0	1	173	310	36893	2	227	313	37293
16720	1	141	0	0	295	33214	0	0	296	33354
16730	6	549	71	9721	167	22198	0	0	244	32468
16740	102	11344	670	84966	317	46830	35	5948	1124	149087
16750	140	17617	553	74535	791	110960	38	6970	1523	210082
16751	3	290	1	87	1	203	0	0	6	580
16760	76	9914	465	54532	468	59526	10	1631	1019	125603
16770	5	692	600	72742	248	33260	3	997	857	107691
16780	27	2784	745	98445	284	37732	13	2593	1070	141554
16790	26	3672	138	18547	452	80715	3	560	619	103493
16800	104	21382	148	27878	516	92872	22	4218	791	146351
16810	283	45273	367	62115	270	48989	73	15950	993	172327
16820	363	53994	476	80867	288	62369	51	12022	1178	209252
16830	185	22903	363	54505	427	59499	20	4098	995	141005
16840	373	49294	440	55650	144	20433	38	7239	995	132615
16850	620	104291	165	25308	88	14907	68	12912	941	157418
16860	162	22382	657	89566	282	36716	27	6931	1128	155595
16880	643	115215	53	6598	50	7413	42	10048	788	139273
16890	384	51282	228	30896	125	20621	6	1036	743	103835
16900	246	34962	81	10359	17	2220	8	1729	353	49270
16910	431	66845	271	43475	139	22900	32	7446	873	140666
16920	230	29209	370	48496	540	76133	19	3575	1159	157413
16930	425	73154	205	35151	56	9409	66	12619	752	130333
16940	375	55620	288	47688	265	44979	7	1330	934	149618
16950	153	20856	287	40581	437	59249	8	1773	885	122458
16970	189	20577	97	12767	44	5545	18	2708	348	41597
16980	507	67552	68	10743	350	47669	25	4443	950	130407
16990	410	52477	63	11687	65	8694	17	2788	554	75646
17000	459	57085	592	79753	280	33320	23	4276	1354	174434
17010	59	6032	129	14951	203	25553	0	0	391	46536
17020	552	75296	34	5206	34	4550	14	3192	634	88243
17030	565	76457	183	25223	153	22657	74	13414	976	137750
17040	200	26299	224	28868	367	58144	14	2831	805	116143
17050	124	13376	114	13870	80	11799	13	3411	331	42456
17060	338	54327	82	19840	75	12923	33	6553	529	93643
17070	771	120707	257	36020	120	17347	17	4075	1165	178149
17080	466	71131	75	14038	109	10320	15	3538	665	99027
17090	136	18198	21	9264	18	1346	3	634	178	29441
17100	724	97806	163	21007	71	10042	18	3631	976	132485
17110	600	70816	50	9764	60	10296	15	4100	725	94977
17120	469	58839	48	5166	196	17279	18	3131	731	84415
17130	179	23460	293	36750	422	66595	14	4314	907	131120
17140	321	43037	207	30590	85	12568	47	7814	661	94008
17150	404	49612	195	29515	186	19910	18	3768	804	102806
17160	717	86298	62	8913	73	8403	27	6722	880	110335
17170	185	26340	175	29499	153	30618	39	7065	553	93522
17180	272	42077	130	20518	83	12465	39	7852	524	82912
17190	231	29317	673	82207	132	20261	8	2737	1045	134522
17220	197	41315	12	8783	147	17188	2	731	359	68017
17230	368	49094	24	7664	136	14670	5	634	533	72061
17240	465	84385	43	25533	102	16975	52	9395	663	136288
17250	508	65288	31	5691	40	11150	14	2711	592	84841
17260	2	103	3	377	0	0	0	0	5	480
17261	0	0	0	0	39	5645	0	0	39	5645
17270	13	1085	9	1414	6	2856	27	4669	54	10023
17280	2	327	0	0	2	125	0	0	3	452
17290	137	21095	17	21133	41	21662	7	17000	203	80890
17300	528	90778	50	19064	117	21538	0	0	695	131380
17310	627	98146	63	18798	161	18407	13	2218	864	137568
17320	517	66821	35	6923	104	9392	30	3909	686	87045
17330	394	47275	14	1006	10	1852	8	835	426	50968
17340	475	60707	44	11068	136	26040	8	12706	663	110520
17350	509	66816	16	13282	52	4600	48	7550	625	92248
17360	613	66318	76	16534	72	20737	45	5599	806	109187
TOTAL	19631	2763796	12229	1818473	12440	1856119	1377	295239	45678	6733627

TABLE A-2 STUDY AREA 1 -WELLINGTON CITY
COMMERCIAL and INDUSTRIAL PROPERTY IN EACH CONSTRUCTION CATEGORY

(Note: area given corresponds to floor area in square metres)

Val NZ ROLL No.	GROUP FLOOR AREAS: Group1 Construction Category: weighted total **	Group1: Floor Area Com	Group1: Floor Area Indust	Group 2 Construction Category: weighted total **	Group 2: Floor Area Com	Group 2: Floor Area Indust	Group 3 Construction Category: weighted total **	Group 3: Floor Area Com	Group 3: Floor Area Indust	TOTAL COMMERCIAL + INDUSTRIAL: Number Properties	TOTAL: weighted total **	TOTAL: Floor Area Com	TOTAL: Floor Area Indust	OTHER COMMERCIAL + INDUSTRIAL (Not Identified by Age in Val NZ data): Number Properties	OTHER: weighted total **	OTHER: Floor Area Com	OTHER: Floor Area Indust
16690	7885	168	33118	1476	56	6093	288	0	1236	189	9648	224	40446	34	3308	299	12915
16700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16701	1789	0	7679	2330	1563	3291	0	0	0	3	4119	1563	10970	0	0	0	0
16702	0	0	0	72	0	310	0	0	0	1	72	0	310	1	536	0	2299
16719	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16730	4664	1021	15637	9801	4083	24542	0	0	0	38	14465	5103	40179	0	0	0	0
16740	4138	3099	4460	5911	3487	10406	1163	0	4991	31	11212	6586	19856	6	7667	433	31049
16750	446	446	0	2035	1840	837	0	0	0	7	2481	2286	837	1	53	0	226
16751	6063	5383	2921	21359	19223	9166	160	160	0	52	27582	24765	12087	16	10554	9357	5136
16760	0	0	0	4800	4800	0	0	0	0	3	4800	4800	0	1	617	617	0
16770	593	477	497	3816	3435	1634	0	0	0	20	4408	3912	2132	2	791	791	0
16780	0	0	0	1005	972	140	0	0	0	4	1005	972	140	1	886	886	0
16790	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16800	0	0	0	365	365	0	0	0	0	1	365	365	0	1	471	471	0
16810	1264	1264	0	0	0	0	220	194	114	7	1484	1457	114	3	2277	2277	0
16820	0	0	0	5354	306	21669	1130	0	4849	19	6484	306	26518	11	5261	2139	13397
16830	1971	1971	0	0	0	0	0	0	0	10	1971	1971	0	1	287	287	0
16840	418	418	0	418	418	0	129	129	0	7	965	965	0	2	575	518	247
16850	0	0	0	145	0	624	3200	555	11348	14	3345	555	11971	3	2147	465	7221
16860	0	0	0	626	626	0	0	0	0	2	626	626	0	0	0	0	0
16880	1082	1082	0	0	0	0	0	0	0	5	1082	1082	0	8	2178	2178	0
16890	856	856	0	1427	1427	0	571	571	0	2	2855	2855	0	2	330	265	277
16900	81	81	0	963	963	0	1044	1044	0	9	2089	2089	0	0	0	0	0
16910	1521	1381	599	235	235	0	216	216	0	12	1972	1832	599	5	1339	1339	0
16920	599	599	0	3264	3264	0	349	349	0	10	4213	4213	0	1	169	169	0
16930	423	423	0	1231	1231	0	0	0	0	4	1654	1654	0	6	2022	2022	0
16940	0	0	0	729	729	0	0	0	0	2	729	729	0	1	844	844	0
16950	977	977	0	62	0	265	0	0	0	2	1039	977	265	2	2388	2388	0
16970	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16980	0	0	0	0	0	0	565	565	0	1	565	565	0	1	323	323	0
16990	756	756	0	2196	2196	0	701	701	0	9	3653	3653	0	6	2674	2674	0
17000	0	0	0	1039	828	907	0	0	0	5	1039	828	907	1	181	181	0
17010	0	0	0	0	0	0	288	288	0	2	288	288	0	2	127	0	546
17020	1686	1686	0	3660	3660	0	2997	2997	0	24	8343	8343	0	4	923	923	0
17030	152	0	652	958	467	2106	1813	1664	638	32	2923	2131	3396	3	752	752	0
17040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17050	0	0	0	261	261	0	677	677	0	2	939	939	0	1	820	820	0
17060	0	0	0	5537	5537	0	171	171	0	3	5708	5708	0	0	0	0	0
17070	722	722	0	564	564	0	2041	2041	0	14	3327	3327	0	1	334	334	0
17080	247	247	0	0	0	0	741	741	0	5	988	988	0	2	1241	1241	0
17090	6099	5118	4214	12614	12312	1296	1373	1286	374	74	20086	18715	5883	6	1704	934	3303
17100	0	0	0	2442	1924	2222	504	504	0	6	2946	2428	2222	3	1890	1890	0
17110	966	130	3588	20542	6819	58898	7912	130	33396	62	29420	7079	95883	16	9801	249	40993
17120	606	606	0	36	0	156	152	152	0	6	794	758	156	6	1355	1337	78
17130	757	757	0	0	0	0	482	482	0	2	1239	1239	0	1	356	356	0
17140	621	621	0	0	0	0	0	0	0	3	621	621	0	1	598	598	0
17150	8154	3046	21925	12029	6386	24221	1954	1617	1444	68	22137	11049	47589	16	8714	2769	25517
17160	927	927	0	0	0	0	1103	1103	0	9	2030	2030	0	2	276	192	361
17170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17180	1386	1290	413	0	0	0	553	553	0	9	1939	1843	413	2	704	704	0
17190	579	478	437	1680	1680	0	15	0	64	10	2274	2158	501	0	0	0	0
17220	0	0	0	154132	141727	53239	11521	10752	3301	78	165653	152479	56540	12	9136	4892	18214
17230	5392	5392	0	51506	51339	717	1088	1088	0	53	57987	57819	717	7	109732	108537	5129
17240	5866	5866	0	94832	94832	0	3921	3921	0	88	104619	104619	0	12	28836	28836	0
17250	4093	4093	0	2169	2169	0	866	866	0	26	7128	7128	0	0	0	0	0
17260	1058	802	1097	1179857	1179602	1097	50212	48670	6617	204	1231127	1229074	8811	19	155756	153907	7937
17261	0	0	0	24531	24311	946	23756	23756	0	20	48287	48066	946	3	32762	32762	0
17270	12902	12601	1292	442784	441802	4212	60787	59884	3876	227	516473	514288	9381	66	183038	181284	7525
17280	1038	838	858	126676	120325	27256	69717	67919	7719	161	197431	189082	35833	31	51155	44615	28071
17290	986	809	756	101943	86981	64218	21870	19573	9858	219	124799	107363	74832	33	11835	4736	30470
17300	4146	4146	0	14731	14731	0	5076	5034	179	29	23953	23911	179	4	836	836	0
17310	1934	1857	332	22363	20518	7917	13030	12639	1678	74	37327	35014	9927	16	12068	9760	9903
17320	1496	750	3201	15531	1537	60059	2439	1767	2882	78	19466	4054	66142	13	8320	3546	20489
17330	4438	4438	0	6804	6804	0	899	899	0	29	12141	12141	0	0	0	0	0
17340	1895	1159	3159	15841	13797	8772	3497	2818	2912	39	21232	17774	14843	2	598	598	0
17350	2749	2749	0	7758	6141	6940	6310	5213	4707	44	16817	14104	11647	11	4940	4940	0
17360	1035	1035	0	572	445	545	726	690	156	17	2334	2171	701	4	1569	1569	0
TOTAL	107458	82566	106834	2393014	2298718	404703	308226	284380	102340	2184	2808698	2665665	613877	418	688054	624840	271304

** For weighted floor area, Industrial floor area has been weighted by a factor of 0.233 to reflect its value relative to commercial floor area.

TABLE A-3 STUDY AREA 1 -WELLINGTON CITY DAY and NIGHTTIME POPULATIONS

Val NZ ROLL No.	TOTAL POPULATION	
	DAY **	NIGHT
16690	537	1248
16700	0	0
16701	395	877
16702	799	1987
16719	217	814
16720	91	274
16730	496	1093
16740	2081	3552
16750	2104	3534
16751	1749	163
16760	1384	3091
16770	1357	2264
16780	1627	2544
16790	809	1773
16800	959	1692
16810	1825	2316
16820	2018	2376
16830	1508	1791
16840	1882	3000
16850	1461	2460
16860	952	1719
16880	1381	2090
16890	2150	4077
16900	698	1381
16910	1832	2551
16920	1783	3030
16930	1715	2087
16940	2147	2789
16950	971	1562
16970	354	627
16980	1246	2442
16990	1250	1897
17000	1803	3235
17010	412	808
17020	1343	2111
17030	1835	2717
17040	1097	2153
17050	591	911
17060	903	1502
17070	2068	3021
17080	1321	2141
17090	1327	672
17100	1769	2955
17110	3566	2539
17120	1310	1912
17130	1943	2967
17140	802	1381
17150	3008	2819
17160	1629	2313
17170	1021	1616
17180	1061	1613
17190	2224	3320
17220	6131	1049
17230	5077	1493
17240	15877	3851
17250	1037	1387
17260	16661	232
17261	2270	42
17270	11758	341
17280	4343	63
17290	5440	2485
17300	1915	2681
17310	2422	3042
17320	2891	2035
17330	3895	2274
17340	2368	2816
17350	3114	3621
17360	1340	1722
TOTAL	157346	134940

** The Daytime population includes an allowance for under 15 population based on the primary school population in the study area

APPENDIX B

Risk Analysis Results

TABLE B-1: STUDY AREA 1 -WELLINGTON CITY DAMAGE TO RESIDENTIAL PROPERTY

Val NZ Roll No.	SCENARIO 1						SCENARIO2					
	Mean Damage Ratio (%)	No. PROPERTIES IN DAMAGE STATE					Mean Damage Ratio (%)	No. PROPERTIES IN DAMAGE STATE				
		None	Light	Moderate	Extensive	Comple		None	Light	Moderate	Extensive	Comple
16690	0.12	93	2.1	0.2	0.06	0.00	8.73	15.4	57.2	16.4	6.21	0.60
16700	0.00	0	0.0	0.0	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00
16701	0.17	319	10.3	1.1	0.26	0.00	11.08	42.1	187.7	68.0	28.66	3.63
16702	0.12	755	16.9	1.8	0.46	0.00	8.41	128.2	464.9	128.5	47.90	4.33
16719	0.09	307	5.1	0.5	0.13	0.00	6.85	58.8	193.9	44.7	14.80	0.75
16720	0.09	290	4.9	0.5	0.12	0.00	6.69	56.3	184.0	41.5	13.56	0.62
16730	0.10	239	4.5	0.5	0.12	0.00	8.17	41.3	147.3	39.7	14.55	1.24
16740	0.14	1091	28.8	3.0	0.79	0.00	10.01	160.6	653.4	213.5	86.32	10.00
16750	0.11	1489	30.6	3.2	0.76	0.00	8.01	261.1	922.6	243.9	88.50	7.31
16751	0.10	6	0.1	0.0	0.00	0.00	7.83	1.0	3.5	0.9	0.33	0.03
16760	0.09	1000	16.7	1.7	0.41	0.00	7.26	185.6	626.6	151.7	52.09	3.36
16770	0.09	841	14.1	1.5	0.34	0.00	6.88	160.6	530.6	122.7	40.69	2.14
16780	0.10	1048	19.6	2.0	0.53	0.00	7.56	190.2	653.7	164.0	57.66	4.17
16790	0.12	604	13.6	1.4	0.37	0.00	8.69	100.1	369.8	105.4	39.93	3.84
16800	0.17	763	24.6	2.6	0.63	0.00	11.86	92.1	442.0	172.1	74.41	9.96
16810	0.20	952	36.2	3.8	0.99	0.00	13.65	92.4	531.5	241.4	109.70	17.57
16820	0.14	1144	30.1	3.2	0.82	0.00	10.98	152.0	670.9	240.8	101.16	12.72
16830	0.11	973	20.0	2.1	0.50	0.00	8.46	164.2	597.4	166.0	62.01	5.67
16840	0.14	966	25.5	2.7	0.70	0.00	10.10	140.8	577.3	190.3	77.28	9.05
16850	0.16	910	27.5	2.9	0.75	0.00	11.07	120.3	535.3	193.8	81.72	10.36
16860	0.12	1100	24.7	2.6	0.68	0.00	8.55	184.6	675.6	189.6	71.27	6.65
16880	0.16	762	23.0	2.4	0.63	0.00	12.04	89.9	439.0	173.7	75.52	10.25
16890	0.14	722	19.0	2.0	0.52	0.00	10.55	100.5	427.3	147.2	60.87	7.43
16900	0.14	342	9.0	1.0	0.25	0.00	10.48	48.0	203.0	69.5	28.63	3.46
16910	0.25	827	39.9	4.2	1.05	0.00	15.34	65.2	444.7	231.6	109.24	21.90
16920	0.18	1116	38.1	4.1	1.04	0.00	11.68	138.1	650.6	249.2	107.23	14.26
16930	0.23	716	31.6	3.3	0.83	0.00	14.82	60.5	389.1	194.4	90.75	17.22
16940	0.22	892	37.6	3.9	1.03	0.00	13.47	88.9	502.8	225.1	101.75	15.88
16950	0.12	863	19.4	2.0	0.53	0.00	8.53	145.2	530.6	148.5	55.77	5.22
16970	0.13	339	8.3	0.9	0.21	0.00	9.50	52.2	204.5	63.5	25.10	2.72
16980	0.12	926	20.8	2.2	0.57	0.00	9.05	148.7	563.3	166.8	64.39	6.55
16990	0.13	539	13.2	1.4	0.33	0.00	9.74	81.3	324.2	103.1	41.19	4.60
17000	0.11	1323	27.2	2.8	0.68	0.00	8.23	227.8	816.5	221.3	81.52	7.04
17010	0.20	375	14.3	1.5	0.39	0.00	12.61	41.4	215.0	89.5	39.56	5.55
17020	0.22	606	25.5	2.7	0.70	0.00	13.32	61.3	342.8	151.6	68.26	10.34
17030	0.32	911	57.1	6.1	1.46	0.00	11.69	116.0	547.6	209.9	90.37	12.00
17040	0.11	787	16.2	1.7	0.40	0.00	8.04	137.6	487.3	129.2	47.01	3.94
17050	0.12	322	7.2	0.8	0.20	0.00	8.74	53.2	197.3	56.5	21.45	2.08
17060	0.14	513	13.5	1.4	0.37	0.00	10.37	72.8	305.2	103.3	42.41	5.08
17070	0.21	1115	44.8	4.7	1.17	0.00	10.44	159.4	671.5	228.9	94.28	11.30
17080	0.25	631	30.4	3.2	0.80	0.00	14.12	58.5	351.3	165.9	76.21	13.17
17090	0.44	162	14.3	1.5	0.37	0.00	15.07	13.8	91.5	46.6	21.88	4.26
17100	0.17	941	30.3	3.2	0.78	0.00	12.46	105.4	538.3	221.1	97.36	13.56
17110	5.24	197	421.4	81.6	24.35	0.43	27.95	0.0	236.5	253.6	182.34	52.25
17120	4.54	247	392.5	70.5	20.76	0.29	26.16	0.0	256.5	257.0	168.80	48.83
17130	0.14	881	23.2	2.5	0.64	0.00	9.46	136.8	533.7	165.0	65.06	6.99
17140	0.14	642	16.9	1.8	0.46	0.00	9.69	97.4	386.7	122.4	48.76	5.42
17150	3.87	322	397.2	65.2	18.81	0.24	21.51	5.9	333.9	278.2	143.95	41.80
17160	6.37	171	550.1	119.2	37.64	1.32	31.58	0.0	243.5	304.8	258.23	72.82
17170	0.15	536	15.1	1.6	0.39	0.00	10.19	77.5	320.2	106.5	43.39	5.08
17180	4.15	196	268.2	45.8	13.36	0.21	21.07	6.4	221.1	178.2	91.76	26.24
17190	0.26	988	49.6	5.2	1.36	0.00	10.96	135.1	595.3	213.3	89.52	11.28
17220	0.56	317	36.7	3.9	0.97	0.00	15.06	27.9	184.2	93.8	44.02	8.57
17230	0.61	466	59.4	6.2	1.55	0.00	19.39	16.3	238.7	169.7	85.62	22.82
17240	0.54	589	65.4	6.9	1.72	0.00	14.15	58.1	349.7	165.6	76.15	13.19
17250	0.25	562	27.1	2.8	0.71	0.00	12.22	66.0	328.6	132.1	57.76	7.94
17260	0.62	4	0.6	0.1	0.02	0.00	17.32	0.3	2.5	1.5	0.73	0.17
17261	6.21	8	24.6	5.2	1.62	0.04	39.70	0.0	6.6	13.2	15.01	4.31
17270	0.74	46	7.3	0.8	0.20	0.00	22.16	0.0	22.0	19.2	10.02	2.98
17280	4.36	1	1.6	0.3	0.08	0.00	31.12	0.0	0.9	1.1	0.90	0.25
17290	0.48	183	17.8	1.9	0.47	0.00	14.79	16.3	104.9	52.3	24.39	4.60
17300	0.15	673	19.0	2.0	0.49	0.00	10.62	93.2	398.9	138.3	57.32	7.02
17310	0.17	834	26.9	2.9	0.69	0.00	11.30	107.5	488.8	180.8	76.80	9.93
17320	0.30	644	37.6	4.0	0.96	0.00	12.16	77.1	381.1	152.4	66.56	9.06
17330	0.68	366	53.0	5.6	1.41	0.00	15.75	29.9	214.6	115.4	54.92	11.47
17340	0.21	634	25.5	2.7	0.66	0.00	12.89	67.6	362.5	154.6	68.84	9.75
17350	0.18	601	20.6	2.2	0.56	0.00	12.61	66.1	343.6	143.0	63.22	8.87
17360	0.18	776	26.5	2.8	0.73	0.00	12.77	83.5	441.5	186.3	82.74	11.68
TOTAL		41504	3480	538	154	2.54		5582	25265	9729	4386	715.17

TABLE B-2: STUDY AREA 1 -WELLINGTON CITY
DAMAGE TO COMMERCIAL and INDUSTRIAL PROPERTY

(a) By VNZ Roll Area

Val NZ Roll No.	SCENARIO 1 Mean Damage Ratio (%)	No. OF NOTIONAL BUILDINGS* IN DAMAGE STATE (ALL 3 CONSTRUCTION GROUPS) None	Light	Moderate	Extensive	Comple	SCENARIO2 Mean Damage Ratio (%)	No. OF NOTIONAL BUILDINGS* IN DAMA((ALL 3 CONSTRUCTION GROUP: None	Light	Moderate	Extensive
16690	0.08	218.8	3.4	0.4	0.1	0.0	6.62	45.5	136.3	30.1	10.1
16700	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
16701	0.01	2.7	0.0	0.0	0.0	0.0	4.17	1.0	1.4	0.2	0.1
16702	0.00	2.3	0.0	0.0	0.0	0.0	4.75	0.7	1.3	0.2	0.1
16719	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
16720	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
16730	1.30	27.7	9.0	0.9	0.2	0.0	19.61	2.0	16.8	11.1	6.3
16740	0.20	35.2	1.3	0.1	0.0	0.0	9.72	8.8	18.7	5.8	2.9
16750	0.10	7.8	0.1	0.0	0.0	0.0	9.03	1.2	4.7	1.4	0.5
16751	0.06	67.4	0.7	0.1	0.0	0.0	6.90	15.4	39.8	9.4	3.3
16760	0.04	4.6	0.0	0.0	0.0	0.0	6.85	0.9	2.9	0.7	0.2
16770	0.03	21.8	0.1	0.0	0.0	0.0	7.31	4.5	13.0	3.2	1.1
16780	0.04	5.4	0.0	0.0	0.0	0.0	7.02	1.0	3.3	0.8	0.3
16790	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
16800	0.27	2.2	0.1	0.0	0.0	0.0	18.67	0.1	1.1	0.7	0.4
16810	0.35	9.5	0.6	0.1	0.0	0.0	16.48	1.0	5.1	2.4	1.4
16820	4.33	12.1	14.1	2.6	0.8	0.0	33.55	0.0	8.5	9.3	8.4
16830	0.02	10.7	0.0	0.0	0.0	0.0	5.77	2.4	6.6	1.3	0.4
16840	0.34	8.7	0.6	0.1	0.0	0.0	18.85	0.7	4.3	2.5	1.5
16850	1.19	12.8	3.7	0.4	0.1	0.0	34.96	0.1	3.9	5.7	5.7
16860	0.14	2.3	0.1	0.0	0.0	0.0	14.04	0.2	1.2	0.6	0.3
16880	0.13	12.4	0.3	0.0	0.0	0.0	9.41	1.9	7.5	2.3	0.9
16890	0.22	4.6	0.2	0.0	0.0	0.0	22.02	0.3	2.0	1.3	0.9
16900	0.41	8.5	0.7	0.1	0.0	0.0	21.78	0.9	3.8	2.3	1.9
16910	0.35	15.2	1.1	0.1	0.0	0.0	17.17	1.4	8.1	4.1	2.4
16920	0.33	10.1	0.7	0.1	0.0	0.0	19.28	0.6	4.9	3.1	1.7
16930	0.23	9.3	0.4	0.0	0.0	0.0	16.41	0.6	4.8	2.7	1.3
16940	0.09	3.4	0.1	0.0	0.0	0.0	9.22	0.5	2.1	0.6	0.2
16950	0.01	4.8	0.0	0.0	0.0	0.0	4.08	2.0	2.3	0.4	0.1
16970	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
16980	0.67	2.0	0.3	0.0	0.0	0.0	35.10	0.0	0.5	0.8	0.8
16990	0.21	14.2	0.6	0.1	0.0	0.0	15.08	2.1	7.1	3.3	1.9
17000	0.11	5.5	0.1	0.0	0.0	0.0	11.05	0.7	3.2	1.2	0.5
17010	1.35	2.2	0.7	0.1	0.0	0.0	51.07	0.0	0.2	0.9	1.3
17020	0.58	25.4	3.1	0.3	0.1	0.0	26.31	1.8	10.9	7.4	6.5
17030	1.75	23.8	10.0	1.2	0.3	0.0	38.69	1.1	8.2	9.5	11.6
17040	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
17050	1.05	2.8	0.7	0.1	0.0	0.0	39.95	0.0	0.7	1.1	1.3
17060	0.10	3.4	0.1	0.0	0.0	0.0	9.82	0.5	2.0	0.6	0.3
17070	7.65	3.9	7.9	2.2	0.9	0.1	59.18	0.0	2.0	2.6	5.0
17080	6.35	2.1	3.6	0.9	0.3	0.0	60.76	0.0	0.7	1.1	2.8
17090	0.93	65.7	12.4	1.5	0.4	0.0	15.98	7.2	40.6	19.3	10.5
17100	0.29	8.6	0.5	0.1	0.0	0.0	15.29	1.3	4.7	1.7	1.1
17110	7.70	20.2	41.1	11.3	4.4	0.6	34.96	0.2	22.2	23.1	22.0
17120	10.10	1.8	6.3	2.0	0.9	0.2	35.83	0.0	3.1	3.3	3.2
17130	0.50	3.1	0.3	0.0	0.0	0.0	23.27	0.3	1.4	0.8	0.7
17140	0.25	4.2	0.2	0.0	0.0	0.0	14.24	0.4	2.3	1.1	0.5
17150	5.46	30.3	41.0	8.8	3.1	0.4	22.39	3.7	36.1	23.5	14.9
17160	16.75	1.0	5.4	2.9	1.6	0.4	52.40	0.0	1.8	2.3	4.1
17170	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
17180	11.95	1.5	6.1	2.2	1.1	0.2	40.56	0.0	2.7	3.1	3.4
17190	0.68	8.8	1.3	0.1	0.0	0.0	16.49	0.7	5.1	2.9	1.4
17220	3.78	38.7	41.8	6.9	2.1	0.1	31.10	0.0	27.5	29.6	23.5
17230	1.51	41.7	15.9	1.8	0.5	0.0	19.10	2.5	27.3	18.0	9.4
17240	0.54	88.9	9.7	1.0	0.3	0.0	11.74	13.0	55.8	20.2	9.4
17250	0.86	21.8	3.6	0.4	0.1	0.0	18.14	2.3	12.5	6.3	3.9
17260	1.60	152.3	61.8	6.9	1.8	0.0	22.71	3.1	91.1	73.5	41.6
17261	24.17	1.5	8.8	6.2	5.1	1.3	79.16	0.0	1.5	3.6	4.7
17270	1.61	205.7	75.2	9.4	2.5	0.0	25.33	6.5	114.6	88.7	59.7
17280	10.25	42.3	96.7	34.9	15.2	3.3	45.71	0.0	46.4	46.8	47.4
17290	1.80	172.2	67.9	9.2	2.5	0.0	23.73	12.6	103.7	69.0	49.0
17300	0.36	29.8	2.1	0.2	0.1	0.0	18.91	2.8	15.0	7.8	5.2
17310	0.86	74.2	14.3	1.5	0.4	0.0	26.31	3.8	33.1	26.2	20.8
17320	1.36	67.6	20.2	2.4	0.6	0.0	21.36	5.1	39.8	24.9	15.9
17330	2.71	15.1	11.5	1.5	0.4	0.0	24.25	0.3	11.2	9.4	5.7
17340	0.41	37.8	3.1	0.3	0.1	0.0	15.03	5.2	21.2	8.4	5.2
17350	0.43	50.0	4.4	0.5	0.1	0.0	21.03	4.6	23.5	13.8	10.5
17360	0.55	18.8	2.1	0.2	0.1	0.0	23.81	1.3	8.5	5.6	4.4
TOTAL		1809	618	122	46	7		177	1093	664	462

* NOTIONAL BUILDING = A building with the average weighted floor area for all buildings in a VNZ roll area . Industrial floor area weighted by a factor of 0.233 to reflect its value relative to commercial floor area. For Group results the N building area is based on the average weighted area of all buildings in the group so that the distribution of number of buildings differs.

TABLE B-2: STUDY AREA 1 -WELLINGTON CITY
DAMAGE TO COMMERCIAL and INDUSTRIAL PROPERTY

(b) By Construction Group

CONST GROUP No.	SCENARIO 1						SCENARIO2				
	Mean Damage Ratio (%)	No. OF NOTIONAL BUILDINGS IN DAMAGE STATE					Mean Damage Ratio (%)	No. OF NOTIONAL BUILDINGS IN DAMAG			
		None	Light	Moderate	Extensive	Comple		None	Light	Moderate	Extensive
GROUP 1	0.97	471	86	11	3	0	13.23	77	291	130	61
GROUP 2	1.71	957	371	47	13	0	20.35	40	602	444	237
GROUP 3	11.18	169	290	112	59	13	70.14	0	23	91	254

NOTE: GROUP 1 = Light Timber Frame and Light Steel Frame with Light Cladding construction types only

GROUP 3 = Unreinforced Masonry only

GROUP 2 = All other 5 construction types considered

TABLE B-3: STUDY AREA 1 -WELLINGTON CITY LOSSES FOR RESIDENTIAL PROPERTY

Val NZ ROLL No.	SCENARIO 1 LOSS ($million)	SCENARIO 2 LOSS ($million)
16690	0.01	0.83
16700	0.00	0.00
16701	0.11	7.84
16702	0.12	9.51
16719	0.03	2.39
16720	0.02	1.96
16730	0.03	2.33
16740	0.16	12.31
16750	0.18	14.81
16751	0.00	0.04
16760	0.09	8.02
16770	0.08	6.52
16780	0.11	9.42
16790	0.12	9.40
16800	0.24	18.14
16810	0.33	24.58
16820	0.28	24.01
16830	0.15	12.47
16840	0.17	13.26
16850	0.24	18.21
16860	0.16	12.44
16880	0.21	17.52
16890	0.12	9.64
16900	0.06	4.54
16910	0.32	21.36
16920	0.24	17.19
16930	0.28	20.18
16940	0.30	19.95
16950	0.13	10.34
16970	0.05	3.69
16980	0.14	11.68
16990	0.08	6.89
17000	0.16	13.42
17010	0.07	4.84
17020	0.16	10.34
17030	0.35	14.17
17040	0.11	8.73
17050	0.04	3.27
17060	0.12	10.15
17070	0.34	18.41
17080	0.21	13.07
17090	0.11	4.15
17100	0.18	14.53
17110	3.73	21.90
17120	2.87	18.22
17130	0.17	12.28
17140	0.13	9.52
17150	3.18	19.46
17160	5.62	30.66
17170	0.12	8.91
17180	3.27	18.26
17190	0.26	12.16
17220	0.36	10.70
17230	0.42	14.60
17240	0.70	20.15
17250	0.16	8.55
17260	0.00	0.07
17261	0.30	2.10
17270	0.06	1.83
17280	0.01	0.12
17290	0.31	10.53
17300	0.19	14.58
17310	0.21	15.39
17320	0.20	8.73
17330	0.26	6.62
17340	0.17	11.75
17350	0.12	9.60
17360	0.16	12.27
TOTAL	29.37	765.55

TABLE B-4: STUDY AREA 1 -WELLINGTON CITY
LOSSES FOR COMMERCIAL and INDUSTRIAL PROPERTY

Val NZ ROLL No.	SCENARIO 1 LOSS ($million)	SCENARIO 2 LOSS ($million)
16690	0.02	1.42
16700	0.00	0.00
16701	0.00	0.28
16702	0.00	0.05
16719	0.00	0.00
16720	0.00	0.00
16730	0.28	4.68
16740	0.06	3.03
16750	0.00	0.38
16751	0.03	4.34
16760	0.00	0.61
16770	0.00	0.63
16780	0.00	0.22
16790	0.00	0.00
16800	0.00	0.26
16810	0.02	1.02
16820	0.76	6.50
16830	0.00	0.21
16840	0.01	0.48
16850	0.10	3.17
16860	0.00	0.14
16880	0.01	0.51
16890	0.01	1.16
16900	0.01	0.75
16910	0.02	0.94
16920	0.02	1.39
16930	0.01	1.00
16940	0.00	0.24
16950	0.00	0.23
16970	0.00	0.00
16980	0.01	0.51
16990	0.02	1.57
17000	0.00	0.22
17010	0.01	0.35
17020	0.08	4.02
17030	0.10	2.35
17040	0.00	0.00
17050	0.03	1.16
17060	0.01	0.92
17070	0.42	3.57
17080	0.21	2.23
17090	0.30	5.75
17100	0.02	1.22
17110	4.53	22.62
17120	0.33	1.27
17130	0.01	0.61
17140	0.00	0.29
17150	2.53	11.40
17160	0.58	1.99
17170	0.00	0.00
17180	0.47	1.77
17190	0.02	0.62
17220	9.90	89.68
17230	3.81	52.86
17240	1.08	25.85
17250	0.09	2.13
17260	33.21	519.78
17261	29.39	105.86
17270	16.85	292.39
17280	38.21	187.49
17290	3.68	53.51
17300	0.13	7.73
17310	0.64	21.44
17320	0.57	9.79
17330	0.49	4.86
17340	0.13	5.41
17350	0.14	7.55
17360	0.03	1.53
TOTALS	149	1486

TABLE B-5: STUDY AREA 1 -WELLINGTON CITY
DAYTIME CASUALTIES

(a) By VNZ Roll Area

Val NZ ROLL No.	SCENARIO 1 : DAY CASUALTY FIGURES					SCENARIO2 : DAY CASUALTY FIGURES				
	No. OF CASUALTIES WITH SEVERITY:					No. OF CASUALTIES WITH SEVERITY:				
	Level 1	Level 2	Level 3	Level 4	Entrapped **	Level 1	Level 2	Level 3	Level 4	Entrapped **
16690	0.00	0.00	0.00	0.00	0.00	0.27	0.06	0.03	0.02	0.10
16700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16701	0.00	0.00	0.00	0.00	0.00	0.10	0.02	0.00	0.01	0.02
16702	0.00	0.00	0.00	0.00	0.00	0.13	0.02	0.01	0.01	0.03
16719	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
16720	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
16730	0.02	0.00	0.00	0.00	0.00	1.61	1.14	0.24	0.95	2.39
16740	0.06	0.01	0.00	0.00	0.00	8.63	2.33	1.12	1.00	4.10
16750	0.00	0.00	0.00	0.00	0.00	0.40	0.10	0.02	0.07	0.17
16751	0.01	0.00	0.00	0.00	0.00	1.33	0.52	0.13	0.35	0.94
16760	0.00	0.00	0.00	0.00	0.00	0.23	0.06	0.01	0.04	0.09
16770	0.00	0.00	0.00	0.00	0.00	0.25	0.09	0.02	0.06	0.15
16780	0.00	0.00	0.00	0.00	0.00	0.24	0.05	0.01	0.03	0.07
16790	0.00	0.00	0.00	0.00	0.00	0.14	0.02	0.01	0.01	0.03
16800	0.00	0.00	0.00	0.00	0.00	0.43	0.13	0.03	0.10	0.26
16810	0.01	0.00	0.00	0.00	0.00	2.21	0.48	0.24	0.20	0.86
16820	0.87	0.18	0.07	0.06	0.23	21.47	7.81	3.32	4.45	15.41
16830	0.00	0.00	0.00	0.00	0.00	0.24	0.03	0.01	0.02	0.05
16840	0.01	0.00	0.00	0.00	0.00	1.22	0.32	0.13	0.17	0.60
16850	0.14	0.02	0.00	0.00	0.00	16.34	4.10	2.17	1.50	7.07
16860	0.00	0.00	0.00	0.00	0.00	0.22	0.06	0.02	0.05	0.12
16880	0.00	0.00	0.00	0.00	0.00	0.45	0.06	0.02	0.03	0.11
16890	0.01	0.00	0.00	0.00	0.00	4.22	1.31	0.56	0.69	2.47
16900	0.01	0.00	0.00	0.00	0.00	2.14	0.53	0.27	0.20	0.90
16910	0.01	0.00	0.00	0.00	0.00	2.10	0.45	0.19	0.21	0.83
16920	0.01	0.00	0.00	0.00	0.00	1.98	0.69	0.23	0.45	1.35
16930	0.00	0.00	0.00	0.00	0.00	1.40	0.49	0.11	0.37	1.00
16940	0.00	0.00	0.00	0.00	0.00	1.01	0.21	0.05	0.13	0.39
16950	0.00	0.00	0.00	0.00	0.00	0.18	0.04	0.01	0.02	0.06
16970	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.01	0.02
16980	0.01	0.00	0.00	0.00	0.00	1.43	0.34	0.17	0.13	0.57
16990	0.01	0.00	0.00	0.00	0.00	2.89	0.85	0.36	0.42	1.52
17000	0.00	0.00	0.00	0.00	0.00	0.36	0.09	0.02	0.06	0.17
17010	0.01	0.00	0.00	0.00	0.00	1.81	0.46	0.25	0.18	0.85
17020	0.05	0.01	0.00	0.00	0.00	10.45	2.81	1.49	1.14	5.14
17030	0.09	0.01	0.00	0.00	0.00	9.50	2.63	1.37	1.12	4.88
17040	0.00	0.00	0.00	0.00	0.00	0.16	0.02	0.01	0.01	0.03
17050	0.02	0.00	0.00	0.00	0.00	3.98	1.11	0.57	0.47	2.02
17060	0.00	0.00	0.00	0.00	0.00	0.62	0.19	0.06	0.12	0.35
17070	0.57	0.12	0.05	0.04	0.16	17.22	5.04	2.80	2.15	9.83
17080	0.29	0.06	0.02	0.02	0.07	11.83	3.22	1.84	1.26	6.16
17090	0.11	0.02	0.00	0.00	0.00	7.27	2.28	1.01	1.17	4.30
17100	0.01	0.00	0.00	0.00	0.00	2.88	0.75	0.36	0.33	1.36
17110	14.19	3.39	1.67	1.18	5.39	129.28	40.57	20.14	19.46	78.28
17120	0.61	0.15	0.08	0.05	0.25	5.05	1.17	0.58	0.52	2.28
17130	0.01	0.00	0.00	0.00	0.00	2.17	0.51	0.27	0.20	0.90
17140	0.00	0.00	0.00	0.00	0.00	0.19	0.03	0.01	0.01	0.04
17150	3.26	0.80	0.40	0.29	1.31	23.89	8.54	3.56	4.92	16.92
17160	1.99	0.49	0.26	0.18	0.83	13.23	3.30	1.79	1.34	6.36
17170	0.00	0.00	0.00	0.00	0.00	0.25	0.04	0.01	0.02	0.06
17180	0.88	0.22	0.12	0.08	0.37	5.84	1.47	0.80	0.59	2.82
17190	0.01	0.00	0.00	0.00	0.00	1.31	0.52	0.13	0.39	1.04
17220	3.35	0.69	0.24	0.22	0.83	106.13	46.41	16.96	30.42	94.31
17230	0.50	0.07	0.01	0.01	0.03	26.49	13.67	3.84	10.17	27.93
17240	0.63	0.09	0.01	0.01	0.01	44.22	15.97	5.56	9.67	30.02
17250	0.03	0.01	0.00	0.00	0.00	2.92	0.80	0.39	0.35	1.47
17260	2.37	0.34	0.04	0.03	0.07	173.42	82.10	26.75	57.13	166.75
17261	51.98	13.64	6.97	5.35	23.77	383.74	120.07	67.48	53.37	241.67
17270	2.93	0.44	0.08	0.06	0.14	231.67	83.28	36.09	46.60	163.81
17280	34.29	8.53	4.42	3.07	14.36	356.65	110.04	60.29	49.04	217.67
17290	1.62	0.25	0.04	0.03	0.08	94.29	31.21	14.22	16.19	59.98
17300	0.06	0.01	0.00	0.00	0.00	11.28	3.25	1.54	1.48	5.91
17310	0.28	0.04	0.00	0.00	0.00	34.04	10.31	4.84	4.92	19.11
17320	0.30	0.04	0.01	0.00	0.01	21.70	8.33	3.20	5.06	16.35
17330	1.42	0.28	0.10	0.08	0.32	41.44	15.40	6.24	9.10	30.50
17340	0.10	0.01	0.00	0.00	0.00	13.38	3.70	1.81	1.60	6.65
17350	0.18	0.03	0.00	0.00	0.00	30.66	8.07	4.05	3.24	14.09
17360	0.02	0.00	0.00	0.00	0.00	4.00	1.16	0.52	0.56	2.13
TOTALS	123.37	29.98	14.62	10.78	48.24	1896.68	650.82	300.34	346.06	1283.83

** The causulty levels include those casualties resulting from entrapment. Entrapment numbers are presented to enable rescue planning

TABLE B-5: STUDY AREA 1 -WELLINGTON CITY
DAYTIME CASUALTIES

(b) By Residential and Construction Group

CONST GROUP	SCENARIO 1 : DAY CASUALTY FIGURES					SCENARIO2 : DAY CASUALTY FIGURES				
	No. OF CASUALTIES WITH SEVERITY:					No. OF CASUALTIES WITH SEVERITY:				
	Level 1	Level 2	Level 3	Level 4	Entrapped **	Level 1	Level 2	Level 3	Level 4	Entrapped **
Residential	0.42	0.07	0.02	0.03	0.03	34.61	9.07	2.15	6.36	17.75
GROUP1	0.06	0.01	0.00	0.00	0.00	4.20	0.59	0.16	0.31	1.13
GROUP2	7.15	1.89	0.27	1.02	2.51	287.97	200.78	42.23	168.12	419.65
GROUP3	115.75	28.01	14.33	9.73	45.69	1569.90	440.38	255.80	171.27	845.30
TOTALS	123.37	29.98	14.62	10.78	48.24	1896.68	650.82	300.34	346.06	1283.83

NOTE: GROUP 1 = Light Timber Frame and Light Steel Frame with Light Cladding construction types only

GROUP 3 = Unreinforced Masonry only

GROUP 2 = All other 5 construction types considered

** The causulty levels include those casualties resulting from entrapment. Entrapment numbers are presented to enable rescue planning

TABLE B-6: STUDY AREA 1 -WELLINGTON CITY NIGHTTIME CASUALTIES

(a) By VNZ Roll Area

Val NZ ROLL No.	SCENARIO 1 : NIGHT CASUALTY FIGURES					SCENARIO 2 : NIGHT CASUALTY FIGURES				
	No. OF CASUALTIES WITH SEVERITY:					No. OF CASUALTIES WITH SEVERITY:				
	Level 1	Level 2	Level 3	Level 4	Entrapped **	Level 1	Level 2	Level 3	Level 4	Entrapped **
16690	0.00	0.00	0.00	0.00	0.00	0.23	0.03	0.01	0.02	0.05
16700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16701	0.00	0.00	0.00	0.00	0.00	0.25	0.04	0.01	0.02	0.06
16702	0.00	0.00	0.00	0.00	0.00	0.32	0.05	0.01	0.02	0.07
16719	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.00	0.01
16720	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
16730	0.00	0.00	0.00	0.00	0.00	0.41	0.21	0.05	0.17	0.42
16740	0.01	0.00	0.00	0.00	0.00	1.36	0.28	0.10	0.14	0.49
16750	0.00	0.00	0.00	0.00	0.00	0.56	0.11	0.03	0.06	0.17
16751	0.00	0.00	0.00	0.00	0.00	0.11	0.04	0.01	0.03	0.07
16760	0.00	0.00	0.00	0.00	0.00	0.34	0.05	0.02	0.03	0.07
16770	0.00	0.00	0.00	0.00	0.00	0.21	0.04	0.01	0.02	0.05
16780	0.00	0.00	0.00	0.00	0.00	0.31	0.05	0.01	0.02	0.07
16790	0.00	0.00	0.00	0.00	0.00	0.31	0.04	0.01	0.02	0.07
16800	0.00	0.00	0.00	0.00	0.00	0.64	0.15	0.04	0.10	0.28
16810	0.00	0.00	0.00	0.00	0.00	1.04	0.15	0.04	0.08	0.27
16820	0.04	0.01	0.00	0.00	0.01	1.93	0.81	0.23	0.59	1.63
16830	0.00	0.00	0.00	0.00	0.00	0.29	0.04	0.01	0.02	0.06
16840	0.00	0.00	0.00	0.00	0.00	0.75	0.11	0.03	0.06	0.19
16850	0.01	0.00	0.00	0.00	0.00	1.32	0.27	0.11	0.13	0.47
16860	0.00	0.00	0.00	0.00	0.00	0.35	0.08	0.02	0.06	0.15
16880	0.00	0.00	0.00	0.00	0.00	0.69	0.10	0.03	0.05	0.17
16890	0.00	0.00	0.00	0.00	0.00	1.55	0.45	0.12	0.32	0.87
16900	0.00	0.00	0.00	0.00	0.00	0.43	0.07	0.02	0.03	0.12
16910	0.00	0.00	0.00	0.00	0.00	1.59	0.26	0.07	0.15	0.50
16920	0.00	0.00	0.00	0.00	0.00	1.21	0.31	0.08	0.21	0.60
16930	0.00	0.00	0.00	0.00	0.00	1.30	0.28	0.07	0.19	0.55
16940	0.00	0.00	0.00	0.00	0.00	1.25	0.22	0.06	0.13	0.41
16950	0.00	0.00	0.00	0.00	0.00	0.26	0.04	0.01	0.02	0.06
16970	0.00	0.00	0.00	0.00	0.00	0.13	0.02	0.01	0.01	0.03
16980	0.00	0.00	0.00	0.00	0.00	0.50	0.08	0.02	0.04	0.12
16990	0.00	0.00	0.00	0.00	0.00	0.72	0.22	0.06	0.16	0.42
17000	0.00	0.00	0.00	0.00	0.00	0.52	0.09	0.02	0.05	0.14
17010	0.00	0.00	0.00	0.00	0.00	0.35	0.06	0.02	0.03	0.10
17020	0.00	0.00	0.00	0.00	0.00	1.23	0.24	0.09	0.12	0.44
17030	0.01	0.00	0.00	0.00	0.00	1.17	0.24	0.08	0.14	0.45
17040	0.00	0.00	0.00	0.00	0.00	0.31	0.05	0.01	0.02	0.07
17050	0.00	0.00	0.00	0.00	0.00	0.37	0.12	0.04	0.08	0.24
17060	0.00	0.00	0.00	0.00	0.00	0.49	0.12	0.03	0.08	0.22
17070	0.04	0.01	0.00	0.00	0.00	1.67	0.59	0.18	0.41	1.18
17080	0.01	0.00	0.00	0.00	0.00	1.34	0.23	0.09	0.11	0.43
17090	0.01	0.00	0.00	0.00	0.00	0.76	0.26	0.07	0.17	0.50
17100	0.00	0.00	0.00	0.00	0.00	1.16	0.20	0.06	0.11	0.36
17110	0.94	0.22	0.10	0.08	0.32	12.00	3.76	1.46	2.22	7.49
17120	0.08	0.01	0.01	0.01	0.01	2.96	0.46	0.13	0.25	0.92
17130	0.00	0.00	0.00	0.00	0.00	0.67	0.10	0.03	0.05	0.16
17140	0.00	0.00	0.00	0.00	0.00	0.31	0.04	0.01	0.02	0.07
17150	0.27	0.06	0.02	0.02	0.08	4.86	1.36	0.40	0.91	2.78
17160	0.20	0.03	0.01	0.01	0.04	4.54	0.66	0.20	0.35	1.34
17170	0.00	0.00	0.00	0.00	0.00	0.39	0.06	0.02	0.03	0.09
17180	0.07	0.01	0.01	0.01	0.01	1.95	0.29	0.09	0.15	0.58
17190	0.01	0.00	0.00	0.00	0.00	1.32	0.41	0.10	0.30	0.81
17220	0.13	0.03	0.01	0.01	0.02	4.71	2.34	0.70	1.71	4.82
17230	0.03	0.00	0.00	0.00	0.00	2.58	0.96	0.25	0.71	1.97
17240	0.04	0.01	0.00	0.00	0.00	3.31	1.17	0.29	0.83	2.26
17250	0.00	0.00	0.00	0.00	0.00	0.68	0.18	0.05	0.12	0.34
17260	0.03	0.00	0.00	0.00	0.00	2.41	1.14	0.37	0.80	2.32
17261	0.43	0.11	0.06	0.04	0.20	3.25	1.01	0.56	0.45	2.03
17270	0.07	0.01	0.00	0.00	0.00	5.46	1.96	0.84	1.11	3.87
17280	0.49	0.12	0.06	0.04	0.20	5.06	1.56	0.85	0.70	3.09
17290	0.16	0.02	0.00	0.00	0.00	9.92	4.46	1.39	3.10	8.94
17300	0.01	0.00	0.00	0.00	0.00	1.77	0.65	0.17	0.46	1.26
17310	0.02	0.00	0.00	0.00	0.00	3.81	1.56	0.47	1.08	3.08
17320	0.02	0.00	0.00	0.00	0.00	1.78	0.60	0.19	0.39	1.17
17330	0.46	0.09	0.03	0.03	0.10	13.96	5.10	2.03	3.04	10.11
17340	0.01	0.00	0.00	0.00	0.00	1.86	0.53	0.15	0.34	0.99
17350	0.01	0.00	0.00	0.00	0.00	2.80	0.76	0.26	0.44	1.39
17360	0.00	0.00	0.00	0.00	0.00	1.16	0.43	0.10	0.31	0.83
TOTALS	3.67	0.78	0.33	0.27	1.02	123.39	38.37	13.11	24.09	75.38

** The causulty levels include those casualties resulting from entrapment. Entrapment numbers are presented to enable rescue planning

TABLE B-6: STUDY AREA 1 -WELLINGTON CITY NIGHTTIME CASUALTIES

(b) By Residential and Construction Group

CONST GROUP	SCENARIO 1 : NIGHT CASUALTY FIGURES					SCENARIO2 : NIGHT CASUALTY FIGURES				
	No. OF CASUALTIES WITH SEVERITY:					No. OF CASUALTIES WITH SEVERITY:				
	Level 1	Level 2	Level 3	Level 4	Entrapped **	Level 1	Level 2	Level 3	Level 4	Entrapped **
Residential	0.85	0.14	0.03	0.05	0.07	66.67	18.53	4.35	13.23	36.51
GROUP1	0.01	0.00	0.00	0.00	0.00	0.52	0.07	0.02	0.04	0.14
GROUP2	0.23	0.05	0.01	0.02	0.04	10.20	7.12	1.50	5.96	14.88
GROUP3	2.58	0.59	0.29	0.20	0.90	46.00	12.65	7.25	4.86	23.85
TOTALS	3.67	0.78	0.33	0.27	1.02	123.39	38.37	13.11	24.09	75.38

NOTE: GROUP 1 = Light Timber Frame and Light Steel Frame with Light Cladding construction types only

GROUP 3 = Unreinforced Masonry only

GROUP 2 = All other 5 construction types considered

** The causulty levels include those casualties resulting from entrapment. Entrapment numbers are presented to enable rescue planning

TABLE B-7: STUDY AREA 1 -WELLINGTON CITY
EFECT OF RESIDENTIAL HIGH RISE CONSTRUCTION ON CASUALTIES

(a) During the Day

DETAILS	SCENARIO 1 : DAY CASUALTY FIGURES					SCENARIO2 : DAY CASUALTY FIGURES				
	No. OF CASUALTIES WITH SEVERITY:					No. OF CASUALTIES WITH SEVERITY:				
	Level 1	Level 2	Level 3	Level 4	Entrapped **	Level 1	Level 2	Level 3	Level 4	Entrapped **
Residential if no high rise	0.28	0.04	0.02	0.02	0.02	27.82	3.92	1.10	2.06	7.14
Residential with high rise	0.42	0.07	0.02	0.03	0.03	34.61	9.07	2.15	6.36	17.75
Increase due to high rise	0.14	0.02	0.00	0.01	0.01	6.79	5.15	1.05	4.30	10.61

(a) During the Night

DETAILS	SCENARIO1 : NIGHT CASUALTY FIGURES					SCENARIO2 : NIGHT CASUALTY FIGURES				
	No. OF CASUALTIES WITH SEVERITY:					No. OF CASUALTIES WITH SEVERITY:				
	Level 2	Level 2	Level 3	Level 4	Entrapped **	Level 1	Level 2	Level 3	Level 4	Entrapped **
Residential if no high rise	0.54	0.08	0.03	0.03	0.04	52.05	7.33	2.05	3.85	13.36
Residential with high rise	0.85	0.14	0.03	0.05	0.07	66.67	18.53	4.35	13.23	36.51
Increase due to high rise	0.31	0.06	0.00	0.02	0.03	14.62	11.20	2.29	9.38	23.15

** The causulty levels include those casualties resulting from entrapment. Entrapment numbers are presented to enable rescue planning

Note: High Rise in this case is considered to be all residential properties with more than 400 sq metre floor area

TABLE B-8: STUDY AREA 1 -WELLINGTON CITY
SUMMARY OF DAMAGE RATIOS and LOSSES

CONST GROUP No.	SCENARIO 1				SCENARIO 2			
	Mean Damage Ratio (%)	Total** weighted Floor area	Total Value $Million	Total Loss $Million	Mean Damage Ratio (%)	Total** weighted Floor area	Total Value $Million	Total* Loss $Million
GROUP 1	0.97	107458	161.19	1.57	13.23	107458	161.19	23.45
GROUP 2	1.71	2393014	3589.52	61.38	20.35	2393014	3589.52	803.61
GROUP 3	11.18	308226	462.34	51.70	70.14	308226	462.34	356.70
Residential	0.51	5804368	5804.37	29.37	11.99	5804368	5804.37	765.55
Unidentified (Comm/Ind)	3.37	688054	1032.08	34.77	29.28	688054	1032.08	302.19
TOTALS			11049	179			11049	2252
Mean Damage Ratio for Comm/Indust (%) =				2.85				28.33
Mean Damage Ratio for Study Area (%) =				1.62				20.38

NOTE: GROUP 1 = Light Timber Frame and Light Steel Frame with Light Cladding construction types only

GROUP 3 = Unreinforced Masonry only

GROUP 2 = All other 5 construction types considered

** Industrial floor area has been weighted by a factor of 0.233 to reflect its value relative to commercial floor area
* Includes 10% additional post EQ inflation

APPENDIX C

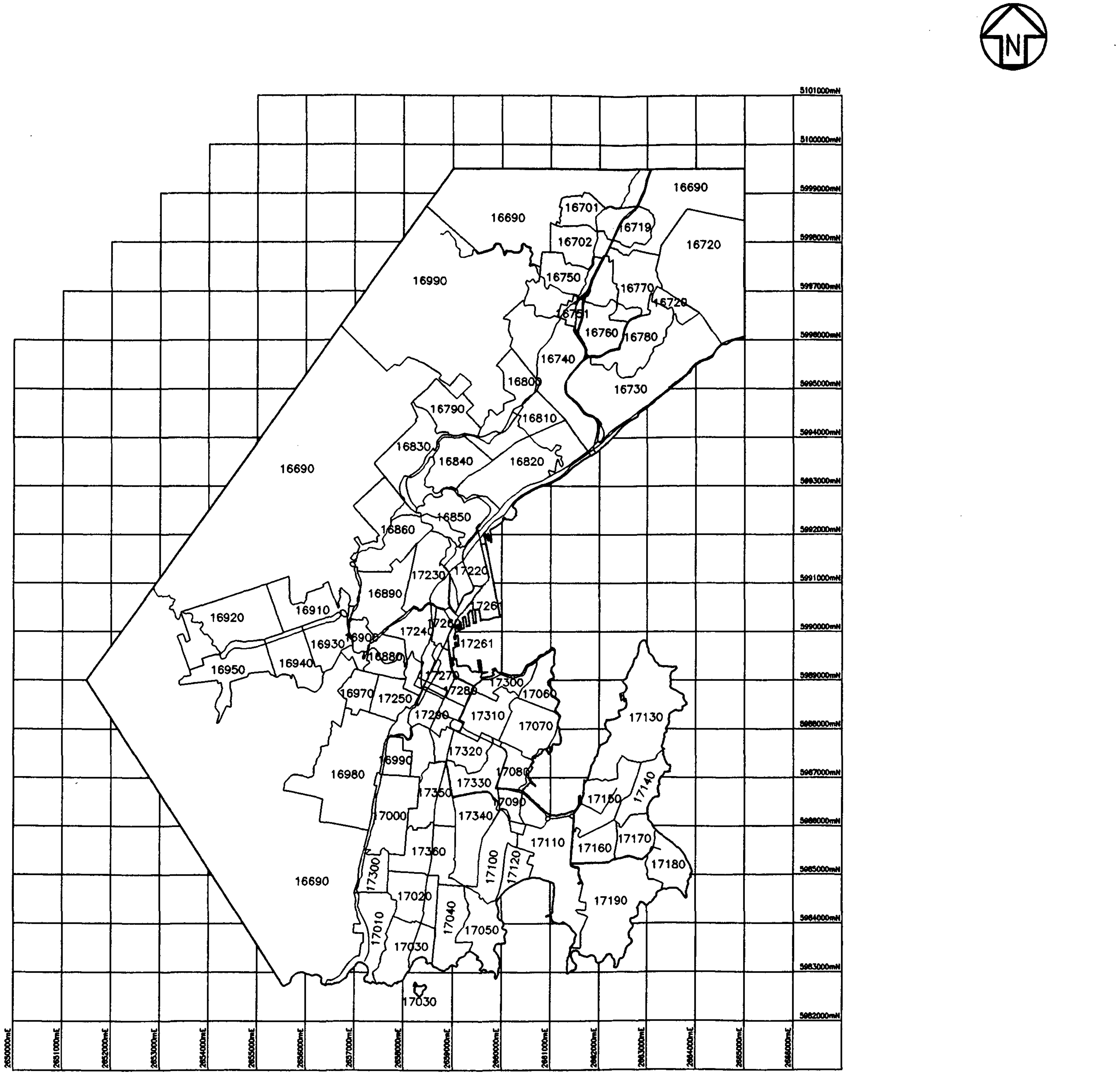
Maps

STUDY AREA 1 - WELLINGTON CITY

VALUATION ROLL NUMBER - SUBURB NAMES

Valuation NZ Roll No	Suburb Name
16690	Rural
16701	Churton Park/Glenside
16702	Churton Park
16719	Grenada Village
16720	Newlands
16730	Ngauranga
16740	Raroa
16750	Johnsonville
16751	Johnsonville City
16760	Paparangi
16770	
16780	Newlands
16790	Ngaio
16840	
16800	Khandallah
16810	
16820	Kaiwharawhara/Cashmere
16830	Crofton Downs
16850	Wadestown/Highland Park
16860	Wilton/Chartwell
16880	Kelburn
17240	
16890	Northland
16900	
16910	Karori
16920	
16930	
16940	
16950	
16970	Highbury
16980	Brooklyn/Kowhai Park
16990	Brooklyn
17000	Mornington/Kingston
17010	Happy Valley

17020	Island Bay
17030	
17040	Southgate
17050	Houghton Bay
17060	Roseneath
17070	Hataitai
17080	Kilbirnie
17090	
17110	
17100	Melrose
17120	Lyall Bay
17130	Mapuhia
17140	Seatoun
17180	
17150	Miramar
17160	
17170	Seatoun Heights
17190	Strathmore
17220	Thorndon
17230	
17250	Aro St
17260	Lambton CBD
17261	Wellington Harbour Front/City
17270	Vivian to Willeston St
17280	Courtenay Place
17290	Hankey/Vivian St
17300	Oriental Bay/Kingston
17310	Mt Victoria
17320	Mt Cook
17330	Newtown
17340	
17350	
17360	Berhampore



NOTES

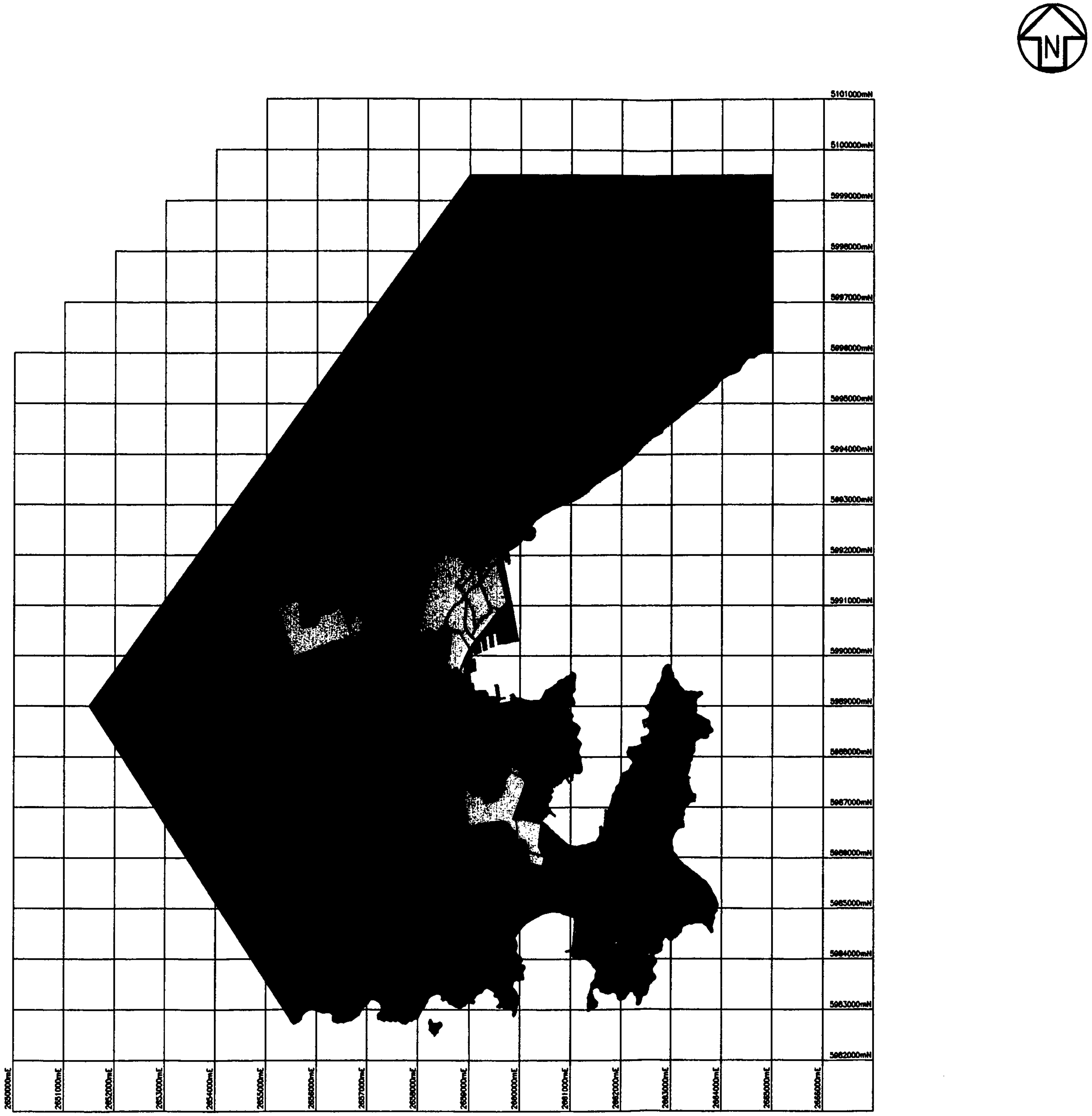
1. Base map of coast, rivers and roads from the Department of Survey and Land Information. Crown Copyright Reserved.

KEY

Roads

1:100000 0 1000 2000 3000 4000 m

Title	NEW ZEALAND VALUATION ROLL NUMBER AREAS
Location	WELLINGTON (STUDY AREA 1)
Client	WELLINGTON REGIONAL COUNCIL
WORKS Consultancy Services	Job No. C5327.00
	Figure Map 1



1:100000 0 1000 2000 3000 4000 m

NOTES

1. Base map of coast, rivers and roads from the Department of Survey and Land Information. Crown Copyright Reserved.

KEY

Roads

RESIDENTIAL PROPERTY MEAN DAMAGE RATIO (PERCENT)
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
> 25

NOTE : Results are averaged over Valuation NZ roll areas

EARTHQUAKE SCENARIOS

SCENARIO 1: A large (M 7), distant (≈100 km), shallow (15–60 km) earthquake producing MM V to MM VI on bedrock over much of the Wellington Region. The probability of this event occurring in the next 50 years is very high (90% or greater).

SCENARIO 2: A large (M 7.5) shallow (< 30 km) earthquake centred on the Wellington–Hutt Valley segment of the Wellington Fault, producing shaking on bedrock in the Wellington Region, ranging from MM X near the fault to MM VII, see Figure 3. Probability of occurrence in next 50 years is about 10%.

Title
RESIDENTIAL PROPERTY DAMAGE : SCENARIO 2

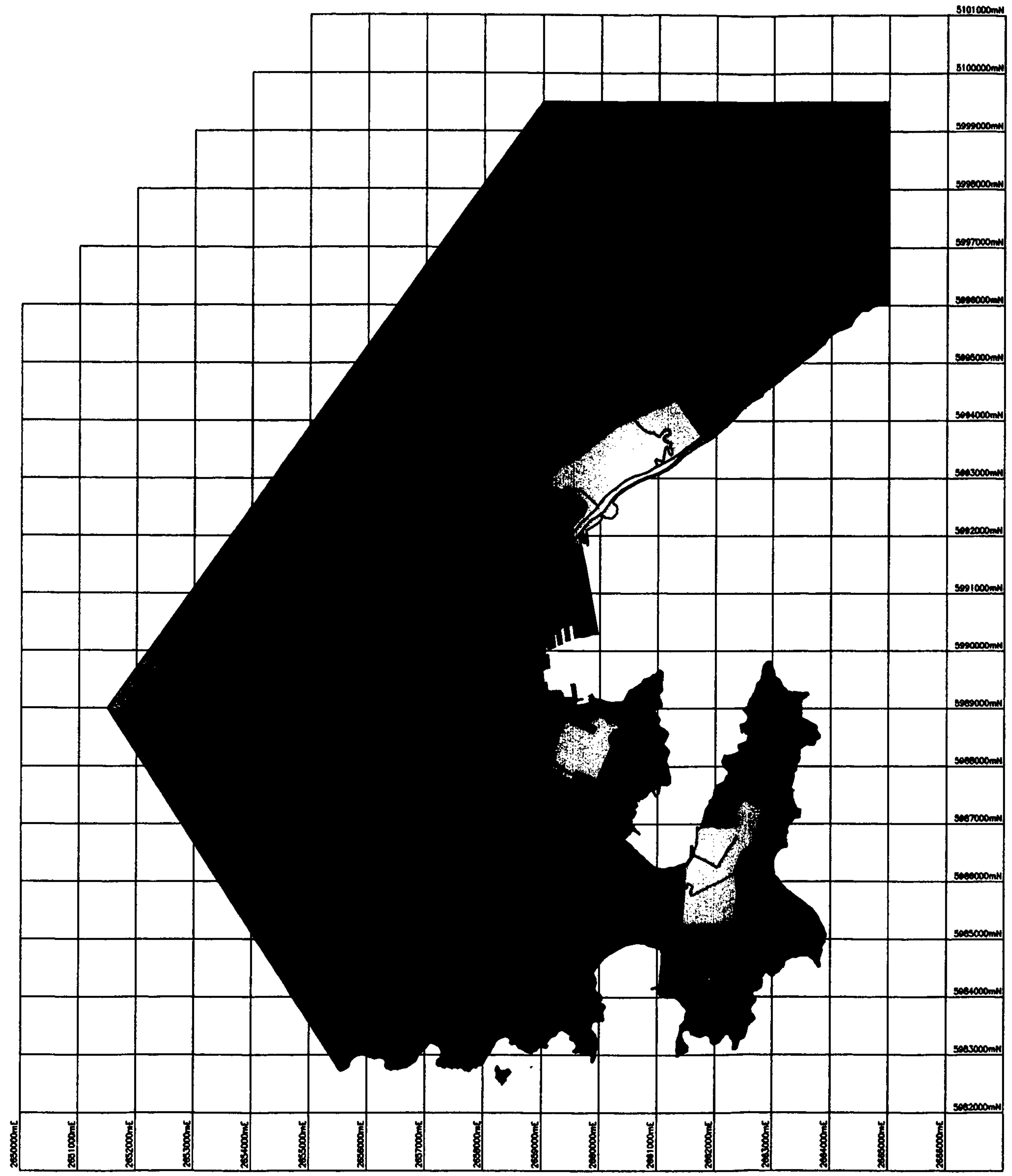
Location
WELLINGTON (STUDY AREA 1)

Client
WELLINGTON REGIONAL COUNCIL

WORKS Consultancy Services

Job No.
C5327.00

Figure
Map 2



NOTES

1. Base map of coast, rivers and roads from the Department of Survey and Land Information. Crown Copyright Reserved.

KEY

Roads

DAMAGE REPAIR COSTS IN EACH VALUATION ROLL NUMBER AREA ($ MILLION)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- > 50

NOTE : Results are averaged over Valuation NZ roll areas

EARTHQUAKE SCENARIOS

SCENARIO 1: A large (M 7), distant (≈100 km), shallow (15–60 km) earthquake producing MM V to MM VI on bedrock over much of the Wellington Region. The probability of this event occurring in the next 50 years is very high (90% or greater).

SCENARIO 2: A large (M 7.5) shallow (< 30 km) earthquake centred on the Wellington–Hutt Valley segment of the Wellington Fault, producing shaking on bedrock in the Wellington Region, ranging from MM X near the fault to MM VII, see Figure 3. Probability of occurrence in next 50 years is about 10%.

Title

PROPERTY REPAIR COST ESTIMATES : SCENARIO 2

Location

WELLINGTON (STUDY AREA 1)

Client

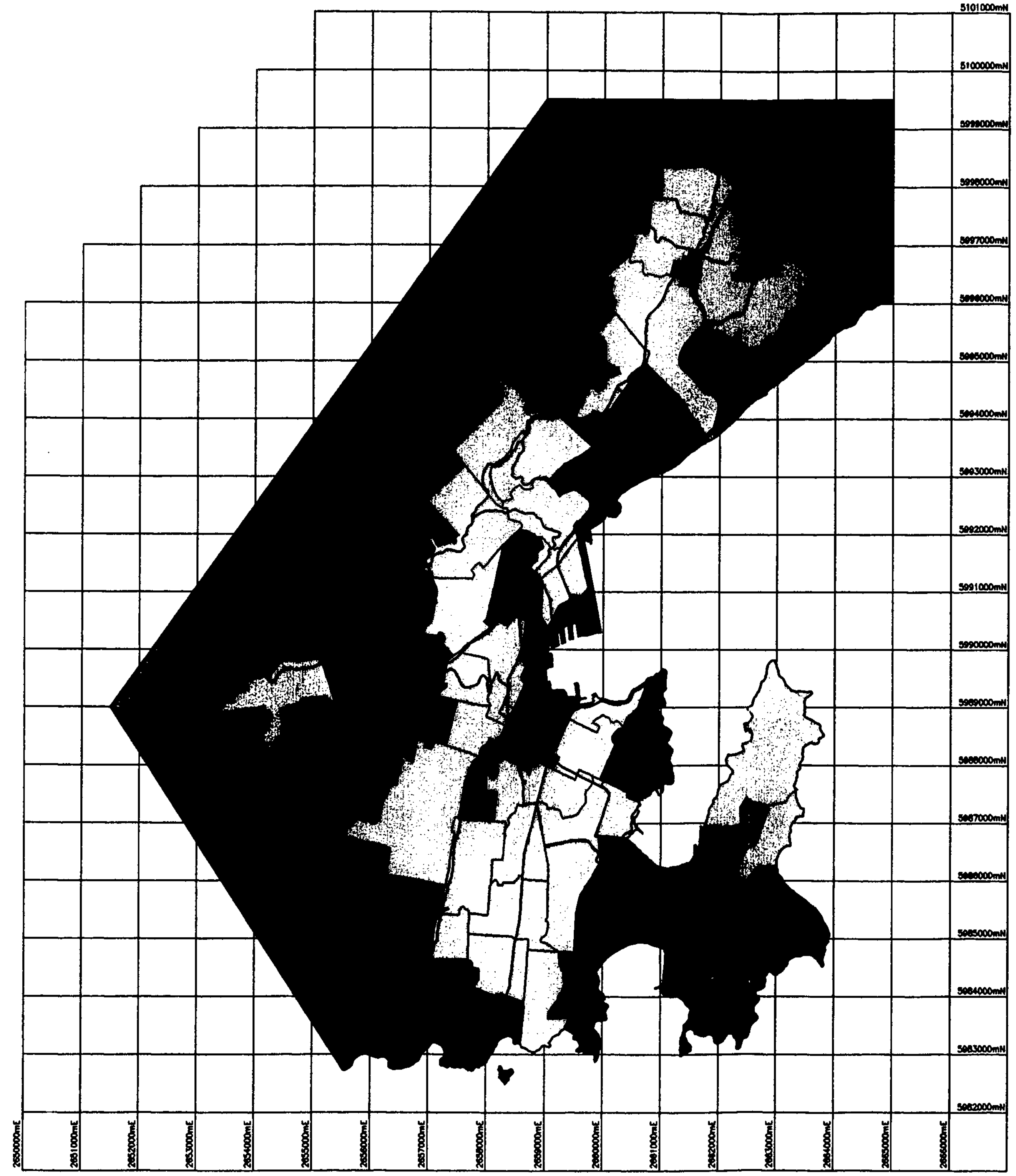
WELLINGTON REGIONAL COUNCIL

WORKS Consultancy Services

Job No. C5327.00

Figure Map 3

1:100000 0 1000 2000 3000 4000 m



NOTES

1. Base map of coast, rivers and roads from the Department of Survey and Land Information. Crown Copyright Reserved.

KEY

Roads

NUMBERS OF RESIDENTIAL PROPERTIES WITH EITHER EXTENSIVE OR COMPLETE DAMAGE IN EACH VALUATION ROLL NUMBER AREA

- 0 – 10
- 10 – 20
- 20 – 50
- 50 – 100
- 100 – 150
- 150 – 200
- 200 – 250
- > 250

NOTE : Results are averaged over Valuation NZ roll areas

EARTHQUAKE SCENARIOS

SCENARIO 1: A large (M 7), distant (≈ 100 km), shallow (15–60 km) earthquake producing MM V to MM VI on bedrock over much of the Wellington Region. The probability of this event occurring in the next 50 years is very high (90% or greater).

SCENARIO 2: A large (M 7.5) shallow (< 30 km) earthquake centred on the Wellington–Hutt Valley segment of the Wellington Fault, producing shaking on bedrock in the Wellington Region, ranging from MM X near the fault to MM VII, see Figure 3. Probability of occurrence in next 50 years is about 10%.

1:100000 0 1000 2000 3000 4000 m

Title
RESIDENTIAL PROPERTIES IN THE EXTENSIVE OR COMPLETE DAMAGE STATE : SCENARIO 2

Location
WELLINGTON (STUDY AREA 1)

Client
WELLINGTON REGIONAL COUNCIL

WORKS Consultancy Services

Job No. C5327.00

Figure Map 4

APPENDIX D

Survey Data

DOMESTIC BUILDING SURVEY DATA

(note: % in group excludes undefined props)

Location: study AREA 3 (Porirua & Tawa)

VALUATION NZ ROLL No	Replace Floor Value Factor	Pre 1940 % in age group	Pre 1940 % >=2 Storey	Pre 1940 FOUNDATIONS % Sloping > 1:4	Pre 1940 % Slab on grade	Pre 1940 % Pile & strip < 800	Pre 1940 % Pile < 800	Pre 1940 % Basement > 800	Pre 1940 % Tile roofs	Pre 1940 Average No of chimney's	Pre 1940 - 1970 % in age group	Pre 1940 - 1970 % >=2 Storey	Pre 1940 - 1970 FOUNDATIONS % Sloping > 1:4	Pre 1940 - 1970 % Slab on grade	Pre 1940 - 1970 % Pile & strip < 800	Pre 1940 - 1970 % Pile < 800	Pre 1940 - 1970 % Basement > 800	Pre 1940 - 1970 % Tile roofs	Pre 1940 - 1970 Average No of chimney's	Post 1970 % in age group	Post 1970 % >=2 Storey	Post 1970 FOUNDATIONS % Sloping > 1:4	Post 1970 % Slab on grade	Post 1970 % Pile & strip < 800	Post 1970 % Pile < 800	Post 1970 % Basement > 800	Post 1970 % Tile roofs	Post 1970 Average No of chimney's
15431	0.85	19.02	10	5	0	80	0	20	5	0.2	41.92	10	5	0	80	0	20	5	0.2	39.06	20	5	10	70	0	20	0	0
15433	0.95	2.98	20	10	0	60	0	40	0	0.2	13.86	20	10	0	60	0	40	0	0.2	83.16	80	5	20	40	0	40	5	0
15435	0.85	2.49	10	5	0	80	0	20	5	0.2	61.41	10	5	0	80	0	20	5	0.2	36.10	10	5	0	70	0	20	0	0
15441	0.9	0.00									0.00									100.00	10	5	0	40	0	60	50	0
15442	1.1	0.00									0.00									100.00	60	5	50	50	0	0	10	0
15444	0.9	12.89	5	10	0	80	0	20	50	0.8	38.14	5	10	0	80	0	20	50	0.8	48.97	5	10	0	80	0	20	50	0.8
15460	1.1	10.56	20	20	0	70	0	30	10	0.3	50.18	20	20	0	70	0	30	10	0.3	39.25	30	20	5	70	0	25	2	0
15470	1.05	0.36	60	10	10	60	0	30	5	0	8.89	60	10	10	60	0	30	5	0	90.74	60	10	10	60	0	30	5	0
15481	1.1	0.47	60	15	5	70	0	25	10	0	0.00									99.53	60	15	5	70	0	25	10	0
15482	1.1	0.00									0.00									99.95	60	20	5	70	0	25	10	0
15484	1.05	0.00									0.00									100.00	60	20	5	70	0	25	10	0
15511	0.9	0.14	10	10	0	70	0	30	0		0.43	10	10	0	70	0	30	0		99.43	10	10	0	70	0	30	0	0.2
15521	0.85	0.00	5	20	0	60	0	40	5	0.2	77.42	5	20	0	60	0	40	5	0.2	22.58	5	10	0	60	0	40	5	0.2
15523	0.75	0.00	30	15	0	70	0	60	60	0.7	81.93	30	15	0	70	0	60	60	0.7	18.07	0	0	0	0	0	0	0	0
15531	0.75	0.00	20	10	0	7	0	30	80	0.8	98.13	20	10	0	7	0	30	80	0.8	1.87	20	10	0	7	0	30	80	0.8
15533	0.8	0.00	20	10	0	70	0	30	80	0.8	89.69	20	10	0	70	0	30	80	0.8	10.31	20	10	0	70	0	30	80	0.8
15541	0.8	0.32	20	10	0	70	0	30	70	0.8	88.33	20	10	0	70	0	30	70	0.8	11.36	10	10	0	60	0	40	0	0.1
15543	0.75	0.00	30	20	0	70	0	30	100	1	98.35	30	20	0	70	0	30	100	1	1.65	0	0	0	0	0	0	0	0
15551	0.75	0.00	30	10	0	80	0	20	100	1	91.35	30	10	0	80	0	20	100	1	8.65	0	0	0	0	0	0	0	0
15553	0.75	0.00	20	10	0	70	0	30	90	0.8	94.17	20	10	0	70	0	30	90	0.8	5.83	10	10	0	40	0	60	0	0
15555	0.9	8.88	10	20	0	40	0	60	60	0.6	30.45	10	20	0	40	0	60	60	0.6	60.67	10	20	0	35	5	60	5	0
15561		0.00									0.00									0.00								
15563	0.9	85.73	10	0	0	30	0	10	20	0.4	0.00	0	0	0	0	0	0	0	0	14.28	0	0	0	0	0	0	0	0
15571	0.75	0.24	10	30	0	20	0	80	70	0.9	84.45	10	30	0	20	0	80	70	0.9	15.31	0	0	0	0	0	0	0	0
15573	0.8	2.51	0.5	10	5	60	0	35	30	0.5	42.22	0.5	10	5	60	0	35	30	0.5	55.27	10	10	0	60	0	40	10	0
15575	0.75	0.20	30	20	0	40	0	60	60	0.7	91.80	30	20	0	40	0	60	60	0.7	8.01	0	0	0	0	0	0	0	0
15577	0.8	7.55	10	10	0	60	0	40	60	0.4	73.64	10	10	0	60	0	40	60	0.4	18.81	20	10	5	35	0	6	5	0
15581	0.95	0.93	10	20	0	30	0	70	20	0.2	6.48	10	20	0	30	0	70	20	0.2	92.59	5	20	0	10	0	90	5	0
15591	0.8	10.57	15	15	0	30	0	70	40	0.5	59.72	15	15	0	30	0	70	40	0.5	29.72	5	20	0	10	0	90	5	0
15593	0.8	0.79	20	15	0	70	0	30	90	0.9	77.87	20	15	0	70	0	30	90	0.9	21.34	0	0	0	0	0	0	0	0
15595	1	0.00									0.60	20	20	5	35	0	60	5	0	99.40	20	20	5	35	0	60	5	0
15601		0.00									0.00									0.00								
15650	0.8	4.36	40	20	0	20	0	80	25	0.8	84.73	40	20	0	20	0	80	25	0.8	10.90	20	30	0	10	0	90	5	0
15660	0.9	2.21	30	30	0	20	0	80	20	0.8	66.28	30	30	0	20	0	80	20	0.8	31.51	30	20	0	20	0	80	5	0
15670	0.9	0.32	20	40	0	30	0	70	15	0.6	55.15	20	40	0	30	0	70	15	0.6	44.53	20	40	0	10	0	90	5	0
15690	0.95	5.57	5	0	0	90	5	5	10	0.4	54.36	5	0	0	90	5	5	10	0.4	40.07	5	0	10	0	0	5	5	0
15710	1.05	0.31	0	0	0	0	0	0	0	0	11.66	70	20	0	10	0	90	5	0	88.04	70	20	0	10	0	90	5	0
15720	0.95	1.87	30	30	0	20	0	80	15	0.5	79.78	30	30	0	20	0	80	15	0.5	18.35	30	30	0	20	0	70	10	0.2
15730	1	2.23	40	20	5	20	2	80	20	0.6	85.26	40	20	5	20	2	80	20	0.6	12.51	60	30	10	20	0	70	5	0
15740	1.05	0.00									88.51	20	40	0	20	0	40	10	0.6	11.49	40	40	10	30	0	60	5	0
15750	1.05	0.00									16.47	90	10	70	10	0	10	5	0	83.53	90	10	70	10	0	10	5	0
16710	0.8	0.00									0.00									100.00	0	70	0	20	0	80	0	0

COMMERCIAL SURVEY DATA

VALUATION NZ Roll No	Pre 1930												1930 - 1970												1970+											
	No of Stories												No of Stories												No of Stories											
	0 - 2						2+						0 - 4						4+						0 - 4						4+					
	Construction type			%			construction type			%			Construction type			%			construction type			%			Construction type			%			construction type			%		
	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3
15431	1			100									9			100									3			100								
15433																									3	0	0	100	0	0						
15435													7	8	0	50	50	0							1	8	7	30	40	30						
15441																																				
15442																									3	4	0	50	50							
15444	1	0	0	100	0	0							7	8	0	50	50	0							3	0	0	100	0	0						
15460	1	0	0	100	0	0																			3	0	0	100	0	0						
15470																									3	0	0	100	0	0						
15481																																				
15482																																				
15484																																				
15511																									7	8	0	50	50	0						
15521																									3	0	0	100	0	0						
15523													8	3	0	80	20	0							7	8	0	50	50	0						
15531													7	8	0	50	50	0							2	0	0	100	0	0						
15533													7	8	2	20	20	60							7	8	0	50	50	0						
15541													7	8	0	50	50	12							7	8	3	44	44	12						
15543																																				
15551													2	8	0	70	30	0																		
15553													7	8	0	40	60	0																		
15555																																				
15561													7	8	9	30	66	4	7	8	0	50	50	0	6	7	8	40	20	40	7	8	6	40	40	20
15563													7	8	0	50	50	0							3	0	0	100	0	0						
15571													7	8	0	50	50																			
15573																			3	0	0	100	0	0	3	0	0	100	0	0						
15575													3	0	0	100	0	0																		
15577													2	7	8	12	44	44							7	8	0	50	50	0						
15581																																				
15591													2	1	0	50	50	0																		
15593													7	5	0	50	50	0																		
15595																																				
15601																									1	0	0	100	0	0						
15650													8	1	0	17	83	0																		
15660													7	8	0	50	50	0																		
15670																																				
15690													4	6	8	20	10	70							3	7	8	30	30	40						
15710																																				
15720																																				
15730																																				
15740													7	5	0	50	50								3	0	0	100	0	0						
15750																																				
16710																									3	0	0	100	0	0						

INDUSTRIAL SURVEY DATA

VALUATION NZ Roll No	Pre 1930						1930 -1970						1970+					
	Construction type			%			Construction type			%			Construction type			%		
	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3	No 1	No 2	No 3
15431							8	1	0	50	50	0	9	8	3	18	19	63
15433							8	0	0	100			9	8	3	16	8	76
15435																		
15441													8	1	3	16	42	42
15442													5	3		50	50	
15444	1	3	0	50	50	0	8	3	1	7	53	40	9	3	1	20	40	40
15460																		
15470																		
15481																		
15482																		
15484																		
15511																		
15521													1	3	0	50	50	0
15523																		
15531																		
15533																		
15541																		
15543																		
15551																		
15553																		
15555																		
15561							9	8	7	27	43	30	7	8	0	50	50	0
15563							3	8	0	70	30	0	8	3	4	30	50	20
15571																		
15573																		
15575																		
15577																		
15581																		
15591							8	7	3	50	30	20	8	0	0	100	0	0
15593																		
15595																		
15601							1	0	0	100	0	0						
15650																		
15660																		
15670													2	0	0	100	0	0
15690							7	8	9	40	50	10						
15710																		
15720													7	8	3	44	40	16
15730																		
15740																		
15750							7			100								
16710													3	4	5	30	30	40

APPENDIX E

Structural Class Descriptions

E1 STRUCTURAL CLASS DESCRIPTIONS

Light Timber Frame:

These are typically single- or multiple-family dwellings or older, small commercial properties. The essential structural feature of these buildings is multiple framing by timber rafters or joists on timber stud walls. Loads are generally light and spans are small. These buildings may have relatively heavy masonry chimneys, tile roofs, and may be partially or fully covered with masonry veneer. Most of these buildings, especially the single-family residencies, are not engineered but constructed in accordance with conventional construction practices or the provisions of building codes for structures not requiring specific design (eg. NZS 3604 Code of Practice for Light Timber Frame Buildings not requiring specific design). Lateral loads are transferred by roof, ceiling and floor diaphragms to equivalent braced or shear walls. The diaphragms are roof panels and floors which may be sheathed with wood, plywood or fibreboard sheeting. Bracing walls are exterior and interior walls sheathed with weatherboard stucco, plaster, plywood, gypsum board, particle board or fibre cement sheeting.

Light Steel Frame:

These buildings are pre-engineered and prefabricated with transverse rigid frames and longitudinal bracing systems. The roof and walls generally consist of lightweight panels. The frames are usually made up from standard steel sections or built up sections, eg. truss elements. The frames are built in segments and assembled on site with bolted or welded joints. Lateral loads in the transverse direction are resisted by the rigid frames with loads distributed to them by bracing elements. Loads in the longitudinal direction are resisted by shear elements which can be either roof and wall panels, an independent system of tension-only rod bracing, or a combination of panels and bracing.

These structures are mostly single storey structures combining diagonal rod-braced frames in one direction and moment resisting frames in the other. Due to the repetitive nature of the structural systems, the type of damage to structural members is expected to be rather uniform throughout the structure.

Exterior cladding may be lightweight curtain wall, brick or block veneer or precast concrete panels. Roof cladding is mostly lightweight.

Precast Concrete Tilt-Up Walls:

These buildings have timber, or steel truss or beam roof system directly supported by the tilt-up walls, with a timber or metal deck roof diaphragm, which often is very large, that distributes lateral forces to precast concrete shear walls. The walls are thin but relatively heavy, while the roofs are relatively light. Older buildings often have inadequate connections for anchorage of the walls to the roof and the panel connections often are brittle. Tilt-up buildings may have more than one storey. Walls can have numerous openings for doors and windows of such size that the wall looks more like a frame than a shear wall. The tilt-up panel forms the exterior cladding.

Steel Moment Resisting Frame:

These buildings have a frame of steel columns and beams generally in rectangular layout in plan and elevation, and support heavy floor construction. Usually the structure is concealed on the outside by exterior walls, which can be of almost any material (curtain walls, brick masonry, or precast concrete panels), and on the inside by ceilings and column furring. Lateral loads are transferred by floor diaphragms to moment resisting frames. The frames developed their stiffness by full or partial moment connections. In some cases, the beam-column connections have very small moment resisting capacity but, in other cases, some of the beams and columns are fully developed as moment frames to resist lateral forces. The frames can be located almost anywhere in the building. Usually the columns have their strong directions oriented so that some columns act primarily in one direction while the others act in the other direction, and the frames consist of lines of strong columns and their intervening beams. Steel moment frame buildings are typically more flexible than shear wall buildings. This low stiffness can result in large interstorey drifts that may lead to relatively greater nonstructural damage.

Reinforced Concrete Moment Resisting Frames:

These buildings are of similar form to steel moment frame buildings except that the frames are reinforced concrete. There is a large variety of frame systems. Some older concrete frames may be proportioned and detailed such that brittle failure of the frame members can occur in earthquakes, leading to partial or full collapse of the buildings. Modern frames in zones of high seismicity are proportioned and detailed for ductile behaviour and are likely to undergo large deformations during an earthquake without brittle failure of frame members and collapse. In such circumstances non structural damage may be relatively high.

Concrete Shear Walls:

The lateral-force-resisting system in these buildings are concrete shear walls that are usually also bearing walls. In older buildings, the walls often are quite extensive, and the wall stresses are low, but reinforcing is light. In newer buildings, the shear walls often are limited in extent, but are detailed for ductile yielding. Commercial construction up to say 8 storeys may feature reinforced hollow concrete block construction as shear walls.

Unreinforced Masonry:

These buildings have perimeter bearing walls of unreinforced brick construction with floors and roofs of either concrete or timber construction. Interior walls may also be of masonry construction and floors may be supported by concrete or timber columns.

The walls may or may not be anchored to the floor or roof diaphragms. Exterior walls may be of solid or cavity brick construction. Lateral loads are distributed by the roof and floor diaphragms and resisted by the brick wall elements. Face loads on wall elements may promote failure by instability or separation from diaphragms.

APPENDIX F

Building Damage State Descriptions

F1 STRUCTURAL DAMAGE STATE DESCRIPTIONS FOR THE CONSTRUCTION TYPES CONSIDERED

<u>Light Timber Frame:</u>

Light Structural Damage: Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.

Moderate Structural Damage: Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across bracing wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.

Extensive Structural Damage: Large diagonal cracks across bracing wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of timber framing and/or slippage of structure over foundations; partial collapse of room-over-garage or other soft-storey configurations; small foundation cracks.

Complete Structural Damage: Structures may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to timber basement wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

<u>Steel Light Frame:</u>

Light Structural Damage: Few steel rod braces have yielded which may be indicated by minor sagging of rod braces; minor cracking at welded connections or minor deformations at bolted connections of moment frames may be observed. Damage evident to brittle forms of wall cladding.

Moderate Structural Damage: Most steel braces have yielded exhibiting observable significant sagging rod braces; some brace connections may be broken; some weld cracking may be observed in the moment frame connections. Brittle cladding forms show extensive damage. Slight damage occurs to lightweight cladding.

Extensive Structural Damage: Significant permanent lateral deformation of the structure due to broken brace rods, stretched anchor bolts and permanent deformations at moment frame members; some screw or welded attachments of roof and wall siding to steel framing may be broken; some purlin and girt connections may be broken.

Complete Structural Damage: Structure is collapsed or in imminent danger or collapse due to broken rod bracing, failed anchors bolts or failed structural members or connections.

Precast Concrete Tilt-Up Walls:

Light Structural Damage: Diagonal hairline cracks on concrete shear wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; minor concrete spalling at few locations; minor separation of walls from the floor and roof diaphragms; hairline cracks around metal connections between wall panels and at connections of beams to walls.

Moderate Structural Damage: Most wall surfaces exhibit diagonal cracks; larger cracks in walls with door or window openings; some shear walls have exceeded their yield capacities indicated by larger diagonal cracks and concrete spalling; cracks may appear at top of walls near panel intersections indicating chord yielding; some walls may have visibly pulled away from the roof; some welded panel connections may have been broken, indicated by spalled concrete around connections; some spalling may be observed at the connections of beams to walls.

Extensive Structural Damage: In buildings with relatively large area of wall openings most concrete shear walls have exceeded their yield capacities and some have exceeded their ultimate capacities indicated by large through-the wall diagonal cracks, extensive spalling around the cracks and visibly buckled wall reinforcement; the plywood diaphragms may exhibit cracking and separation along plywood joints; partial collapse of the roof may result from the failure of the wall-to-diaphragm anchorages; and falling of wall panels due to failure of connections.

Complete Structural Damage: Structure is collapsed or is in imminent danger of collapse due to failure of the wall-to-roof anchorages, splitting of wall plates, or failure of plywood-to-wall plate nailing; failure of beam connections at walls; failure of roof or floor diaphragms; failure of the wall panels and their connections.

Steel Moment Resisting Frame:

Light Structural Damage: Minor deformations in connections or hairline cracks in few welds.

Moderate Structural Damage: Some steel members have yielded exhibiting observable permanent rotations at connections; some welded connections may exhibit major cracks through welds or some bolted connections may exhibit broken bolts or enlarged bolt holes.

Extensive Structural Damage: Most steel members have exceeded their yield capacity resulting in significant permanent lateral deformation of the structure. Some of the structural members or connections may have exceeded their ultimate capacity exhibited by major permanent member rotations at connections, buckled flanges and failed connections. Partial collapse of portions of structure is possible due to failed critical elements and/or connections.

Complete Structural Damage: Significant portion of the structural elements have exceeded their ultimate capacities or some critical structural elements or connections have failed resulting in dangerous permanent lateral displacement, partial collapse or collapse of the building.

Reinforced Concrete Moment Resisting Frames:

Light Structural Damage: Flexural or shear type hairline cracks in some beams and columns near joints or within joints.

Moderate Structural Damage; Most beams and columns exhibit hairline cracks; in ductile frames some of the frame elements have reached yield capacity indicated by larger flexural cracks and some concrete spalling; nonductile frames may exhibit larger shear cracks and spalling.

Extensive Structural Damage: Some of the frame elements have reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete and buckled main reinforcement; nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices which may result in partial collapse.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability.

Concrete Shear Walls:

Light Structural Damage: Diagonal hairline cracks on most concrete shear wall surfaces; minor concrete spalling at few locations.

Moderate Structural Damage: Most shear wall surfaces exhibit diagonal cracks; some shear walls have exceeded yield capacity indicated by larger diagonal cracks and concrete spalling at wall ends.

Extensive Structural Damage: Most concrete shear walls have exceeded their yield capacities; some walls have exceeded their ultimate capacities indicated by large, through-the wall diagonal cracks, extensive spalling around the cracks and visibly buckled wall reinforcement; partial collapse may occur due to failure of nonductile columns not designed to resist lateral loads.

Complete Structural Damage: Structure has collapsed or is in imminent danger or collapse due to failure of most of the shear walls and failure of some critical beams or columns.

Unreinforced Masonry

Light Structural Damage: Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movement of lintels; cracks at the base of parapets.

Moderate Structural Damage: Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; few individual masonry units may fall off the walls or parapets.

Extensive Structural Damage: In buildings with relatively large area of wall openings most walls have suffered extensive cracking; some parapets and gable end walls have fallen. Beams or trusses may have moved relative to their support.

Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse due to in-plane or out-of-plane failure of the walls.

F2 NONSTRUCTURAL DAMAGE STATE DESCRIPTIONS FOR COMMON NONSTRUCTURAL BUILDING COMPONENTS

Partition Walls

Light Nonstructural Damage: A few cracks may be observed at intersections of walls and ceilings and at corners of door openings:

Moderate Nonstructural Damage: Cracks would be larger and more extensive requiring repairs of cracks and repainting, some partitions may require replacement of gypsum board or other finishes.

Extensive Nonstructural Damage: Most of the partitions are cracked and a significant portion would require replacement of finishes; door frames in the partitions may also be damaged and require re-setting.

Complete Nonstructural Damage: most or all finishes would have to be removed, damaged studs repaired, and walls be refinished; most door frames would also have to be repaired and replaced.

Suspended Ceilings:

Light Nonstructural Damage: A few ceiling tiles may have moved or fallen down, especially if heavy tiles are used.

Moderate Nonstructural Damage: Falling of tiles is more extensive; in addition the ceiling support framing (t-bars) may disconnect and/or buckle at few locations; lenses may fall off a few light fixtures.

Extensive Nonstructural Damage: The ceiling system may exhibit extensive buckling, disconnected t-bars and falling ceiling tiles; ceiling may have partial collapse at few locations and few light-fixtures may fall.

Complete Nonstructural Damage: The ceiling system is buckled throughout and/or fallen and requires complete replacement.

Exterior Wall Panels:

Light Nonstructural Damage: There may be slight movement of the panels, requiring realignment.

Moderate Nonstructural Damage: The movements are more extensive; connections of panels to structural frame may be damaged requiring further inspection and repairs; some window frames may need realignment.

Extensive Nonstructural Damage: Most of the panels are cracked or otherwise damaged and misaligned, and most panel connections to the structural frame may be damaged requiring thorough inspection and repairs; few panels may fall or be in imminent danger of falling; some window panes are broken and pieces of glass may have fallen.

Complete Nonstructural Damage: Most panels are severely damaged, most connections are broken or severely damaged, some panels have fallen and most may be in imminent danger of falling; extensive glass breakage and falling.

Electrical-Mechanical Equipment, Piping, Ducts:

Light Nonstructural Damage: Vulnerable equipment (eg. unanchored or on spring isolators) may move and damage attached piping or ducts.

Moderate Nonstructural Damage: Movements are larger and damage more extensive; piping may leak at few locations; elevator machinery and rails require realignment.

Extensive Nonstructural Damage: Equipment on spring isolators would topple and fall; other unanchored equipment may slide or fall braking their connections to piping and ducts; leaks may develop at many locations; anchored equipment may indicate stretched bolts or strain at anchors.

Complete Nonstructural Damage: Equipment is damaged by sliding, overturning or failure of its supports and is not operable; piping is leaking at many locations; some pipe and duct supports may have failed causing pipes and ducts to fall or hang down; lift rails are buckled or have broken supports and/or the counterweight has jumped off its rails.