Chapter 2
Earthquake Hazards

Introduction

Studies of moderate to large earthquakes and seismicity in Hawke’s Bay indicate that the region is one of the most earthquake prone areas of New Zealand. Strong earthquake shaking in excess of Modified Mercalli Intensity VII has been felt in Hawke’s Bay on at least 19 occasions in recorded history.

Hawke’s Bay has a minimum of 22 known active faults and folds within its onshore and offshore regions that are capable of producing strong earthquake shaking in the future. At least 5 of these are capable of producing levels of earthquake shaking similar to those experienced in 1931 on the Heretaunga Plains.

Large subduction thrust earthquakes on the interface between the Australian and Pacific plates occur frequently and are capable of producing high levels of shaking over a large part of the region.

Hazard Studies

In 1993 the Hawke’s Bay Regional Council (HBRC) with the support of territorial local authorities, engaged the Institute of Geological and Nuclear Sciences (IGNS) to carry out a series of studies into the earthquake hazard in Hawke’s Bay.

These studies took place over 5 years and included:

- Summarising and giving an overview of existing earthquake hazard information;
- Documenting the location of existing faults and folds and estimating the recurrence intervals of large earthquakes;
- Developing a regional numerical earthquake hazard model by preparing maps showing the level of ground shaking intensity expected at various return periods;
- Determining the nature of subsurface materials within Hawke’s Bay and their liquefaction potential, highlighting the main urban areas;
- Determining the susceptibility of subsurface materials to amplified ground shaking, highlighting the main urban areas;
- Estimating the location, size and likely recurrence of large subduction thrust earthquakes in the region.

This has provided a comprehensive and up to date record of the earthquake hazard in the region.

It has also resulted in the preparation of maps of the effects of "scenario" earthquakes resulting from surface fault and subduction zone seismic movements.

Hawke’s Bay Tectonic Setting

Hawke’s Bay is on the Australian tectonic plate. The Pacific plate starts sliding westward beneath the Australian plate at the Hikurangi Trough about 160 km east of Napier, and becomes progressively deeper below the surface to the west. At this latitude the two plates are converging at an oblique angle at about 50mm/yr.

![Figure 1: Direction and average rate of relative plate movement](image)

The down-going Pacific Plate dips gently (about 6°) immediately west of the trough but steepens beneath Hawke’s Bay to about 25°. The zone between the trough and the axial or main ranges of the North Island is one of intense deformation. Oblique contractual forces generated by the subduction process cause folding and faulting within the zone.

The Heretaunga Plains is a tectonic depression developed between folds within the zone during the last 1.5 million years. Up to 1 km of gravel, sand and silt overlie the limestone and sandstone bedrock.
The gravel-filled basin comprising the Ruatanawha Plains has been formed by a series of west-dipping, north-east-trending reverse faults in the area during the last 1.5 million years. Reverse faulting elevated the hills to the east of the plains resulting in sediment deposits on the relatively low land of the Ruatanawha Plains.

Sea level has risen about 12m since the end of the cold period of the last glaciation (c.18,000 years ago), as a result of climatic warming and polar icecaps melting. Sea level reached its present position c. 6,000 years ago, and has remained more or less stable. The Heretaunga Plains were once more extensive but much of the land was covered by intertidal marine silts during the rise in sea level. Subsequently, there have been continuing deposits of sediment from the mountain ranges to the west together with gravel deposits as a result of regular changes in the course of the Tukituki, Ngaruroro and Tutaeakuri rivers. These have built the Plain up above sea level and shifted the coastline eastwards.

The most recent large eruption of Taupo c. 1,800 years ago saw a rapid build-up of large quantities of river deposited Taupo pumice on the Heretaunga Plains. The pumice has been eroded in places by alluvial processes, but up to 10 m of pumice gravel and sand are found in many parts of the Plains. The build-up of aggregates has continued in the rivers, so that 5 – 10 m of alluvial sediment now overlies the pumice in parts of the Heretaunga Plains.

Geologically Hawke's Bay is characterised by a western belt of greywacke axial ranges, bounded to the east by two belts of younger marine sediments that are separated by a low-lying belt of weaker non-marine deposits and shallow marine deposits.

**Earthquake Terminology**

Magnitude, Modified Mercalli Intensity and Peak Ground Accelerations are terms frequently used to describe earthquakes and their effects.

The Magnitude (M) is a measure of the energy released by an earthquake at its source and is calculated from seismographic records. For pre-instrumental earthquake observations the Magnitude has been estimated by comparing them with later instrumentally recorded events.

The widely used Modified Mercalli Intensity scale (MM) categorises non-instrumental observations of the felt effects of an earthquake on people, fittings (furniture, crockery, etc) structures and the environment. There are 12 levels on the scale, but only the first 10 (i.e.: up to MM 10) have been reliably observed in New Zealand.

Appendix I to this chapter contains full descriptions of the Modified Mercalli Intensity scales.

Peak Ground Acceleration (PGA) refers to the maximum horizontal acceleration measured during an earthquake at the ground surface and is usually expressed as a percentage of gravity.

The distribution of peak ground accelerations from an earthquake are shown on isoseismal maps, with each isoseismal line enclosing areas experiencing approximately equal intensity of shaking or equal peak ground acceleration.

**Earthquakes Affecting Hawke's Bay since 1840**

In recent times Hawke’s Bay has experienced moderately higher levels of seismicity than most other areas of the country (see figure 3). Since records began 5 large earthquakes (M> 6.9) are known to have occurred, most of which were shallow events.
Begg et al 1994 (see Reference 1 to this chapter), contains a description of the large earthquakes that have affected the Hawke's Bay region.

**Earthquakes in Hawke's Bay**

The Hawke's Bay region is the site of numerous earthquakes because it is close to the boundary of two tectonic plates. These earthquakes result from the sudden release of stresses built up by relative movement between the Pacific and Australian plates over considerable periods of time. The normal subduction process produces these stresses within each of the two plates and along the subduction interface between them. This leads to three types of earthquakes occurring in distinct portions of the earth's crust, as shown in Figures 5a and 5b and discussed below:

Hawke's Bay has also experienced felt intensities of up to MM7 from large earthquakes occurring outside the region.

Many moderate magnitude events have occurred within the region. The location of earthquakes of M ≥ 5.0, which are known to have caused intensities ≥ MM5 at Wairoa, Napier, Hastings, Waipawa or Waipukurau, are shown in Figure 4.

The three principal types of earthquakes in Hawke's Bay are as follows:

- Type A earthquakes occur within the over-riding Australian Plate from the transfer of stress because of coupling between the two plates at the subduction interface (= "upper plate" earthquakes);
- Type B earthquakes occur at the interface between the subducting Pacific Plate and the over-riding Australian Plate (= "subduction interface");
Type C earthquakes occur in the upper part of the subducting Pacific Plate as it bends downwards beneath the Australian Plate (= "deep focus" earthquakes; Figure 5b). A typical, or "generic", model of a subduction zone can be compiled from world-wide studies, as has been done by Byrne et al. (1988) (Figure 5a). There is almost always a wide "active margin" in which deformation, earthquakes (Type A) and possibly volcanism, occur in the overlying plate. The active margin extends from near the "trench", where subduction begins, and continues inland for some distance. Usually, but not always, the magnitude of these Type A earthquakes is less than that of large subduction interface (Type B) events. However, Type A events may be shallower and closer to population centres and present a greater seismic hazard. Earthquakes that occur within the subducted plate (Type C) are occasionally quite large magnitude.

As yet there is no method for assessing the seismic hazard of Type C earthquakes. However, they are thought to pose a lesser danger to the region than Type A earthquakes. This is because they occur at a great depth within the descending Pacific Plate (>25 km beneath Napier, >40 km beneath the northern Ruahine Range) and because that plate may be relatively decoupled from the Australian Plate, limiting seismic energy. For these reasons Type C earthquakes are not considered further in this report.

Active Faults of Hawke’s Bay

Fault ruptures associated with earthquakes can occur in the earth’s crust. Those that are shallow enough to extend upwards to the ground surface form surface fault traces. Most ruptures that generate a surface trace are associated with large earthquakes, so active fault traces signal likely sites for future large earthquakes.

Major active onshore faults and folds of the Hawke's Bay region are discussed in detail in Reference 1. Their characteristics are updated in Reference 2, by Beggs et al.

In order from west to east they are:

Ruahine Fault
The Ruahine Fault is a strike-slip fault separating the stable microcontinental platform area of New Zealand from the zone of deformation known as the East Coast Deformed Belt, that extends to the Hikurangi Trough. The Ruahine and Mohaka faults are two of the major active faults of the Hawke’s Bay region and are also major strands of the Wellington fault system.

Waipuna, Big Hill and Thorn Flat, Patoka, Hinerua, Wakarara and Rangiora Faults.
These faults are probably related to the Ruahine and Mohaka faults.

Mohaka Fault
The Mohaka Fault is a major NE tending strike-slip fault which, together with the Ruahine Fault, forms one of the principal structural features of the eastern North Island.

Taniwha, Waikopiro, Oruwahero and Glendown Faults
These faults have been identified in the Ruataniwha and Takapau areas.

Napier – Hawke Bay Fault
The Napier-Hawke Bay Fault trends NW from Bridge Pa, possibly as far south as Tīkokino, through Te Awa and offshore.

The 1931 Hawke's Bay earthquake (M 7.8) is thought to have been caused by rupture of this fault. The line of zero change in elevation during the 1931 earthquake is currently regarded as the most accurate location of the surface projection of the fault. This is supported by the presence of a series of springs, which presumably resulted from disruption of an aquifer. The 1931 rupture of the Napier – Hawke Bay Fault was the first for at least 1800 years. The stratigraphic record from Ahuriri Lagoon indicates that subsidence has been the dominant direction of tectonic movement during the last 3500 years, in contrast to the uplift experienced in the 1931 event.


**Waipukuru – Ponhawa Shear Zone**

A number of strike-slip faults tending NNE NE between Waipukuru and Pakipaki were trenched, mapped and logged as part of the IGNS study and are reported in detail in Reference 2.

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**Hauamoana Fault Zone**

A NNE trending belt of normal faults extends from the coast at Clifton from 70km south beyond Wanstead. A large number of discontinuous fault traces make up a zone that varies in width from several hundred metres to about 8km.

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This zone was studied in detail and reported in Reference 2.

**Major active offshore structures include:**

- Napier – Hawke Bay Fault.
- Kidnappers Anticline/Hauamoana Fault Zone.
- Lachlan Ridge 20km east of Kidnappers Ridge.

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**Hikurangi Trough**

The axis of the Hikurangi Trough lies about 160km to the east of the Hawke’s Bay Coast. The trough is not a seismogenic source in its own right but a geomorphological feature that is one indicator of the tectonic environment of the North Island. It represents the surface expression of the subduction plate boundary and is the line along which the Pacific plate starts dipping below the eastern edge of the Australian plate.
Subduction Zone Earthquakes

The second main seismic hazard in the Hawke's Bay region is rupture of the gently dipping subduction interface that exists beneath the region (Type B earthquakes).

During a subduction interface rupture, there may not be any primary surface rupture. The history of subduction zone earthquakes can be evaluated by the pattern of coastal emergence or submergence. The pattern is also related to crustal faults. As a result it is very difficult in Hawke's Bay to determine and analyse these earthquakes by geologic evidence.

Historical data from active margins around the world shows that subduction zone earthquakes are among the largest. The hazard associated with subduction faults is difficult to quantify but is an important element of seismic assessment for the Hawke's Bay region.

The subduction zone in the North Island is unusual in two ways. First, a much greater width of the convergent margin is above sea level than is the case in most other subduction zones. This means that large subduction events which are normally offshore, as in Japan for example, may occur much closer to populated areas in New Zealand. Second, the direction of convergence is not perpendicular to the general strike (NE-SW) of the major geologic features and the subducted plate. This is known as oblique convergence and results in the presence of the major, strike-slip faults parallel to the coast in the overriding plate, such as the Wellington, Wairarapa, Ruahine, and Mohaka Faults. Earthquakes on these faults account for a large part of the component of convergence parallel to the coast. However, the component of motion perpendicular to the coast remains largely unaccounted for by these faults. It is usually assumed that this motion is taken up by some combination of slip on the subduction interface (seismic or aseismic), and slip during thrust type earthquakes on shallow faults between the Hikurangi Trough and the axial mountain ranges, such as in the Waipukurau-Poukawa area. It is the relative partitioning of slip between these various tectonic components that determines the potential for large subduction earthquakes in the region.

In order to estimate the location and size of large subduction thrust earthquakes in Hawke's Bay we must first establish the portion of the interface which slips during such events.

Using two methods, IGNS has estimated the average width at about 45km. The length of plate moving based on previous ruptures is 120km, which extends from just north of Cape Turnagain almost to Mahia. If this 120km segment of the plate were to rupture in a single subduction thrust event over a width of 45km, a magnitude 7.7 earthquake could be expected. Such an event is likely to produce an average slip of 3 metres between the plates.

To assess the likely recurrence of such an event, the project used the average relative movement between plates, adjusted for shortening of the overlying plate and factored for seismic slip to total slip. This has resulted in an estimated recurrence of about 550 years for such a subduction thrust event in Hawke's Bay.

Such events would be expected to produce subsidence above the down dip end of the seismogenic zone. Hull (1986) has used pwr layers in the Ahuriri Lagoon near Napier to demonstrate that the 1931 co-seismic uplift in this region was a reversal of a subsidence trend. This subsidence could have been produced by large subduction thrust events. The last down drop of ~1m
occurred about 500 years ago, and rapid downdrop of
8m occurred during the period 1750-3500 years ago.
Elastic dislocation modeling indicates that a
maximum of 1m of subsidence will occur above the
downdip end of the seismogenic zone as a result of 4m
of slip on the fault zone defined above. Thus the
downdrop at Ahuriri lagoon some 500 years ago would
be broadly consistent with the model for a subduction
thrust event. Similarly, if the total 9m of subsidence in
the last 3500 years identified by Hull (1986) was to
have occurred in similar sized events, a recurrence
interval of some 400 years is suggested. Although there
are many uncertainties this is also broadly consistent
with the recurrence intervals estimated above.

**Numerical Assessment of the Earthquake Hazard**

As part of their studies IGNS carried out a regional
revision of nationally based earthquake hazard
calculations.

These computer calculations used the following source
data:
- A catalogue of 1007 shallow earthquakes greater
  than M4 from 1840-1993;
- 728 deep earthquakes;
- Data from 40 active fault sources;
- The earthquake parameter for the subduction zone
  beneath Hawke's Bay.

The study predicted values of Modified Mercalli
Intensity (MM), and Peak Ground Acceleration
(PGA) for average ground conditions, such as the firm
alluvium that underlies many of the towns of southern
Hawke's Bay and the firmest parts of Napier and
Hastings.

A few parts of the region are on very firm sites that are
likely to experience less intense shaking than predicted
in this study. However many places are on soft ground
that will amplify the intensity of shaking. Amplifi-
cation factors, identified by mapping ground
conditions throughout the region in the latter part of
the studies, need to be incorporated to produce final
estimates of the earthquake hazard.

The earthquake hazard results are mainly based on
ground motions that have a 10% probability of being
exceeded in 15 years, 50 years and 500 years,
corresponding to 142, 475 and about 5000-year return
period events.

The 142-year return period event is likened to the
Operating Basis Event - one that can be expected with
reasonably high probability. The 475-year event is
likened to the Design Level Event (DLE) and
corresponds to the New Zealand Loadings Standard
(NZS 4203:1992) for many structures. The 5000-year
event is likened to the Maximum Design Event
(MDE). The MDE has a low probability of occurrence
but it is important that critical facilities and structures,
such as hospitals, fire stations and key lifeline services,
perform well even in this extreme event.

The results of the numerical assessment are presented
in Figures 7 to 12.