Vulnerability of New Zealand Ports to Natural Hazards

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SUMMARY
Ports are an important part of a country's infrastructure, both in terms of facilitating trade and aiding recovery immediately following an earthquake. In New Zealand ports facilitate the transfer of up to 99% of all exports and imports by volume and thus are important to the success of the country's economy. However, these ports are vulnerable to natural hazards which can cause significant damage and impact their operation. This study investigates the current state of New Zealand ports and their vulnerability to natural hazards. Publicly available data on New Zealand ports was supplemented by data sourced from port companies and used to construct a database of the New Zealand ports, including both the wharves' physical characteristics such as number, size, age, material properties and economic characteristics such as asset value, cargo volumes and cargo value. The vulnerability of New Zealand ports to seismic, tsunami and volcanic hazards was then examined.

Keywords: Ports, vulnerability, New Zealand, natural hazards

1. INTRODUCTION

Ports are complex commercial and physical entities at the interface between sea and land transport. They have strategic significance to New Zealand's economy, facilitating the transfer of up to 99% of all exports and imports by volume (New Zealand Trade and Enterprise, 2010). Further to the economic importance, the Civil Defence Emergency Management Act (2002) has identified ports as lifelines that need to be in operation following a natural hazard event. Ports have a vital role in delivering aid, emergency water supplies, construction materials, heavy equipment and other goods needed for facilitating a rapid recovery of the local region. The damage to ports as a result of natural hazards can result in significant short and long term losses. Short term losses include repair costs, business interruptions and damaged cargo, while long term losses can result from the permanent relocation of shipping operations to other ports because of interim loss of capacity at the damaged port. The effect of natural hazards on ports was evident in the 1995 Great Hanshin earthquake, Japan, where damage to the port in Kobe was estimated at 1 trillion yen (NZD$15 billion) and took almost 2 years to repair. The disruption caused by the closure of the port was valued at 30 billion yen (NZD$453 million) per month due to the loss of port related industries and trade (Chang, 2000). Likewise, the 2010 Darfield earthquake in the Canterbury region caused $50 million worth of damage to Lyttelton Port (TVNZ, 2010). The aim of this paper is to characterise New Zealand ports in terms of their physical and economic characteristics and examine their vulnerability to natural hazards.

2. OVERVIEW OF NZ PORTS

The New Zealand port environment is one of constant change and adaption in response to both internal and external forces. Currently there are 14 companies that own the major NZ ports having authority over 116 wharves, with a combined berthing length of 22 km and a total asset value approaching $2.1 billion. These port companies where formed after passing of the Port Companies Act in 1989 with all the shares going to the regional councils. Even though several port companies are public listed, all New Zealand ports are still majority owned by regional councils. Figure 1 shows the location NZ's major ports.

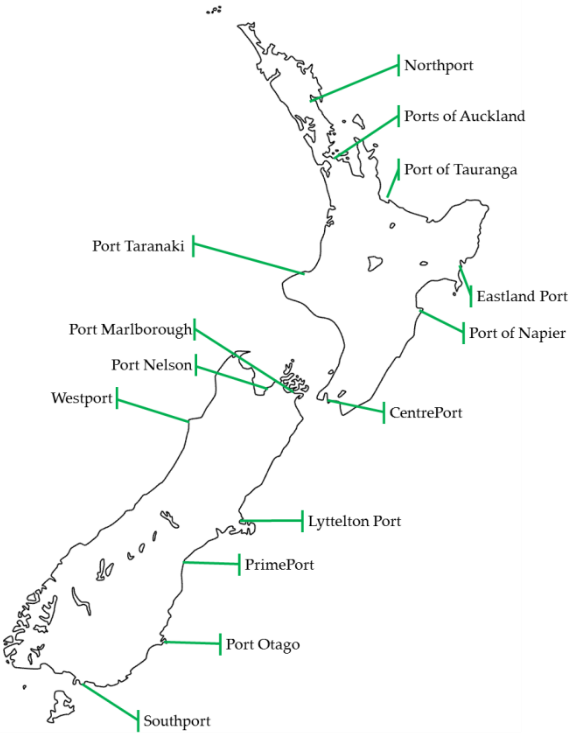

Figure 2.1. Location of NZ's major ports

2.1. Physical characteristics

The key physical part of a port is the wharves used for the berthing a ship and transfer of goods to and from the ship. The highest number of wharves was constructed in the 1950s followed by a similar period of wharf construction in the 1960s. Beyond the 1970s new wharf construction has been constant every decade with an average 10% of wharves being constructed every decade. Only a small percentage of wharves were constructed before the 1950s with the majority being constructed before the 1920s.

Wharves consist of various combinations of piers, walls and decks and there is no standard characterisation of structure type in the literature (International Navigation Association, 2001). For the purpose of this study wharves have been characterised into three broad structure types according to the front used for ship berthing. Wharves can either consist of a solid or open berthing front. Open berth structures consisting of a deck extending from the fill to the berth front and supported on piles are classified as 'pile-supported'. Solid berth structures consist of a deck resting on fill with a vertical front wall. Structures with a concrete front wall were classified as 'quay wall', and when the wall was constructed using sheet-piles the structure was classified as 'sheet-pile'. In NZ the vast majority of wharves are pile-supported structures.

2.2. Economic characteristics

There has been a steady increase in the amount of cargo handled by New Zealand ports, with the total value of cargo handled increasing by 230% between 1989 and 201 (Statistics NZ, 2011). At the individual port level Figure 2 shows that Ports of Auckland and Port of Tauranga are the largest in terms of volume of cargo handled. The Port of Tauranga handles greater volumes however the Ports of Auckland handles greater number of containers. Port Taranaki, Port of Napier, CentrePort, Port

Nelson and Port Otago are of medium size and handle similar volumes of cargo and containers. Notwithstanding the small volumes of cargo handled by Port Marlborough, it is a very important port because it handles a large amount of passenger traffic.

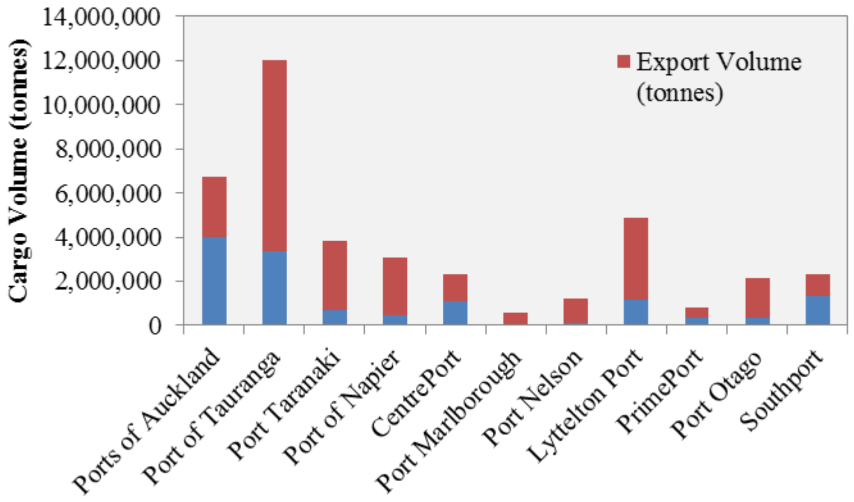

Figure 2.2. Total cargo volumes at each port. Adapted from (Statistics NZ, 2011)

3. VULNERABILITY TO SEISMIC HAZARDS

Seismic hazards have been the cause of significant damage in ports throughout history. The primary cause of damage in an earthquake is ground shaking which causes inertial forces to develop in the wharves causing significant structural damage and collapse. Aside from the direct damage to structures, ground shaking can also cause ground failure. Ground failure is less likely to cause spectacular structural collapses, but is frequently the cause of major disruptions which can lead to prolonged loss of function and income, even for undamaged areas. For example, the port in Lyttelton experienced significant damage as a result of ground deformations during the 2010-2011 Canterbury earthquake sequence. There was no structural collapse however there was significant damage to the pavement and the wharves

3.1. Overview of NZ seismicity

New Zealand is a seismically active region straddling the boundary of the Australian and Pacific tectonic plates. Stirling et al. (2002) identified four seismic zones. The northwest-dipping Hikurangi subduction zone is located to the east of the North Island where the Pacific plate is forced under the Australian plate. At the far south-western end of the South Island, is the southeast-dipping Fiordland subduction zone were the Australian plate is forced under the Pacific plate. Under the South Island the two plates push past each other sideways in a zone known as the axial tectonic belt. In addition, it is possible to identify a zone of active crustal extension (10 mm/yr) referred to as the Taupo Volcanic Zone. The relative plate motion results in the presence of numerous active faults, a high rate of small-to-moderate ($M < 7$) seismic events, and the occurrence of several large and great earthquakes (Oyarzo-Vera et al., 2011). It is estimated that New Zealand has around 14,000 earthquakes each year, with between 100 and 150 having a magnitude sufficient to be felt. However in the 15 years between 1992 and 2007 New Zealand experienced 30 earthquakes of magnitude 6 or more (GNS Science, 2009). The level of seismic hazard at a site depends on the influence of the different faults and the characteristics of the earthquakes that could be expected

3.2. Site classes

A key step in understanding the vulnerability of ports to seismic hazards is determining a soil site class for each port as defined by the New Zealand Seismic Design Standard, NZS1170.5 (Standards New Zealand, 2004). The site class indicates the type of soil present on site and accordingly this has an effect on the degree of amplification of the bedrock ground motions at the ground surface. The possible assignments for most of the ports can span a range of site classes, depending on the exact location but for the purpose of broad study a single general value was assigned to each port using low resolution maps. A more accurate assignment of site classes requires more site specific geotechnical information. Table 3.1 indicates that the majority of ports are located on soil type D which is a deep or very soft soil. The remainder of wharves lie on shallow soils with a corresponding site class C.

Table 3.1. Site class assignments for New Zealand ports

Port	Site class
Northport	D (deed or very soft soils
Ports of Auckland	C (shallow soils)
Port of Tauranga	D (deed soils to E (very soft soils
Port Taranaki	C (shallow to D (deep) – mainly C
Eastland Port	C (shallow) – possible D (deep) at outer edge
Port of Napier	C (shallow) inner to D (deep) in outer port
CentrePort	D (deep)
Port Marlborough	C (shallow)
Port Nelson	D (deep)
Westport	D (deep) to E (very soft)
Lyttelton Port	D (deep) but partly B (rock close to higher ground
PrimePort	D (deep) – basalt from 3 to 12 m may be present at site, but it overlies gravel for hundreds of metres
Port Otago	C (shallow)
Southport	D (deep) but E (very soft) is possible in places

3.3. Seismic hazard curves

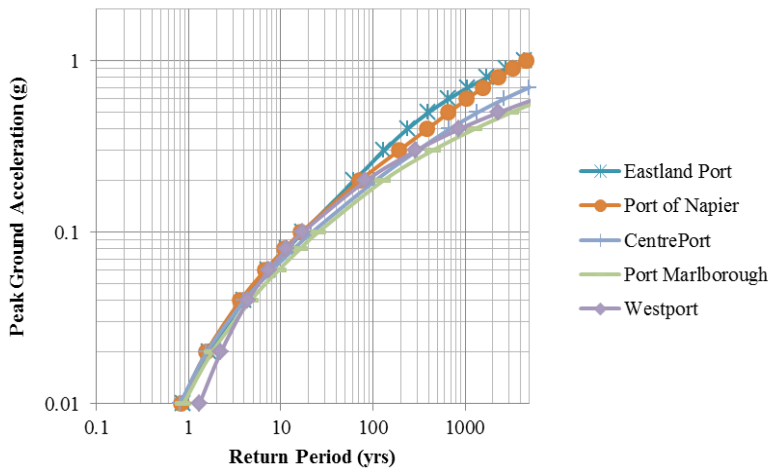

Figure 3.1. Seismic hazard curve for ports with high seismic exposure. Adapted from McVerry (2012)

An initial measure of exposure to ground shaking is a seismic hazard curve in which the expected Peak Ground Acceleration (PGA) at a site is plotted against return period. Seismic hazard curves generated using the New Zealand National Seismic Hazard Model (NZNSM) were provided by GNS Science for all port locations (McVerry, 2012). The seismic hazard curves can be grouped into three broad categories corresponding to high, medium and low seismic exposure. The ports located closest to the well-known faults in New Zealand unsurprisingly have the highest seismic exposure as shown by the seismic hazard curves in Figure 3. These ports are Eastland Port, Port of Napier, CentrePort, Port Marlborough and Westport. Figure 4 shows the seismic hazard curves for Port Tauranga, Port Taranaki, Port Nelson, PrimePort, Port Otago and Southport which all have a medium seismic exposure. The remaining Ports of Auckland and Northport have the lowest seismic exposure as shown in Figure 5. A seismic hazard curve for Lyttelton Port has not been developed due to the uncertainty in the NZNSM as a result of the on-going seismic activity in the region

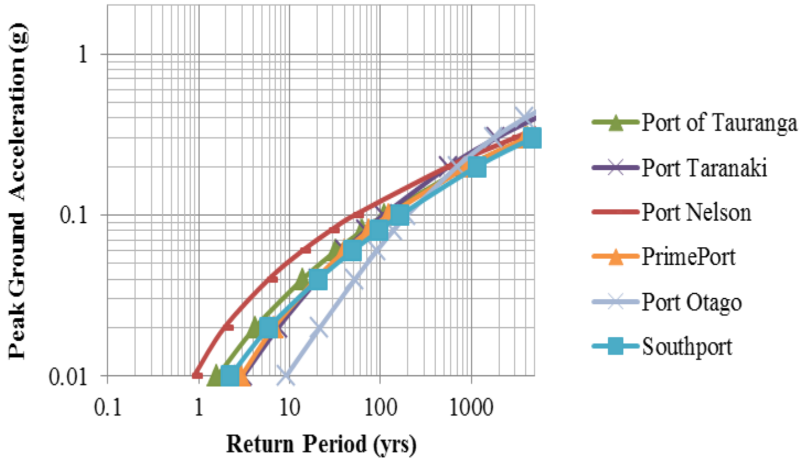

Figure 3.2. Seismic hazard curve for ports with medium seismic exposure. Adapted from McVerry (2012)

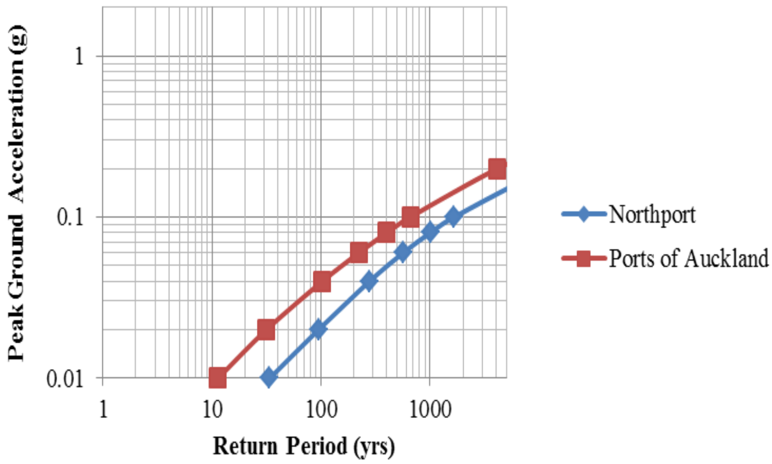

Figure 3.3. Seismic hazard curve for ports with low seismic exposure. Adapted from McVerry (2012)

3.4. Reclamation

Evidence from previous earthquakes indicates that significant damage at ports occurs as a result of liquefaction in the ground backing the berthing structures due to the presence of saturated cohesionless soils which are the most susceptible to liquefaction. Furthermore it is common for ports to be situated on non-engineered reclaimed land thus increasing their vulnerability to ground failure. Consequently understanding the reclamation history of a port is important in reviewing its vulnerability to seismic hazards. In New Zealand all the ports are located on reclaimed land of varying age and quality. The majority of the reclamations immediately backing the wharves have been constructed after the 1950s. However, in several cities the land outside of the port was reclaimed in the 1800s and early 1900 and consequently is predicted to be of poor quality considering the rudimentary construction techniques used to reclaim the land

4. VULNERABILITY TO TSUNAMI HAZARDS

4.1. Overview of tsunami hazard

A tsunami occurs when a large body of water is displaced suddenly generating large waves that inundate coastlines causing significant damage. This sudden displacement of water can occur as a result of a large submarine or coastal earthquake in which significant uplift or subsidence of the seafloor or coast occurs. Tsunamis can also be triggered by underwater landslides, large landslides from coastal or lakeside cliffs and volcanic eruptions (e.g., under-water explosions or caldera collapse, pyroclastic flows and atmospheric pressure waves) (Berryman, 2006).
NZ's coastline is vulnerable to Tsunamis the following potential sources:

Local sources: New Zealand's location on a plate boundary means that it experiences many large earthquakes with some causing large tsunami. For example, the 1947 M7.1 earthquake off Gisborne affected 120 km of coastline, with a tsunami of 10 m maximum height occurring along tens of kilometres of coast north of Gisborne.

Regional sources: Submarine or coastal landslides in the close vicinity of New Zealand's or from island and submarine volcanoes can cause tsunamis reaching New Zealand in 1-3 hours.

Distant sources: Tsunami generated by large earthquakes at distant locations, such as South America, western North America and the Aleutians in the north Pacific Ocean, can also be damaging in New Zealand. For example, the M9.5 Chile earthquake produced a 25 m high tsunami locally, over 10 m in Hawaii, and nearly 4 m in New Zealand.

4.2. Tsunami impacts

The damage from tsunamis results from the impact of a swiftly flowing torrent of water on infrastructure causing uplift and scouring. The water flow also carries debris which can cause significant damage upon impact against structures. Similar to earthquakes, tsunamis can cause spillage of chemicals and hazardous substances causing fire and contamination. Finally, the ponding of potentially large volumes of seawater will cause medium- to long-term damage to buildings, electronics and fittings. Ports are the first parts of the city to be inundated by tsunami waves due to their location at water's front. This can cause significant damage to infrastructure (berths, cranes and buildings) and cargo stored at the port. Also the significant amount of debris that can potentially be carried by the water flow can cause damage to structures within and outside the port (Berryman, 2006).

New Zealand has experienced tsunami in the historical past, but few lives have been lost and damage to property and infrastructure has been modest. For example in the 1985 M8.2 Wairarapa earthquake causing a wave height of up to 10 m in some locations. However damage was minimal and there were no recorded fatalities. The large historical tsunami events that impacted New Zealand occurred when shoreline development was very modest by comparison with the present, so the fragility is now much greater (Berryman, 2006).

4.3. Tsunami hazard curves

In tsunami hazard curves tsunami wave height is plotted against return period to provide a measure of exposure to tsunami hazards. All the tsunami hazard curve were originally developed for NZ city centres but considering that most ports are located adjacent to the CBD these curves have been used to represent the tsunami risk to ports. The hazard curves have been grouped into high, medium and low tsunami exposure. The highest tsunami exposure is predicted in CentrePort and Eastland Port with a wave height between 7 to 10 m at a 1000 year return period, as shown in Figure 6. Lyttelton Port, Port of Napier and PrimePort are only exposed to a medium tsunami risk with a corresponding wave height between 4.5 and 6 m, shown in Figure 7. The remainder of the ports (shown in Figure 8) are exposed to a low tsunami risk between 2 to 4 m. Tsunami hazard curves for Westport and Port Marlborough have not been developed due to lack of information (Berryman, 2006).

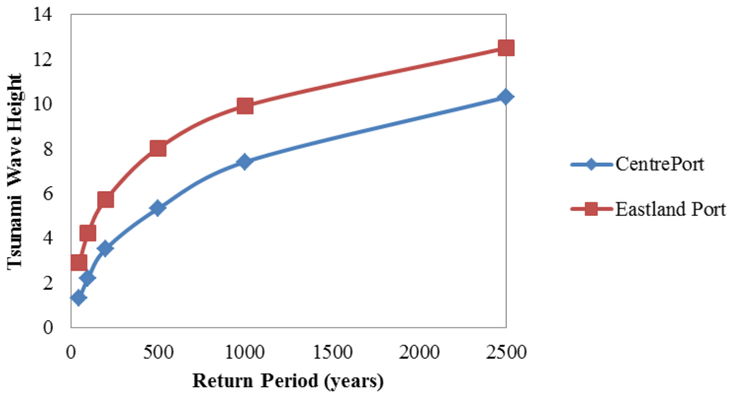

Figure 4.1. Tsunami hazard curves for high exposure ports. Adapted from Berryman (2006)

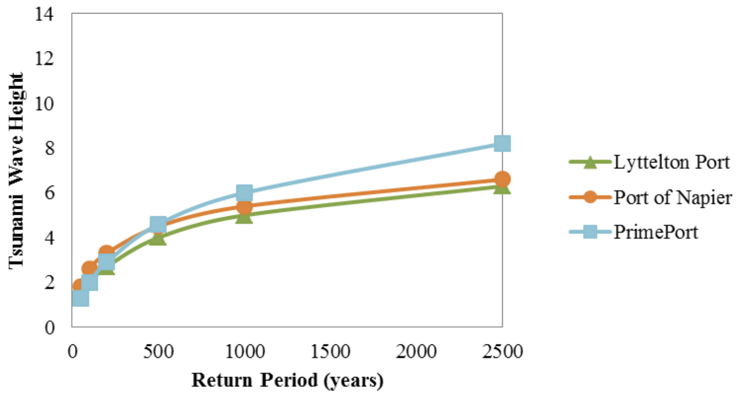

Figure 4.2. Tsunami hazard curves for medium exposure ports. Adapted from Berryman (2006)

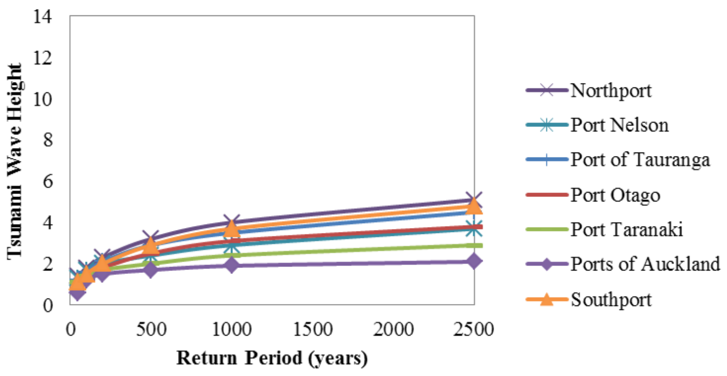

Figure 4.3. Tsunami hazard curves for low exposure ports. Adapted from Berryman (2006)

For all the ports on the east coast of NZ the greatest risk for a 500 year return period event is from distant sources in South America. The exception to that is the Port of Napier for which the greatest tsunami risk is from the local subduction zone or offshore faults. Port Taranaki located in the west coast of the North Island, CentrePort in the south of the North Island and Port Nelson located in the north of the South Island all face the greatest tsunami risk from sources in the subduction zone (Berryman, 2006).

5. VULNERABILITY TO VOLCANIC HAZARDS

5.1. Overview of NZ volcanism

New Zealand is characterised by both a high density of active volcanoes and a high frequency of eruptions. Volcanic activity in New Zealand occurs in six main areas, five in the North Island (shown in Figure 5.1) and one offshore to the northeast in the Kermadec Islands. Most New Zealand volcanic activity in the past 1.6 million years has occurred in the Taupo Volcanic which is an area from White Island in the east to Ruapehu in the west (Wilson et al., 1995). The 6 key volcanic areas can be classified into three volcanic types as follows:

Volcanic Fields: These are found primarily in Auckland and Northland and are a result of small eruptions that occur over wide geographic areas. Once a volcanic cone is created it usually no longer erupts in the same location. It is difficult to predict the size and location of the next eruption until it is very imminent.

Cone volcanoes: These volcanoes produce a large cone as a result of successive eruptions in the same location thus accumulating magma flow to increasing the size of the volcano. Mount Taranaki and Ruapehu are examples of these types of volcanoes. The same route to the surface is used repeatedly by the magma so sites of future eruptions predictable.

Caldera volcanoes: these volcanoes are caused by large eruptions that cause the ground surface to collapse forming a large hole the contents of which are spread widely because of the size of the eruption. Taupo and Okataina (which includes Tarawera) are examples of these types of volcanoes (Wilson et al., 1995).

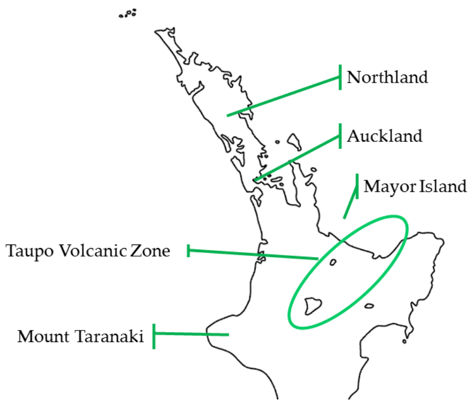

Figure 5.1. Volcanic sources in the North Island, New Zealand. Adapted from Wilson et al. (1995)

5.2. Volcanic hazard impacts

Damage to ports as a result of volcanic eruptions can be caused from two types of volcanic hazards. Ports located in the close vicinity (within a few kilometres) of volcanic eruptions are susceptible to significant damage from magma pyroclastic flow which can cause irreparable damage to all infrastructures. However the more common damage results from accumulating ash fall on wharves thus inhibiting movement of equipment or accumulating ash fall on roofs causing collapse. In the event of ash fall at a port, operations at the port can resume as soon as the ash is cleaned up assuming no roof collapses have occurred. In comparison to other hazards a volcanic eruption is the least significant hazard to port operations and consequently in previous volcanoes the port was used for the evacuation of citizens even throughout the eruption. For example in the 2008 eruption of the Chaiten Volcano in southern Chile the port in the town of Chaiten was used for the evacuation of a large percentage of the population throughout light ash falls (total of 20 – 50 mm) (Johnston & Houghton, 1995).

5.3. Volcanic hazard exposure

5.3.1. Lava flow

The only ports exposed to the risk of lava flow are Northport as a result of an eruption in the Puhipuhi-Whangarei Volcanic Field (PWVF) or Kaikohe-Bay of Islands Volcanic Field (KBVF) and the Ports of Auckland as a result of an eruption in the Auckland Volcanic Field (AVF). The activity of both PWVF and KBVF is debatable with the last eruption occurring 250,000 and 50,000 years ago, respectively. However, the exact location of a future eruption is unknown and could produce up to 10 km of lava flow. An eruption in the AVF is predicted to generate up to 3 km of lava flow (Smith & Allen, 2010; Northland Regional Council, 2007). Port Taranaki is in the immediate vicinity of Mount Taranaki however hazard studies indicate that in any future eruptions will result in lava flows away from the port (GNS Science, 2010).

5.3.2. Ash fall

A large portion of NZ is exposed to ash fall as a result of a large eruption in the TVZ or smaller eruptions in the AVF and Mount Taranaki. Table 2 summarises the exposure of ports to the risk of ash fall. Information is not available for all ports.

Table 5.1. Summary of exposure to ash fall in NZ ports

Port	Source and return period	Exposure
Northport	TVZ with a 100 – 2000 years return period	1 – 100 mm (Beetham et al., 2004)
Ports of Auckland	AVF with 100 - 1000 years return period	>10 mm of ash (Beca Infrastructure Ltd, 2009)
	TVZ with 100 - 2000 years return period	1 – 100 mm dependent on wind direction and strength (Beca Infrastructure Ltd, 2009)
Port of Tauranga	White Island with a 1000 year return period	1 – 50 mm dependent on wind direction (Cole et al., 2010)
	Okataina Volcanic Centre (OVC) with an unknown return period	100 mm of dependent on wind direction and strength (Nairn, 2010)
Port Taranaki	Mount Taranaki (unknown return period)	0.1 – 0.25 m (GNS Science, 2010)
Eastland Port	OVC with a 300 – 700 year return period	1 – 1500 mm dependent on wind direction (Gisborne District Council, 2012)
	Taupo Volcanic Centre (TVC) with a 250 – 5000 year return period	1 – 600 mm dependant on wind direction (Gisborne District Council, 2012)
Port of Napier	TVZ for a 1000 year return period	50 – 100 mm dependent on wind direction and strength (Civil Defence, 2012)
CentrePort and South Island ports	TVZ	Potential for ash fall. No studies on exposure

6. FUTURE RESEARCH

This research is part of a larger research project being conducted at the University of Auckland that is aimed at increasing the resilience of NZ ports to natural hazards. The next phase in the research is aimed at developing a set of generic wharf models that representative of the type of wharves found in NZ. Numerical models will then be generated for each wharf type followed by numerical simulations to generate fragility curves.

7. CONCLUSION

In conclusion the study on NZ ports has indicated that there is a wide variety in exposure to natural hazards throughout the ports. Seismic hazard is closely aligned to the main faults that run through the centre of New Zealand. In contrast volcanic hazard is centred primarily in the TVZ and the AVF. The primary tsunami hazard is from a South American source which exposes the east coast of the North Island to the greatest tsunami risk.

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