# A Review of New Zealand Port Infrastructure and Their Vulnerability to Natural Hazards

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## Abstract

Ports are strategically significant to New Zealand's economy, facilitating the transfer of up to 99% of all New Zealand exports and imports by volume. Ports are also a lifeline that must be immediately operational following a natural hazard, as stipulated by the Civil Defence Emergency Management Act (2002). The study reported here is the first phase of a larger research project that focuses on improving the resilience of New Zealand port systems to natural hazards. The aim of this initial study was to review and characterise port infrastructure and examine their exposure and vulnerability to natural hazards. For the majority of New Zealand ports the natural hazards that pose the highest risk are seismic and tsunami hazards.

To characterise the current state of New Zealand ports, physical and economic characteristics were collected from public sources and through collaboration with port companies. The physical data collected included number, size and age of structures, material properties and development history of the port. Economic data collected included value of assets and cargo volumes. Using this data a general representation of the vulnerability of New Zealand port infrastructure to seismic and tsunami hazards is presented here.

**Keywords:** natural hazards, seismic risk, ports, port infrastructure, vulnerability

# 1 Background

The damage to port systems 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 port systems 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 of New Zealand caused $50 million worth of damage to Lyttelton Port (TVNZ, 2010) and the 1931 Napier earthquake raised the ground in the Ahuriri Lagoon, resulting in the closure of Napier's main port at the time (Bryan, 1952).

A study was undertaken to characterise New Zealand port infrastructure and evaluate their vulnerability to natural hazards. This study formed the first phase of a larger multi-phased collaborative research project developed at The University of Auckland, with the support of the New Zealand Natural Hazards Research Platform (NHRP). The aim of the project was to increase the resilience of New Zealand port systems to natural hazards.

# 2 Summary of Ports

For the purpose of this study port infrastructure was defined as any fixed structure used primarily for berthing and providing access to shipping vessels. This definition excludes a number of other structures found at ports such as buildings, sheds, floating pontoons, cranes and utilities. Information was collected on 14 companies with authority over 104 wharves, having a combined berthing length of 19 kms and a total asset value approaching $2.5 billion. The two largest ports in terms of value of cargo handled are Ports of Auckland and Port of Tauranga, followed by Lyttelton Port (before the 2011 Christchurch earthquakes) and Port Otago. The comparative size of New Zealand ports is shown in Figure 1 by the size of the circle symbols for each locality. Port size was measured by the value of cargo traded from 1989 to 2011.


**Figure 1: Size of New Zealand ports measured by total value of cargo handled**

## 3 Physical Characteristics

### 3.1 Construction Date

In most cases the construction date of a wharf structure was easily identifiable. However, in some cases the wharf had undergone significant rehabilitation or was built in stages over several years. In these marginal cases, the wharf was assigned a representative construction date that was a combination of the relevant dates weighted by berth length.

The distribution of wharf construction dates is plotted in Figure 2 showing the 1950s as the most common construction period, corresponding to an age between 51-60 years. The next most common construction period is the 1960s. In the period from 1970 to 2011 the rate of wharf construction was approximately constant. Another method of presenting this data, in which construction dates are weighted according to the structure's berth length, is presented in Figure 3. This method takes into consideration the fact that structures with greater berthing space are usually more important, clearly showing the same trend as for Figure 2.

### 3.2 Structure Type

Each wharf is a unique structure designed to resist live loads from machinery and cranes, impact loads from docking ships, and earthquake loads. These structures consist of various combinations of piers, walls and decks. Due to this range of construction types there is no standard characterisation for structure type in the literature (International Navigation Association, 2001). For the purpose of this study wharves were characterised into three broad structure types according to the characteristics of the wharf frontage 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'. Figure 4 shows that pile-supported structures are by far the most common structure type, with 80% of the available berthing space provided by pile-supported structures. Sheet-pile construction was used in 16% of berthing space and quay walls were used in the remaining 4%.

### 3.3 Materials

Figure 5 shows that the material most commonly used in the construction of wharf superstructures (decks) is reinforced concrete, with 92% of decks constructed using concrete and the remainder being split between timber and a combination of timber and concrete. Concrete is also the most commonly used material in the construction of wharf substructures (walls and piles), as shown in Figure 6. However, concrete was used in only 51% of substructures, with 32% constructed using timber and the remaining 17% constructed using steel.

## 4 Economic Characteristics

There has been a steady increase in the amount of cargo handled by New Zealand ports, with Figure 7 showing that the total value of cargo handled increasing by 230% between 1989 and 2011. However, this upward trend is not necessarily the case for individual ports, which can experience large fluctuations in the amount of cargo handled, especially so for ports dependent on trade from single large exporters. For example, prior to August 2009, dairy imports and exports accounted for approximately 50% of PrimePort's (Timaru, South Island) trade. This trade was lost immediately when Fonterra (a dairy company) transferred their cargo through Lyttelton Port (Bailey, 2009).

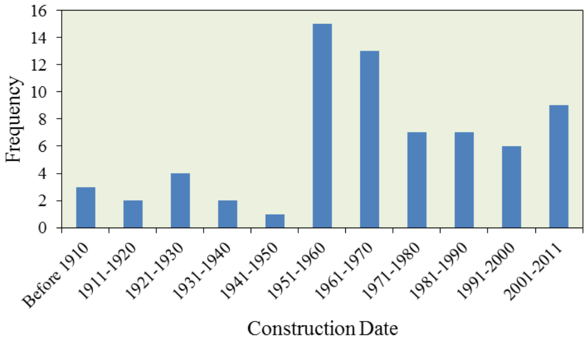


Figure 2: Histogram of wharf construction dates

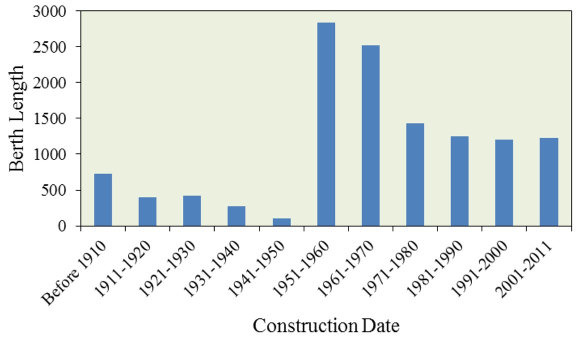


Figure 3: Distribution of construction dates according to berth length

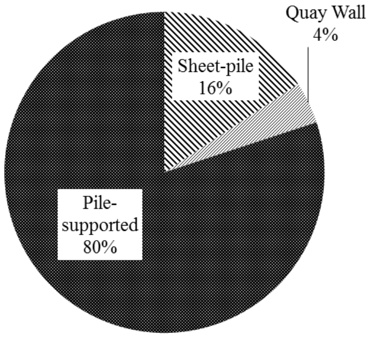


Figure 4: Ratio of wharf structure type

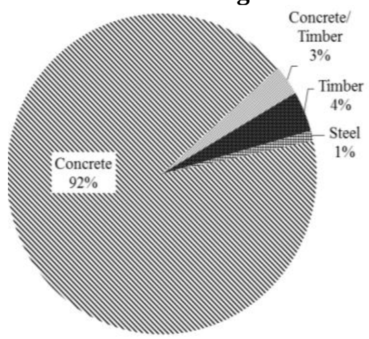


Figure 5: Ratio of superstructure construction material

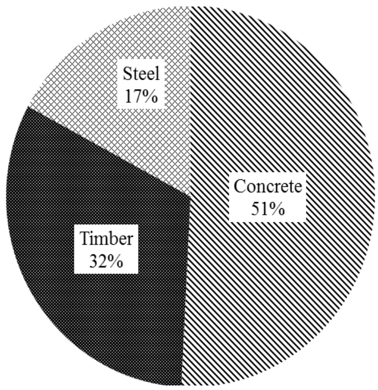


Figure 6: Ratio of substructure construction material

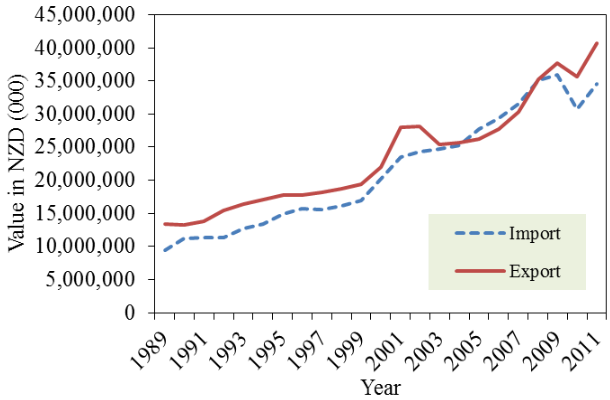


Figure 7: Value of total cargo handled by New Zealand ports

## 5 Seismic Hazard

New Zealand is a country of moderate seismicity, resulting from its location at the boundary of the Pacific and Australian tectonic plates. However, seismic hazard varies considerably between individual ports and is controlled by their distance from active sources. This variability in seismic hazard is captured in the New Zealand Standard for Structural Design Actions, NZS 1170.5:2004 (Standards New Zealand, 2004) through the hazard factor, Z (Oyarzo-Vera, McVerry, & Ingham, 2011). Using this hazard factor, seismic hazard curves were generated for all New Zealand ports and are plotted in Figure 8a. The hazard factor is a crude approximation of seismic hazard because it does not allow for site effects, which can significantly alter ground shaking (International Navigation Association, 2001). Considering that many New Zealand ports are located on low quality reclaimed land (usually non-engineered), these PGA values are likely to increase. However, for the purpose of this initial study these effects were ignored, and the analysis will be refined once detailed geotechnical data is collated.

Analysis of Figure 8a reveals three levels of seismic demand: high, medium and low. High seismic demand has been defined as a PGA greater than 0.6g, wharves with a PGA less than 0.3g were defined as low seismic demand, and medium seismic demand was assigned to wharves having a PGA of 0.3-0.6g. CentrePort, Port Napier and Eastland Port are subject to the highest seismic demand; Port Marlborough, Westport and Port Nelson are subject to a medium seismic demand and Lyttelton Port, Port of Tauranga, Port Taranaki, Southport, PrimePort, Port Otago, Ports of Auckland and Northport are subject to the lowest seismic demand. It is important to clarify that the 2010 Darfield and 2011 Christchurch earthquakes were on previously unidentified faults, which is one of the reasons why Lyttelton Port was assigned a low seismic demand in design standards even though it suffered significantly in the Christchurch event. As a result of these events, the hazard factor will be increased to account for modifications to the seismic hazard (Holden, et al., 2011).

### 5.1 Vulnerability

Vulnerability is a measure of the difference between seismic demand (seismic hazard curve) and seismic capacity (port characteristics). NZS 1170.5:2004 stipulates that ports have an importance level of 3, corresponding to an earthquake annual probability of 0.001 or a return period of 1000 years. Therefore as an approximate measure of seismic demand, the PGA for a 1000 year event was determined for each wharf.

The assigned construction date of a wharf was used as an approximate measure of seismic capacity. Assuming that all wharves were designed according to the relevant earthquake loading standards at the time of construction, it was assumed that wharves built prior to 1976 are non-ductile. The year 1976 corresponds to the release of NZS 4203:1976, which was a major revision of the New Zealand Loadings Standards (Megget, 2006), although it is important to note that New Zealand’s earthquake loading standards have never specifically addressed wharf structures. This lack of guidance gave wharf designers significant leeway when determining earthquake loads. According to the above 1976 criterion, there are 12 wharves (12%) in the most vulnerable category (high seismic demand and non-ductile structure) and 17 wharves (17%) in the next most vulnerable category (medium seismic demand and non-ductile structure).

## 6 Tsunami Hazard

Damage caused by the Indian Ocean tsunami in 2004, and the more recent Japanese tsunami in 2011 are a reminder of the destructive forces associated with tsunamis (Mimura et al., 2011, Sheth et al., 2006). In this regard the most comprehensive study of tsunami hazard in New Zealand was compiled by Berryman (2006). All the likely sources of tsunamis that can affect New Zealand were examined by evaluating their potential to generate tsunamis, the likely waves produced, and their impact on the principal urban centres in New Zealand. A key output of the study was tsunami hazard curves (expected tsunami wave height against return period) for key population centres. For the purpose of comparing the hazard at different ports, the hazard curves for the population centres was assumed to represent the hazard curve for the port. This approximation is reasonable considering that most ports are located in the immediate vicinity of urban centres. The hazard curves for all New Zealand ports except for Westport and Port Marlborough are plotted in Figure 8b.

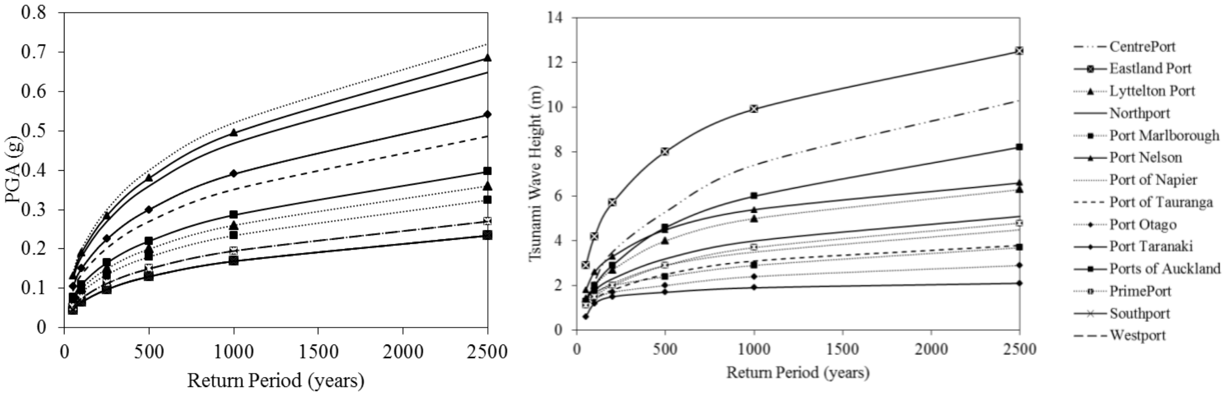


**Figure 8: Hazard curves for New Zealand ports. (a) Seismic hazard, (b) Tsunami hazard**

The greatest tsunami hazard is expected at Eastland Port, located on the exposed east coast of New Zealand, with an expected wave height of 8.0 m for a 500 year return period. The largest contribution to this hazard is from distant source (e.g. South America) tsunamis. Conversely, Ports of Auckland has the lowest tsunami hazard, with an expected wave height of 3.6 m for a 500 year return period. Similarly, the biggest contribution to this hazard is from distant source tsunamis.

## 7 Conclusion

Port infrastructure was reviewed and their vulnerability to natural hazards was examined. Information was collected on a total of 104 wharves with a combined berthing length of 19 kms and a total asset value approaching NZ$2.5 billion. The greatest number of wharf structures was constructed between 1950 and 1970 and the most common structure type was pile-supported structures. 90% of the decks and 51% of the substructure was constructed using concrete. For 73% of the wharves lateral capacity was provided using raked piles. The output from this study will be used in the development of a virtual port and the development of fragility models.

## 8 Acknowledgements

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