Performance of Ports in Recent Earthquakes

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Critical Structures

8.5% average annual growth
Recent Earthquakes

- 12 January 2010 Mₕ7.0 Haiti
- 27 February 2010 Mₕ8.8 Maule, Chile
- 4 September 2010 Mₕ7.1 Darfield, New Zealand
- 22 February 2011 Mₕ6.3 Christchurch, New Zealand
- 11 March 2011 Mₕ9.0 Tohoku, Japan

Port de Port-au-Prince
North Wharf

South Pier
Temporary Berths

from Werner et al. (2011)

South Pier

from Werner et al. (2011)
South Pier

a) Single Pile Repair Form in Yard

b) Rebar Cage Installation

from Werner et al. (2011)

South Pier

c) Rebar Cage Installed - Two-Pile Repair

d) Placement of Form around Rebar

from Werner et al. (2011)
South Pier

e) Installed Form

f) Pumping of Concrete into Form

from Werner et al. (2011)

South Pier

g) Completed Cap Above Water: Single-Pile Repair

h) Completed Cap Below Water: Single-Pile Repair

from Werner et al. (2011)
Lyttelton, New Zealand

Port of Lyttelton – CQ1
Port of Lyttelton – CQ1

Port of Lyttelton – CQ1
Port of Lyttelton – CQ1

Port of Lyttelton – CQ3 and CQ4
Port of Lyttelton – CQ3

Port of Lyttelton – CQ3
### Port of Lyttelton – CQ4

![Port of Lyttelton – CQ4](image)

### Port of Lyttelton

<table>
<thead>
<tr>
<th>Berth</th>
<th>Length (m)</th>
<th>Cargo</th>
<th>Built</th>
<th>Piling</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CQ1</td>
<td>230</td>
<td>Coal</td>
<td>1960s</td>
<td>Timber</td>
<td>• 300 mm lateral displacement in September 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 230 to 400 mm lateral movement in February 2011</td>
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<td>• Up to 1 m vertical displacement</td>
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<td></td>
<td></td>
<td></td>
<td>• First coal train arrived on March 5 (11 days)</td>
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<td></td>
<td></td>
<td>• First ship loaded on March 15 (21 days) using “fixed point” loading</td>
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<tr>
<td>CQ2</td>
<td>214</td>
<td>Inactive</td>
<td>1960s</td>
<td>Timber</td>
<td></td>
</tr>
<tr>
<td>CQ3</td>
<td>176</td>
<td>Containers</td>
<td>1973</td>
<td>Steel (610 mm )</td>
<td>• 250 mm lateral displacement in February 2011</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>• Damage to piles</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Operational by March 9 (15 days)</td>
</tr>
<tr>
<td>CQ4</td>
<td>235</td>
<td>Containers</td>
<td>1994</td>
<td>Precast Concrete</td>
<td>• 200 mm lateral displacement in February 2011</td>
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<td></td>
<td></td>
<td>• Damage to piles</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Cranes B and C derailed</td>
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<td></td>
<td></td>
<td></td>
<td>• Operational by February 26 (4 days)</td>
</tr>
</tbody>
</table>
Are there plans to conduct a vulnerability assessment? 

- Yes 57%
- No 43%

What is the nature of seismic risk mitigation plans?

- None 17%
- Required/Formal 39%
- Informal 44%

23 ports in areas with “high” seismic hazard
Seismic Risk Analysis

Performance-Based Seismic Design

- **Two-Level Approach**
  - Operating Level Earthquake (OLE)
    - 72-year return period
    - “Shall not result in significant structural damage”
    - “Repairs shall not interrupt wharf operations”
  - Contingency Level Earthquake (CLE)
    - 475-year return period
    - “May result in controlled inelastic structural behavior”
    - “Temporary loss of operations shall be restored within an acceptable period of time”

- **Performance-Based**
  - Total losses with a return period of X years shall not exceed $Y million
  - Average annual loss shall not exceed $X million
  - Probable maximum loss (i.e., 90% probability of non-exceedance) shall be less than $X million for the OLE (or CLE)
Acknowledgements

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