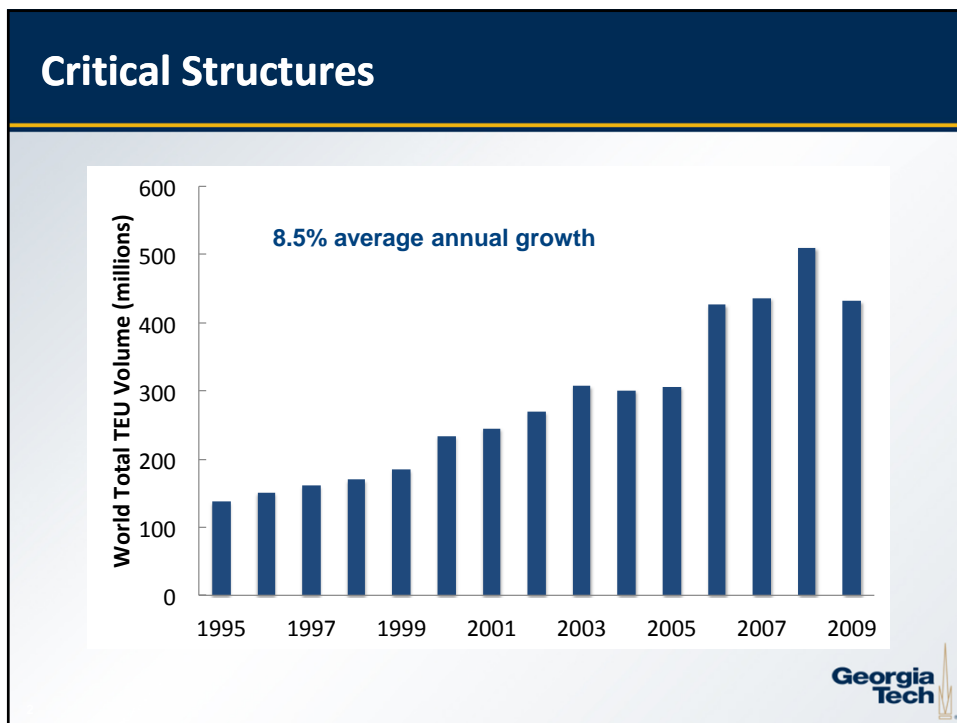


# Performance of Ports in Recent Earthquakes

Glenn J. Rix

Georgia Institute of Technology



## Recent Earthquakes

- 12 January 2010  $M_w$  7.0 Haiti
- 27 February 2010  $M_w$  8.8 Maule, Chile
- 4 September 2010  $M_w$  7.1 Darfield, New Zealand
- 22 February 2011  $M_w$  6.3 Christchurch, New Zealand
- 11 March 2011  $M_w$  9.0 Tohoku, Japan



## Port de Port-au-Prince





## North Wharf



## North Wharf

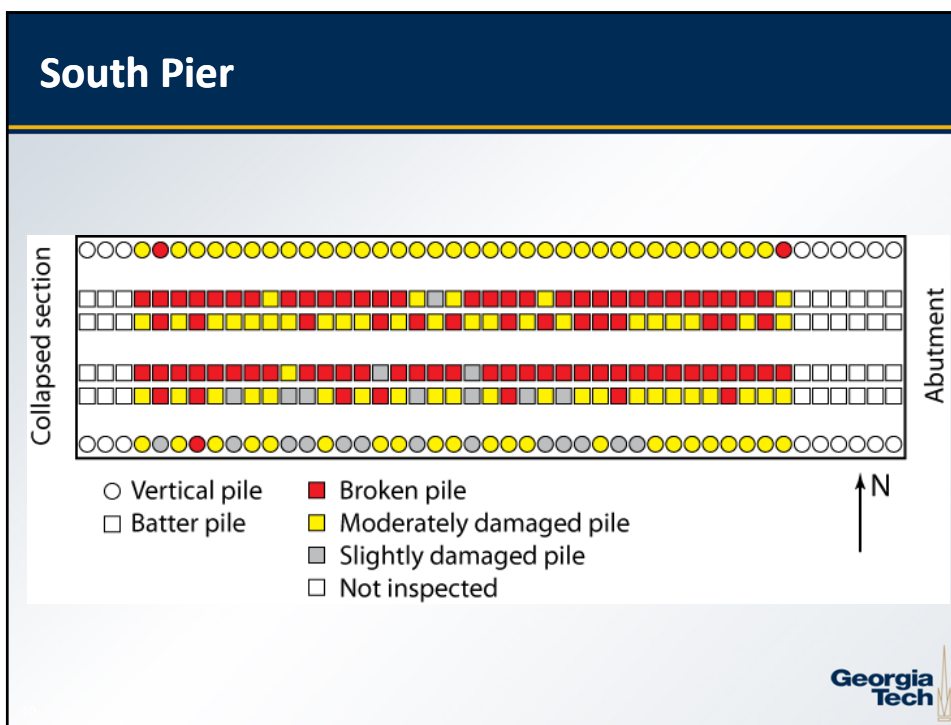
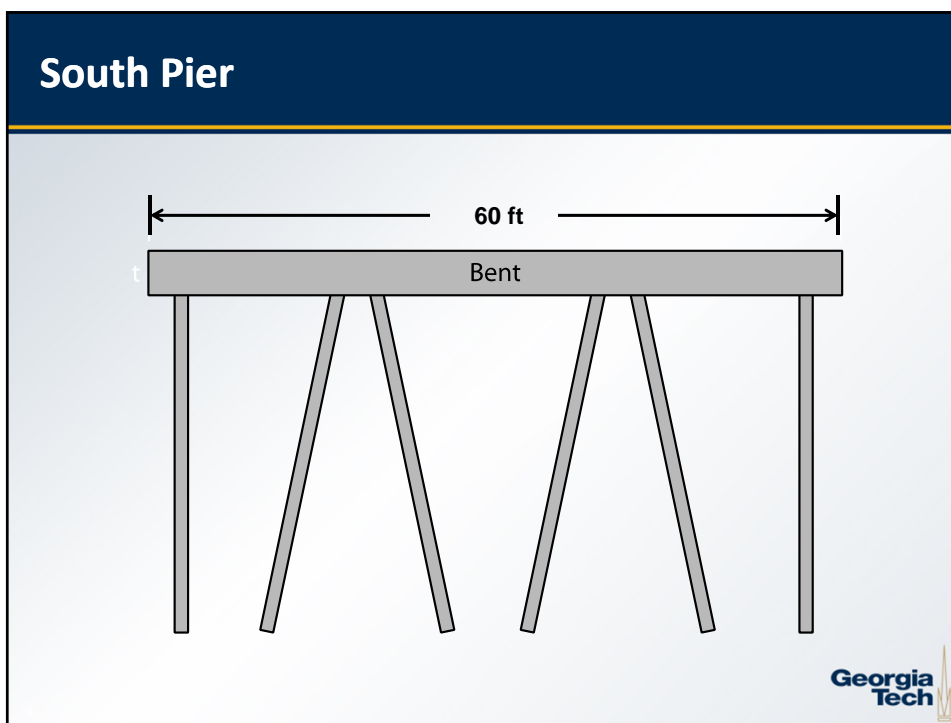


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## South Pier

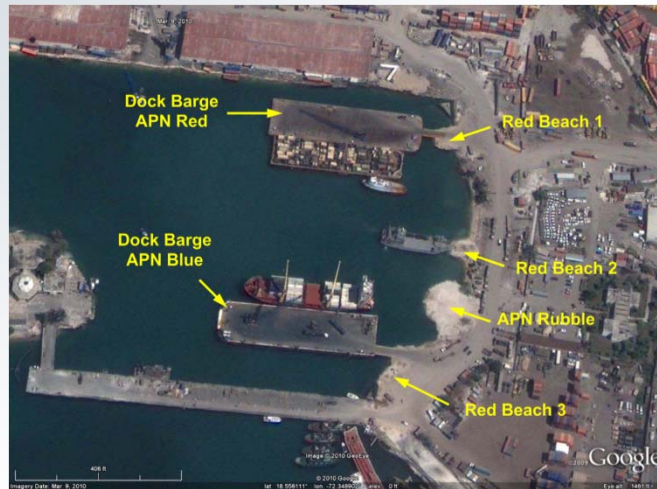


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## Temporary Berths



from Werner et al. (2011)



## South Pier



from Werner et al. (2011)



## South Pier



from Werner et al. (2011)  
US Navy



## South Pier



from Werner et al. (2011)  
US Navy



## South Pier



e) Installed Form



f) Pumping of Concrete into Form

from Werner et al. (2011)  
US Navy



## South Pier



g) Completed Cap Above Water:  
Single-Pile Repair



h) Completed Cap Below Water:  
Single-Pile Repair

from Werner et al. (2011)  
US Navy





## Lyttelton, New Zealand



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## Port of Lyttelton – CQ1



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## Port of Lyttelton – CQ1

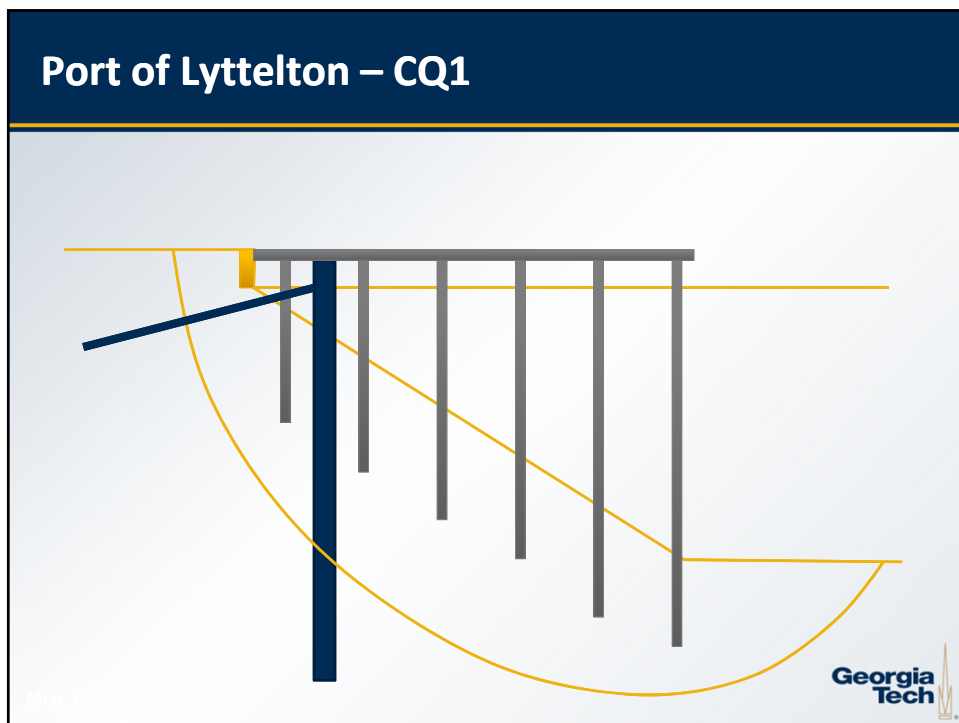
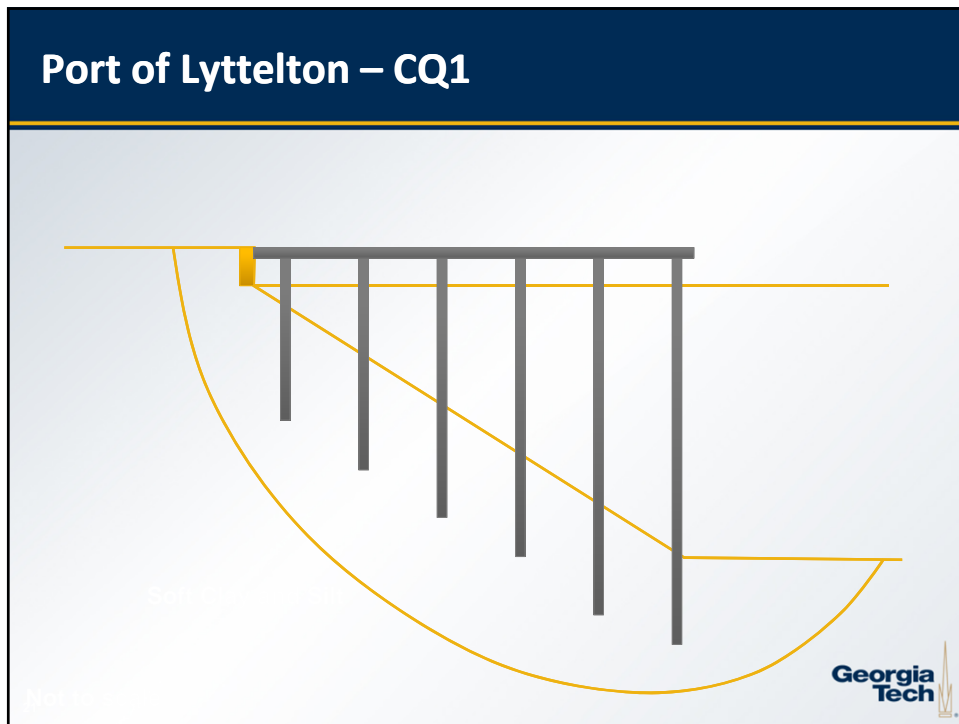


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## Port of Lyttelton – CQ1



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## Port of Lyttelton – CQ1



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## Port of Lyttelton – CQ1



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## Port of Lyttelton – CQ1



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## Port of Lyttelton – CQ3 and CQ4



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## Port of Lyttelton – CQ3



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## Port of Lyttelton – CQ3



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## Port of Lyttelton – CQ3



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## Port of Lyttelton – CQ4



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## Port of Lyttelton – CQ4



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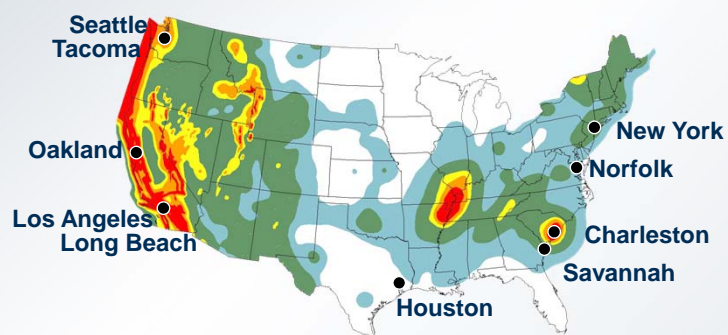
## Port of Lyttelton

| Berth | Length (m) | Cargo      | Built | Piling           | Comments  |
|-------|------------|------------|-------|------------------|---|
| CQ1   | 230        | Coal       | 1960s | Timber           | <ul style="list-style-type: none"> <li>300 mm lateral displacement in September 2010</li> <li>230 to 400 mm lateral movement in February 2011</li> <li>Up to 1 m vertical displacement</li> <li>First coal train arrived on March 5 (11 days)</li> <li>First ship loaded on March 15 (21 days) using "fixed point" loading</li> </ul> |
| CQ2   | 214        | Inactive   | 1960s | Timber           |   |
| CQ3   | 176        | Containers | 1973  | Steel (610 mm )  | <ul style="list-style-type: none"> <li>250 mm lateral displacement in February 2011</li> <li>Damage to piles</li> <li>Operational by March 9 (15 days)</li> </ul>   |
| CQ4   | 235        | Containers | 1994  | Precast Concrete | <ul style="list-style-type: none"> <li>200 mm lateral displacement in February 2011</li> <li>Damage to piles</li> <li>Cranes B and C derailed</li> <li>Operational by February 26 (4 days)</li> </ul>   |

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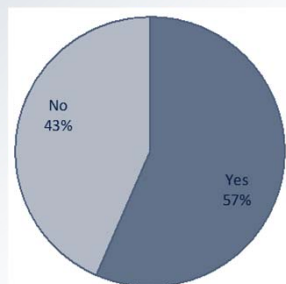
## U.S. Container Ports



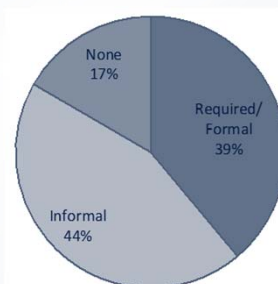
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## Port Survey

Are there plans to conduct a vulnerability assessment?



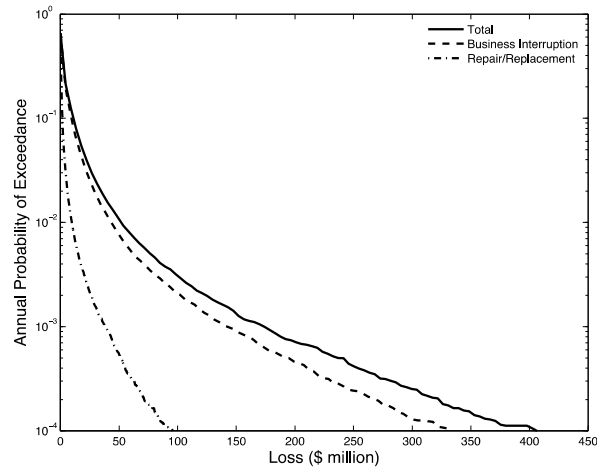
What is the nature of seismic risk mitigation plans?



23 ports in areas with "high" seismic hazard

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## 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
  - or
  - Average annual loss shall not exceed \$X million
  - or
  - Probable maximum loss (i.e., 90% probability of non-exceedance) shall be less than \$X million for the OLE (or CLE)





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