Earthquake Damage in a Precast Concrete Parking Garage in Christchurch, New Zealand

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Building Description

- Completed in 2007
  - Designed with a ductility factor of 1.25 (R equivalent of 1.17)
  - Design base shear coefficient of 0.56g

- Five story parking garage
  - One basement level

Bridge linking garage and adjacent building

Building Description

- Precast walls and columns
- Precast hollowcore floor elements with CIP topping
- Gravity beams cantilever at perimeter of the building
  - Soldier panels (walls) are decoupled from the gravity system

Concrete strength specified as 4.4 ksi

Estimate strength based on Schmidt hammer tests

<table>
<thead>
<tr>
<th>Element</th>
<th>f'c  (ksi)</th>
<th>Error (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-W Wall</td>
<td>7.6 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>N-W Footing</td>
<td>6.8 ± 0.9</td>
<td></td>
</tr>
</tbody>
</table>

Background

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Magnitude</th>
<th>Distance</th>
<th>PGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darfield EQ</td>
<td>Sep 4, 2010</td>
<td>7.1</td>
<td>22 mi</td>
<td>0.24g</td>
</tr>
<tr>
<td>Christchurch EQ</td>
<td>Feb 22, 2011</td>
<td>6.3</td>
<td>5</td>
<td>0.47</td>
</tr>
<tr>
<td>Aftershock</td>
<td>Jun 13, 2011</td>
<td>6.0</td>
<td>6</td>
<td>0.24</td>
</tr>
<tr>
<td>Aftershock</td>
<td>Dec 23, 2011</td>
<td>6.0</td>
<td>6</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Earthquake PGA:

- Average PGA recorded 1.2 miles from GeoNet station

Repair Sequence

- Detailed inspection
- Further investigation advised
- Inspection
- Inspection
- Final report
- Repair (2 months)
- Repair (1 month)
- Repair (7 months)
Darfield Earthquake

- **Damage overview**
  - Rapid inspection
  - No damage
  - Repair cost: Ø

Christchurch Earthquake

- **Damage overview**
  - Rapid inspection
  - Detailed inspection report calls for additional investigation.
  - Repair cost: Ø

- **Component**
  - Soldier panels:
    - 9 of 10 were cracked (0.5 mm width).
    - Some spalled regions.
    - Repair strategy: Inject cracks.
  - Corner walls:
    - 2 of 4 had minor cracks.
    - 1 of 4 had significant spalling.
    - Repair strategy: Inject cracks.
  - Wall-to-floor connections:
    - Topping cracks.
    - Repair strategy: Replace spalled concrete.

- **Component Damage Repair strategy**
  - Soldier panels:
    - Flexural cracking (1 to 2 mm width).
    - Replaced lowest panel (9 of 10).
  - Corner walls:
    - Flexural cracking and spalling.
    - Replaced lowest panel (1 of 4).
  - Wall-to-floor connections:
    - Fractured dowels.
    - Repair strategy: Drill-and-bond dowels.

June Aftershock

- **Damage overview**
  - Rapid inspection
  - Detailed investigation
  - Repair cost: 9.4% of initial cost
  - 2 months of down time

- **Component**
  - Soldier panels:
    - Replaced lowest panel.
  - Corner walls:
    - Fractured dowels.
    - Repair strategy: Drill-and-bond dowels.
  - Wall-to-floor connections:
    - Fractured dowels.
    - Repair strategy: Drill-and-bond dowels.

- **Component Damage Repair strategy**
  - Soldier panels:
    - Replaced lowest panel.
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  - Wall-to-floor connections:
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    - Repair strategy: Drill-and-bond dowels.
Ambient Vibration Results

- Ambient vibration recording on each level
- Earthquake monitoring captured 6 aftershocks

<table>
<thead>
<tr>
<th>Direction</th>
<th>Period (sec) Design</th>
<th>Period (sec) Measured</th>
<th>Measured damping ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-S</td>
<td>0.24</td>
<td>0.16</td>
<td>3%</td>
</tr>
<tr>
<td>E-W</td>
<td>0.34</td>
<td>0.31</td>
<td>3%</td>
</tr>
<tr>
<td>Torsion</td>
<td>0.23</td>
<td>0.23</td>
<td>4%</td>
</tr>
</tbody>
</table>

* 2 panels missing, 4 repaired, 4 damaged
* Some torsion present

June Aftershock

- Wall-to-floor connection failure
  - One wall, three levels
  - Repair strategy
    - Reinstate connection to original design strength.

- Flexural damage in precast panels
  - Typical soldier panel
  - Corner wall toe spalling

- Flexural damage in precast walls
  - Repair strategy: Replace lowest panels
    - 9 of 10 soldier panels
    - 1 of 4 end walls

- Flexural damage in precast panels
  - Repair strategy: Grout injection
**June Aftershock**

- Spalling induced by inter-element pounding
- Nonstructural elements
  - Four instances of wall damage from barrier railings.
  - Repair strategy:
    - Remove spalled concrete
    - Check bolts
    - Patch concrete
    - Ideally these would not have been tied to the LFRS, but barrier loads required this detail.

**December Aftershock**

- Damage overview
  - Similar to the Feb. 22 event but to a lesser extent.
  - Repair cost: 2.8% of initial cost
  - Less than 1 month of down time
  - Material testing of starter bars for strain hardening where cracks > 0.5mm.

**Summary**

- Observations from the case study:
  - Example of anticipated performance from new construction of a nominally ductile structure subjected to repeated seismic demands at or above the design scenario (horizontal and/or vertical).
  - Facility was under repair and nonoperational for 3 months.
  - Repair costs were 11.4% of initial cost.
  - Direct revenue losses not included.
  - Repairs used conventional materials.
  - Original design strength was reinstated as the repair objective.
  - Two repair catalysts:
    - Walls were decoupled from the gravity system, which facilitating their replacement.
    - Capacity protecting the wall starter bars enabled a rapid replacement of the bottom panels.

- From an inspection point of view the carpark was great as all the structure was exposed for viewing which made inspection time quicker.
- Protecting the wall starter bars worked well. This enabled a rapid repair and limited the scope of the replacement.
- The additional reinforcement in the helical ramp appears to have worked well with little damage to the diaphragms.
- This building along with many others in Christchurch showed the importance of seismic isolation of non structural elements. Consequences of not isolating these elements was seen in spalling to the clip-on spandrel panels and the damage to the vehicle barriers. Something which should be considered in the future.
- Consideration of building stability post event is needed to allow repair work on a building during periods of significant aftershocks is needed. Repair strategies must be implemented quickly enough for anticipated aftershocks.
- Better education of clients and the community is needed.
  - Expectations of operation post event are not in line with performance delivered.
  - The public of Christchurch appears slightly better versed in this now but other communities could benefit from addressing the expectation.

**Thank you!**