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

Hannah Clarke
José Restrepo
Matthew Schoettler

Sponsors

Acknowledgments

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Robert Nigbor — NEES @ UCLA
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Stefano Pampanin
Sahin Tasligedik
Umut Akguzel
Patricio Quintana Gallo

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

Helical ramp configuration

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

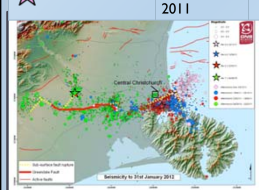
Estimated strength based on Schmidt hammer tests

Element	f'_c (ksi)	Error (ksi)
N-W Wall	7.6	± 1.0
N-W Footing	6.8	± 0.9

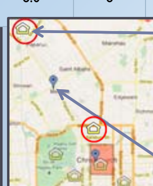
Background

Event	Date	Magnitude	Distance	PGA *
Darfield EQ	Sept. 4, 2010	7.1 MI	22 mi	0.24 g
Christchurch EQ	Feb. 22, 2011	6.3	5	0.47
Aftershock	June 13, 2011	6.0	6	0.24
Aftershock	Dec. 23, 2011	6.0	6	0.26

171 days
111 days
193 days



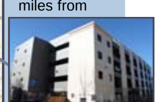
http://www.geonet.org.nz/



http://maps.google.com/

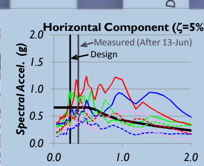
GeoNet station

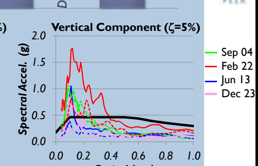
*Average PGA recorded 1.2 miles from



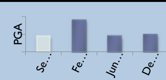
Repair Sequence

http://maps.google.com/

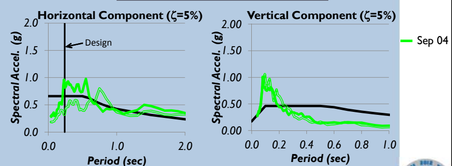




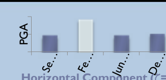
Darfield Earthquake



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

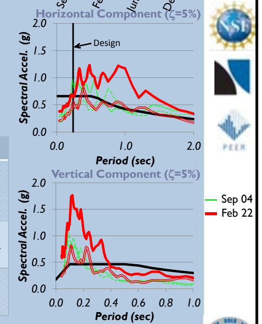


Christchurch Earthquake

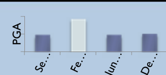


- Damage overview
  - Rapid inspection
  - Detailed inspection report calls for additional investigation.
  - Repair cost: Ø

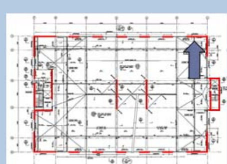
Component	Damage	Repair strategy
Soldier panels	9 of 10 were cracked (0.5 mm width). Some spalled end regions.	Inject cracks. Replace spalled regions.
Corner walls	3 of 4 had minor cracking. 1 of 4 had significant	Inject cracks. Replace spalled regions..
Wall-to-floor connections	Topping cracks	Replace spalled concrete. Inspect bars.

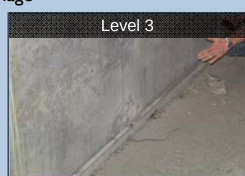


Christchurch Earthquake



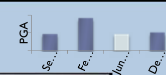
- Wall-to-floor connection damage

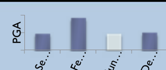




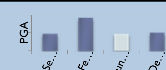
- Repair strategy
  - Further investigation recommended. Inspection report dated June 13th, the day of the June aftershock.

June Aftershock



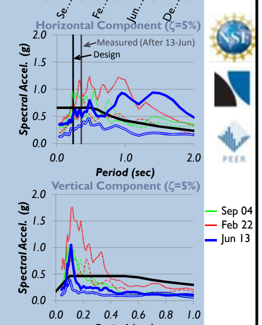


June Aftershock

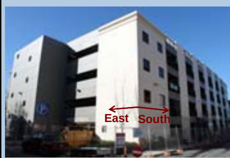


- Damage overview
  - Rapid inspection
  - Detailed investigation
  - Repair cost: **9.4%** of initial cost
  - 2 months of down time

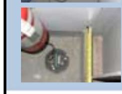
Component	Damage	Repair strategy
Soldier panels	Flexural cracking (1 to 2 mm width)	Replaced lowest panel (9 of 10)
Corner walls	Flexural cracking and spalling	Replaced lowest panel (1 of 4)
Wall-to-floor connections	Fractured dowels	Drill-and-bond dowels. Reinstate topping.



Ambient Vibration Results



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

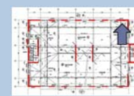


Direction	Period (sec)		Measured damping ratio*
	Design	Measured*	
N-S	0.24	0.36	3%
E-W	0.34	0.31+	3%
Torsion		0.23	4%

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

June Aftershock

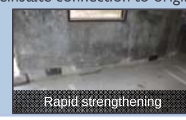
- Wall-to-floor connection failure
  - One wall, three levels




Kinked dowel


Fracture

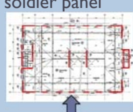
  - Repair strategy
    - Reinstate connection to original design strength.

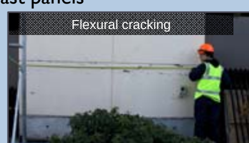

Rapid strengthening


Dowel replacement

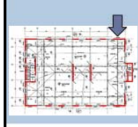
June Aftershock

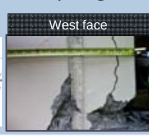
- Flexural damage in precast panels
  - Typical soldier panel



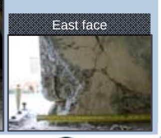

Flexural cracking

  - Corner wall toe spalling




West face


South face


East face

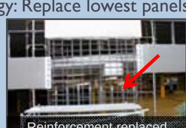
June Aftershock

- Sample damage map

June Aftershock

- Flexural damage in precast walls
  - Repair strategy: Replace lowest panels

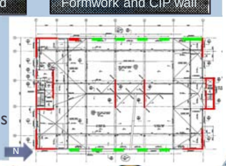

Panel removal


Reinforcement replaced


Formwork and CIP wall

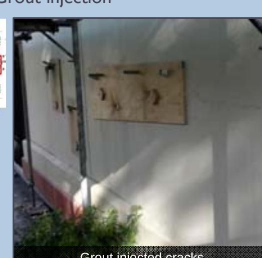

Repaired panel

Replacement schedule:
- 9 of 10 soldier panels
- 1 of 4 end walls

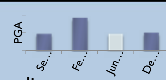


June Aftershock

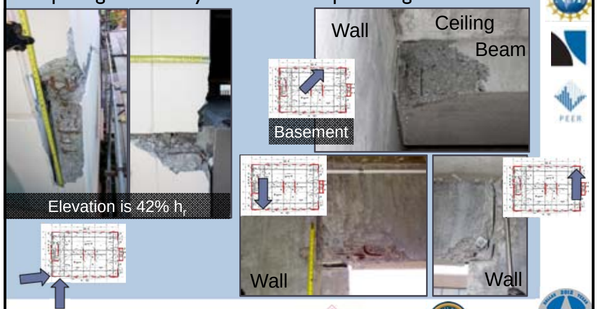
- Flexural damage in precast panels
  - Repair strategy: Grout injection


Grout injected cracks

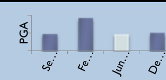
June Aftershock



- Spalling induced by inter-element pounding



June Aftershock



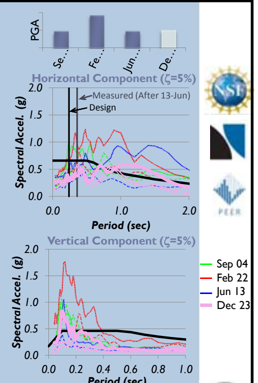
- Nonstructural elements
  - Four instances of wall damage from barrier railings.

  - 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: **2.0%** of initial cost
  - Less than 1 month of down time
  - Material testing of starter bars for strain hardening where cracks > 0.5mm.

Component	Damage	Repair strategy
Soldier panels	Cracking as before. None to the panels previously injected.	Cracks injected. Some patch repair.
Corner walls		
Wall-to-floor connections	Some delamination, but less than before. Inspection, but no rebar damage.	Concrete patch



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.

Summary

- 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 this expectation.

Thank you!