Quantifying Loss of Function of Critical Building Systems due to Recent Seismic Events

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Talk Outline

- Motivation of research.
- Methods for damage data collection on field missions around the world.
- Summary of recent seismic events: Feb 27th 2010 Maule EQ, April 4th 2010 Mexicali EQ, and the Feb 22nd 2011 Christchurch EQ.
- Impact of critical healthcare systems in Chile, New Zealand, and Mexico.
- Summary of lessons.
Motivation of Research

There’s a need to develop more accurate models of the functional impact of buildings due to hazard-induced damage.
Reconnaissance Work

- Collect perishable data to inform mathematical models of buildings and systems.
- Develop survey tool for damage and impact assessment.
- Test the tool and modify accordingly.
- Continuously collect feedback from locals.
- Analyze data and use the data to feed into loss models.
- Our goal is to collect data from critical buildings that are part of a healthcare
What is a system of buildings?

- As engineers, we typically think of the “structural system” or the “nonstructural system” of a building.
- Consider buildings that together form a networked system.
- Building systems can be grouped by owner, occupancy type, shared resources, etc.
- Hospitals in a circumscribed region form a critical building system.
Recent Seismic Events

Photo Credit: Wikipedia
2010 Maule Earthquake

- $M_W$ 8.8
- Sat, Feb 27, 2010
- 3:34 am
- 523 fatalities
- 800,000 displaced people
- 15,000 jobs were lost
- Economic damage estimates close to $30B
- Destruction concentrated in Concepción, Talcahuano, Valdivia, Arauco, Coronel, Los Angeles, Talca and Maule areas
2010 Mexicali “Easter” Earthquake

- $M_W$ 7.2, 0.59g PGA
- Sun, April 4, 2010
- 3:40 pm
- 2 fatalities
- 4,389 residences with major damage
- economic damage estimates > $50M
- largest EQ in region since 1982
- most severe shaking felt in rural areas
2011 Christchurch Earthquake

- $M_W$ 6.3, 1.5g PGA
- Tues, Feb 22, 2011
- 12:51 pm
- 184 fatalities
- 1,788 red-tagged residences
- Economic damage estimates > $20B
- Feb eq was the largest aftershock of the main event in Sept
- ~50% buildings are unusable in the CBD
Impact to Critical Healthcare Infrastructure
Communication System Damage

- **Chile**: landlines and cellular phones disrupted for 3-7 days for all seven facilities surveyed.
- **Mexico**: landlines and cellular phones disrupted for <24 hrs for all three facilities surveyed.
- **New Zealand**: landlines down for 20 min—5 days and cellular phones disrupted for 6—24 hrs for the six facilities

*Loss of communication was the most consistent issue identified by hospital.*

Photo Credit: C. Urzua Acuña
Communication System Damage

- **Chile**: there was no plan for emergency communication in facility or between facilities, particularly to the centralized headquarters of the health system that lead to isolated hospital ‘islands’.

- **Mexico**: satellite phones and 800 MHz radios were used as backup as well as runners.

- **New Zealand**: handheld radios were available as backup for the public hospitals as well as
Power Utility Damage

- **Chile**: all seven facilities lost municipal power for varying time periods; the longest outage lasting 7 days.
- **Mexico**: all facilities lost municipal power for ~9 hrs.
- **New Zealand**: all six facilities lost municipal power for varying time periods; the longest outage lasting 18 hrs.

Photo Credit: TCLEE report showing live-tank circuit breaker damage.
Power Backup

• **Chile**: all seven facilities had emergency backup power, but the backups successfully turned on for only 43% of the facilities; scattered problems with generators (e.g., insufficient power for important medical equipment, such as radiology)

• **Mexico**: all facilities had backup power, which worked well

• **New Zealand**: all facilities had backup power, but there were scattered problems with the generators (e.g., sediment clogging in the Chch Hospital and intermittent power with generators).
Water and Wastewater Damage

- **Chile**: 5 of the 7 facilities lost municipal water.
- **Mexico**: no problems with water; also residents are accustomed to drinking bottled water so those supplies were readily available.
- **New Zealand**: the hospitals in Chch reported loss of municipal water for many days. When water was restored, there were issues getting sufficient pressure in pipes for fire sprinklers and boilers.

Photo Credit: A. Bavis of repairs to water mains outside Chch Hospital damaged by liquefaction.
Water Backup

- **Chile**: all seven facilities had water backup systems, such as rooftop water tanks, or underground storage tanks; there were some issues with successful distribution of water due to damaged components (e.g., pumps).
- **Mexico**: no facilities have backup water storage on site.
- **New Zealand**: the main hospital has access to artisanal wells, but there were issues pumping water from the ground to the above-ground tank (too much silt being initially pumped in); ½ million-litre capacity tank system was installed to provide emergency water for crucial systems. New tank under construction at Talcahuano—not quite in time.
Structural Damage

- **Chile**: 1 of the 7 facilities had moderate structural damage; this hospital braced by concrete frames with shear walls suffered buckled steel roof trusses and severe racking of its penthouse due to torsion and steel roof trusses buckled; spalled concrete of columns, cracking in shear walls, and collapsed in-fill walls.

- **Mexico**: no severe structural damage was observed.

- **New Zealand**: one of the hospitals suffered permanent deformation shutting down its maternity ward and part of its ICU; a lot of damage to separation joints.
Buckled Steel Roof
Damaged Penthouse
Nonstructural Damage

- **Chile**: broken pipes, collapsed ceilings, heavy partition wall damage, oxygen tanks suffered tensile yield failure of threaded fasteners and punching shear failure of the tank leg, widespread elevator damage, collapsed furniture (including medical record storage); mechanical and medical equipment damage resulted in loss of hot water affecting kitchen, laundry, and sterilization services, which forced hospitals to sterilize off site, and disrupted diagnostic services.

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Los Angeles Hospital: fallen light fixtures and mechanical registers, in addition to ceiling panels.

Photo by Holmes
Retrofit: packing tape used to keep dust out of ICU showed excellent seismic performance!
Retrofit: clips used to stabilize ceiling tiles at Talca Hospital (new building).
Cracked and spalled infill wall in patient room.
Still working on straightening out Talcahuano medical records after 3 weeks
• Elevators suffered significant failures in Chile, most due to derailed counterweights; patients were carried down stairs or ramps.
• In Mexico and NZ where elevators continued to function, staff were fearful of riding in them and thus relied on dark stairwells instead.
- caused two floors to be evacuated in NZ
- caused at least three buildings to be evacuated in Chile
- shut down 3 of 6 ORs in relatively new building in Chile
Evacuation of Patients

• The need to evacuate patients is a significant failure because it:
  – is extremely dangerous for patients
  – takes staff away from serving externally injured
  – creates demand for patient space, possibly off site.

• Mutual aid
  – no patients were emergently transferred to other facilities (probably due to poor communications)
  – patients were temporarily housed on site
  – many were discharged to their homes
  – in a few cases, patients were transferred later
Summary

- Hospitals do not have to collapse to be rendered inoperable.
- Functional losses are usually due to non-structural damage.
- Communications systems are critical!
- Redundancy is necessary for water, power, and sewage systems.
- Information of hazard mitigation efforts need to be better communicated to the public.

- In NOLA, we remember the important lesson from Katrina: hospitals must be prepared to be on their own for 2-3 days in a major event.
...and so do engineers!!

Thank you.