

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



Photo Credit: C. Cienfuegos Rascon

100 YEARS
JOHNS HOPKINS ENGINEERING
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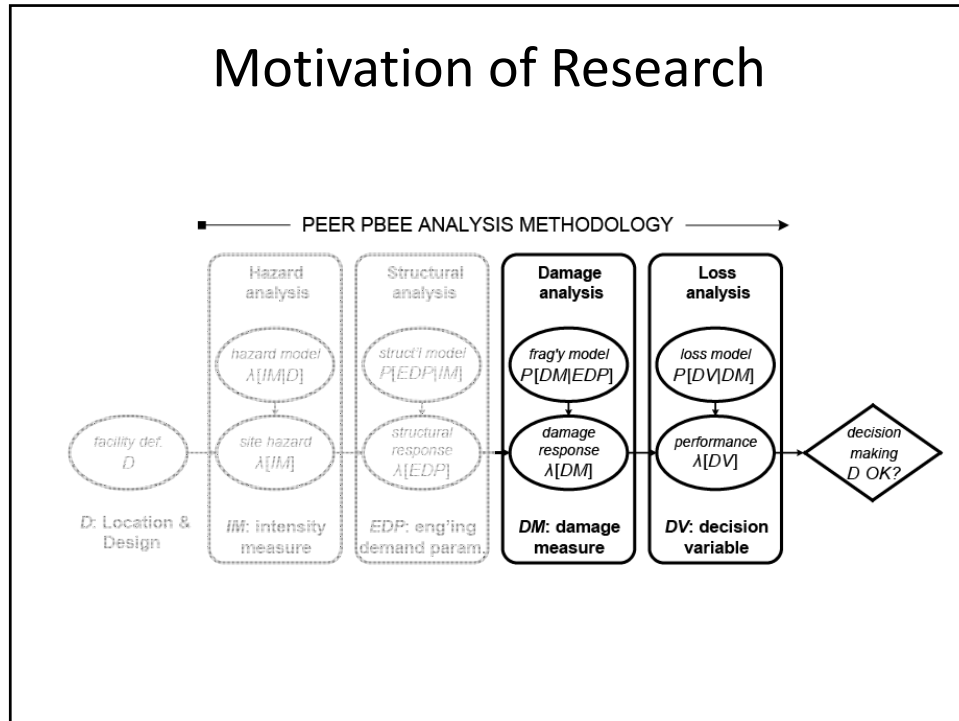
Judith Mitrani-Reiser, PhD
Assistant Professor of Civil Engineering

EERI Annual Meeting:
Learning from the Past to Protect the Future

Talk Outline

- Motivation of research.
- Quantifying loss of function.
- 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.
- Future research directions.

Motivation of Research

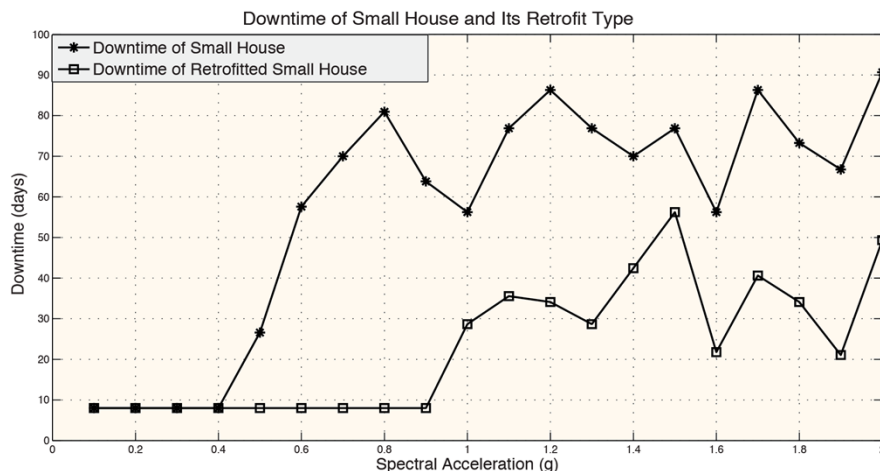


Downtime in ATC-58

The overall occupancy interruption time for a damaged building is extremely challenging to quantify. Therefore, the ATC-58 procedures provide the following measures of occupancy interruption:

1. The length of time necessary to conduct repairs,
2. The need to procure items with long lead-times,
3. The probability that the building will be placarded as unsafe for occupancy.

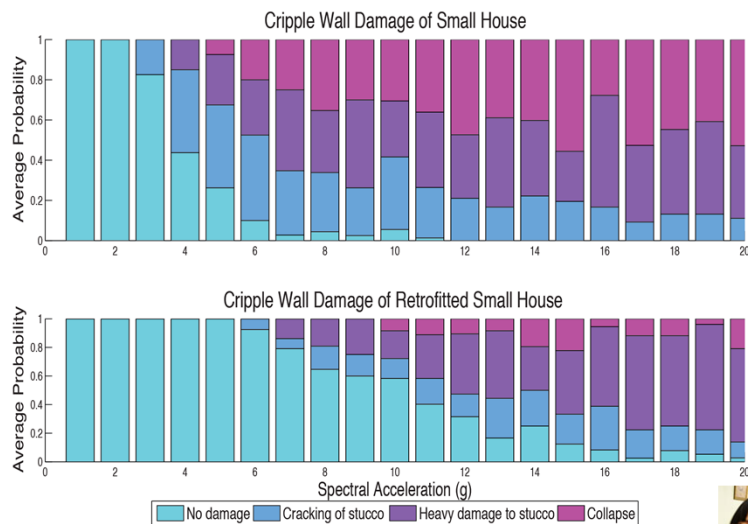
Quantifying Downtime



Poster: *Downtime Assessment for Woodframe Residential Buildings*



Quantifying Downtime



Poster: *Downtime Assessment for Woodframe Residential Buildings*



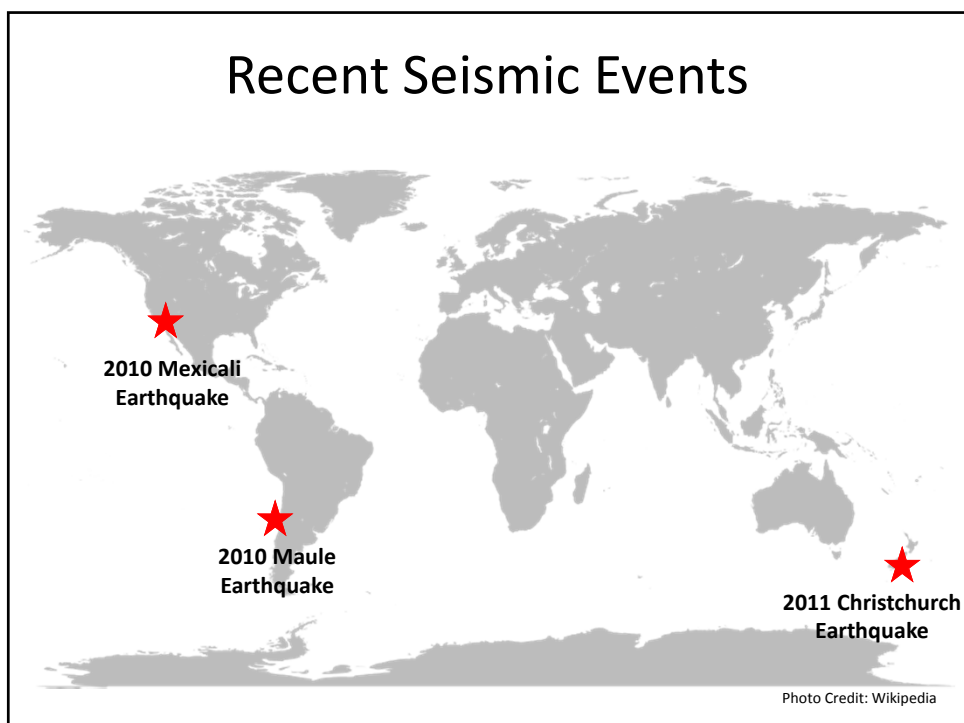
Downtime v2.0

- For very specialized building occupancies (i.e., healthcare facilities), the above procedures will not suffice in capturing the loss of building functionality and the inability to provide primary services.
- There's a need to develop more accurate models of the functional impact of buildings due to hazard-induced damage.
- It is necessary to develop more accurate relationship between occupancy-specific services (functions) and earthquake damage.
- A systematic procedure of simultaneously capturing building damage and loss of function has resulted.

Reconnaissance Work

- Collect perishable data to inform mathematical models of buildings and systems.
- Develop survey tool for damage and impact assessment that can be used over time and for various seismic events.
- Test the tool and modify accordingly for specific community.
- 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 system.

Recent Seismic Events



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 surveyed.



Photo Credit: C. Urzua Acuna

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

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 runners.



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.



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).



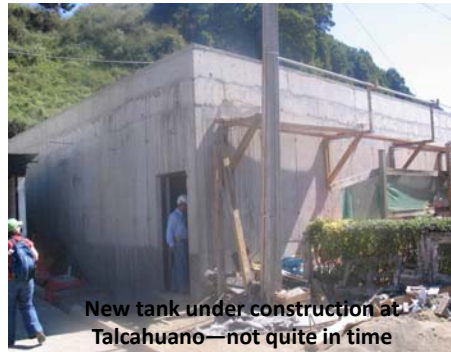
Water and Wastewater Damage

- **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, and after water was restored, there were issues getting sufficient pressure in pipes for fire fire sprinklers and boiler.



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.



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.





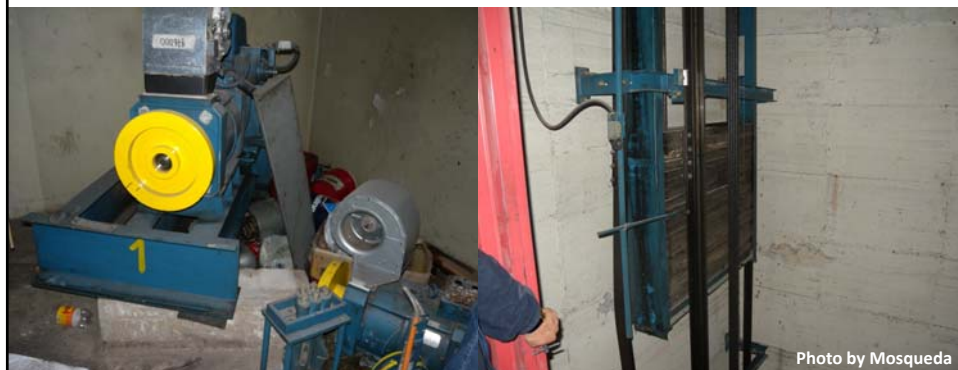
Nonstructural Damage

- **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.
- **Mexico:** 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).
- **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.





- 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.





Still working on straightening out Talcahuano medical records after 3 weeks



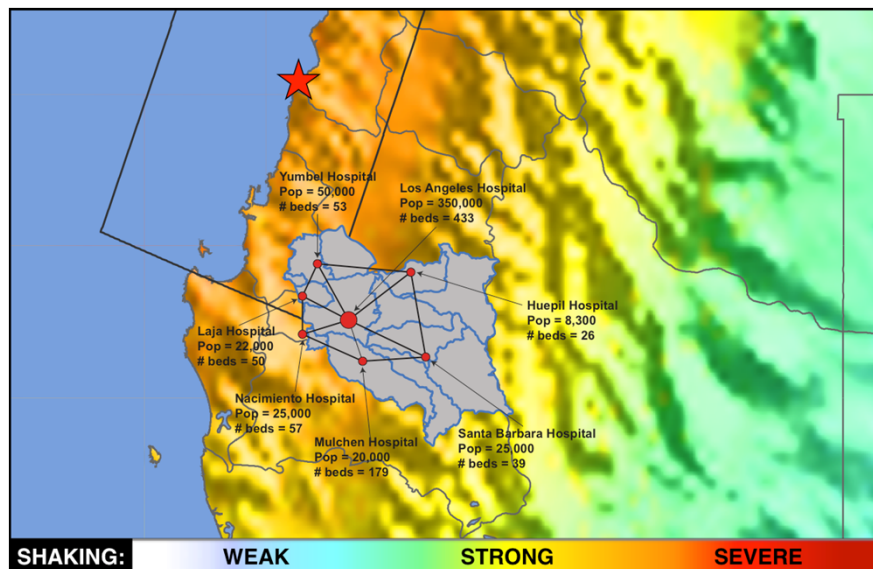
Summary of Damage from Recent Events

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

What is a system of buildings?

- 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**.

A Hospital Network in Chile

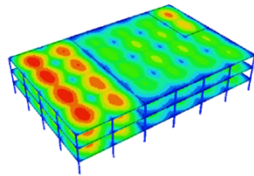


Systems Modeling of People Interacting with the Built Environment



Systems Modeling of People and the Built Environment

(a) 3D FEM model simulation



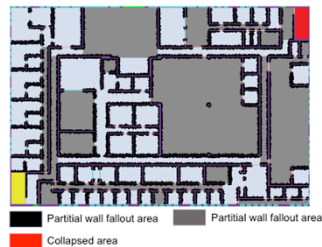
(b) Magnitude of the response parameters

Response Parameter	1 st floor	2 nd floor	3 rd floor	Roof
PDA (g)	0.9	1.7	2.9	3.4
TD	0.0308	0.0474	0.0346	NA

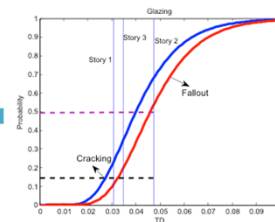
PDA: peak diaphragm acceleration

TD: peak transient drift ratio

(d) Damaged building map in the evacuation model



(c) Fragility curve



Poster: *The Study of Evacuation Time and Patterns After an Earthquake using Agent-Based Modeling*



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Thank you.

The Johns Hopkins Systems Institute

"As an engineer I think you have a responsibility.
We have to not just care about erecting a structure.
We have to think about its lifetime and what kind
of impact it's going to have on society."