

# **APPLYING RESILIENT RATING SYSTEMS FOR PREDICTING CONTINUED OPERABILITY OF HOSPITALS AFTER EARTHQUAKES**

Megan Boston  
University of Waikato

Judy Mitrani-Reiser  
Johns Hopkins University

# Expectations of Hospitals



“It is the intent of the Legislature that hospital buildings that house patients who have less than the capacity of normally healthy persons to protect themselves, and that must be **reasonably capable of providing services to the public after a disaster**, shall be designed and constructed to resist, insofar as practical, the forces generated by earthquakes, gravity, and winds.”

–Alfred E Alquist Hospital Facilities Seismic Safety Act of 1983

1. **Protect the lives of patients and health workers** by ensuring the structural resilience of health facilities.
2. Ensure that health facilities and health services are **able to function in the aftermath of emergencies and disasters**, when they are most needed.
3. Improve the emergency management capacity of health workers and institutions

–World Health Organization

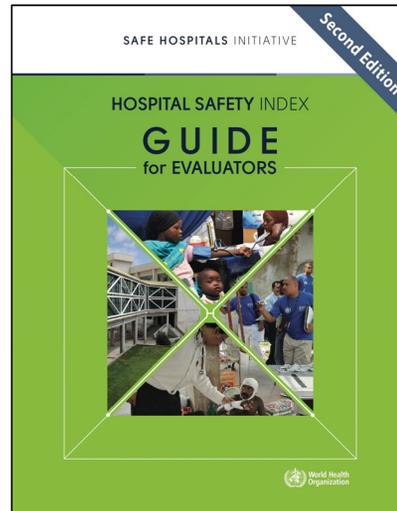
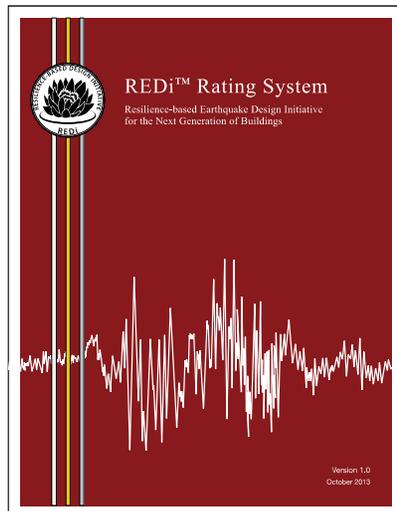
# Motivation

- When an earthquake hits, we expect our hospitals to remain functional....
- 1971: San Fernando
- 1985: Mexico
- 1994: Northridge
- 1999: Taiwan
- 2010: Chile
- 2011: Christchurch
- 2015: Nepal
- 2017: Mexico



Photo: Kaiser Permanente Hospital, Jonathan Alcorn, LA Times

# Resilient Rating Systems

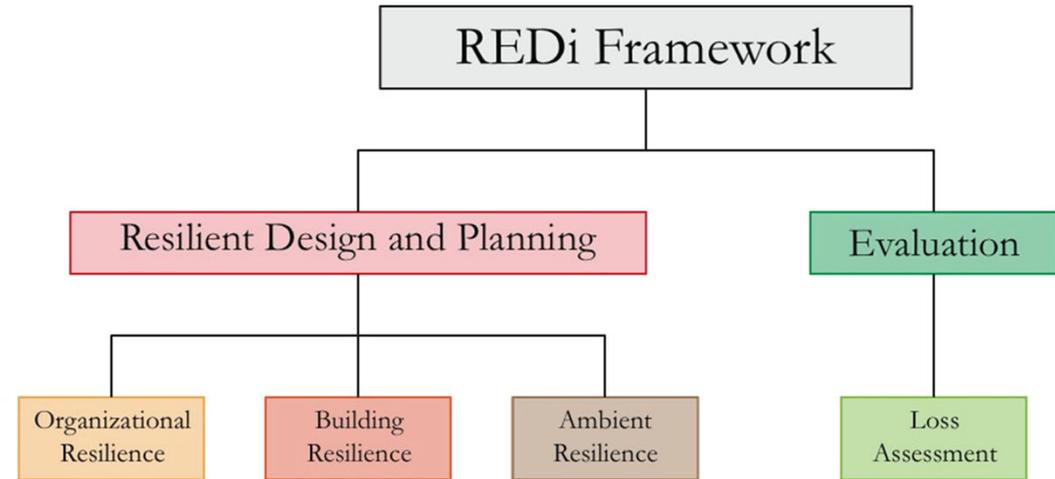
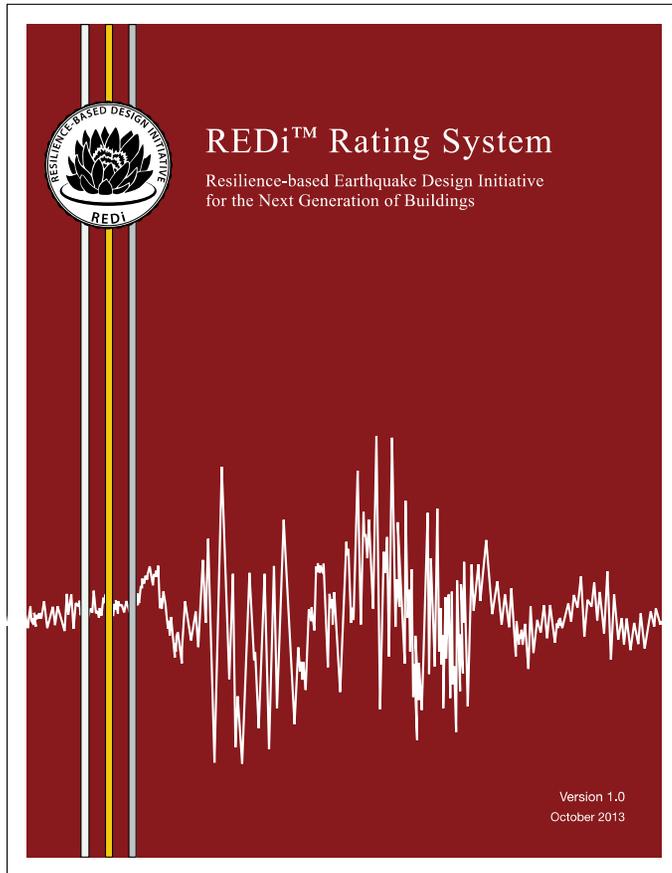




Office of Statewide Health  
Planning & Development

Structural Performance Categories		Non-structural Performance Categories	
SPC 1	Building poses significant risk of collapse, danger to the public	NPC 1	Equipment does not meet anchoring or bracing requirements
SPC 2	Compliance with pre 1973 building code. Meets life safety requirements but unlikely to be repairable or functional.	NPC 2	Bracing and anchoring of key systems such as: communication, emergency power, medical gases
SPC 3	Compliance with HSSA prior to 1994. Meets life safety requirements but unlikely to be repairable or functional.	NPC 3	NPC 2 and bracing and anchoring of nonstructural elements in critical care, clinical labs, pharmaceutical, radiology, and sterilization areas
SPC 4	Compliance with HSSA after 1994, may have structural damage that will hinder hospital services	NPC 4	NPC 3 plus proper anchoring and bracing of all architectural, mechanical, electrical, and medical equipment
SPC 5	Compliance with HSSA after 1994, reasonably capable of providing services after a major event	NPC 5	NCP 4 plus 72 hours of onsite water and holding tanks.

# REDi Rating System



	Downtime: Re-occupancy	Downtime: Functional Recovery	Direct Financial Loss	Occupant Safety
Platinum	Immediate (green tag)	< 72 hours	< 2.5%	Injury unlikely
Gold	Immediate (green tag)	< 1 month	< 5%	Injury unlikely
Silver	< 6 months (yellow tag)	< 6 months	< 10%	Injury possible but structural collapse unlikely



STARS	SAFETY	DAMAGE	RECOVERY
    	<p><b>Injuries and blocking of exits unlikely</b> Fatality <math>&lt; 3 \times 10^{-5}</math></p> <p><b>Serious injuries unlikely</b> Fatalities <math>&lt; 1 \times 10^{-4}</math></p> <p><b>Loss of life unlikely</b> Fatalities <math>&lt; 4 \times 10^{-4}</math></p> <p><b>Loss of life possible in isolated locations</b> Fatalities <math>&lt; 4 \times 10^{-3}</math></p> <p><b>Loss of life likely</b> Fatalities <math>&gt; 4 \times 10^{-3}</math></p>	<p><b>Minimal Damage</b> Repair cost <math>&lt; 5\%</math></p> <p><b>Moderate Damage</b> Repair cost <math>&lt; 10\%</math></p> <p><b>Significant Damage</b> Repair cost <math>&lt; 20\%</math></p> <p><b>Substantial Damage</b> Repair cost <math>&lt; 40\%</math></p> <p><b>Severe Damage</b> Repair cost <math>&gt; 40\%</math></p>	<p><b>Hours to days</b> Recovery <math>&lt; 5</math> days</p> <p><b>Days to weeks</b> Recovery <math>&lt; 4</math> weeks</p> <p><b>Weeks to months</b> Recovery <math>&lt; 6</math> months</p> <p><b>Months to 1 year</b> Recovery <math>&lt; 1</math> year</p> <p><b>More than 1 year</b> Recovery <math>&gt; 1</math> year</p>



Rating	Risk of Harm (Safety)	Damage	Repair Time
★★★★★	Extremely Low	Minimal	Days
★★★★	Very Low	Moderate	Weeks
★★★	Low	Significant	Months
★★	Moderate	Substantial	> 6 Months
★	High	Severe	> 1 year

		Worksheet 1			Overall Safety Rating			Notes	
Commercial		Safety			***			(Replace with building-specific notes)	
Building Details	Name	Tower Block 7/5 Richter Street, Quaketown			Overall combined	E-W	N-S	Building	Shows overall rating and safety score in each direction - based on the lowest individual scores in the relevant column.
	Assessor	ABC Consulting Engineers			Safety Ratings	***	***	***	
	Reviewer	DEF Structural			Safety Scores	100	100	100	
Stability Assessment	Item	Attribute	Measure	IL2 NBS min	User input Building Scores		Combined Ratings: Structure : Site : Building Stability	E-W N-S Building	Shows the overall score in each direction without considering "Non-structural Elements"
			Capacity = at ULS Demand = 500-yr at ULS		E-W	N-S	*** *** *** 100 100 100	*** *** *** 100 100 100	
Stability Assessment	Site	Overall site stability	Capacity / Demand	100	130	120	Combined ratings Site : Building Stability	E-W N-S Building	Shows the results of examining the stability of the Site and of the Building as a whole. Including this means that these important issues are considered.
	Building	Building overall stability		100	140	120		*** *** *** 130 120 120	
Structural Capacity Assessment	Primary Structure	Basic Capacity at ULS	Capacity / Demand <small>(Figures used must take account of integrity, ductility, consequences of failure, capacity design, asymmetry and lack of separation from other buildings)</small>	100	100	100	Rating for Primary Structure only	E-W N-S Building *** *** *** 100 100 100	Shows the result of examining the Primary Structure on its own, including foundations, regardless of stability or floor/stair issues. Estimation of ULS Capacity / ULS Demand using the NZSEE Guidelines 2016 is deemed to have taken account of factors noted.
Structural Capacity Assessment	Floors and Stairs	Diaphragm action	Capacity / Demand	100	120	120	Rating for Floors and Stairs	E-W N-S Building	A separate item for floors and stair recognises the particular issues with these items in the Canterbury Earthquakes
		Vertical support		100	120	120		*** *** ***	
		Stair support		100	150	150		120 120 120	
Structural Capacity Assessment	"Non-structural" Elements	Cladding Glazing Ceilings Partitions Building Services Appendages	Capacity / Demand	100 100 100 100 100 100	120 120 120 NC NC NC	120 120 120 NC NC 100	Rating for "Non-structural" Elements	E-W N-S Building *** *** *** 120 100 100	These results need to be derived according to the scale of safety issues involved. Items that would "fail" which have no significant safety issues should be excluded. Insert "NC" (Not Critical) instead of number.
User Input: Items in red type require or allow user input. Items in green type are calculated or determined by worksheet.									
Note 1: A basic score of 100 represents minimum assessment for design-level performance of a new building of IL2 Category. With modifying factors an average new building of this type is expected to score about 130.									
Note 2: Data for both directions is required. If an attribute is clearly not critical in one direction enter "NC" or a higher score for that direction and add a note.									

Source: <https://quakestar.org.nz/commercial-buildings/>

# Hospital Safety Index

SAFE HOSPITALS INITIATIVE

Second Edition

HOSPITAL SAFETY INDEX

GUIDE for EVALUATORS



World Health Organization

Hospital Safety Index: GUIDE FOR EVALUATORS

2.1 Prior events affecting hospital safety		Safety level		OBSERVATIONS
Low	High	Low	High	
1. We have been prior structural damage to the hospital in a week of natural phenomenon	Low	<input type="checkbox"/>	<input type="checkbox"/>	Building is a new construction, there is no prior structural damage or no event has occurred since construction has completed
2. Was the hospital built under repaired or new safety standards?	Low	<input type="checkbox"/>	<input type="checkbox"/>	Hospital was built to current code requirements and all safety standards were fully applied (HCR)
3. Has remedial or modification affected structural behavior of the facility?	Low	<input type="checkbox"/>	<input type="checkbox"/>	No to being remedial or modification has been done in the building (HCR)

2.2 Safety of the structural system and type of materials used in the building		Safety level		OBSERVATIONS
Low	High	Low	High	
4. Condition of the building	Low	<input type="checkbox"/>	<input type="checkbox"/>	The building is in good condition, there is no deterioration from anything to any of the structural elements, no cracks (HCR)
5. Construction material used	Low	<input type="checkbox"/>	<input type="checkbox"/>	The building material is high quality, no cracks (HCR)
6. Detection of non-structural elements with the structure	Low	<input type="checkbox"/>	<input type="checkbox"/>	There are no non-structural elements with the structure, no cracks (HCR)
7. Position of building beams of spanning and vertical effects	Low	<input type="checkbox"/>	<input type="checkbox"/>	Structure is built in accordance with the design and all beams are in the correct position (HCR)
8. Structural redundancy	Low	<input type="checkbox"/>	<input type="checkbox"/>	The hospital design has a high level of redundancy, no cracks (HCR)
9. Structural detailing including connections	Low	<input type="checkbox"/>	<input type="checkbox"/>	Building was built to all and all connections are in good condition (HCR)
10. Safety of foundation	Low	<input type="checkbox"/>	<input type="checkbox"/>	Foundations are all designed and meet code requirements to both base and moment frame building

## Structural

## Nonstructural

Hospital Safety Index: GUIDE FOR EVALUATORS

3. Elements related to non-structural safety

Nonstructural Elements include part of the Building system of the building. They include but not limited to: elevators, escalators, and systems that are necessary for the operation of the building.

3.1 Critical systems		Safety level		OBSERVATIONS
Low	High	Low	High	
<b>3.1.1 Electrical systems</b>				
14. Generator has capacity to meet 100% of demand	Low	<input type="checkbox"/>	<input type="checkbox"/>	Generator has capacity to meet 100% of demand for the entire hospital (HCR)
15. Regular tests of generator performance are carried out on critical areas	Low	<input type="checkbox"/>	<input type="checkbox"/>	Generator performance tests are carried out on critical areas (HCR)
16. Generator protected from damage due to natural phenomena	Low	<input type="checkbox"/>	<input type="checkbox"/>	Generator is protected from damage due to natural phenomena (HCR)
17. Safety of electrical systems, cables, and cable ducts	Low	<input type="checkbox"/>	<input type="checkbox"/>	Electrical systems, cables, and cable ducts are safe (HCR)
18. Redundant system for local electric power supply	Low	<input type="checkbox"/>	<input type="checkbox"/>	Redundant system for local electric power supply (HCR)
19. Protection for control panel, overload breaker switch, and cables	Low	<input type="checkbox"/>	<input type="checkbox"/>	Control panel, overload breaker switch, and cables are protected (HCR)
20. Lighting system for areas of the hospital	Low	<input type="checkbox"/>	<input type="checkbox"/>	Lighting system for areas of the hospital (HCR)
21. Unusual electrical systems installed in hospital grounds	Low	<input type="checkbox"/>	<input type="checkbox"/>	Unusual electrical systems installed in hospital grounds (HCR)
<b>3.1.2 Telecommunications systems</b>				
22. Condition of antennas and antenna housing	Low	<input type="checkbox"/>	<input type="checkbox"/>	Condition of antennas and antenna housing (HCR)
23. Condition of base-station systems (transmit and telephone connections)	Low	<input type="checkbox"/>	<input type="checkbox"/>	Condition of base-station systems (transmit and telephone connections) (HCR)
24. Condition of alternate communications systems	Low	<input type="checkbox"/>	<input type="checkbox"/>	Condition of alternate communications systems (HCR)

## Structural

Hospital Safety Index: GUIDE FOR EVALUATORS

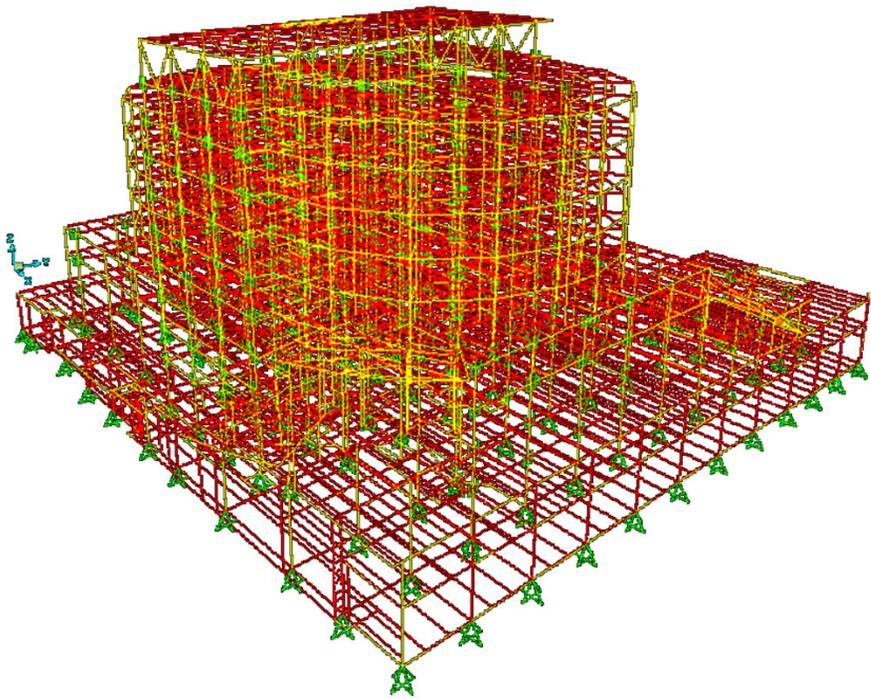
4. Safety based on functional capacity of hospital

Functional Capacity of hospital refers to the ability of the hospital to continue to operate in the event of a disaster.

4.1 Organization of the Hospital Disaster Committee and the Emergency Operations Center		Level of organization		OBSERVATIONS
Low	High	Low	High	
41. Committee has been formally established to respond to major events or disasters	Low	<input type="checkbox"/>	<input type="checkbox"/>	Committee has been formally established to respond to major events or disasters (HCR)
42. Committee membership is multidisciplinary	Low	<input type="checkbox"/>	<input type="checkbox"/>	Committee membership is multidisciplinary (HCR)
43. Each member is aware of his/her specific responsibilities	Low	<input type="checkbox"/>	<input type="checkbox"/>	Each member is aware of his/her specific responsibilities (HCR)
44. Space is designated for the hospital Emergency Operations Center (EOC)	Low	<input type="checkbox"/>	<input type="checkbox"/>	Space is designated for the hospital Emergency Operations Center (EOC) (HCR)
45. The EOC is in a protected and safe location	Low	<input type="checkbox"/>	<input type="checkbox"/>	The EOC is in a protected and safe location (HCR)
46. The EOC has complete system and computers	Low	<input type="checkbox"/>	<input type="checkbox"/>	The EOC has complete system and computers (HCR)
47. Both internal and external communications systems in the EOC function properly	Low	<input type="checkbox"/>	<input type="checkbox"/>	Both internal and external communications systems in the EOC function properly (HCR)
48. The EOC has an alternate communications system	Low	<input type="checkbox"/>	<input type="checkbox"/>	The EOC has an alternate communications system (HCR)

## Functional

# Hospital Rating Results



OSHPD

SPC: 5

NPC: 4

REDi



**SILVER**

Downtime-Reoccupancy: 0 days

Downtime-Functional: 114 days for repairs

Direct Financial Loss: 0.4%

Occupant Safety: No expected injuries

QuakeStar

SAFETY ★★★★★

DAMAGE ★★★★★

RECOVERY ★★★★★☆

United States  
Resiliency Council

Hospital Safety Index

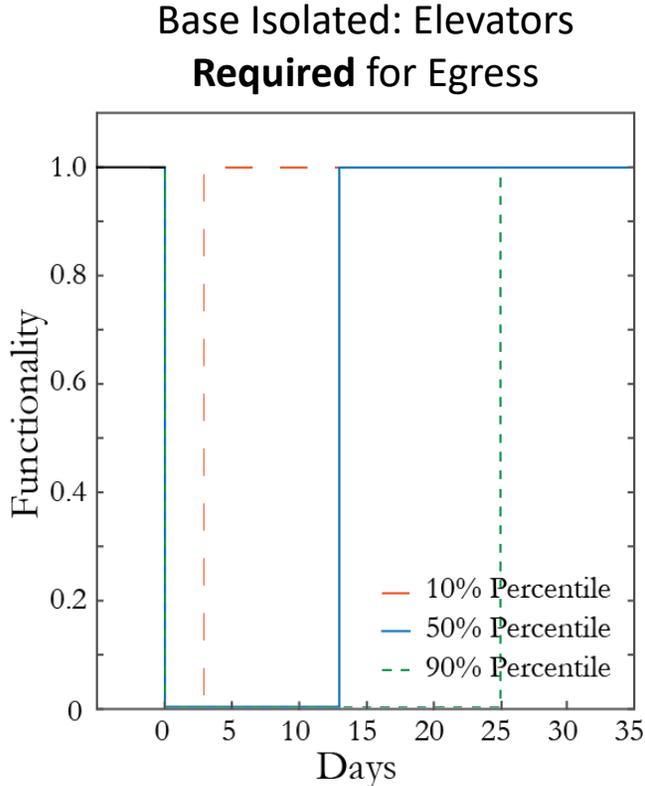
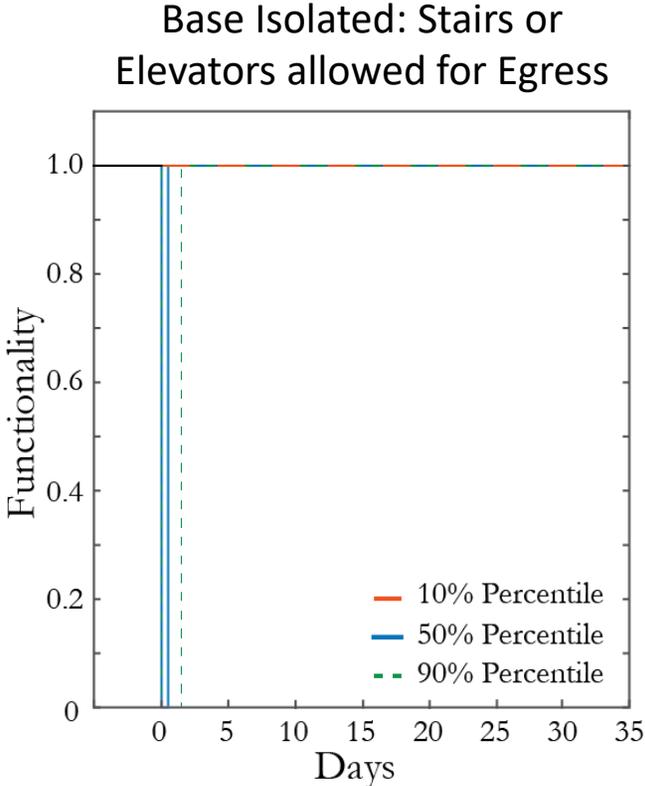
**A**  
**0.91**

Structural: 0.98

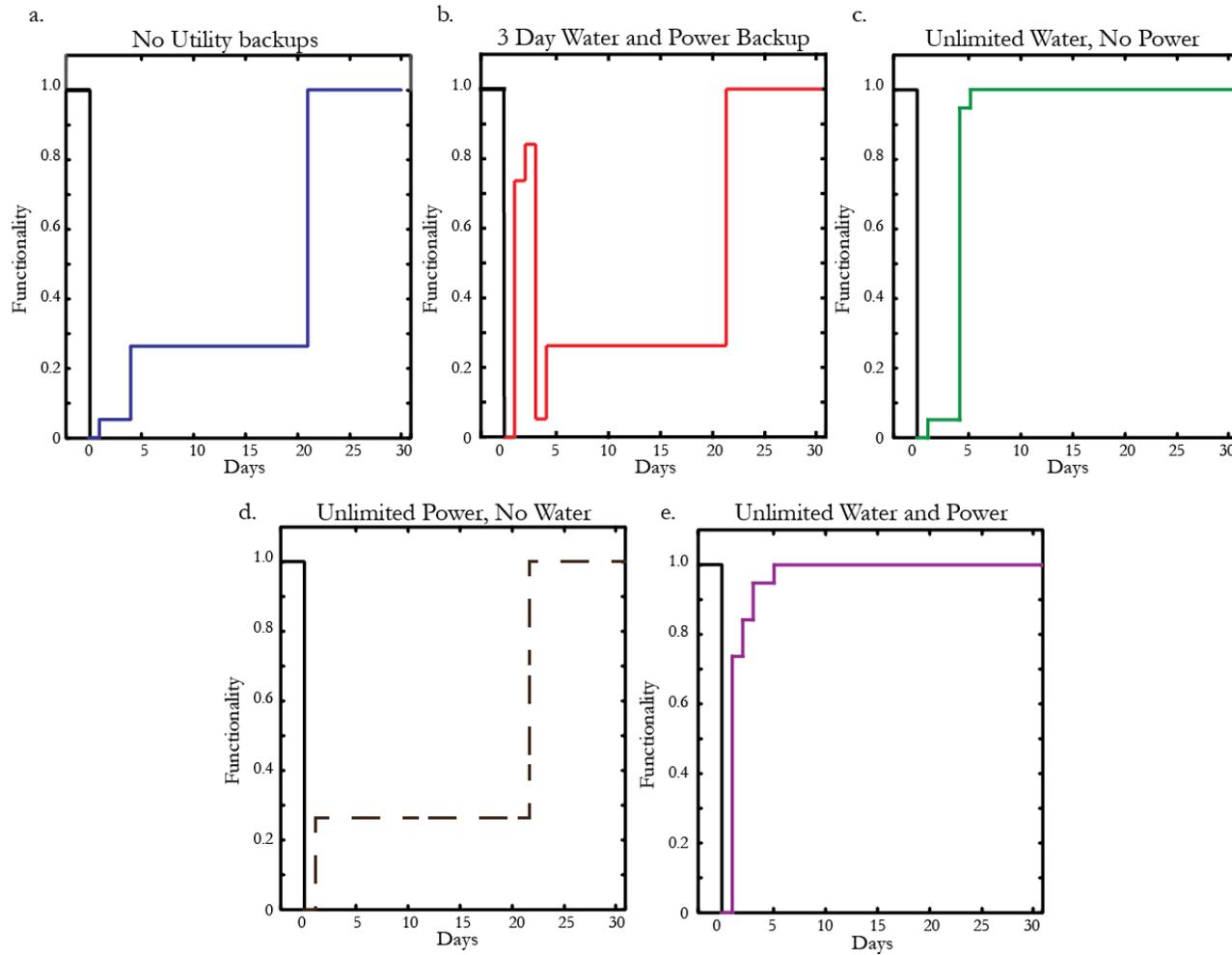
Nonstructural: 0.86

Functional: 0.81

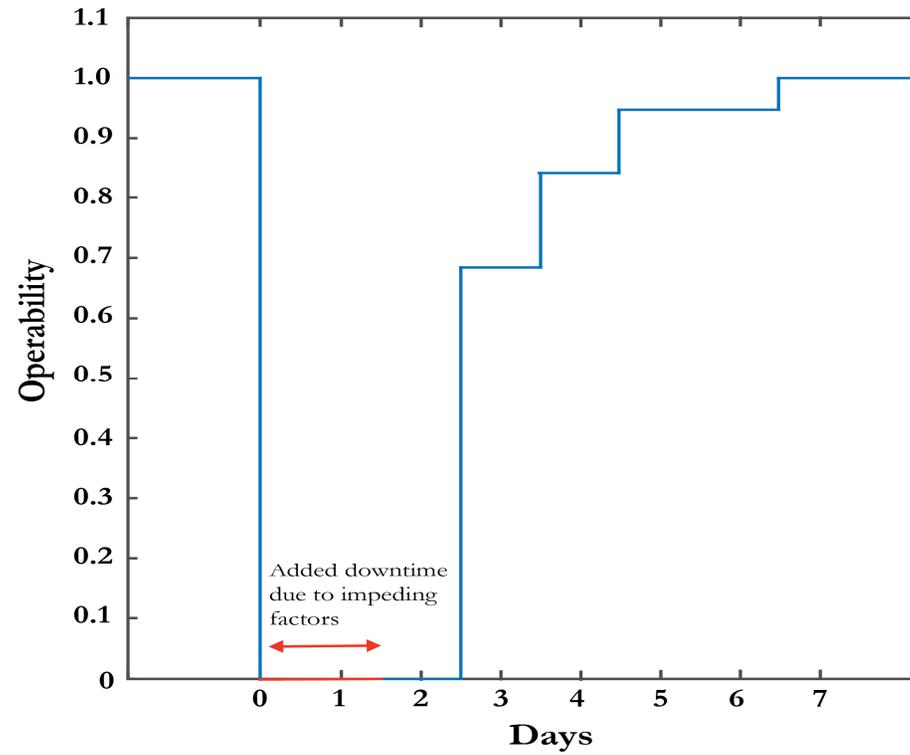
# Resilience: Elevators



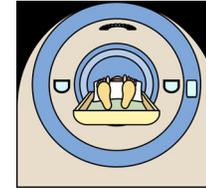
# Functionality—Utilities



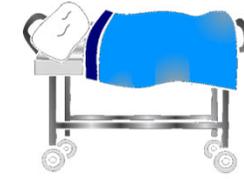
# Functionality—Impeding Factors



**Staff**



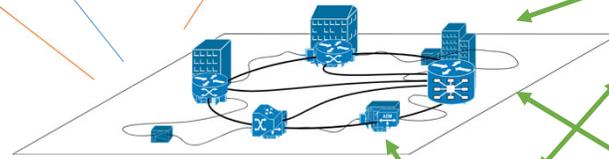
**Stuff**



**Space**



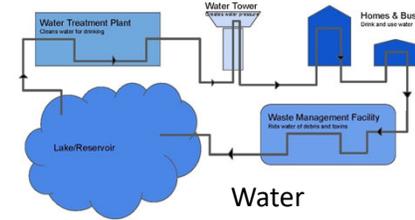
**Infrastructure Lifelines**



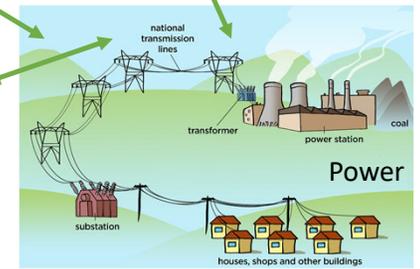
**Transportation**



**Communications**



**Water**



**Power**

# Conclusions

- REDI, USRC, QuakeStar
  - Detailed comprehensive assessments that consider building performance and recovery levels
  - Inconsistency of criteria for rating systems
  - Nonspecific to building occupancy type
  - Disaster specific
- OSHPD
  - Generalized performance categories
- Hospital Safety Index
  - Quick assessment that requires limited calculations and only considers immediate impact
  - Specific to hospitals
  - Accounts for all hazards
- Overall
  - Rating Systems focus on the performance of the physical building, largely neglect business continuity
  - None of the rating systems provide enough detail in the immediate recovery time frame to provide emergency managers enough information to predict the immediate and short term operability of hospital after an earthquake