

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

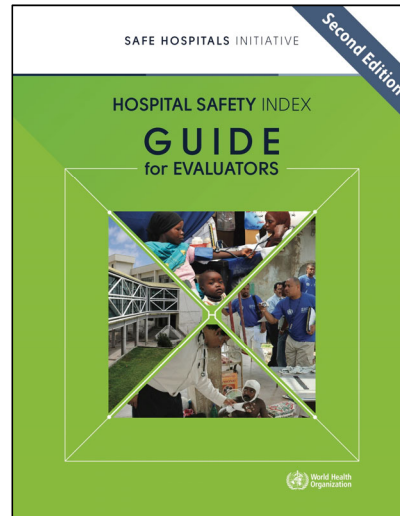
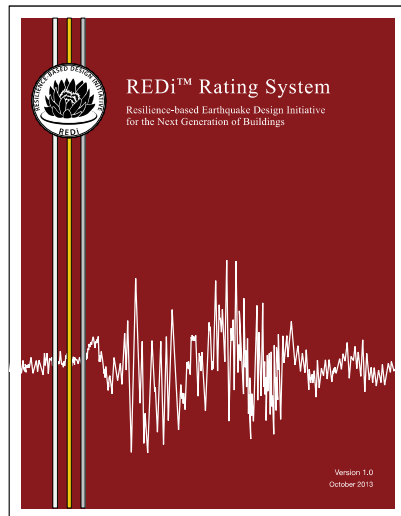
Motivation

- 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

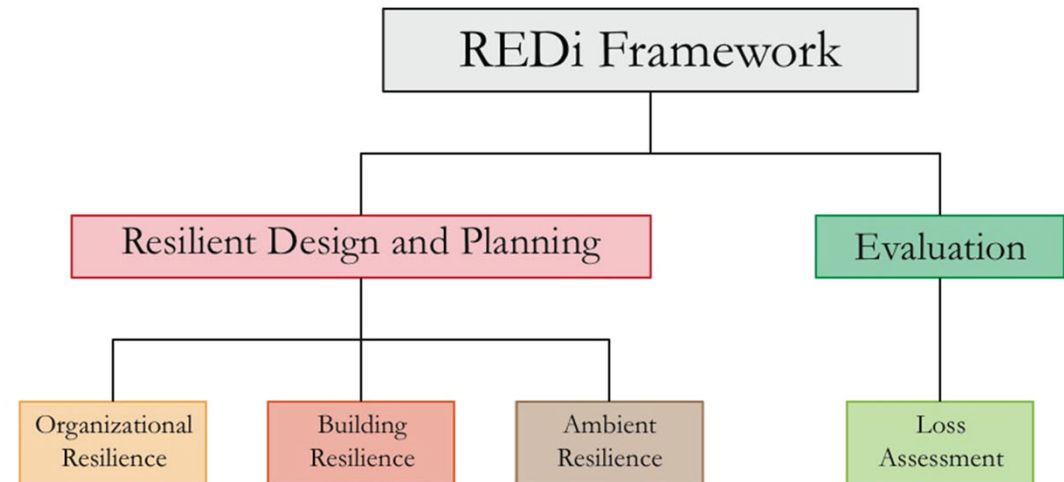
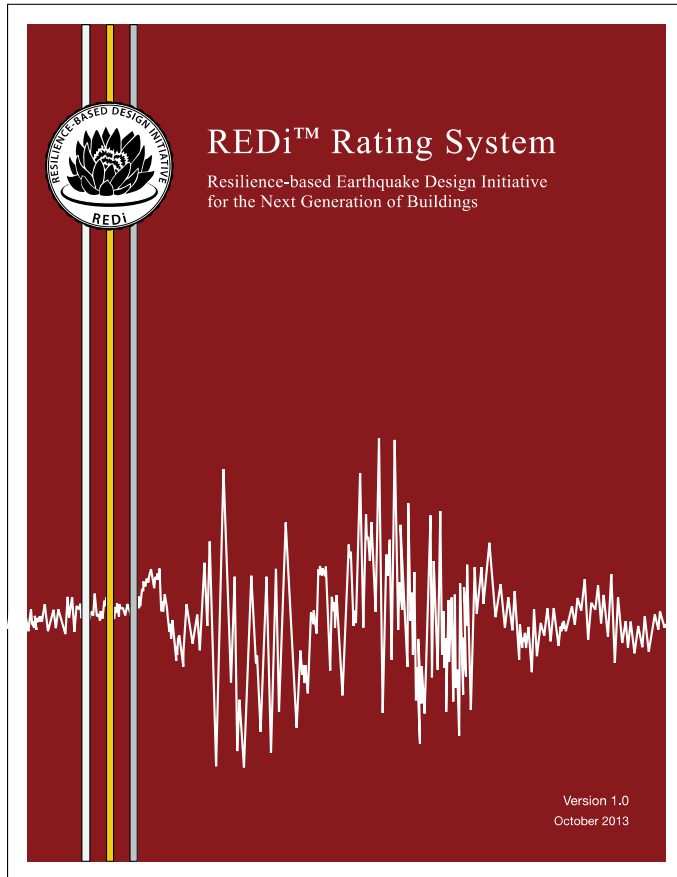
Resilient Rating Systems





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



U.S. RESILIENCY COUNCIL
Rating Building Performance in Natural Disasters

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



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	
	Item	Attribute	Measure	IL2 NBS min	User input Building Scores E-W N-S		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				*** *** *** 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 (Figures used must take account of integrity, ductility, consequences of failure, capacity design, asymmetry and lack of separation from other buildings)	100	100	100	Rating for Primary Structure only		E-W N-S Building	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.
							*** *** *** 100 100 100			
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	Capacity / Demand	100	120	120	Rating for "Non-structural" Elements		E-W N-S Building	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.
		Glazing		100	120	120	*** *** ***			
		Ceilings		100	120	120	120 100 100			
		Partitions		100	NC	NC				
		Building Services		100	NC	NC				
		Appendages		100	120	100				
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





Hospital Safety Index: GUIDE FOR EVALUATORS

2.1 Prior events affecting hospital safety		Safety level (Low, Average, High)	OBSERVATIONS
1. Has there been prior structural damage to the hospital as a result of natural phenomena?	<div><div></div><div></div><div></div></div>		Building is in new construction, there is no prior structural damage and no event has occurred since construction has completed
2. Has the hospital had earlier reported ongoing safety incidents?	<div><div></div><div></div><div></div></div>		Hospital was built to current code requirements and all safety standards were fully applied (HSCs)
3. Has the hospital had earlier reported structural damage to the facility?	<div><div></div><div></div><div></div></div>		No building remodeling or modification has taken place in the building (HSCs)
2.2 Safety of the structural system and type of materials used in the building		Safety level (Low, Average, High)	OBSERVATIONS
4. Condition of the building	<div><div></div><div></div><div></div></div>		The building is in good condition, there is no significant loss pertaining to any of the structural elements, no visible cracks
5. Construction materials used	<div><div></div><div></div><div></div></div>		The building material is high quality, no cracks (HSCs)
6. Interaction of non-structural elements with the structure	<div><div></div><div></div><div></div></div>		Non-structural walls are built, anchored to the structure and are not fully sharing seismic loads
7. Position of building elements of spanning, and structural effects	<div><div></div><div></div><div></div></div>		Structure is built around the hospital and about 1 meter above ground, it is not sharing seismic loads with the building, the building is not sharing seismic loads with the structure
8. Structural redundancy	<div><div></div><div></div><div></div></div>		The hospital design has multiple structural elements that can share loads, redundancy is not shared with the building (HSCs)
9. Structural detailing, including connections	<div><div></div><div></div><div></div></div>		Building was designed to 2010 and 2015 building codes and standards (HSCs)
10. Safety of foundation	<div><div></div><div></div><div></div></div>		Foundation was designed to meet depth requirements for both low and medium seismic building

Structural

Hospital Safety Index: GUIDE FOR EVALUATORS

3. Elements related to non-structural safety		Safety level (Low, Average, High)	OBSERVATIONS
3.1 Critical systems			
3.1.1 Electrical system			
14. Generator has capacity to meet 100% of demand	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
15. Regular tests of generator performance are carried out on critical areas	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
16. Generator protected from damage due to natural phenomena	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
17. Redundant system for local electric power supply	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
18. Protection for critical areas of the hospital	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
19. Lighting system for critical areas of the hospital	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
20. Electrical system installed in hospital grounds	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
3.1.2 Telecommunications system			
21. Condition of antennas and antenna bearing			
22. Condition of line-of-sight systems (Internet and telephone connections)	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand
23. Condition of alternative communications systems	<div><div></div><div></div><div></div></div>		Generator has capacity to meet 100% of demand

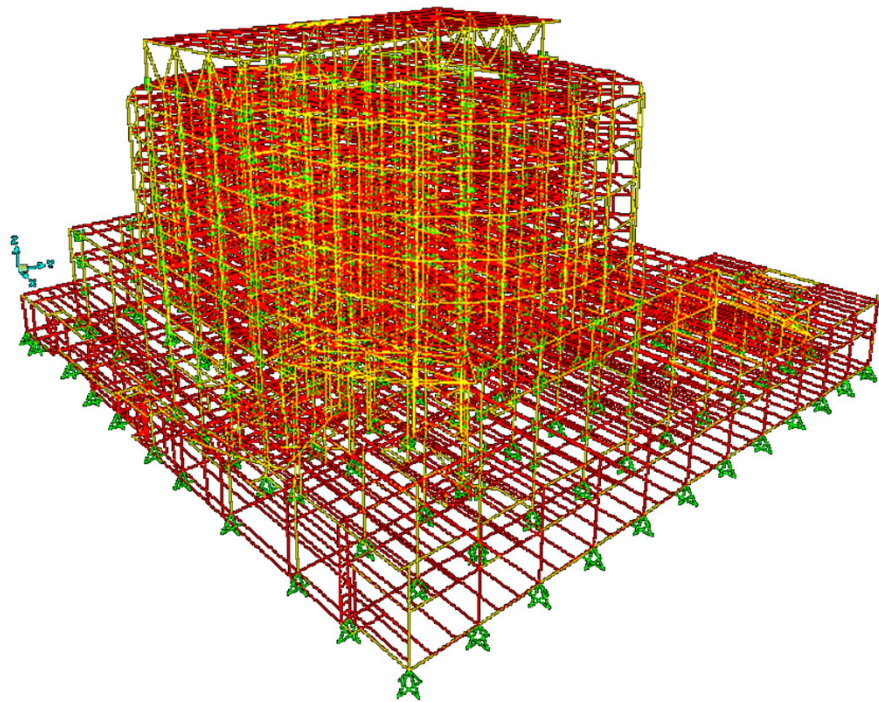
Nonstructural

Functional

Form 2: SAFE HOSPITAL CHECKLIST

4. Safety based on functional capacity of hospital		Safety level (Low, Average, High)	OBSERVATIONS
4.1 Organization of the Hospital Disaster Committee and the Emergency Operations Center			
4A. Committee has been formally established to respond to design events or disasters	<div><div></div><div></div><div></div></div>		Committee has been formally established to respond to design events or disasters
4B. Committee membership is multidisciplinary	<div><div></div><div></div><div></div></div>		Committee membership is multidisciplinary
4C. Each member is aware of his/her specific responsibilities	<div><div></div><div></div><div></div></div>		Each member is aware of his/her specific responsibilities
4D. Space is designated for the hospital Emergency Operations Center (EOC)	<div><div></div><div></div><div></div></div>		Space is designated for the hospital Emergency Operations Center (EOC)
4E. The EOC is in a protected and safe location	<div><div></div><div></div><div></div></div>		The EOC is in a protected and safe location
4F. The EOC has a complete system and computers	<div><div></div><div></div><div></div></div>		The EOC has a complete system and computers
4G. Both internal and external communications systems in the EOC function properly	<div><div></div><div></div><div></div></div>		Both internal and external communications systems in the EOC function properly
4H. The EOC has an alternative communications system	<div><div></div><div></div><div></div></div>		The EOC has an alternative communications system

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

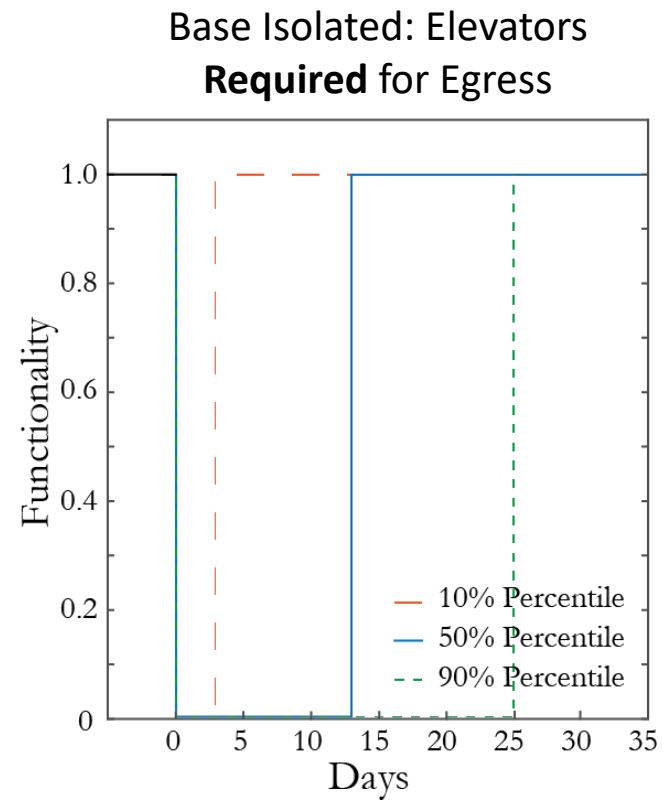
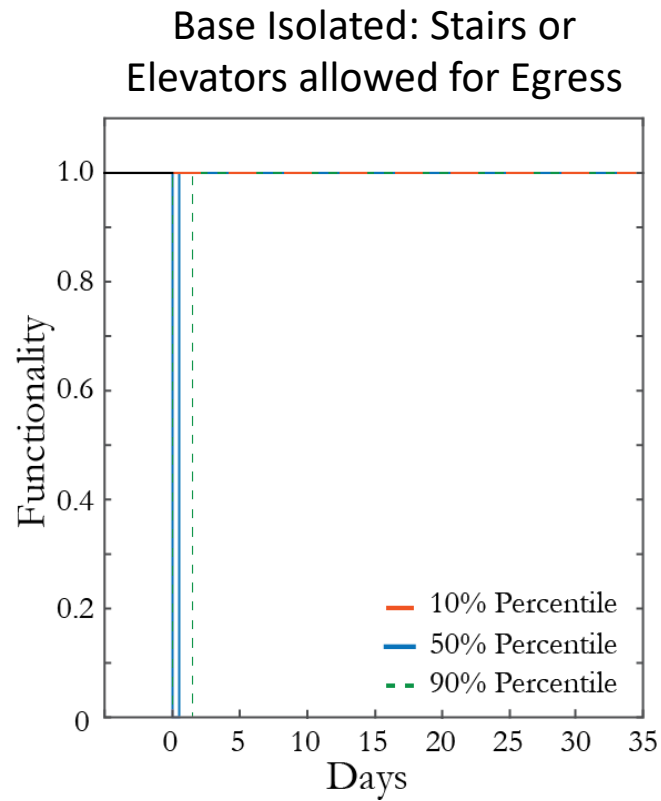
A
0.91

Structural: 0.98

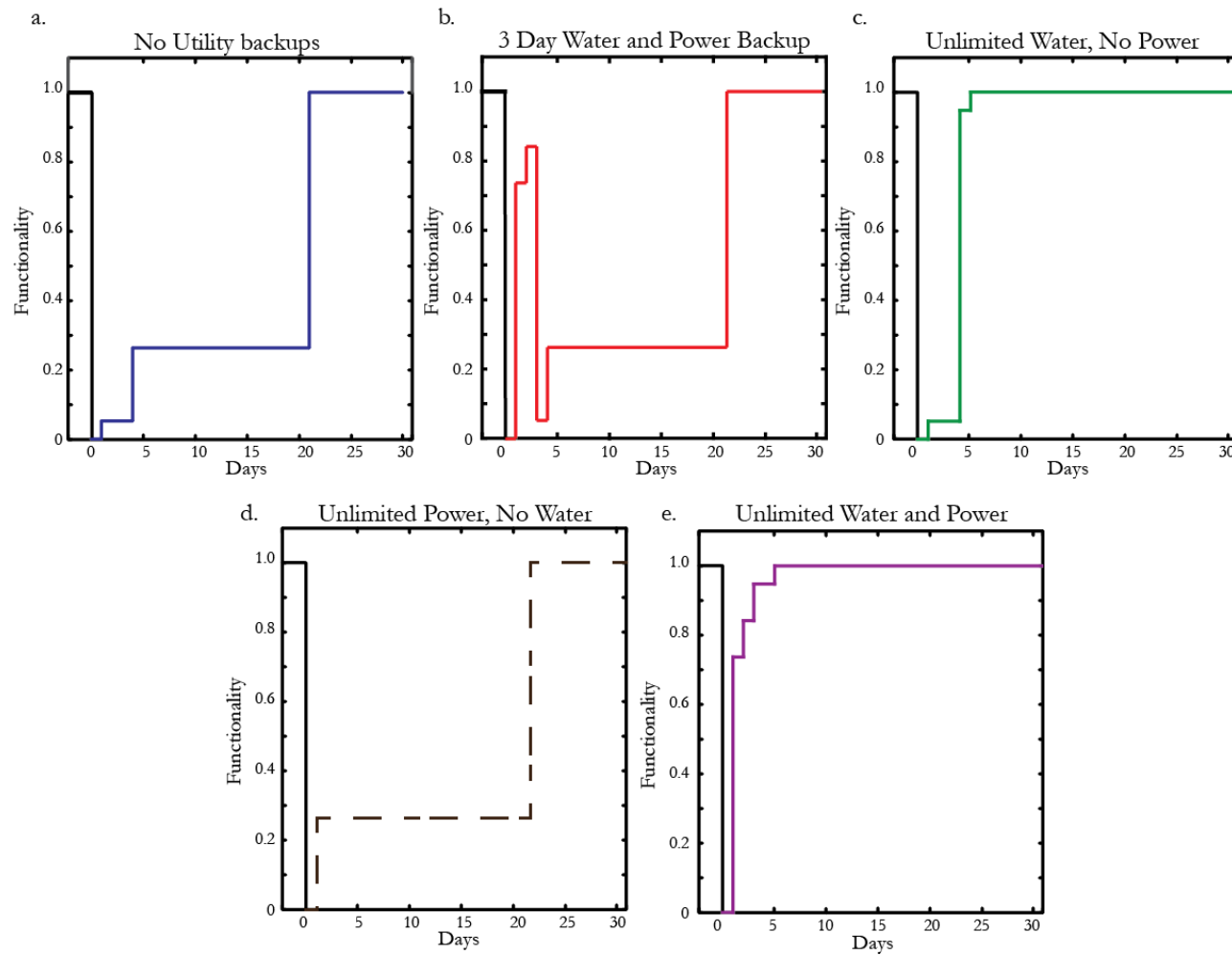
Nonstructural: 0.86

Functional: 0.81

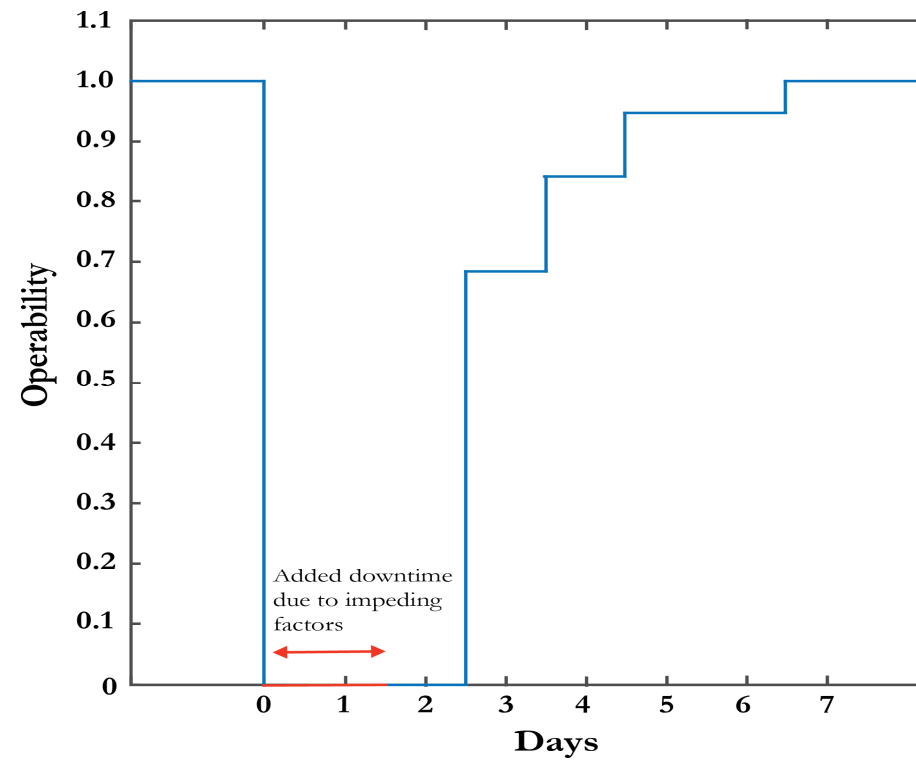
Resilience: Elevators



Functionality—Utilities



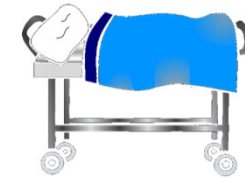
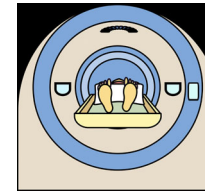
Functionality—Impeding Factors



Staff



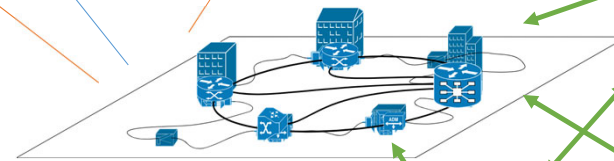
Stuff



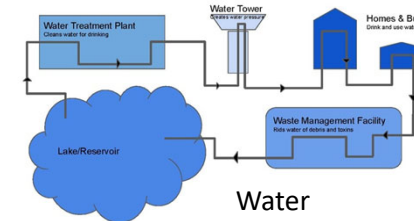
Space



Infrastructure Lifelines



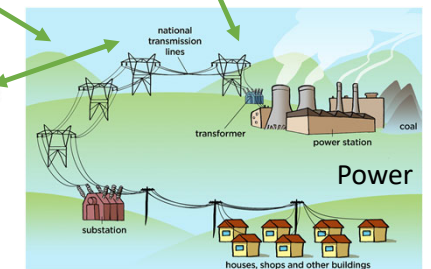
Communications



Water



Transportation



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