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

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Expectations of Hospitals

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

“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
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
Resilient Rating Systems

U.S. Resiliency Council
Rating Building Performance in Natural Disasters

QuakeStar
Building Performance Rating

REDi™ Rating System
Recommended Earthquake Design Strategy for the Next Generation of Buildings

SAFE HOSPITALS INITIATIVE
HOSPITAL SAFETY INDEX
GUIDE for EVALUATORS

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

Resilience-based Earthquake Design Initiative for the Next Generation of Buildings

### REDI Framework

- **Resilient Design and Planning**
  - Organizational Resilience
  - Building Resilience
  - Ambient Resilience

- **Evaluation**

### REDI Rating System Table

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum</td>
<td>Immediate (green tag)</td>
<td>&lt; 72 hours</td>
<td>&lt; 2.5%</td>
<td>Injury unlikely</td>
</tr>
<tr>
<td>Gold</td>
<td>Immediate (green tag)</td>
<td>&lt; 1 month</td>
<td>&lt; 5%</td>
<td>Injury unlikely</td>
</tr>
<tr>
<td>Silver</td>
<td>&lt; 6 months (yellow tag)</td>
<td>&lt; 6 months</td>
<td>&lt; 10%</td>
<td>Injury possible but structural collapse unlikely</td>
</tr>
<tr>
<td>STARS</td>
<td>SAFETY</td>
<td>DAMAGE</td>
<td>RECOVERY</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>----------</td>
<td></td>
</tr>
</tbody>
</table>
| ★★★★★ | Injuries and blocking of exits unlikely  
Fatalities < 3x10^-5 | Minimal Damage  
Repair cost < 5% | Hours to days  
Recovery < 5 days |
| ★★★★★ | Serious injuries unlikely  
Fatalities < 1x10^-4 | Moderate Damage  
Repair cost < 10% | Days to weeks  
Recovery < 4 weeks |
| ★★★★ | Loss of life unlikely  
Fatalities < 4x10^-4 | Significant Damage  
Repair cost < 20% | Weeks to months  
Recovery < 6 months |
| ★★★ | Loss of life possible in isolated locations  
Fatalities < 4x10^-3 | Substantial Damage  
Repair cost < 40% | Months to 1 year  
Recovery < 1 year |
| ★★ | Loss of life likely  
Fatalities > 4x10^-3 | Severe Damage  
Repair cost > 40% | More than 1 year  
Recovery > 1 year |
| ★ | | | |
# QuakeStar Building Performance Rating

**Worksheet 1**

<table>
<thead>
<tr>
<th>Commercial</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall Safety Rating</strong></td>
<td>***</td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td>(Replace with building specific notes)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Details</th>
<th>Overall combined</th>
<th>E-W</th>
<th>N-S</th>
<th>Building</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safety Ratings</strong></td>
<td>***</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td><strong>Safety Scores</strong></td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

### Building Details

- **Name:** Tower Block 7/8 Richter Street, Quaketown
- **Assessor:** ABC Consulting Engineers
- **Reviewer:** DEF Structural

### Building Safety

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

### Safety Performance

- **Capacity:**
  - Site: Overall site stability
  - Building: Building overall stability
  - Primary Structure: Basic Capacity at ULS
- **Combined Ratings:**
  - Structure: Site: Building Stability
  - Site: Building Stability

### Structural Capacity Assessment

- **Floors and Stairs:**
  - Diaphragm action
  - Vertical support
  - Diaphragm
  - Glazing
  - Ceilings
  - Partitions
  - Building Services
  - Hydraulics

- **Non-structural Elements:**
  - Capacity: Demand

### User Input

- Items in red text require or allow user input. Items in green text are calculated or determined by worksheet.

### Notes

1. A basic score of 100 represents minimum assessment for design-level performance of a new building of ULS Category. With modifying factors, an average new building of this type is expected to score about 130.
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
Hospital Rating Results

<table>
<thead>
<tr>
<th>OSHPD</th>
<th>SPC: 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>REDI</td>
<td></td>
</tr>
<tr>
<td>QuakeStar</td>
<td></td>
</tr>
<tr>
<td>United States Resiliency Council</td>
<td></td>
</tr>
<tr>
<td>Hospital Safety Index</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NPC: 4</th>
</tr>
</thead>
</table>

**Silver**
- Downtime-Reoccupancy: 0 days
- Downtime-Functional: 114 days for repairs
- Direct Financial Loss: 0.4%
- Occupant Safety: No expected injuries

**Safety**
- 4 stars

**Damage**
- 4 stars

**Recovery**
- 4 stars

**A**
- Structural: 0.98
- Nonstructural: 0.86
- Functional: 0.81

**0.91**
Resilience: Elevators

Base Isolated: Stairs or Elevators allowed for Egress

Base Isolated: Elevators Required for Egress
Functionality—Utilities

(a) No Utility backups
(b) 3 Day Water and Power Backup
(c) Unlimited Water, No Power
(d) Unlimited Power, No Water
(e) Unlimited Water and Power
Functionality—Impeding Factors

![Graph showing operability over days with added downtime due to impeding factors](image)
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