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

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Abstract

Immediately after a major earthquake, critical facilities need to remain operational, continuously providing healthcare services. Continued operability is dependent on the physical performance of healthcare facilities during the earthquake. Several earthquake resilience-rating systems provide a translation of technical building evaluation data into quick summaries of expected building performance and resilience. These ratings provide an approximation of the intended building performance in relation to safety, loss of function , and repair cost. However, the translations between engineering assessments and rating systems is inconsistent, with the same rating-system inputs producing different resilience estimates. The lack of standardization across rating systems can cause confusion for accurately predicting building outcomes. Further, the level of recovery detail is broad with timeframes measured in weeks, months, or even years. While this may be sufficient for many facilities, it is insufficient for others. For example, critical facilities require estimates of building functionality within minutes, hours, and days of the event to support emergency operations. However, current rating systems and engineering evaluation methods lack the proper resolution to provide this level of detail, making the current rating systems inadequate for emergency planners and may provide communities with a false sense of general preparedness. This paper examines the effectiveness of various resilience-rating systems to predict the overall functionality in a hospital after an earthquake and the issues in converting building performance evaluations into resilience ratings. Further, it presents an additional methodology for addressing resolution gaps in estimating building functionality immediately after the event.

Introduction

It is essential that critical-care facilities remain functional and operational following a major disruptive event. These facilities provide continued and ongoing care of existing patients, and provide rapid and emergency treatment to the potential surge of injured patients caused by the disaster. Hospitals and other critical-care facilities damaged by disruptive events, such as an earthquake, are commonly evacuated or closed (Achour et al. 2011; Blakeborough 1994; Nagata 2017). Structural damage as well as many other types of damage or outages can hinder hospital operability. Non-structural damage and infrastructure outages have also been the cause for hospital evacuation, reduced operability, and extended closures (Achour 2011; Myrtle 2005). This creates a burden on other healthcare centers and negatively affects the community's ability to recover.

To ensure continued functionality of hospitals and other critical care facilities, it is important to estimate the performance and resilience of the building and the organization after a disaster. Hospital resilience, or the ability of the hospital to bounce back and recover from disruptions, must consider the overall condition and safety of the hospital's physical facility and the operability of all the services the hospital provides to the public. One way of uniformly assessing hospitals is through a resilience rating system.

Rating Systems

A number of resilience rating systems have been developed to assess building performance and resilience to an earthquake. Existing resilience rating systems commonly address safety (occupant safety during the event), damage (financial cost to repair the building), and recovery (time required to make necessary repairs to the building). Each rating system varies in their assessment of post-disaster functionality. Further, the outputs, which are intended to be informative to the public and stakeholders, differ between the rating schemes. Five different rating systems are discussed below, including: the OSPHD Seismic Performance Categories, the United States Resiliency Council Rating System, QuakeStar, Resilience-based Earthquake Design Initiative, and the Hospital Safety Index.

OSHPD Seismic Performance Categories. In accordance to the Alfred E. Alquist Hospital Seismic Safety Act (HSSA) (State of California 1983), hospitals in California are expected to meet certain performance standards during an earthquake. Hospitals that fail to meet a high seismic performance category must be retrofitted or closed. Hospital performance is measured in terms of both structural and non-structural behavior. Structural and non-structural building performance is determined by professional engineering consultants and submitted to the Office of Statewide Health Planning and Development (OSHPD) (OSHPH 2001). The results are published by OSPHD for use in community and regional planning.

The structural performance of the hospital building is classified into structural performance categories (SPC). The categories address the building's potential for collapse, risk to life and injury, and how damage influences the ability of the hospital to provide services after a major event. There are five main structural performance categories, ranging from SPC 1 (buildings at risk of collapse) to SPC 5 (buildings reasonably expected to be able to provide continued care). Non-structural performance is also divided into five non-structural performance categories (NPC); the categories build upon each other and refer to how well the non-structural components in the hospital are secured and anchored. The SPC and NPC performance categories are summarize in Table 1 (OSHPD 2001).

Table 1. OSHPD Structural and Nonstructural Performance Categories (OSHPD 2001)

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.

United States Resiliency Council (USRC) Rating System. The USRC rating system was developed as a tool to translate loss assessment results to outputs that are meaningful to the public (USRC 2015). The rating system is applicable to all types of building occupancies, but is limited to earthquake resilience. USRC measures resilience based on a buildings predicted performance in terms of safety, damage, and recovery time. The safety category assesses the collapse probability of the building, the likelihood of injury or death, and the ability to safely exit the building. Building damage is dependent on the cost ratio of repairing the building to the cost of the building. Recovery is the amount of time it estimated until the building can be used for its intended purpose. Recovery in the USRC system neglects added disruptions due to lifeline and infrastructure failures, financing and permitting time, and contractor mobilization. To receive a rating, a building must have an engineering loss assessment performed. Two loss assessment methods are permitted. The first is an adaptation of SEAONC Earthquake performance rating system (SEAONC 2015) that assess buildings based on ASCE-31 (ASCE 2003). The second loss assessment method follows the FEMA P-58 Guidelines for Performance Based Earthquake Engineering. Damage, loss, and estimated recovery are used from either method to determine the USRC rating for the building. Buildings can receive one to five stars in each of the three categories. One star typically represents low resilience (unsafe building, high damage, or long recovery) whereas five stars represents high resilience (safe, low damage and fast recovery). Table 2 show the requirements for achieving each level of resilience in the USRC system. The USRC rating is based on the performance of the physical facility and not on the performance of the hospital as an organization.

Table 2. USRC Rating System Requirements

Stars	*Safety*	*Damage*	*Recovery*
★★★★★	Injuries and blocking of exits unlikely	Minimal damage	Days
★★★★	Serious injuries unlikely	Moderate damage	Weeks
★★★	Loss of life unlikely	Significant damage	Months
★★	Loss of life possible in isolated locations	Substantial damage	< 1 year
★	Loss of life likely	Severe damage	> 1 year

QuakeStar Rating System. The QuakeStar rating system, developed in New Zealand, is modeled after the USRC rating system (QuakeStar). Similar to USRC, QuakeStar gives buildings a one-to-five star rating in three areas: risk of harm (safety), damage, and repair time (recovery). QuakeStar allows for results from several types of loss assessments to be used as input for determining the rating. Damage and recovery estimates are based on the %NBS (New Building Standard) for the building and the building performance in terms of the building site, the primary structural system, the floors and the stairs, and the non-structural elements. Recovery ratings are based on the time required for just the repairs, and can be adjusted based on the added time required for repairs plus utility restoration and other external factors.

Resilience-based Earthquake Design Initiative (REDi). Another rating system rating system that builds off the FEMA P-58 Guidelines for Performance Based Earthquake Engineering is REDi, developed by the engineering firm Arup (Almufti 2014). REDi is an earthquake specific platform that is applicable to all building occupancy types. In addition to providing a resilience rating for the building, REDi provides a comprehensive planning and design guidelines to help ensure that new buildings meet required standards and performance expectations. REDi takes a holistic approach for determining a resilience rating and considers factors beyond the loss-assessment used by USRC and QuakeStar. To achieve a REDi rating, a building must reach certain performance criteria determined through a loss assessment, and meet certain prescriptive requirements to help ensure business and organizational continuity after the earthquake. Additionally, REDi requires building owners to consider risks posed by ambient factors such as nearby buildings at risk of collapse. REDi also includes the impacts of utility disruptions and impeding factors (permitting, inspection, financing, and engineer and contractor mobilization) in the loss assessment calculations for determining the overall rating of the building. The recovery period, referred to as downtime in the REDi methodology, is broken into two categories: re-occupancy and functional. Re-occupancy is the time required for a green tag, or to safely occupy the building. Functional downtime is the time required until the building can be used for its intended purpose. Functional recovery requires all utilities to be restored and accounts for all impeding factors in the repair time to be accounted for. A REDi-rated building will be given a platinum, gold or silver certification based on meeting target values for downtime, direct financial losses and occupant safety. The benchmark requirements for each certification is given in Table 3, where all three categories must be met in order to achieve a target level.

Table 3. REDi Certification Requirements

Certification	*Downtime*		*Direct Financial Loss*	*Occupant Safety*
	Re-occupancy	*Functional*		
Platinum	Immediate (Green Tag)	< 72 hours	< 1%	Injury is unlikely
Gold	Immediate (Green Tag)	< 1 month	< 5%	Injury is unlikely
Silver	< 6 months (Yellow Tag)	< 6 months	< 10%	Injury is possible but structural collapse is unlikely

Hospital Safety Index. The Hospital Safety Index, developed by the World Health Organization is a qualitative survey developed to rapidly assess expected hospital functionality after a disruptive event. The Hospital Safety Index is specific to hospital buildings (WHO 2008a; WHO 2008b). The Index attempts to assess the likelihood of hospital functionality from any type of disruptive event, including natural, manmade or biological events. The safety index is determined by evaluating a hospital based on 145 criteria. The criteria items are divided up into three categories: structural, nonstructural, and functional. Each criteria is assessed based on the current conditions, the design, or other aspect and is assigned a low, average or high value. The items in each category are combined to create the individual category index values. The individual index values are weighted as follows: 50% for structural, 30% for nonstructural, and 20% for functional. The weighted sum of these indices is used to get the total index value for the hospital. The index value will be a numerical value between 0 and 1. This value is the probability of the hospital surviving an emergency and maintaining functionality. The index number is also translated into a classification level or a grade indicating predicted outcomes, see Table 4. The main advantage of the Hospital Safety Index is that it provides hospital owners and emergency managers a rapid and inexpensive way to predict functionality. For areas with many hospitals at risk, this index is a useful resource for identifying the hospitals that are most at risk of disruption so that limited funds can be allocated where they will have the most impact. Another important factor of the Hospital Safety Index is the functionality category. This category assesses the hospital organization, emergency management procedures, staffing and supplies. This critical component of hospital functionality is missing from the other rating systems.

Table 4. Hospital Safety Index Values and Meaning

Safety Index	*Classification*	*Predicated Outcomes*	*Recommendation*
0.66-1.0	A	Hospital is likely to function	Continue to improve emergency and disaster management
0.36-0.65	B	Ability of the hospital to function after a disaster is at risk	Short-term intervention is needed
0.0-0.35	C	Hospital is unable to function following a disaster	Urgent intervention is needed

Case Study Building

To compare the different rating systems, a case study hospital is selected and analysed; the results from each rating system are compared. The case study hospital used in this study is modeled after an existing hospital located in California. The structural system of the hospital is a steel moment frame with added base isolation for lateral resistance. This hospital is selected to demonstrate the results of a building that is built beyond code requirements and is expected to remain functional following a design level earthquake. The hospital tower houses acute care services such as intensive care, emergency, surgery, and inpatient. It is assumed that the hospital has taken appropriate organizational planning into account and that there are emergency policies and procedures in place for an emergency. As several of the rating methodologies require a loss assessment, a model of the hospital building was analyzed following FEMA P-58's (FEMA 2012) loss assessment methodology. A non-linear time history structural analysis was run using the computer software ETABS (CSI 2017) to obtain the maximum drift and acceleration at each floor. The results were used in PACT (FEMA 2012) analysis to predict the structural and non-structural damage in the hospital building.

Results and Discussion

Following the required procedures for the different rating systems, the results of the expected resilience ratings for the hospital are summarized in Figure 1. The QuakeStar resilience rating was not determined, as the rating methodology is very similar to the USRC methodology. The OSHPD results were found by looking up the hospital building in the OSHPD public database. The remaining results, USRC, REDi, and the Hospital Safety Index, were determined using the results from the loss assessment.

While there are similarities between the results, the information presented to public is inconsistent between the different rating systems. For example, under the REDi methodology the building only receives a silver certification. Silver certification is generally the result expected for a code conforming building that has not had added earthquake resisting provisions provided. The case study hospital utilizes base isolation, which should decrease the damage to the building and increase the resilience, this is seen in the loss analysis results. However, REDi requires that the external utilities be considered when determining the downtime required for functional recovery. Based on predicted water, power, and gas outages in the location of the building following an earthquake (Almufti 2014), the functional recovery is extended beyond the 72 hours or 1 month time frame to receive a platinum or gold certification. In addition to the utility outages, the inspection, mobilization, and recovery time that is considered in the REDi rating is not directly included in the other systems. The REDi rating provides a more complete picture of the requirements to achieve functionality in the hospital.

The SPC rating for the OSHPD structural performance is a 5. This indicates that the hospital should be reasonably capable of continued operability based on structural damage. This is consistent with the loss-assessment results used to determine the damage and recovery times for the REDi and USRC ratings.

However, it neglects the potential downtime due to elevator shutoffs, inspections, and repairs. Elevator damage is one of the primary sources of damage and recovery time in the loss assessment results. Further, the NPC score of 4 indicates that the facility does not have a 72 hour onsite supply of water or power. The absence of both will lead to forced evacuations or hospital closures if the main utilities are damaged. Thus, the actual ability of the hospital to function is compromised by the lack of onsite backup utilities but is not directly accounted for in the OSHPD results.

Figure 1. Hospital resilience rating results for four of the rating systems.

The hospital receives five stars for safety and damage in the USRC rating system. It receives 4 stars for recovery. This means that the hospital is expected to take one or more weeks to achieve functional recovery. Several weeks of downtime for a hospital is a far cry from the continued and immediate functionality expected of hospitals following an earthquake. Further, as the USRC does not consider utility outages or repair delays due to inspection, permitting, financing, and mobilization, the recovery time is optimistic and could be misleading to stakeholder looking for a quick recovery of their facility.

The hospital receives a high probability of continued functionality after an earthquake with the Hospital Safety Index. The advantage of this system is that it considers the emergency procedures and plans in place for the hospital. This is important because hospital resilience needs to be based on the hospital providing continued service in addition to the performance of the physical building. A downside of the Hospital Safety Index is that it lacks the time dimension and instead provides a probability that hospital will either be functional or not.

Further, it is important to note that with the exception of the Hospital Safety Index, none of the ratings directly address the ability of the hospital to provide continued care at peak operability (Boston 2017). Rather, they focus primarily on the physical facility. Resilience is measured and based on how the building performs and the length of time required to restore the building. The capacity, operability, and functionality of the hospital as a health care facility is not considered. Therefore, the results from the rating systems provide an incomplete picture of the actual ability of the hospital to continue to operate at the intended capacity immediately after an earthquake and during the recovery period. An occupation specific resilience rating system needs to be developed that addresses the unique and specific needs of critical care facilities. This system should combine the physical performance of the building with the operational requirements of the facility. Such a rating system would provide more specific and detailed information to hospital emergency planners, stakeholder, and the public.

Conclusions

A limitation of several rating systems is that they assess building performance in terms of the immediate safety of building occupants, the repair cost, and the repair time. Other areas of resilience, such as resourcefulness or adaptive capacity of the internal organizations, are omitted and not considered. While the rating systems present the resilience of the physical building, they do not fully represent the resilience of the internal organizations housed within the building. As such, their results have limited application to critical facilities such as a hospitals. Another dimension that is important to hospital resilience that is missing from each of the existing rating systems is the capacity to measure partial functionality of the hospital over time. It is possible that hospitals with limited or localized damage will continue to operate at a reduced capacity while repairs are made.

To preserve the operability of hospitals, it is vital to consider more than the performance of the building; the impact of the building's performance on the ability of the hospital to continue to provide clinical and non-clinical services also must be considered. Each of the existing rating systems provide valuable information, however the way the results are currently presented to stakeholders and the public are misleading to the actual resilience and functionality of a hospital after a disaster.

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