Introduction

Hospitals are a critical component to community resilience following disasters. Hospitals need to be able to provide needed medical assistance to people injured during the earthquake and continued care to those already in the hospital. Recent policies and guidelines have emphasized the need for hospitals to remain operational following a major disaster. To remain functional, it is critical to understand what types of physical damage contribute to losses of specific hospital services and the loss of the hospital as a whole. In addition to structural damage, damage to non-structural components such as suspended ceilings, partition walls, and piping, can severely hinder the hospital’s ability to continue providing life saving treatment.

The necessity of hospitals to continue to operate and function following an earthquake highlight the need to move beyond code design and beyond performance-based design. Performance-based design moves beyond code-based design by considering the potential for damage and downtime of the building. However, it does not provide needed information on the ability of critical facilities, such as hospitals, to continue to operate in the presence of minor to moderate nonstructural damage. Thus, a further level of understanding and analysis is required to accurately predict realistic functionality of a hospital immediately after an earthquake and during the recovery period. Resilience-based design adds an additional level of analysis that maps physical damage to actual hospital services and operations to provide a depiction of what real time functionality of a hospital will actually be.

Fault Tree Analysis

For this method of resilience-based design, fault trees are used to map estimated physical damage and downtime (determined following a P-58 PACT assessment) to clinical and non-clinical hospital services. The fault tree analysis is rerun at each point in time to provide a re-evaluation of hospital services for re-occupancy and functional recovery. The fault tree analysis is used to determine if the hospital service is operable. Due to the decrease of damaged components in the base isolated building, there is a lower loss of operability in the hospital as a whole compared to the moment frame.

Results

Figure 3. Example of damage distribution for two designs of a hospital building. The one on the left is a steel moment frame design with a long period. The one on the right is the same hospital with added base-isolation. The results show the percentage of times a component is damaged to a hinder functionality over time. The damage and downtime estimates to determine the operability of all hospital services to estimate the functionality of the hospital at any time during the recovery timeframe. Plot the change in functionality over time. Make adjustments to the design until all requirements are met.

Figure 4. For each realization of the damage and downtime analysis, the results can be felt into the fault trees to determine what hospital services are inoperable or operable immediately after the earthquake and during the recovery. The results above are for the realization that had the median amount of downtime for all the results. Hospital components that were damaged and required repairs to meet re-occupancy and functional recovery were used as input to the fault tree analysis. Based on the layout of the hospital, the location of physical damage, and the fault tree logic, each hospital service is analyzed to determine if it is operable. Due to the decrease of damaged components in the base isolated building, there is a lower loss of operability in the hospital as a whole compared to the moment frame.

Figure 5. The operability of each service can be combined to estimate the overall functionality of the hospital over time. The graphs above show the resilience curves for the two hospital models. Resilience is shown as the functionality of the hospital over time. Due to more severe and distributed damage in the moment frame model, this model experiences a longer period of reduced services and restoration of functionality. Base isolated model has lower sensitivity to the earthquake than the base isolated model which has a rapid recovery and functionality restoration after an earthquake.

Conclusions

Resilience-based design with fault tree analysis can be used:
- in scenarios to predict loss-of-service to one or more hospital services given a set of damage
- in probabilistic assessments of building performance following a performance-based design analysis
- for rapid real time analysis of a hospital’s current state of operability following an event
- for developing emergency planning scenarios
- to inform decisions on placement of critical equipment, hospital services, and general hospital layout to improve services the hospital can render following an earthquake.

Future Work

This resilience-based design framework can be expanded to:
- different building occupancy types
- multi-hazard analysis
- city wide resilience analysis