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VULNERABILITY AND SEISMIC RISK: CONSIDERATIONS FOR CALIFORNIA HOSPITALS

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ABSTRACT

Risk management includes three components: 1) understanding potential losses to facilities and to operations; 2) developing hazards mitigation plans to strengthen and protect the physical plant for life safety and operations; and 3) strategic planning for business resumption and operational contingencies. Continued operations is critical in hospitals for a variety of reasons, such as life safety, continuity of service, the protection of public assets, service interruption and capital losses, as well as the risk of financial ruin from long term closure. The potential impacts of downtime in hospitals has shaped California policies.

Introduction

In Performance Based Earthquake Engineering (PBEE), the key variables in loss modeling are known as the "3Ds: Deaths, Dollars, and Downtime." Secondary economic aspects include service interruption and opportunity costs from losses. For hospitals, downtime is a critical aspect because of the cascading impacts on post-disaster health services.

In the PBEE methodology, downtime is composed of two components: 1) The "rational"—that is, the actual time to repair building components damaged and refinish spaces for use; and 2) The "irrational"—that is, the time needed for mobilization, tasks and decisions unrelated to the damage specifics, such as financing, relocation of occupants, manpower to manage the repairs, as well as economic and regulatory uncertainty that could slow the repair process (Comerio 2006).

As part of our research we completed a study of nearly 5,000 building department records of damaged buildings which required permits for repairs after the Northridge earthquake. For buildings that needed repair, the time between the earthquake and the receipt of a certificate of occupancy was two years. For buildings with damage so extensive that they were rebuilt, the time needed was 4 years (Blecher and Comerio, 2007). Case studies of two major universities also show that major buildings require two to three years at a minimum for repairs, and that financing and other mobilization tasks can add years to the repair process. This type of data allows us to build "downtime" into our loss estimates with some degree of certainty (Comerio 2005).

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Downtime Data Sources

Downtime, recognized as a key measure of "post-earthquake operability," is one of the main decision variables proposed by PEER and the ATC-58 Project for performance assessment of structures (Mitrani-Reiser, 2007). Downtime includes the time necessary to plan, finance, and complete repairs on facilities damaged in earthquakes or other disasters. It is an essential component of loss modeling, because it is one measure of operational failure in lifelines and business interruption in buildings (Comerio (2006). Because the PEER methodology is a probabilistic framework, estimates of data from earthquake intensity to building damage are based on empirical evidence and professional judgment. Downtime is one component of the loss module of this framework and empirical data is critical to calibrating the model and estimating downtime values for earthquake-damaged buildings.

There were three main sources of data for the PEER downtime research: 1) the building department records from the Loma Prieta and Northridge earthquakes, a case study of the Stanford Campus Losses after Loma Prieta, and 3) detailed loss estimates for the UC Berkeley Disaster Resistant University Program.

PEER Downtime Data Survey

The building department records are described in another paper at this conference (Comerio and Blecher 2010) but in summary, we looked at the building department records for approximately 4900 residential buildings of which 74% were damaged by the Northridge earthquake. The mean time to occupancy for buildings affected by the Northridge earthquake at 27 months (2.2 years) was more than 2.5 times that of Loma Prieta buildings. Most of this difference is due to the mean time to occupancy for repaired buildings, which at 25 months (2.1 years) is almost 6 times that for Loma Prieta. Furthermore, for both earthquakes the vast majority of buildings were repaired rather than demolished or rebuilt.

The analysis focused on time to occupancy measures as a function of tag color, building type and Single Family versus Multi family structures—one measure of building size/building use. These variables were used as they are the most relevant for residential buildings, they have consistent and recognized definitions among interested parties (such as building authorities, construction professionals, owners and academics) and the data was available. Overall, the mean times to occupancy for repaired buildings of almost 2 years and for demolished and rebuilt buildings of almost 3.5 years for a population consisting almost entirely of low-rise wood-frame structures has significant implications for the post-earthquake strategies of governments, builders and owners. The time to occupancy for larger and more complex buildings could easily exceed these figures. The Stanford case study is an example.

Stanford Case Study

The availability of financing was a major factor in the time required for Stanford University to repair buildings that were substantially damaged and closed by the 1989 Loma Prieta earthquake. At Stanford University, 25 of approximately 400 buildings were closed by university officials and county inspectors. Another 242 buildings had minor cosmetic or nonstructural damage, which was not hazardous and easily repaired by campus physical plant staff. The closed buildings had 850,000 square feet, representing 8 percent of the total campus space. Of this, 40 percent was repaired quickly, but 41 percent was delayed by financing issues, with construction starting four to eight years after the earthquake. Nineteen percent of the space was closed permanently (Comerio 2006).

Construction repairs on nine buildings, representing forty percent of the space, began six to eighteen months after the earthquake. Four of the buildings were completed in less than one year and the other five were completed in one to three years. The projects in this quick-repair category included dormitories, critically needed offices in one department, and the Memorial Church. Re-housing displaced students and replacing the lost offices were each seen as essential to campus operations. Memorial Church was and is the symbolic center of the campus. For these repair projects, the campus committed internal funds (and organized a special fundraising initiative for the church) without waiting for federal assistance.

On the eight buildings with 41 percent of the damaged space, it took five to nine years to complete construction. This space housed classrooms, offices, a library and a museum. All but one small building was considered a high priority campus space. The primary reason for the delay was the extensive process required to obtain funding from the Federal Emergency Management Agency (FEMA). In interviews with staff at the Stanford Land and Buildings Office, there was a consensus that if funding has not been an issue, the key factor influencing the sequence of repairs would have been surge, the relocation of functions to accommodate construction work (Comerio 2005).

UC Berkeley Estimates

In a study of losses for the University of California, Berkeley, Comerio (2000) developed a simplified method of estimating downtime which included repair time and manpower. State financing was assumed to be available, and relocation of functions was thought to be possible within the campus setting, and the economic conditions were modeled separately. The study defined downtime as the amount of time needed to inspect buildings and assess damages, set priorities, secure funding, complete architectural and engineering drawings, secure bids and complete repairs. Downtime was quantified based on estimates of structural and nonstructural damage for each building by construction type, function and size. The key assumption, distinguishing this method from other approaches is that the time needed for repair for damages sufficient to close a building includes time for professional engineering design and review, contract procurement, as well as construction repair time.

The research illustrates the key distinction between minor damage that can be repaired by university maintenance and construction crews, and major damage requiring engineering design and review. There is a clear gap between the minor damage clean-up times and the years needed for redesign and repair of a closed building. Although this study was completed before the data on Stanford University's repair program was collected, the combined efforts suggest that financing, surge and other factors would extend the two to three year estimates even longer.

Implications for Hospital Downtimes

The data available on building closures and repair times from recent disasters suggests that repair times fall into two major categories: 1) quick repairs completed within two years of the event, and 2) medium-term repairs requiring three to ten years to mobilize and undertake construction. Obviously, some of the damaged and closed sock is demolished or replaced and that will require three to ten years or more as well. Additional data from other disaster experience will help clarify the downtime performance of larger building types as they are compared to the proportion of specific building types damaged or closed. However the limited data available suggests that larger buildings such as hospitals could be closed for extensive periods if the damage to structural systems is significant or if nonstructural repairs are more extensive than maintenance crews can manage.

The Commitment of Authorities in California Hospital Safety

California has had a long-term focus on hospital safety and the next sections relate some of the history and commitment to limiting damage and downtime in hospitals. For the past thirty years, California has actively pursued the regulation of hospital design. This included the following key measures:

- The 1972 Hospital Safety Act Governs New Buildings and Provides for Professional Oversight of Hospital Design
- The 1978 Act Focuses on Concerns about Pre-act Buildings
- The Creation of OSHPD (Office of Statewide Health Planning and Development)
- The 1989 Inventory of All State Hospitals
- The Seismic Safety Commission Recommends all Hospitals Comply with Regulations
- The 1994 Hospital Seismic Safety Act Requires Upgrades of Existing Hospitals

In a survey of hospitals conducted in 1990, only about one third of the buildings and one quarter of the total hospital building area was expected to survive a significant earthquake. In the 1994 Northridge earthquake 57% of the Pre-Act buildings were red and yellow tagged, and 61% had major nonstructural damage. This data indicates that more effort was needed in the regulation of hospitals.

The 1994 Hospital Safety Act required that Building evaluations and compliance plans be submitted to the State Offices (OSHPD) by January 1, 2001. The law stated that hospital buildings with a high risk of collapse cannot be used for acute care purposes after January 1, 2008, and specified that these buildings must be retrofit (to a “life safe” performance), demolished, or abandoned for acute care use by that date. In addition, high risk nonstructural systems were to be mitigated in accordance with priorities and timelines to be set in regulation by OSHPD, in consultation with the Hospital Building Safety Board. All facilities were to be in substantial compliance the intent of the act by January 1, 2030.

The key issues in the 1994 Hospital Act were that a) performance categories were defined for both structural and nonstructural components; and b) the performance categories become public knowledge.

Table 1. ATC Survey of Hospitals in 1990 (Holmes 2002).

Survivability Index Classification	**Number of Buildings (%)**	**Building Area (%) ft^2/1000 m^2/10,763**	**Number of Beds (%)**
A	854 (32%)	21,644 (24%)	14,875 (16%)
B	7 (<1%)	102 (<1%)	11 (<1%)
C	1,244 (47%)	50,306 (54%)	52,459 (58%)
D	297 (11%)	12,687 (14%)	15,549 (58%)
E	125 (5%)	4,997 (5%)	5,809 (2%)
F	146 (5%)	2,662 (3%)	2,115 (2%)
Total	2,673 (100%)	92,398 (100%)	91,050 (100%)

Table 2. Performance of Hospitals in the Northridge Earthquake by the California Seismic Safety Commission (Holmes 2002).

Performance of all Buildings at 23 Hospital Sites with One or More Yellow or Red Tagged Buildings		
Type of Damage	Number (%) of Buildings	
	Pre Act	Post Act
Structural Damage		
Red tagged	12 (24%)	0 (0%)
Yellow tagged	17 (33%)	1 (3%)
Green tagged	22 (43%)	30 (97%)
Nonstructural Damage		
Major	31 (61%)	7 (23%)
Minor	20 (39%)	24 (77%)
Total Buildings	51	31

Key Issues in Regulation of Hospitals

The key issues in the regulation of hospitals include 1) the performance categories defined for structural and nonstructural components, and 2) the fact that the performance categories became public knowledge. There were 2,467 Buildings under regulation with only approximately 1,000 in compliance in1991. The 2008 deadline has passed but the state has given many institutions extensions due to the critical economic conditions in the state. For example, many hospitals were given 5 year extensions (to 2013) for economic hardship and community impacts. Hospitals which submitted completed drawings for new replacement buildings were given extensions until 2015. Others in areas of low-seismicity, or those who could demonstrate extremely low probability of collapse were given extensions to 2030.

As Holmes (2002) concluded in his paper: "The current California Hospital Seismic Safety Program evolved over thirty years due to careful planning by advocates of seismic safety in California and the occurrence of several damaging earthquakes. Adjustments to the law itself as well as the implementation regulations have been needed from time to time…. However, there is no question that the program has significantly improved the seismic performance of the overall acute care medical system in California."

Standards and Regulations needed to implement the law shall be adopted by June 30, 1996 including:

Definition of structural vulnerabilities and evaluation standards

Definition of nonstructural vulnerabilities and evaluation standards

Standards for retrofit

Building evaluations and facility compliance plans shall be submitted to OSHPD by January 1, 2001;Facility owners, 60 days after approval by OSHPD, shall:

Submit building performance categories to local emergency service agencies

Use the performance information to improve emergency training, response and recovery plans;

Hospital buildings with a high risk of collapse cannot be used for acute care purposes after January 1, 2008. These buildings must be retrofit (to a "life safe" performance), demolished, or abandoned for acute care use by that date;

High risk nonstructural systems (Pre and Post Act) shall be mitigated in accordance with priorities and timelines to be set in regulation by OSHPD, in consultation with the Hospital Building Safety Board;

All facilities shall be in substantial compliance the intent of the HSSA by January 1, 2030.

Figure 1. Summary of the 1994 California Hospital Regulations.

Conclusions

Downtime is an important component of loss modeling. In addition, it has been defined as one of the three decision variables in performance-based engineering assessment to represent structural design alternatives in economic terms. Downtime estimates are meaningful to individual, corporate, or institutional owners that depend on specific physical space for operations. Downtime estimates are equally important for insurance analysts and loss modelers to calculate the economic impacts of natural and man-made disasters.

Modeling downtime requires a formula that combines three critical elements: 1) The first component of downtime is an estimate of construction repair time for individual facilities damaged (and rendered uninhabitable) by a disaster. 2) The second component of downtime is an estimate of the mobilization time needed for various building stocks, such as housing, office space, universities, etc. with a significant proportion of buildings closed. This should include a probabilistic estimate of non-damaged related closures. The third component of downtime is a representation of the economic conditions in the region at the time of the event. This will provide the sensitivity needed to increase or delay the rate of recovery based on economic conditions. The economic adjustment factor will vary by market sector and will need to be adjusted to represent conditions in each of the impacted sectors.

As will all loss modeling, much greater detail is needed for any building or hospital specific estimate. However in all cases, data on a building's structural performance is linked to data on operational and economic conditions to estimate the time needed for repair or recovery of functions after a disaster. Downtime is conditional on the scale of damage in an individual structure, as well as the scale of damage in a stock of buildings in the affected region, as well as the economic conditions particular to the building function as well as the general state of the economy in the region. To accurately assess vulnerability for any building type such as hospitals, all of these components need to be included.

In California, the authorities have taken hospital safety into consideration for more than 30 years and the current efforts to upgrade hospital facilities throughout the state are a prime example of downtime-avoidance, and a recognition of the importance of these facilities to society.

Acknowledgments

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