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HOSPITAL CRITICAL NONSTRUCTURAL SYSTEMS, DEPARTMENTS AND EQUIPMENT DURING AND FOLLOWING MAJOR SEISMIC EVENTS

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Abstract

Hospitals and other critical care facilities play a critical role in provision of emergency and other health services following a major disaster. Earthquakes are among the most unpredictable of natural disasters, and higher magnitude events in urban areas have the potential for significant injury and damage to persons and facilities. Recent earthquakes have revealed that nonstructural failures are emerging as a critical factor limiting the continued functionality of hospitals and critical care facilities at the time their services are most needed.

In an effort to assess the vulnerability of hospitals and critical care facilities to reduced functionality due to nonstructural failures, a series of research inquiries sought information from engineering and medical personnel. This research also identified which nonstructural systems were critical to support the functioning of the critical hospital departments and medical equipment over the life cycle of a major seismic event. This paper reports the results of survey research and in-person, in-depth interviews with doctors, nurses, leaders of major hospital departments and facility engineers who were on-site during or shortly after major seismic events in Los Angeles, Seattle, Taiwan, and Turkey to identify the major causes of reduced functionality due to nonstructural failures and damage to equipment and medical supplies.

Introduction

Recent earthquakes in Japan, Taiwan, Turkey and the United States have focused attention on the role and function of hospitals during and following major seismic events. In the 1971 San Fernando Earthquake, 85 percent of the fatalities occurred in hospitals and Steinbrugge et al. (1980) estimate that in a large-scale earthquake in the San Francisco region, approximately one-third of the deaths would occur in hospitals. While improved building codes and increased code enforcement have reduced the susceptibility of the structures to catastrophic failures, similar improvements in the performance of nonstructural systems have not been realized. Failures of

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structural and nonstructural components continue to cause the deaths of patients and staff (USC, 2000).

FEMA notes that the functionality of a hospital is highly dependent on the functioning of most of its nonstructural elements and many of these are highly susceptible to damage in even a fairly mild earthquake (FEMA, 1989). In 1983 the Coalinga Earthquake's, (6.7 magnitude on the Richter Scale) damaged the district hospital's X-ray equipment, computers, laboratory analyzers, emergency radio equipment and emergency generators (Tierney, 1983). The Loma Prieta Earthquake caused little structural damage but had a significant impact on the nonstructural components. Elevators suffered significant damage, communication systems failed, patient records were spilled, laboratory equipment was damaged and laboratory chemicals fell and pharmaceuticals were strewn all over the floor (California Seismic Safety Commission, 1991).

While life safety remains the primary focus of seismic design, recent experience suggests that the damage to nonstructural systems and the building contents is an important and as yet unresolved concern. Indeed, experience from other earthquakes suggests that nonstructural damage is a major factor affecting the functionality of hospitals and other health care buildings (Seismic Safety Commission, 1984). They indicated that damage to these elements can disable an otherwise structurally sound building while posing risk to those who are in the building at that time. Experience with the 1994 Northridge earthquake revealed that failure of backup emergency power was a factor in one patient's death and other nonstructural failures, notably damage to sprinklers, domestic water and chiller lines, led the evacuation of over nine hundred patients (Seismic Safety Commission, 1994). While Olive View Hospital, which was severely damaged in the 1971 San Fernando Earthquake and rebuilt to revised earthquake standards experienced minimal structural damage in the 1994 Northridge Earthquake, 377 patients were evacuated because of nonstructural failures.

Critical Hospital Systems

In a severe earthquake, acute care hospitals and facilities must remain functional to respond to the needs for medical attention and critical care. To do so, not only must the building structures remain safe for continued occupancy, but their nonstructural systems must remain functional as well. While improvements in the structural performance of hospitals have been made in recent years, similar steps to improve the nonstructural systems remain elusive. A major factor noted by FEMA (1989) is the lack of consensus on which items are essential to the continuing functioning of hospitals. Following the 1971 San Fernando Earthquake the Veterans Administration identified nine areas that were either high hazard or high priority functional concerns (Stone Marraccini and Patterson, 1976). In a systematic examination of two case study facilities McGavin and his associates (1986) examined over 160 hospital equipment items deemed representative of a community-based medical center. From these 15 were identified a life support equipment. Still opinions continue to differ as to which systems or components are critical or essential in maintaining the functionality of hospitals and critical care units (FEMA, 1989).

Methods

In order to evaluate the vulnerability of nonstructural components and to assess their importance to the continued functioning of hospitals, researchers from the schools of engineering, medical and health management sought to identify which nonstructural systems were critical in maintaining the functioning of a hospital during and following a major earthquake. A review of policy studies, research and engineering reports that examined damage to the nonstructural components of hospitals and critical health care facilities caused by earthquakes in the United States was conducted. Most of the recent published findings concentrated on the San Fernando (1971), the Loma Prieta (1989) and Northridge (1994) earthquakes. These findings, particularly the analyses

of the Northridge event, were used to identify nonstructural systems that may be critical to the functioning of hospitals following a major earthquake. The systems identified in these studies were presented to two panels of experts with experience in hospital design and construction. They were asked to indicate, using a survey instrument, which systems were critical to ensuring the continued functioning of a hospital following a major seismic event (USC 2000). To provide a medical perspective, two group interviews with nurses, doctors and administrative personnel at two major public hospitals evacuated due to nonstructural failures were also conducted.

Information from these interviews were used to construct a five part survey questionnaire to identify the types of problems hospitals faced during and following an earthquake and to indicate the impact of these on the ability of the hospitals to remain functional following that event. The first three parts of the questionnaire were designed to be completed by the hospital's disaster coordinator, safety officer or facilities director. The fourth and fifth parts of the questionnaire were to be completed by department heads of major hospital departments. The questionnaire was pretested using a sample of hospitals which were not proximate to the epicenter. As a result of the pretest several questions were rewritten, several dropped or were modified to allow for comments or clarifying information.

A sample of hospitals proximate to the epicenter of the Northridge Earthquake was identified and asked for their assistance in the completion of the survey instrument. After reviewing the questionnaire those hospitals felt they would not be able to complete the survey either because the key people were no longer at that facility, they felt that the survey would take more time than they could provide, or a general reluctance to participate in another survey of the earthquake and the subsequent damage. However, some of the hospitals were willing to assist us and agreed to arrange for in-depth interviews with staff who were at the facility at the time of the earthquake. Two of these facilities had suffered significant nonstructural damage leading to the evacuation of patient care areas, two suffered some structural damage and nonstructural damage and three sustained mainly nonstructural damage to their patient care units. Those interviewed included administrative, medical, nursing personnel for key patient care departments as well as leaders from diagnostic and support departments.

While these interviews were underway, a major earthquake struck Turkey (August 17, 1999). Shortly thereafter, 10 public hospitals from the provinces of Kocaeli, Sakarya, Bolu and Yalova were contacted by USC-affiliated research associates to see if they would participate in our research study. The researchers explained the purpose of the research and they agreed to complete the five part survey questionnaire examining the extent of damage or loss they experienced, the impact of this damage on the operation of the hospital and their assessments of the importance of different medical systems to the functioning of the hospital during and following the earthquake. Following the second Duzce Earthquake on November 19, the USC-Affiliated research team contacted hospitals in the Bolu province and obtained additional survey information from 6 more hospitals.

At the same time the Turkish surveys were underway, a magnitude 7.6 earthquake struck central Taiwan. Colleagues at the Nongovernmental Hospital Association were contacted to see if they could assist in surveying a sample of the hospitals damaged by the earthquake. With their assistance 10 hospitals, representing a mix of small and large public and private facilities, agreed to complete our survey questionnaire. Instead of using interviewers to complete the survey, as was done in Turkey, participants were mailed a copy of the survey, which had been translated into Chinese. All completed and returned the survey to our associates in Taiwan. These data were augmented by two visits to the surveyed hospitals in Taiwan to collect additional in depth information about from medical, nursing and administrative personnel in the most severely damaged of the hospitals in Taiwan. These interviews, paralleling those completed in the United

States, were conducted in Chinese by medical, management and engineering researchers from the National University of Taiwan and the United States.

The final set of interviews occurred following the Nisqually Earthquake in the state of Washington (2000). Three hospitals, one proximate to the epicenter and two in Seattle were contacted and agreed to participate in the study. As with the previous interviews, physicians, nurses, clinical staffs from the laboratory, radiology, pharmacy, and dietary departments, along with personnel from support units such as central supplies, plant and maintenance, engineering and biomedical engineering participated in the study.

Findings

Overall, more than two hundred personnel, 131 from medical care departments and 84 administrative and support departments contributed information about critical nonstructural systems, departments and equipment (Table 1). Fifty-four worked in academic medical centers, 111 were from major medical centers and 50 were from community hospitals.

Interview and survey information were used to identify critical nonstructural systems. As the information in Table 2 indicates, power followed by water and communication was most frequently mentioned as critical to their functioning. While damage to piping has been a source of diminished functionality of hospitals, the need for electrical service to support patient care equipment, diagnostic and treatment functions is clearly apparent.

Table 1: Title and Hospital Affiliation of In depth Interview Participants

Type of Facility	Physician	Nurse	Other Medical	Administration	Engineering	Other Non-Medical
Academic Medical Centers	17	15	4	3	5	10
Major Medical Centers	13	29	23	10	21	15
Community Hospitals	5	13	12	4	9	7
TOTAL	35	57	39	17	35	32

Changes in medical treatment and the role of technology in the treatment and care of patients has increased the use of monitors, ventilators and other critical life support items. These responses seem to reflect these changes.

Table 2: Critical Life Line Systems

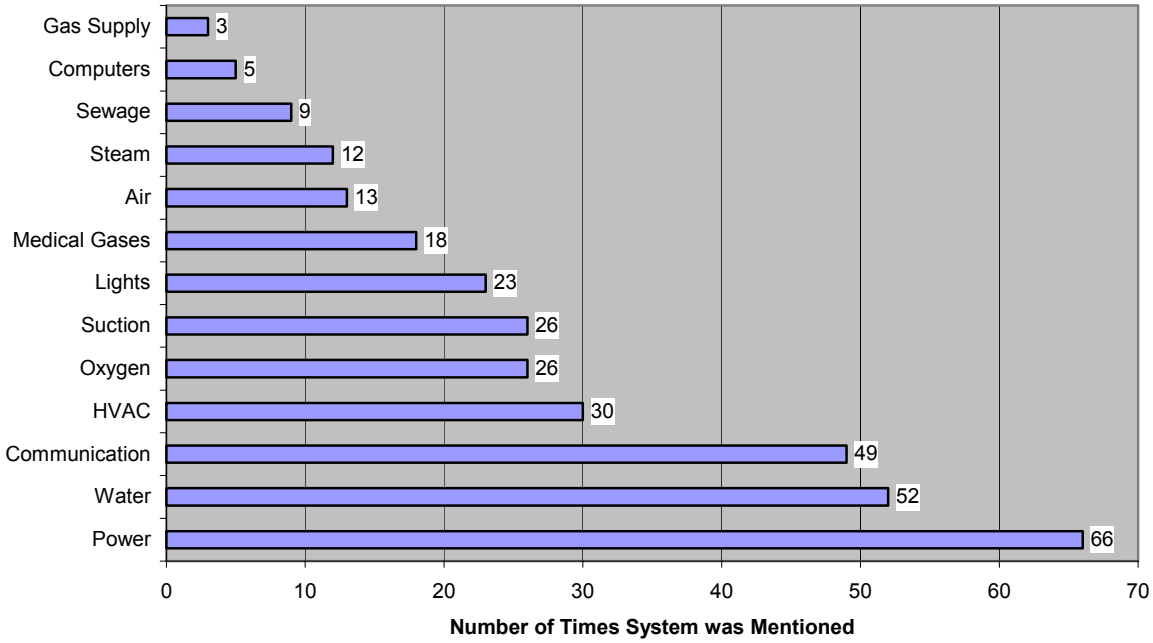


Table 3 lists the critical equipment identified by medical and non medical personnel. Unlike the responses for critical lifeline systems, there is a considerable range and variation in the equipment items identified as critical. These variations reflect the differences in the role and the need for life support equipment in the various clinical and patient care areas. Monitors (22) and ventilators (22) were the most frequently mentioned items and are also among the most frequently used life support items. X-ray (17), defibrillators (16) and anesthesia machines (13) were the next frequently mentioned items, followed by sterilizing equipment (13), refrigerators (11) and computers (11). Interestingly these items were infrequently mentioned as being damaged in the earthquakes we studied.

Respondents also mentioned a number of departments that were critical to their functioning (Table 4). Eight appear to make up the critical core of the hospitals we studied. Interesting, pharmacy was mentioned most frequently by the respondents. Pharmacies are critical to the functioning of most patient care activities including nursing units, surgical and treatment areas and many diagnostic services. Laboratory (23), radiology (23), the emergency room (22), ICU (22), operating rooms (21), central supply (17) and nursing care units (16) appear to be part of this critical patient treatment core.

A final element of this research was to determine whether there were differences in the importance of certain medical systems at different points of time following and earthquake.

Table 3: Critical Life Support Equipment

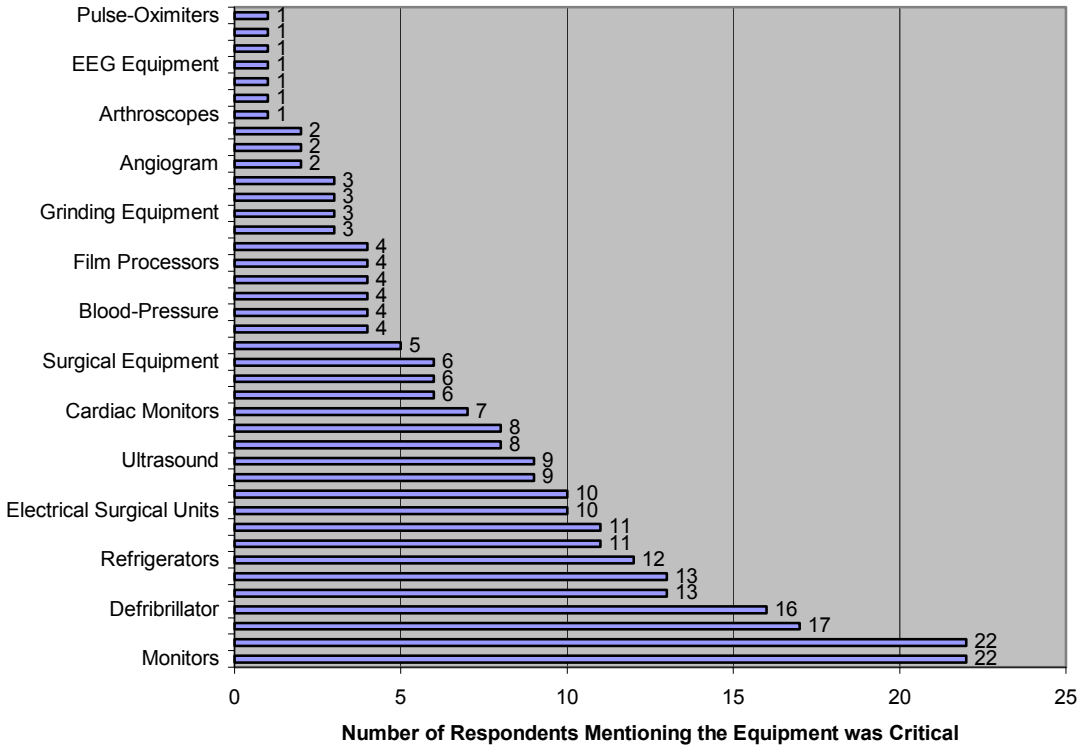
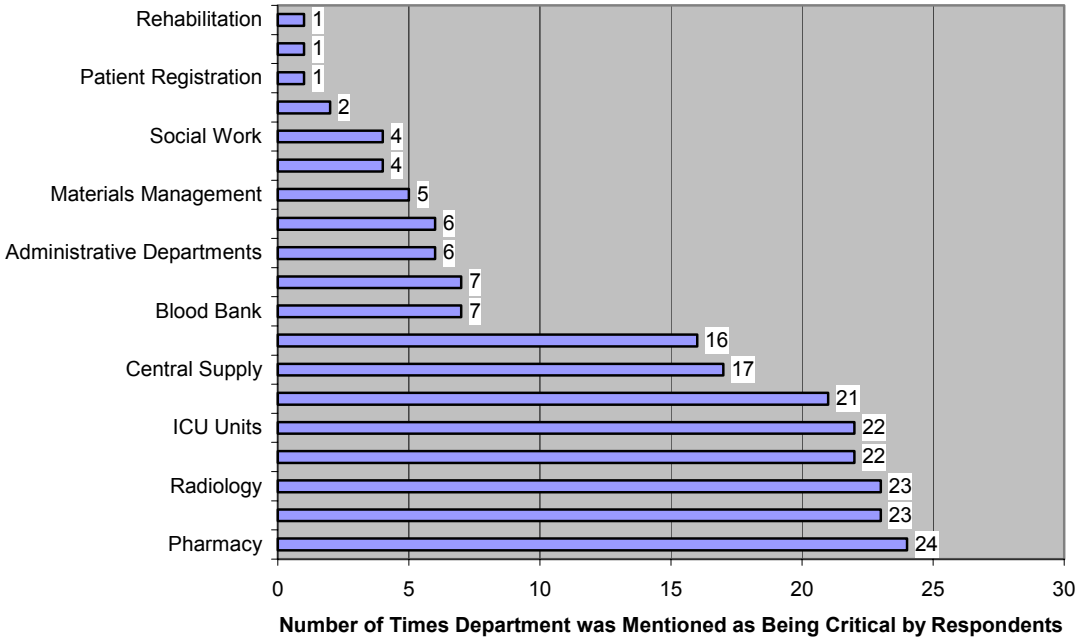


Table 4: Critical Hospital Departments



As Table 5 indicates, there is significant variation in the importance of different hospital departments at different phases of an earthquake. Immediately following an earthquake four departments were identified as essential[3] to the functioning of the hospital. These results support the interview finding which also identified pharmacy as the most important department. Further, it was the only department that these respondents indicated was essential for the functioning of the hospital at any point of time following an earthquake. Nursing care units' functionality was nearly as important at pharmacy.

Five departments—ICU/CCU, blood bank, nursing care, pharmacy and communications systems were identified as being essential to the functioning of a hospital immediately following an earthquake. During the stabilization period, two departments were mentioned by all respondents as being essential to the functioning of a hospital during the stabilization phase following an earthquake. During the cleanup and recovery phases, nursing care and pharmacy departments were mentioned by all respondents as being essential to the functioning of the hospital. These same departments also were identified as essential during the transition to normal operations.

Table 5: The Importance of Departments at Different Points of Time Following an Earthquake

Systems	Immediately Following the Earthquake	During Stabilization	During Recovery & Cleanup	Transition to Normal Operation
Medical Systems				
Emergency Room	1.10	**1.00**	1.10	1.10
Operating Room	1.11	1.11	1.11	1.11
Recovery Room	1.33	1.33	1.33	1.22
ICU/CCU	**1.00**	1.14	1.25	1.14
NICU	1.40	1.50	1.43	1.33
Blood Bank	**1.00**	1.22	1.44	1.33
Diagnostic Systems				
Laboratory	1.80	1.70	1.30	1.20
Radiology	1.60	1.50	1.20	1.10
Imaging (MRI/CT Scan)	1.67	1.56	1.56	1.44
Patient Support Systems				
Nursing Care	**1.00**	1.10	**1.00**	**1.00**
Central Supply	1.30	1.10	1.10	1.10
Pharmacy	**1.00**	**1.00**	**1.00**	**1.00**
Housekeeping	2.00	1.60	1.30	1.30
Medical Records	1.50	1.30	1.10	1.10
Laundry	2.38	2.11	1.67	1.44
Dietary	1.75	1.78	1.56	1.33

[3] 1=Essential to the functioning of the hospital at this point following the seismic event, 2=important but not essential to the functioning of the hospital at this point following the seismic event, 3=useful but not important to the functioning of the hospital at this point following the seismic event, 4=not needed at this point following a seismic event.

Overhead Services				
Data Processing	1.78	1.67	1.44	1.22
Maintenance	1.67	1.44	1.33	1.44
Purchasing	1.38	1.56	1.22	1.11
Business Office	1.56	1.44	1.33	1.33
Security	1.33	1.44	1.44	1.44
Biomedical Engineering	1.75	1.75	1.75	1.75
Communication Systems	**1.00**	1.11	1.11	1.11

Other departments identified as being almost as important to the functioning of a hospital during the different phases of an earthquake include the trauma department, operating rooms, central supply, and communications systems. All in all, nine departments—trauma, operating room, ICU/CCU, central supply, nursing care, pharmacy, medical records and communications were seen as improbable to the functioning of a hospital throughout the earthquake event. Combining the results from the interviews and hospital surveys, six medical care areas (pharmacy, nursing care units, central supply, operating room, ICU/CCU and emergency room) emerge as the core areas essential to the functioning of hospitals.

Conclusions:

While the research literature may not agree on which systems and components are critical or essential in maintaining the functionality of the hospital this study of 40 hospitals in three countries suggests that if the hospitals remain structurally sound in the core patient care and support areas (trauma, operating room, ICU/CCU, central supply, nursing care, and pharmacy) and are provided with a communications capacity, have electrical services, water and are able to dispose of waste products they may well be able to meet their patient care obligations following a major earthquake. All of this assumes that sprinklers systems and water lines do not have significant damage, that staff members are able to report for duty or remain on the premises, that patients are able to access the facility and that needed supplies and other consumables are able to be replenished. At the same time, it is important to recognize the adaptive capacity and inventive abilities of the staffs of health care facilities to respond to structural and nonstructural elements. Even when parts of hospitals suffered catastrophic structural failures or experienced major damage to sprinklers or water systems, or the significant interruption in the electrical and communication systems, services were provided and patients were treated.

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