APPLICATION OF EARTHQUAKE ENGINEERING INFORMATION IN HOSPITAL EMERGENCY RESPONSE AND RECOVERY

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1. THE NEED FOR AN ENLARGED ENGINEERING ROLE IN HOSPITAL EMERGENCY RESPONSE AND RECOVERY

It is obvious that engineers are needed to engineer the construction of hospital buildings. It is less obvious that they are also needed if a hospital is to effectively respond to and recover from an earthquake, because the response and recovery roles in hospital disaster planning are typically considered the province of medical personnel, hospital administrators, and government planners. The use of engineering in hazard reduction efforts, that is, implementing measures to prevent damage by retrofitting structural and nonstructural components or designing new buildings to high standards, is a major subject in its own right. That topic, which is the dealt with by several of the other papers in this volume, is outside the scope of this paper and is discussed here only in passing.

2. INTERNAL AND EXTERNAL DISASTERS

In the United States, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) directs hospitals to consider two kinds of disasters. An Internal Disaster affects the hospital facility itself, such as a fire or hazardous materials release within a hospital building. An External Disaster, such as a transportation accident nearby that brings numerous injured patients to the hospital for care, does not affect the hospital facility directly but imposes a sudden demand for emergency services. An earthquake is one of the rare kinds of disaster that is simultaneously an internal and external disaster: "Emergency plans for earthquakes must take into account the fact that the same shaking that just inflicted an internal disaster on your facility also caused an external disaster in your community or region." (Reitherman, 1989, p. 15-1). The kinds of damage and disruption that occur externally or internally are difficult to understand or control unless engineering expertise is employed. This is especially true with regard to damage within the facility.

3. EXAMPLES FROM CALIFORNIA EARTHQUAKES

Examples of the range of effects on hospitals, and how those effects could have been minimized if engineering had been more strategically employed, can be drawn from recent California earthquakes.

3.1 1971 San Fernando Earthquake

Of the 58 fatalities caused by building damage, 50 occurred in hospitals. The worst damage to medical facilities occurred at the Veterans Administration Hospital in Sylmar where two large buildings collapsed. Even though the hospital site was right on the edge of the heavily urbanized San Fernando Valley, it took one hour and 22 minutes before a fire department helicopter happened to spot the collapses and send help. (Reitherman, 1986, p. 119) The reason for such a delay? The phones didn't work, the hospital's radio was in one of the collapsed buildings, and the first message orally delivered by a hospital staff member to a nearby government facility was mistaken with an already received report of damage to a different nearby hospital. Knowing in advance that telephone service is likely to be disrupted, and that even radio systems are not invulnerable, a hospital can put more attention into devising reliable alternative means of reporting major problems at their site and verifying that the message was properly received.

3.2 1987 Whittier Earthquake

"Over-reporting" as well as under-reporting of damage can occur. In this earthquake, the news media reported that the "roof had collapsed" at one skilled nursing facility, whereas actually only some suspended ceiling tiles had fallen. At the fourth floor of a hospital, the staff reported a "crack" several inches wide in the concrete floor—certainly a crack of catastrophic structural proportions if that report had proved accurate. As this report by the staff was triggering the initial phase of evacuation, it was quickly determined by engineers that this "crack" was a seismic separation joint between two wings. A little bit of engineering deflated the report of a dangerous crack in the floor system down to minor architectural cover plate distress across a seismic joint.

3.3 1989 Loma Prieta Earthquake

As happened in 1971, the hospital that was most badly damaged in this earthquake, Watsonville Community Hospital, did not efficiently convey a message for assistance. Its plight—structural damage that led to the building being demolished, lack of utility services, nonstructural debris throughout, and evacuation of the staff and patients to the parking lot—was quite significant enough to merit extensive outside aid, and yet such aid was delayed. Anticipating communications outages, an individual hospital can adequately plan for back-up means of communication and double check to make sure that requests for help are registered.

3.4 1994 Northridge Earthquake

Olive View Medical Center evacuated 377 patients, primarily because of water damage and water and power outage. (This was a 1980's building built to replace the Olive View Hospital severely damaged in the 1971 earthquake). At the Sepulveda Veterans Administration Hospital, broken water pipes spewed water into the building for several hours, even after the staff and patients had evacuated: Procedures to have the building operations and maintenance staff turn off the water would have greatly reduced damage. This requires some structural engineering insight into the probable performance of a facility. Sprinkler lines broke at 20 health care facilities, and non sprinkler piping broke at 29 facilities, so this kind of damage is not rare. (Murray, 1994) Some of these facilities, such as Olive View Hospital or the Sepulveda VA hospital, experienced very strong shaking with peak ground acceleration near 1 g, but many hospitals with significant nonstructural damage were in locales where the acceleration was half or less that level. Even some newly constructed hospitals in California that met the standards of the California Hospital Seismic Safety Act (for example, Olive View Medical Center) experienced piping leaks in the Northridge Earthquake, so hospitals should not assume that earthquake-resistant construction means zero chance of damage. Effective response requires engineering of a facilities and fire protection type to be able to plan how to operate the proper valves if significant leaks materialize. Turning a fire sprinkler system off is a serious matter that compromises fire safety, so it must be done judiciously.

Following the Northridge Earthquake, one recommendation made was to require hospitals to “develop earthquake disaster plans that account for realistic scenarios of the post-earthquake condition of their specific buildings, and the availability and reliability of water, power, communication, and other services.” (California Seismic Safety Commission, 1994, p. 187). In California, the hospital earthquake disaster exercises the author has observed have rarely realistically accounted for effects such as elevator and electrical outage, possible structural damage and the need for immediate engineering evaluation, or water leakage, and yet from an engineering standpoint, these potential impacts are quite plausible given strong ground motion. The combined approach—using hazard reduction techniques to try to prevent damage, but also using emergency response planning to foresee how to control the damage that may occur—is far superior to relying on only one approach.

4. EMERGENCY RESPONSE

The emergency response phase of an earthquake can last varying amounts of time, but it is often defined as the first three days after the earthquake. As a practical matter, most of the significant response typically occurs within the first 24 hours, and the first hour is the most important. Beginning right after the shaking stops, decisions made in the response phase also have an effect on longer-term recovery. For example, if a hospital closes certain functions, and doctors and patients temporarily use other facilities nearby, those physicians and patients may end up permanently aligned with the facilities they thought they were just temporarily using.

4.1 Emergency Response to External Effects

An individual hospital does not control its surrounding utility infrastructure or the roads in its city, it does not run the telephone system of the region, and it is not responsible for coordinating the emergency response activities of agencies such as national disaster management bureaus or local fire departments. Nevertheless, an individual hospital should take these external factors into account in its emergency response planning, and engineering advice can be of help in this effort. Table 1 lists the major kinds of external impacts of an earthquake on a hospital, and for each, there are useful planning techniques indicated.

Table 1: Range of External Impacts and Associated Emergency Planning Measures

Potential External Impact in the Region	Useful Emergency Response Techniques
Telephone Outage: Very likely, even without system damage, because of overload of calls. Telephone central exchange offices with racks of equipment are vulnerable unless equipment is seismically anchored. Cellular phones are radio-based only for a small portion of the call route, but may in some cases work more reliably.	Conduct earthquake drill without use of telephone messengers needed to deliver news or requests t outside agencies; radio system must be earthquake protected to be a true back-up system. Automat procedures for off-duty staff needed in absence o telephone communication between residences an the hospital.
Electrical Outage: Extremely likely even in regions where the power system has benefitted from seismic engineering; restoration times, however, are generally short (hours to days).	Restraint essential, but even so, less than 100% of hospital is so served; facility operators will need t operate generators for extended periods of time, ne just as in brief tests.
Water Outage: Heavy damage if ground failure (e.g., liquefaction, settlement, slides) occurs;	Emergency water conservation plan should b developed in advance.

restoration times can extend to weeks or months.	
Sewage: Similar to water damage, with breakage of underground lines related to soft soils and ground failures; long repair times.	Back-up plan required. Location of sewer lines nea water lines increases the vulnerability of the wat system if sewer line breakage occurs.
Automobile Transportation: Bridge damage can affect large segments of a transportation route; landslides or liquefaction are the chief causes of damage to surface roads; electrical outages cause traffic jams when traffic signals do not operate.	Nearest routes onto the hospital site should b surveyed for closure hazards, such as overhea electrical lines. Alternate routes for ambulance should be planned.
Natural Gas: Underground lines can be damaged by soil deformation as for water and sewer lines.	Emergency procedures needed if the heating syste does not function due to fuel outage.
Radio: Seemingly invincible to earthquakes, but equipment is subject to damage as are back-up power generators; overload of usage of emergency channels also common after earthquakes.	Anchorage of all radio components neede including towers or antennas on roof, and back-u power supply. However, difficulty in radi communication should still be anticipated.

The context for making valid assumptions about the kinds of external effects that will materialize should be taken from regional scale loss estimation studies. These approximate forecasts of the damage that would occur in future hypothetical earthquakes are commonly produced in seismic regions by national emergency management agencies. In the USA, the earliest of these studies, beginning with Algermissen et al. (1972), were primarily aimed at providing approximate estimates of the medical demand (number of seriously injured people in the region) as compared to medical supply (the capacity of hospitals to provide post-earthquake services, taking into account the damage they would suffer). In the current national standard for earthquake loss estimation in the USA, the HAZUS software published by the Federal Emergency Management Agency (NIBS, 1999), forecasts of casualties remains a central concern. The algorithms in that method result in most of the predicted serious casualties and the fatalities resulting from structural collapse, while many more injuries of a lighter level would result from nonstructural damage and a "background level" of slight injuries from causes such as falling or getting cut after an earthquake by exiting a building containing broken glass and other debris. An individual hospital cannot conduct a regional scale loss estimation study on its own, but if recent and thorough studies have not been produced in the hospital's area, it is appropriate for the hospital to voice a request that such applied research be done.

4.2 Emergency Response to Internal Effects

The need for engineering advice becomes most evident in connection with planning and carrying out emergency response actions to cope with damage and disruption within the facility.

The most serious potential impact is severe structural damage. The best means of deciding the significance of this damage is to quickly obtain the structural engineering services of a qualified professional. This plan should be in place prior to the earthquake. The engineer should pre-tour the facility, and a set of structural drawings ("blueprints") should be available. Interim plans for having hospital facility engineers spot particular warning indicators before a structural engineer can arrive should be listed for each specific building. For example, a building may have an entrance canopy that might exhibit dangerous cracking that could quickly be dealt with by using an alternate entrance. The hospital should have a discussion in advance with the government agency or agencies that are responsible for carrying out building inspections after earthquakes. If the decision is made to evacuate a building or a portion thereof, it will suddenly become an emergency response task overriding almost all others, and such a decision cannot be made lightly. On the other hand, because almost all earthquakes are followed by aftershocks (except for earthquakes with deep foci in some areas of the world where subduction zones exist), it is important to conservatively evaluate a building's post-earthquake state. As an approximate rule, an earthquake one magnitude unit smaller than the main shock can be expected with a reasonable probability within a few days after the main shock. Sometimes an aftershock of this size does not materialize, while on the other hand, there may be a following earthquake that is the same size or even larger than the initial earthquake.

Of the various kinds of nonstructural damage, water pipe breakage is one of the most disruptive. The hazard reduction or damage prevention approach is to brace the piping and include allowance for relative movement at the necessary locations, such as across seismic joints. In combination with that approach, the emergency planning technique should be used: Train the facility staff to operate valves to compartmentalize leaks as much as possible. A hospital's water system, including fire sprinklers, may be very complex, and advance training and clear diagrams of the zones of the system are needed. Quickly compiling and making sense of this information on the water system layout in the chaotic post-earthquake environment may be impossible.

To quickly tabulate the damage that has occurred in a hospital, pre-printed forms should be tailored to each hospital. Different wings of a building, or different buildings on a site, should be itemized. The precise source of the report of damage and the time of the report should be included. The generic column headings that can be particularized to produce a damage reporting form for a given hospital can be adapted from this list (Reitherman, 1986):

Structural damage
Nonstructural damage - general contents and equipment
Nonstructural damage - ceilings and overhead components
Nonstructural damage - elevators
Water system
Electrical system – including back-up power
Heating-ventilating-air conditioning system
Sewage
Telephone; radio
Natural Gas
Hazardous materials
Fires
Injuries to staff, patients
Number of beds in service, or other measures of serviceability

5. THE RECOVERY PHASE

The response and recovery phases tend to overlap rather than be clearly defined. Response actions tend to be aimed at containing the problems that have just arisen, while recovery aims at fully restoring the facility's function. The key use of engineering in the recovery phase is to conduct more detailed evaluations of the state of the facility and determine the need for repairs. In the USA, because most hospitals are covered by federal disaster assistance provisions, this is partly a detailed bookkeeping task that hospitals undertake to try to maximize their disaster payments. In the first hours after an earthquake, it may only be necessary to know that partitions are "cracked but stable." The pertinent desiderata in the recovery context include other questions, however, such as: Can the partition be repaired by patching and painting or is removal and replacement required, and what is the cost estimate for each? Should the partition be rebuilt as it was, or should it be upgraded? For example, should an unreinforced masonry partition be repaired or replaced in-kind, or should it be retrofitted or replaced with reinforced masonry to make it perform more safety in the next earthquake? Modernization of a hospital after an earthquake, as well as repair of earthquake damage, is almost always a goal of the hospital staff and administration, since hospitals last a long time and thus many are old and in need of renovation. Planning a facility renovation may seem like the last thing a hospital has time to do in the weeks following an earthquake, but that is the time when such plans must be made.

The recovery phase, unfortunately, may last a decade or more. Some of those years may be attributable to legal disputes and financial issues, while in any event, it is a multi-year process to make major repairs to a hospital, and probably five years or more to plan, design, obtain approvals and/or financing, and construct a new hospital building. In the current case of the USA, there is a great deal of instability in the healthcare industry. A hospital that was marginal in terms of its cost to operate as compared to its revenue or patient service level may end up a casualty of an earthquake—simply too expensive to repair or replace. Seismic safety is increasingly an issue of long-term viability for hospitals.

6. METHODS OF INCORPORATING ENGINEERING ADVICE

The available methods for incorporating engineering advice into a hospital's emergency response and recovery plans range from simple and inexpensive to more elaborate. An easy way to obtain some engineering insights is to include an engineer at a planning meeting where a disaster plan is being discussed. The engineer might be the design engineer of the facility or an engineer from a government agency. An engineer cannot casually provide precise predictions as to how a given facility will respond, but he or she may be able to comment on whether planning scenarios realistically include the kinds of structural and nonstructural damage that may occur. The discussion can extend to looking at a regional scale loss estimation study to extract the particular context of a given hospital—to see what kinds of road outages in the vicinity might be expected, for example. Returning to a point made in the opening of this paper, hazard reduction techniques such as structural retrofitting to prevent collapse are very important, and the discussion of potential vulnerabilities in the emergency response planning context may plant the seeds for such an engineering project. The techniques discussed here are not mutually exclusive. To the contrary, they tend to reinforce each other and form a more effective overall mixture of countermeasures than is the case when a hospital relies on a single line of defense.

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