HOSPITAL SEISMIC SAFETY PROGRAM AND STRONG MOTION INSTRUMENTATION

Chris Tokas and Roy Lobo

Office of Statewide Health Planning and Development
Sacramento, California

Abstract

The need for functioning hospitals after a major earthquake is obvious and rarely disputed. While emergency field hospitals, medical tents, and air-lifts to available facilities are often used to supplement for damaged hospitals, they will never provide a sufficient substitute. Only modern health care facilities, located within the damaged region and capable of functioning at full capacity can adequately provide the needed medical assistance.

The Health and Safety code requires insofar as practicable California hospital buildings to continue to provide services after a disaster and designed and constructed for forces generated by earthquake, gravity, and wind. While the expected operational performance of new hospital buildings can be estimated with a reasonable degree of accuracy, the performance of existing structural, non-structural and operational components are more difficult to ascertain. The degree of nonstructural damage or inherent structural damage can be difficult to ascertain immediately after a seismic event. Current seismic codes have come a long way since the start of seismic design. However there is a large inventory of the hospital buildings that predate modern seismic codes. Even hospital buildings designed with modern seismic codes have not been seriously tested in a large urban earthquake. With practical and monetary limits to laboratory testing, it makes sense to instrument hospital buildings to determine actual performance in an earthquake. There is also a need for use of the instrument recordings to provide automated damage indicators in these instrumented hospital buildings. Such instrumented damage indicators are required to supplement the traditional visual inspections immediately after a seismic event to make quick and reliable decision on whether to evacuate damaged buildings.

Hospital Seismic Safety Program

The 1972 Seismic Safety Act

The Hospital Seismic Safety Act (HSSA) as originally proposed called for the immediate strengthening or replacement of all hospital buildings that did not meet the modern standards. However, it was quickly realized that this was an economic impossibility. The proposed law was changed to apply only to new hospital buildings and existing hospital buildings undergoing substantial structural remodel or expansion and, therefore, all hospitals licensed at the time were "grandfathered" in – that is, they were not required to meet the new statewide standards. T he intent was to bring any building whose useful life was being extended by a modernization program up to the modern seismic standards. However, the rate of retrofitting or replacing pre-

73 hospital buildings was much too slow. The unexpected result was to maintain the existing facilities as they are and build new facilities as needed.

In Northridge Earthquake of January 1994, several of these older hospitals sustained significant damage. Hospitals built in accordance with the standards of the Seismic Safety Act resisted the Northridge earthquake with minimal structural damage, while several facilities built prior to the act experienced major structural damage and had to be evacuated. It must be noted that certain nonstructural components of the hospitals did incur damage, even in facilities built in accordance with the structural provisions of the Seismic Safety Act.

Table 1. Performance of all hospital buildings in the Northridge Earthquake at 23 hospital sites with one or more yellow or red tagged buildings**.**

	Number (%) of Buildings	
Type of Damage	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

The lessons from the Northridge Earthquake clearly showed that the majority of California's hospitals located in regions of highest seismicity do not comply with the new "functionality" standards and their expected performance during a major earthquake varies from moderate damage to complete collapse. The California Legislature clearly understood that a program was needed to require hospitals to improve the seismic resistance of their existing buildings in a phased and prioritized manner with the ultimate goal of full strengthening or replacement. The legislative response was Senate Bill (SB 1953), which required that all hospitals meet statewide seismic safety standards. SB 1953 Seismic Retrofit Program

SB 1953 was introduced on February 25, 1994. It was signed into law on September 21, 1994 and became effective on September 22, 1994. The bill was an amendment of the Hospital Seismic Safety Act (HSSA) of 1983.

The first step in the retrofit program was the seismic evaluation of individual buildings. The evaluation placed each building in a Structural Performance Category (SPC), and a Nonstructural Performance Category (NPC). There are five levels of each performance category. The combined SPC and NPC rating of a building constitutes its overall seismic performance category. Buildings assigned to the Seismic Performance Category 1 (SPC 1) were built before the 1973 standards were enacted and assumed to pose a significant risk of collapse and public danger.

The SPC's were based on a plan as expressed in the law. Buildings which represent a "potential risk of collapse or pose a significant loss of life" have been required to be closed, retrofitted, or removed from acute care use by January 1, 2008. There is a provision in the law which allows delays in compliance with the 2008 deadline. The provision says, "A delay in this deadline may be granted by the office upon a demonstration by the owner that compliance will result in a loss of health care capacity that may not be provided by other general acute care hospitals within a reasonable proximity". This was further defined in the California Administrative Code to be a maximum of five years thereby moving the compliance dead line to 2013. Almost all hospitals but 13 have applied and received this extension.

In the last few years several legislative mandates (due to economic pressures as well as other factors) amended the HSSA to allow for various extension paths to the January 1st 2013 seismic compliance deadline while leaving the compliance requirements for the full compliance date of 2030 unchanged.

Hospitals with buildings in the SPC 1 category (those in most danger of collapsing in an earthquake or other natural disaster) must be upgraded or removed from service by January 1, 2013, 2015, or 2020 – depending on the path they have chosen. The parameters and requirements for these paths are explicitly defined in the various legislatively amendments by SB 306, SB1661, SB 499, SB 608 and SB 90 made to the HSSA. There are a few variations for specific circumstances, but those dates are the significant extensions authorized by law.

The latest amendment is SB 90 which authorizes the Office of Statewide Health Planning and Development (OSHPD) to provide hospitals with an extension of up to seven years on an existing seismic safety deadline provided certain requirements are met. OSHPD would consider requests for extensions on a case by case basis based on the following criteria: (1) structural integrity of the building; (2) community access to care if the hospital building were to close; and (3) financial capacity of the hospital to complete the construction projection.

Early indications on SB 90 extension requests are that only about one third of the applicants are applying for the full seven year extension. The others extension requests vary from a couple of months to full seven years.

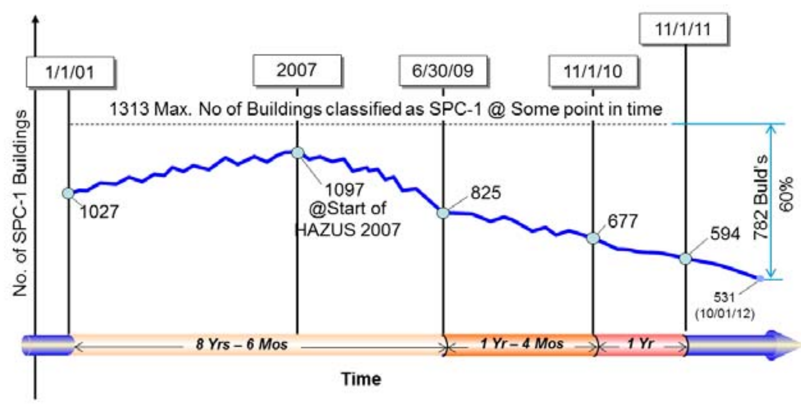

Figure 1 Rate of Removal of dangerous buildings (SPC-1) from the General Acute Care Hospital Building inventory.

That being said, hospitals are making progress. The numbers show that the program has come a long way. Thus, California hospitals indeed are safer today, but there is still work to do.

The final steps will occur between years 2013 and 2030. The law requires the buildings to be in substantial compliance with the Act by January 1, 2030 and all general acute care hospitals must be able to remain operational beyond that point in time.

During this 17 year period, retrofitting and new construction is expected to reach substantial compliance, that is, buildings housing patients will not collapse in a damaging seismic event and the systems serving critical care will continue to function in a design level earthquake.

Looking back at the first steps of the program as well as looking ahead at the approaching 2013 deadline it is imperative to point out how much progress has been achieved. While the critics may point out that not enough progress has been made, 60% of hospitals buildings rated as more dangerous have already been reclassified as SPC-2 or higher by retrofit or analysis. Some have been removed and many more will be added to that list by January 2013.

There are various paths to full operational compliance as the law allows for a “phased in” approach to meet the 2030 deadline while allowing interim deadlines. The seismic compliance regulations prior to 2007 required a full seismic evaluation of the buildings to be performed. This path appeared not to be achieving the desired results, and a new risk based approach had to be adopted.

Risk Based Seismic Evaluation of Pre 1973 Hospital Buildings Using the HAZUS Methodology.

The seismic evaluation of the existing hospital buildings yielded a surprisingly large number of buildings that required either retrofit or replacement and which constituted a large proportion of all acute care hospital buildings in California.

After careful evaluation of the SPC-1 hospital building inventory, it became obvious that all the SPC-1 buildings do not represent the same risk to life due to a major earthquake. Even though all hospital buildings were evaluated using the same regulatory requirements, the analysis varied highly with respect to sophistication and accuracy since the seismic evaluations were performed by different engineers across the state.

OSHPD, keenly aware of the cost of retrofitting, attempted to require only the absolute minimum and give as much flexibility as possible for compliance. It is important to point out that OSHPD has looked for ways to lessen the impact of the seismic retrofit program without jeopardizing safety. That has been achieved by constantly re-examining the program and realigning it by adopting policies to provide flexibility in its implementation, or by looking forward at the national level to adopt state of the art seismic retrofit standards.

In 2005, after careful evaluation through a variety of options, OSHPD selected the HAZUS earthquake loss estimation methodology as a tool to re-examine and assess the seismic risk for each SPC-1 hospital building. Utilizing the HAZUS methodology would rank the SPC-1 buildings based on their relative risk, thereby enabling the policy makers to implement *“Worst First” Compliance with the Hospital Seismic Safety Requirements.* The results of such a re-examination would allow hospitals to focus their resources appropriately on the “worst buildings first”.

The HAZUS methodology may be implemented using "default" engineering parameters that affect building performance. However, the default values were developed for "generic" model building types and they are not generally applicable to individual buildings. Furthermore, the HAZUS default damage functions are appropriate for fairly regular buildings, but tend to underestimate damage in buildings with "significant structural weaknesses". A significant structural weakness is an attribute that causes the building to perform significantly worse than average. While building-specific analysis are not feasible for assessing the seismic risk of each SPC-1 hospital building, it was recognized that more appropriate engineering parameters that affect building performance should be developed to better represent the types comprising the SPC-1 building inventory. OSHPD augmented the algorithms of the HAZUS default parameters, thus permitting the appropriate adjustment in order to account for significant structural weaknesses where they occur.

The HAZUS/AEBM methodology provided the California hospital seismic compliance program the tools needed to examine and assess the seismic risk of each building individually in order to identify buildings that most likely will experience a catastrophic failure in the event of an earthquake and thereby focus on available resources to retrofit such buildings first.

Currently 319 buildings have been reclassified as SPC-2 using the HAZUS 2007 regulations and 58 buildings have been reclassified to SPC-2 using the HAZUS 2010 regulations. There are still 531 SPC-1 buildings in our inventory that are either to be reclassified or can no longer provide acute care services.

The OSHPD Seismic Instrumentation Program for Hospital Buildings.

The California Strong Motion Instrumentation Program (CSMIP) was established following the 1971 San Fernando Earthquake to increase the limited set of data on strong earthquake shaking. The CSMIP authorities emanate from the Public Resources Code, Section 2700:

> *There is hereby established in the State of California a strong-motion instrumentation program for the purpose of administering the program and of acquiring strong-motion instruments and installing and maintaining such instruments as needed in representative geologic environments and structures throughout the state.*

However, Section 2709.1 of the Public Resources Code states the following:

(a) No strong-motion instrumentation shall be installed pursuant to this chapter in the structural types identified in subdivision (b) unless funds proportionate to the construction value as called for under Section 2705 are received from organizations or entities representing these structural types, or the instrumentation is specifically called for by the Seismic Safety Commission in urgency situations.

(b) The structural types subject to this section include all of the following:
(1) Hospitals.
(2) Dams.
(3) Bridges.
(4) Schools.
(5) Powerplants.

OSHPD under the authorities of the HSSA and specifically section 129680(d):

> *. . .It is further the intent of the Legislature that the office, with the advice of the Hospital Building Safety Board, may conduct or enter into contracts for research regarding the reduction or elimination of seismic or other safety hazards in hospital buildings or research regarding hospital building standards.*

has created the Hospital Building Instrumentation Program under contract with the CSMIP for the installation, maintenance, and monitoring of seismic instrumentation of hospital buildings. The primary goal of the program is not that much different than those reported by several authors in a variety of engineering journals and publications: Learn from earthquakes by materializing all the steps of the scientific methodology: observation, hypothesis, prediction of the consequences of that hypothesis, and observations to test those predictions. *"Predictive modeling is at the heart of building engineering. Predictive modeling is central to everything earthquake engineers do from post-earthquake investigations to retrofitting buildings, to designing buildings to performance base engineering" [Stepp 2002].*

There are three main approaches to evaluate seismic behavior and performance of structural systems: 1) Laboratory testing, 2) Analysis of mathematical models using Computerized Simulation methods, and 3) Real world laboratory.

The merits of each approach have been enumerated and debated repeatedly by many authors of earthquake engineering publications and journals. In the case of earthquake engineering, laboratory experimentation can be used to test many hypotheses. However, laboratory testing is infeasible because of size, cost etc., so the best option is to take advantage the real world laboratory of earthquake experience.

The problems with the real-world laboratory are that earthquakes occur infrequently. Therefore in optimum test areas (seismically prone areas) we have selected hospital buildings with varying seismic resistive systems, installed integrated arrays of instruments to measure, and capture the ground motion at the selected site near the subject building as well as the response of the structure to the subject ground motion.

The data gathered from a well-designed hospital instrumentation program will satisfy in part the goals of the HSSA with regards to earthquake engineering research by providing the basic source data to improve understanding of the behavior and potential for damage of such structures under the forces generated and imposed by catastrophic earthquakes. As a result of this understanding, design and construction practices can be modified so that future earthquake damage is minimized and the objectives of the HSSA are fully met – continuous operation.

Hospital buildings are instrumented through two separate paths: 1) Required instrumentation under the California Building Code (CBC) provisions and 2) Hospital Building Safety Board (HBSB) - Instrumentation Committee recommendation and selection process.

CBC Requirements for Hospital Building Instrumentation.

Section 1615A.1.40 of the CBC requires the following for hospital building instrumentation:

> ***Earthquake Motion Measuring Instrumentation and Monitoring. [OSHPD 1 & 4]** . . . For buildings with a seismic isolation system, a damping system or a lateral force resisting system (LFRS) not listed in ASCE 7 Table 12.2-1, earthquake motion measuring instrumentation and monitoring shall be required. . . .*
>
> ***Instrumentation:** There shall be a sufficient number of instruments to characterize the response of the building during an earthquake and shall include at least one tri-axial free field instrument or equivalent. A proposal for instrumentation and equipment specifications shall be forwarded to the enforcement agency for review and approval. The owner of the building shall be responsible for the implementation of the instrumentation program. Maintenance of the instrumentation and removal/processing of the records shall be the responsibility of the enforcement agency.*

Furthermore Section 3415A.1states the following:

> ***Earthquake recording instrumentation of existing buildings.** All owners of existing structures, selected by the enforcement agency for the installation of earthquake-recording instruments, shall provide space for the installation and access to such instruments. Location of said instruments shall be determined by the enforcement agency. The enforcement agency shall make arrangements to provide, maintain, and service the instruments. Data shall be the property of the enforcement agency, but copies of individual records shall be made available to the public on request and the payment of an appropriate fee.*

Hospital Buildings with seismic isolation and or passive energy dissipation are required by the CBC to be instrumented. Different types of applications of such systems will perform differently. Instrumentation provides the opportunity to reveal which type of such systems is more effective than others. OSHPD wants to promote buildings with new and innovative seismic resistant systems of predictable seismic response and behavior. However, occasionally designs of hospitals buildings are submitted for review that use such seismic resistance systems (deemed as experimental) are not permitted by the CBC because the building code has not caught up with technology. In those cases, OSHPD under the provisions of “alternate means of compliance” permits such systems for hospital construction provided that such building will are instrumented prior to the issuance of the certificate of occupancy. Examples are Buckling Restrained Braced Frames, Steel Plate Shear Walls, new soil stabilization systems that become part of the building foundation, etc. In such cases, the owner is responsible for the cost of the instrumentation and installation with OSHPD responsible for the maintenance of the instrumentation and data retrieval through CSMIP.

Hospital Building Safety Board (HBSB) - Instrumentation Committee Recommendations and Selection Process.

The goal of OSHPD with the assistance of the HBSB Instrumentation Committee is to instrument with a sufficient array of sensors (including a free field) station two hospital buildings per year in addition to any buildings required to be instrumented by the CBC.

The committee works from a list of candidate hospital buildings that have been selected for instrumentation. The list of candidate hospital buildings has been formulated by the committee based on specific eligibility criteria. Some of eligibility criteria that the Committee considers in order to place a building on the list of candidate hospital buildings for instrumentation is as follows:

1. Close proximity to one or more of the many major California faults capable of generating a large earthquake(s) (M>6.5)
2. Sites w/ high probability of seismic event(s)
3. Type of structural system
4. Soil type (soft soil)
5. Tall interstory heights
6. Adjacency to other buildings (pounding)
7. Buildings with projecting wings
8. Template Buildings on the same site
9. Building system configuration (irregularities)
10. Seismically retrofitted buildings
11. Buildings reassessed from an SPC-1 level to an SPC-2 through the HAZUS methodology

Since the inception of the Hospital Building Instrumentation Program, fifty-five (55) hospital buildings have been instrumented. Each such instrumented building has a well optimized number of sensors placed at critical locations to generate meaningful data that characterizes the response of the subject buildings in order to help the scientific and engineering community in assessing design/analysis procedures thereby validating the mandates of the HSSA. Figure 2 illustrates one such hospital instrumentation scheme.

Figure 3 illustrates all locations of instrumented hospital buildings - CBC required and HBSB Instrumentation and Committee selected - superimposed on the California probabilistic hazard map depicting regions with PGAs greater than 20% in 20 years on alluvial soil conditions.

Why the Need for a Separate Inventory of Instrumented Hospital Buildings?

Based on the preceding discussion, California hospital buildings are different than other less essential occupancy buildings in the state. The California hospital buildings are separated into two major classifications: Pre-Act buildings and Post-Act buildings. Pre-Act buildings were permitted prior to March 7, 1973 and are not in compliance with the HSSA. Post Act buildings were permitted and constructed after March 7, 1973 and are in compliance with the requirements of the HSSA. Post-Act buildings possess higher strength and stiffness than typical buildings built in the same era under the requirements of the model code enforceable at that time. The response of hospital buildings will be very different than nonhospital building of the same era even though they are built of the same material, structural system engineering methodologies etc. Strong motion records from hospitals buildings tell the story of different performance. Figure 4 illustrates the recorded accelerations from a 1 story Hospital in Templeton during the San Simeon Earthquake of December 22, 2003. The building is Post Act vintage and despite the

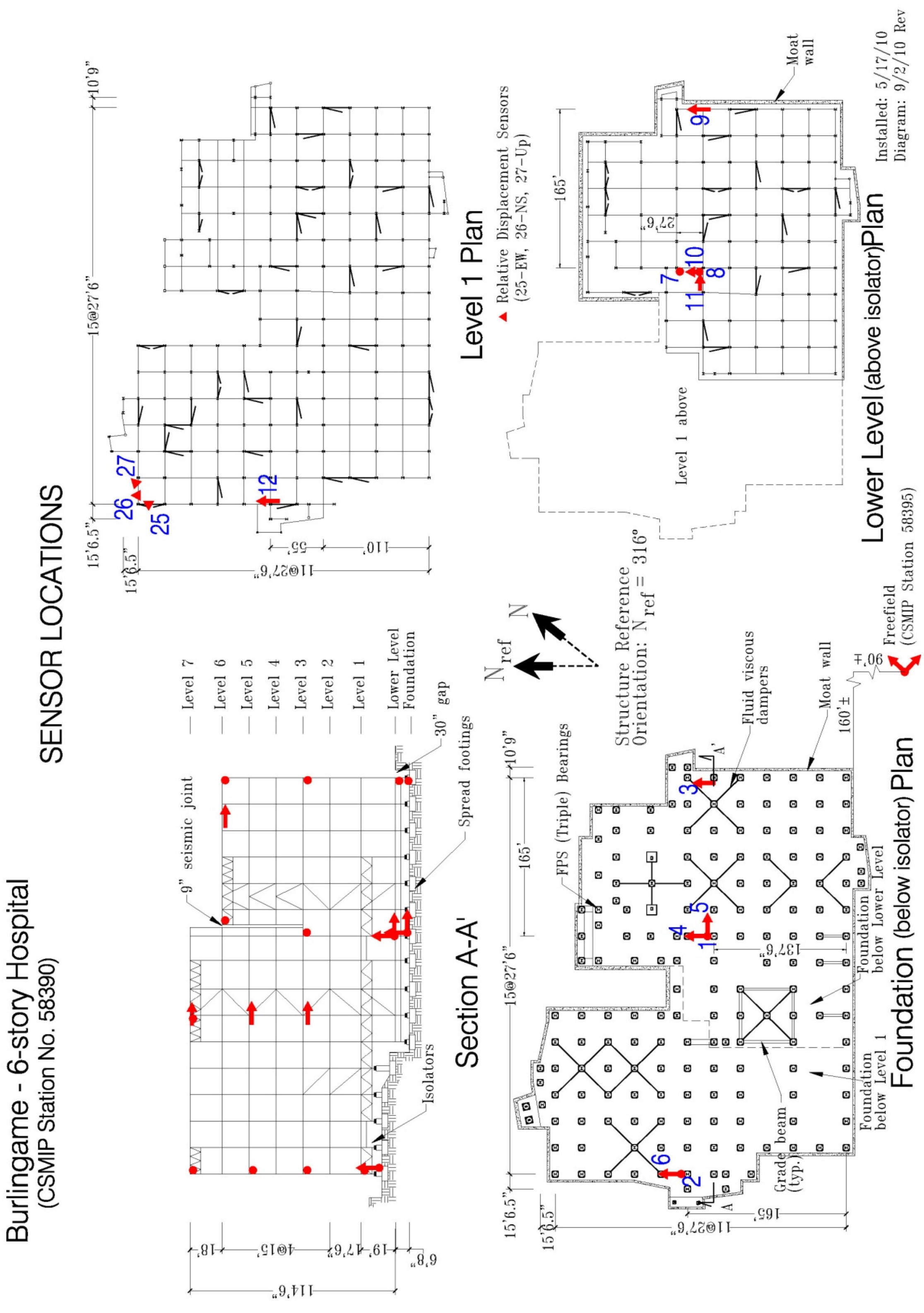

Figure 2. Example of Hospital Building Instrumentation Layout

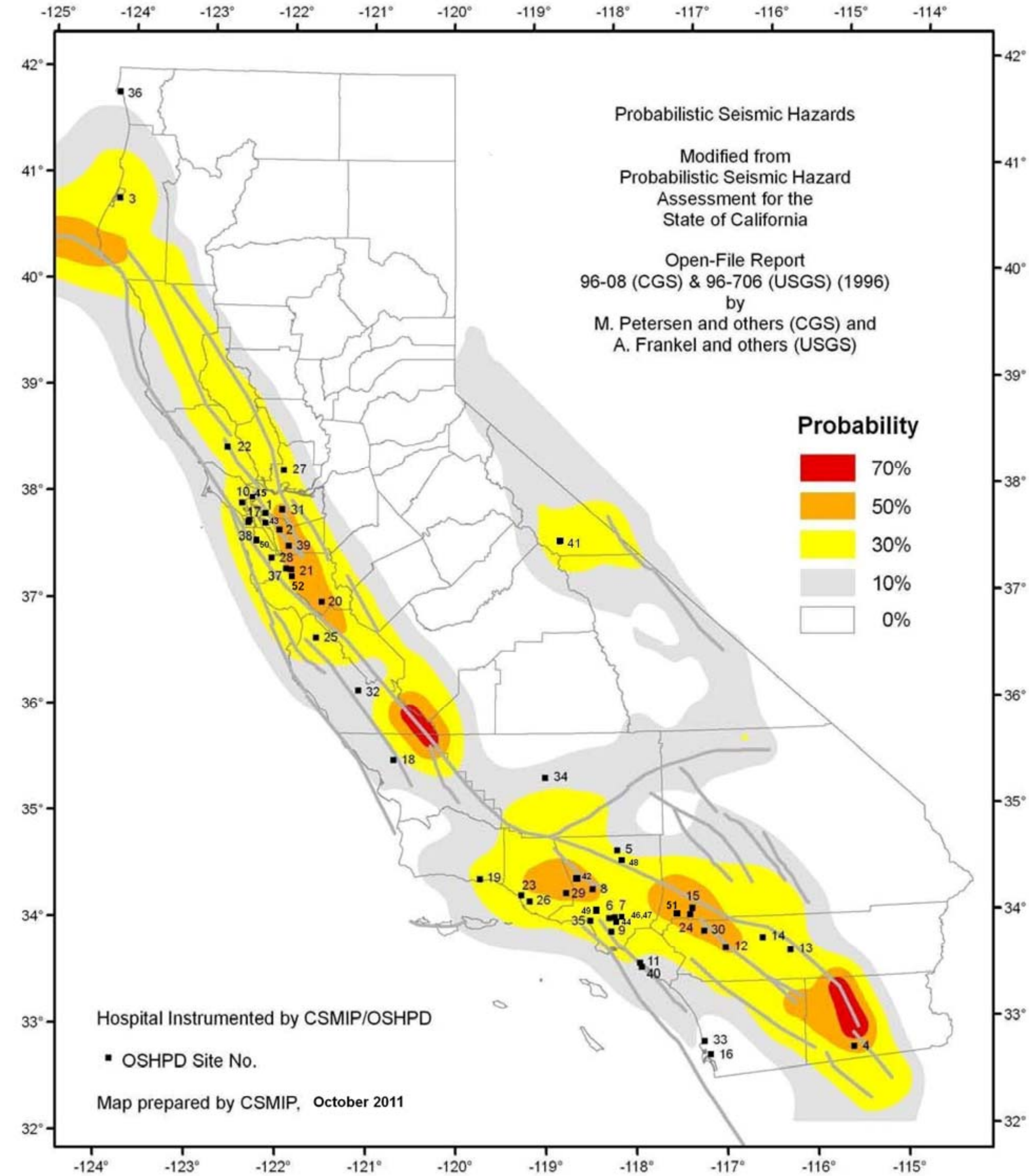

Figure 3. Instrumented Hospital Buildings by SMIP/OSHPD for sites with PGA > 0.2g in 20 years on alluvial soil conditions.

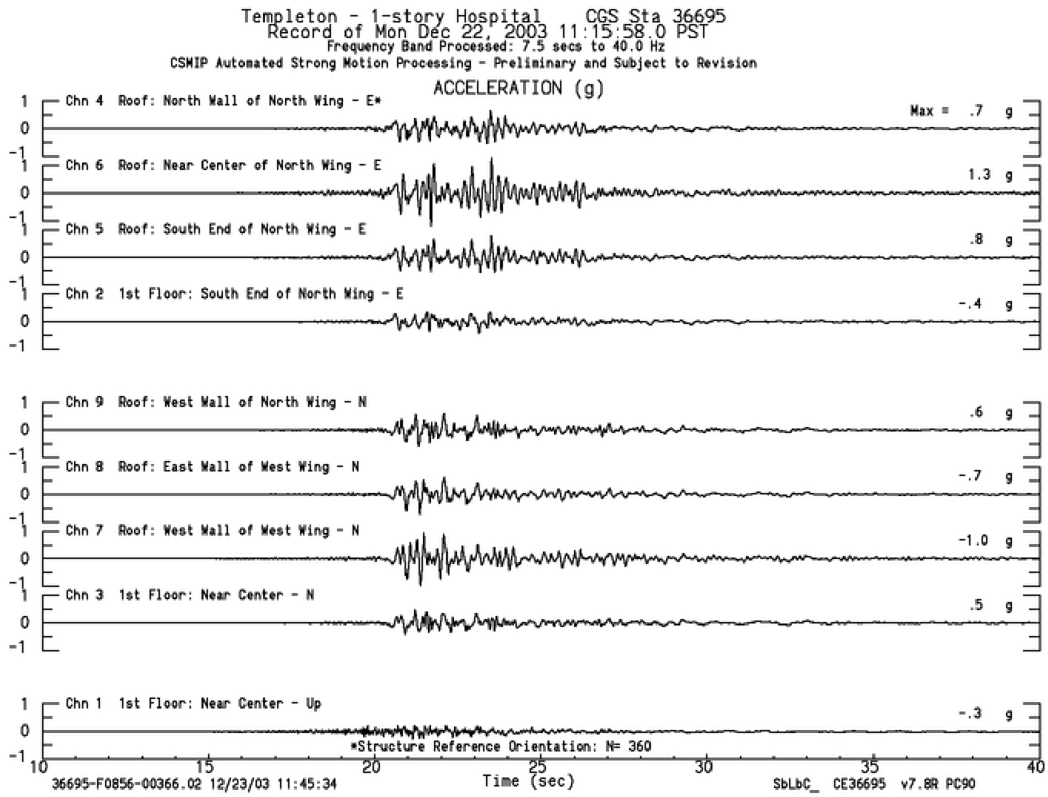

Figure 4. Recorded accelerations from the 1 story Hospital in Templeton during the San Simeon Earthquake of December 22, 2003

strong demand from the ground motion, the structure had enough strength and did not suffer any structural damage during the earthquake.

More importantly hospital building instrumentation is one of the performance indicators validating the requirements of HSSA.

The HAZUS methodology has been recently used as a means to reclassify buildings from posing a significant risk of collapse and a danger to the public (SPC-1), to buildings that do not significantly jeopardize life, but may not be repairable or functional following strong ground motion (SPC-2). However, this HAZUS methodology is mostly untested in a strong seismic event; the need for seismic instrumentation becomes obvious. Because of the infrequent and unpredictable nature of when and where an earthquake will occur, it is important to start such preparation early, so that valuable information useful to develop earthquake protective technology is not lost.

Emergency Response

OSHPD has statutory authority (HSSA, Section 130025) and responsibilities in the event of a seismic event, or other natural or manmade calamity to activate its emergency response center and mobilize a specialized team of authorized representatives in order to examine the hospital building structure(s) or systems affected by such an event. Furthermore the same section of the HSSA requires that:

> *. . . . If, in the opinion of the office, the structural integrity of the hospital building or any system has been compromised and damaged to a degree that the hospital building has been made unsafe to occupy, the office may cause to be placed on the hospital building either a red tag, a yellow tag, or a green tag.*

The California Seismic Instrumentation Program in general as well as the Hospital Instrumentation Program are an essential tool for the OSHPD emergency response and recovery operations. Seismic networks (CSIN) along with instrumented buildings provide OSHPD real time earthquake data to respond efficiently and effectively in a seismic event and carry out its statutory responsibilities.

Utilizing the ShakeMaps which are usually available within minutes of the occurrence of strong shaking along with strong motion records from instrumented buildings, specific GIS information that the office has developed over the years and other intelligence information collected from the field, the office can structure a very efficient plan of response to deploy its resources in the most effective manner. That means number assessment teams, which facilities first, etc. A recent example of such response is the latest significant seismic events in Brawley in South California on August 26, 2012.

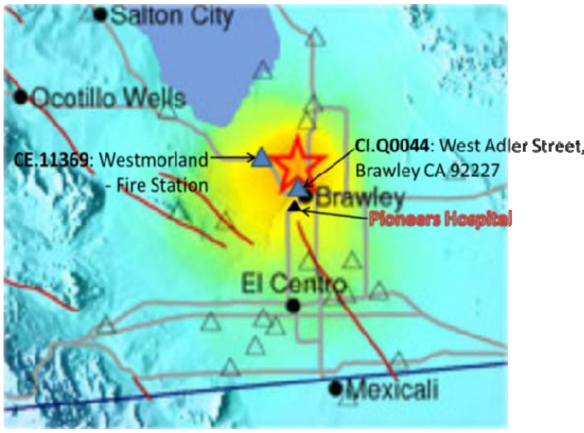

Figure 5. ShakeMap Brawley M5.5 Earthquake August 26, 2012

CI.Q0044: West Adler Street, Brawley CA 92227 — Agency: Southern California Seismic Network

Lat: 32.9860 Lon: -115.5469 Distance: 3.0 km from source

Intensity: **7.8** Location: 345 West Adler Street, Brawley CA 92227

Station Comp	Max Vel (cm/s)	Max Acc (%g)	PSA: 0.3 sec (%g)	1.0 sec (%g)	3.0 sec (%g)
01.HNN	**39.6971**	**45.1719**	98.6657 -T	**42.7503**	6.5662
01.HNE	36.0459	28.7961	70.3703 -T	19.7977	**10.2899**
01.HNZ	11.2906	49.2668	30.9127 -T	6.8925	4.5785

Figure 6. Strong Motion Record, Station SCSN-CI.Q0044, Brawley M5.5 Earthquake August 26, 2012

Having the appropriate strong motion information along with detailed structural system information (Steel SMRF Systems used in the subject hospital buildings) focused the OSHPD post-earthquake assessment team on what to look for and the recommendations to make to the hospital owner for a detailed post-earthquake evaluation report.

Conclusions

1. Looking back at the first steps of the hospital seismic safety program as well as looking ahead at the approaching 2013 deadline it is imperative to point out that significant progress has been achieved.
2. The hospitals are making progress. California hospitals indeed are safer today, but there is still work to do.
3. The HSSA requires hospitals to be in substantial compliance with the HSSA by January 1, 2030 and all general acute care hospitals must be able to remain operational beyond that point in time.
4. The hospital seismic instrumentation program is monitoring the pulse and health of the HSSA.
5. Performance based engineering is the next step in the profession. The hospital instrumentation program will give the capability to the earthquake engineering community to validate the predictions of risk analysis tools such as HAZUS and PACT.

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