Seismic Instrumentation of Healthcare Facilities

A White Paper on the Usefulness and Benefits of Seismic Instrumentation of Healthcare Facilities

By the
Hospital Building Safety Board
Instrumentation Committee

Presented to
California Department of Health Care Access and Information (HCAI)

October 26, 2023

Acknowledgments

The Hospital Building Safety Board Instrumentation Committee of the Department of Health Care Access and Information (HCAI) acknowledges the support, encouragement, knowledge, and wisdom of individuals who contributed to the development of this white paper. These individuals are Steve Bohlen, Tim McCrink, Khalid Mossalam, Daniel Swensen, Evan Reis and Derek Skolnik. In addition, HCAI staff provided important information and data needed for this white paper, and their enthusiastic support and encouragement are gratefully appreciated.

Contents

Chapter 1 – Introduction

California is a high seismic region, and over the years, California hospitals have suffered various degrees of damage and destruction because of earthquakes. Assessing the safety and functionality status of a healthcare facility by the current means of dispatching inspectors and engineers to perform visual inspections is a time-consuming process when time is of critical importance. The status of different facilities must be ascertained with sufficient accuracy as soon as possible so that the health needs of the population can be addressed, and plans be made for sending those in need of healthcare to places where such critical care can be provided at the time it is most needed.

There is no shortage of examples of California healthcare facilities suffering damage during earthquakes. A few examples of such damage and destruction are presented in Figures 1 to 5.

Figure 1*. Damage to the San Jose Agnew Mental institution during the 1906 San Francisco earthquake.*[1]

[1] https://digitalcollections.detroitpubliclibrary.org/islandora/object/islandora%3A173675

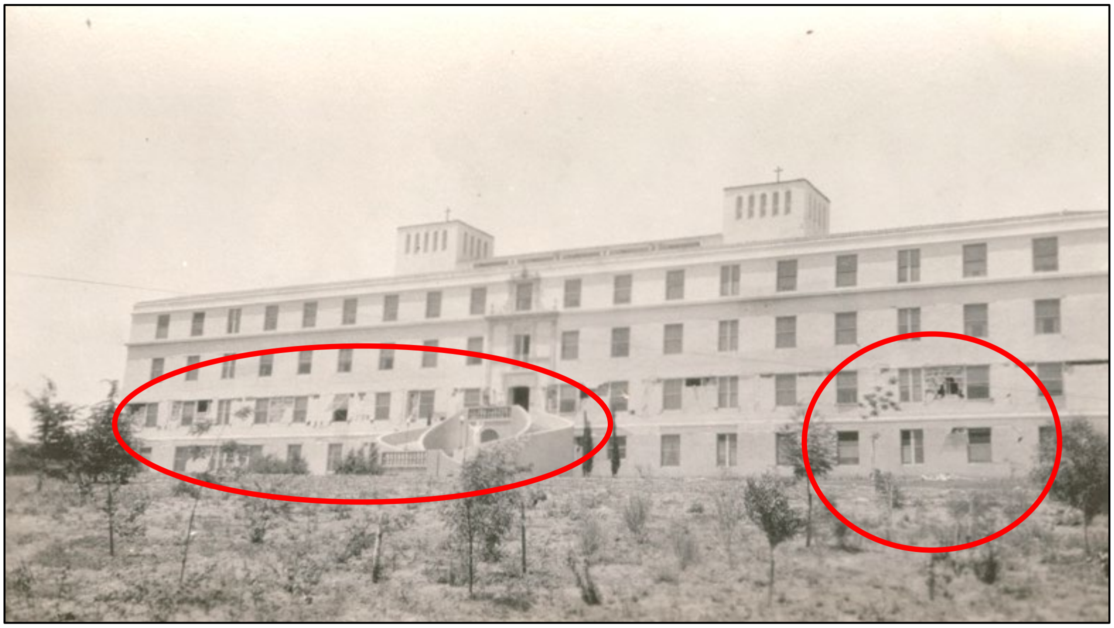


Figure 2. *Damage to the Santa Barbara St. Francis hospital during the 1925 Santa Barbara earthquake.*[2]

Figure 3. *Damage to the Seaside Hospital during the 1933 Long Beach earthquake.*[3]

---

[2] https://calisphere.org/item/57af5e1a488743b85ca15f26c005d972/

[3] https://calisphere.org/item/16513a666bc7b5e32c461d7f3581a330/

***Figure 4**. Damage to the original Olive View Hospital during the 1971 San Fernando earthquake; this facility was demolished and replaced by a new hospital building.*[4]

[4] https://library.usgs.gov/photo/index.html#/?terms=olive%20view%20hospital

Figure 5. *Damage to the Kaiser Permanente clinic building in Granada Hills during the 1994 Northridge earthquake.*[5]

In the Northridge Earthquake of January 1994, several of these older hospitals sustained significant damage. Hospitals built in accordance with the standards of the HSSA Act resisted the Northridge earthquake with minimal structural damage, while several facilities built prior to the HSSA Act experienced major structural damage and had to be evacuated. It must be noted that certain nonstructural components did incur significant damage which resulted in evacuation of a number of these hospitals although these hospitals were HSSA Act compliant.

An important goal of hospitals is to be able to continue to operate and serve the patient community after a major earthquake. However, the building itself may have been damaged and, consequently, may pose a hazard to patients and staff. It is critical that hospital management has the tools and information necessary to make a rapid decision on whether to evacuate, reduce services, or other operation changes. Early assessment of the integrity of the hospital buildings affected by the earthquake is valuable in this decision-making process. For resilience and sustainability of California's hospitals, it is also necessary to assess their structural condition periodically to facilitate necessary repairs and retrofitting measures.

As it will be explained in this white paper, seismic instrumentation at a relatively modest cost (see Figures 6 to 8) has the potential of providing hospital owners, operators, and public officials with timely information regarding the post-earthquake status and vital information for assessing whether the facility is safe or unsafe, operational or not, and/or whether it should remain in

[5] https://www.latimes.com/local/lanow/la-me-ln-concrete-list-earthquake-20140121-story.html

service or be evacuated until repairs are made.

The target audience for this white paper is hospital owners, managers, and operators as well as public officials and the general public.

(a) examples of sensors to measure accelerations.

(b) examples of sensors which can be used to directly measure displacements.

Figure 6. *Sensors that have been and can be installed at hospitals for seismic instrumentation and structural health monitoring.*

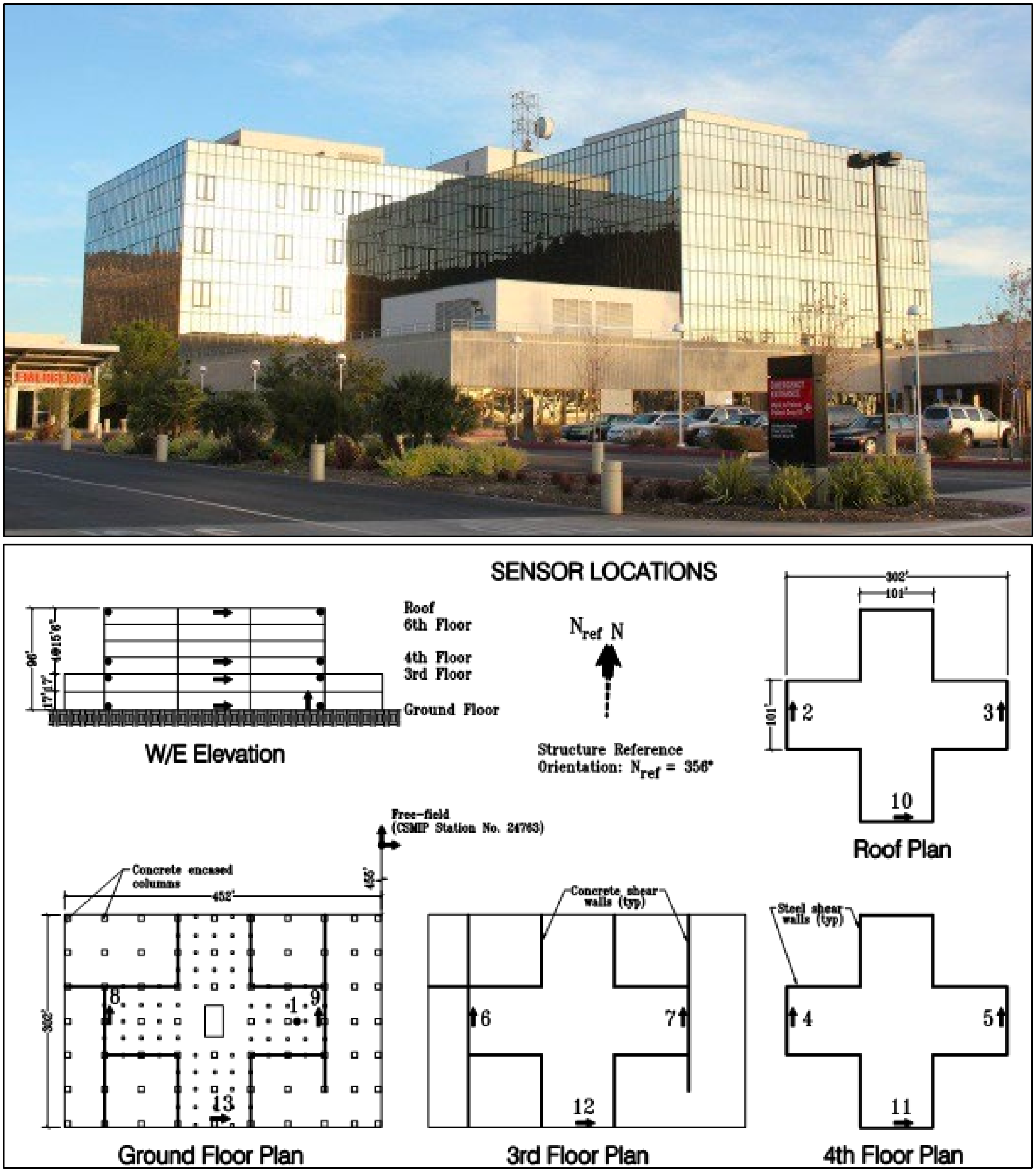


Figure 7*. Photo (top) and sensor lay out diagram (bottom) of the six-story Olive View-UCLA Medical Center (New Sylmar County Hospital). Arrows in the schematic diagram show the locations and indicate the directional sensitivity of the strong-motion sensors (accelerometers). The sensors are connected to a central data acquisition system in the building.*[6]

[6] https://www.strongmotioncenter.org/cgi-bin/CESMD/stationhtml.pl?staID=CE24514&network=CGS

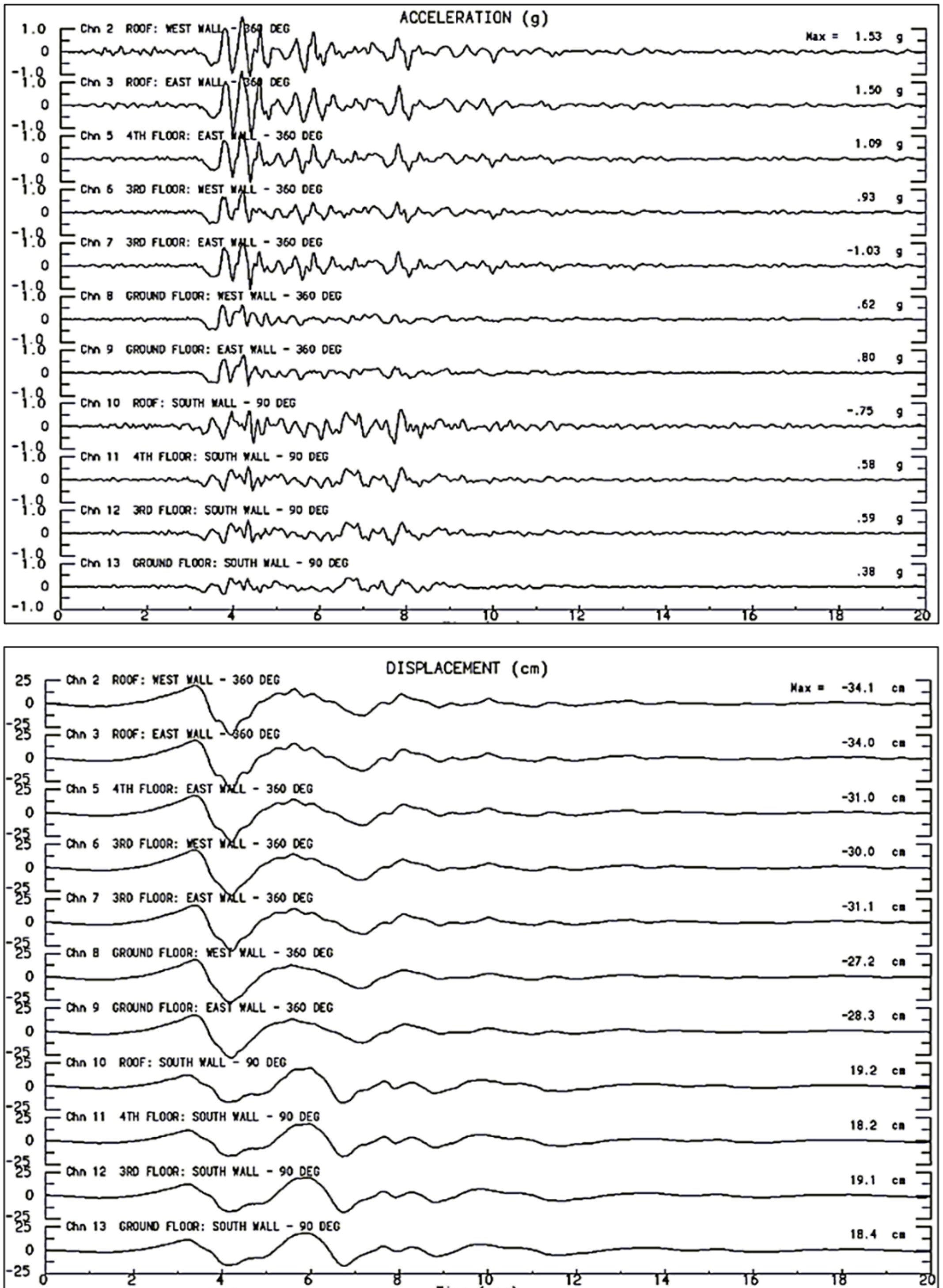


Figure 8. *Structural responses (accelerations at the top and displacements at the bottom) recorded by seismic instrumentation system installed at the new Sylmar County Hospital during the 1994 Northridge earthquake.*[7]

[7] https://www.strongmotioncenter.org/cgi-bin/CESMD/stationhtml.pl?staID=CE24514&network=CGS

Chapter 2 – Current Status of HCAI Instrumentation

In response to these needs explained in the previous section, for almost 40 years the Department of Health Care Access and Information (HCAI – formerly the Office of Statewide Health Planning and Development or OSHPD) has long supported and continues to support hospital instrumentation in collaboration with the California Strong Motion Instrumentation Program (CSMIP) of the California Geological Survey (CGS - https://www.conservation.ca.gov/cgs/smip). These instruments record motions in hospital buildings when earthquakes occur and are essential in understanding the behavior of these hospital buildings due to and during the earthquakes.

The records obtained from the sensors in instrumented buildings can also provide the basic source data to improve understanding of the behavior and potential for damage of such structures under the forces generated and imposed by strong earthquakes. As a result of this understanding, design and construction practices can be and have been modified so that future earthquake damage is minimized and the objective of maintaining continuous operation can be met as explained in the next section of this white paper.

CSMIP has been instrumental in performing installation, maintenance, and data recovery from seismic instrumentation in hospitals through an interagency agreement (IAA) with HCAI since 1984. Currently, close to 90 hospital buildings across the state have been instrumented under this IAA under HCAI jurisdiction (see Figure 9 and Appendix A Table). It should be noted that 90 instrumented hospital buildings represent a very small percentage of total hospital buildings in California. Therefore, more widespread instrumentation of hospitals is needed in order to rapidly assess the status of most, if not all, hospital buildings in California following a major earthquake.

Hospital Buildings with seismic isolation and or passive energy dissipation systems are required by the California Building Code (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. HCAI promotes construction of buildings with new and innovative seismic resistant systems with predictable and improved seismic response and behavior. However, designs of hospitals buildings submitted for review that use such seismic resistance systems which may not yet be codified in the CBC because the building code has not caught up with the latest technology. In those cases, HCAI under the “alternate means of compliance” provisions for lateral force resisting systems permits such systems for hospital construction provided that such buildings are instrumented prior to the issuance of the certificate of occupancy. In such cases, the owner is responsible for the cost of the instrumentation and installation with HCAI being responsible for the maintenance of the instrumentation and data retrieval through CSMIP.

Each year, HCAI provides funding for instrumentation of selected existing hospital buildings. Most hospital buildings are instrumented with accelerometers. Most of the instrumented hospital buildings are in regions of high or very high seismic hazard. With the assistance of the Hospital Building Safety Board (HBSB) Instrumentation Committee, HCAI may select two existing hospital buildings per year to be instrumented with a sufficient array of sensors in addition to any buildings required to be instrumented as required by the CBC. The cost of instrumentation of these buildings selected for instrumentation by the HBSB Instrumentation Committee is paid for by HCAI. Each such instrumented building has a well optimized number of sensors placed at critical locations to generate meaningful data that characterize the response of the subject buildings. The data that have been collected from instrumented hospital buildings are freely available to the public online from the HCAI sites[8,9] or website of the Center for Engineering Strong Motion Data.[10]

[8] https://hcai.ca.gov/construction-finance/facility-detail/

[9] https://hcai.ca.gov/construction-finance/seismic-compliance-and-safety/emergency-response-operations/

[10] https://www.strongmotioncenter.org /

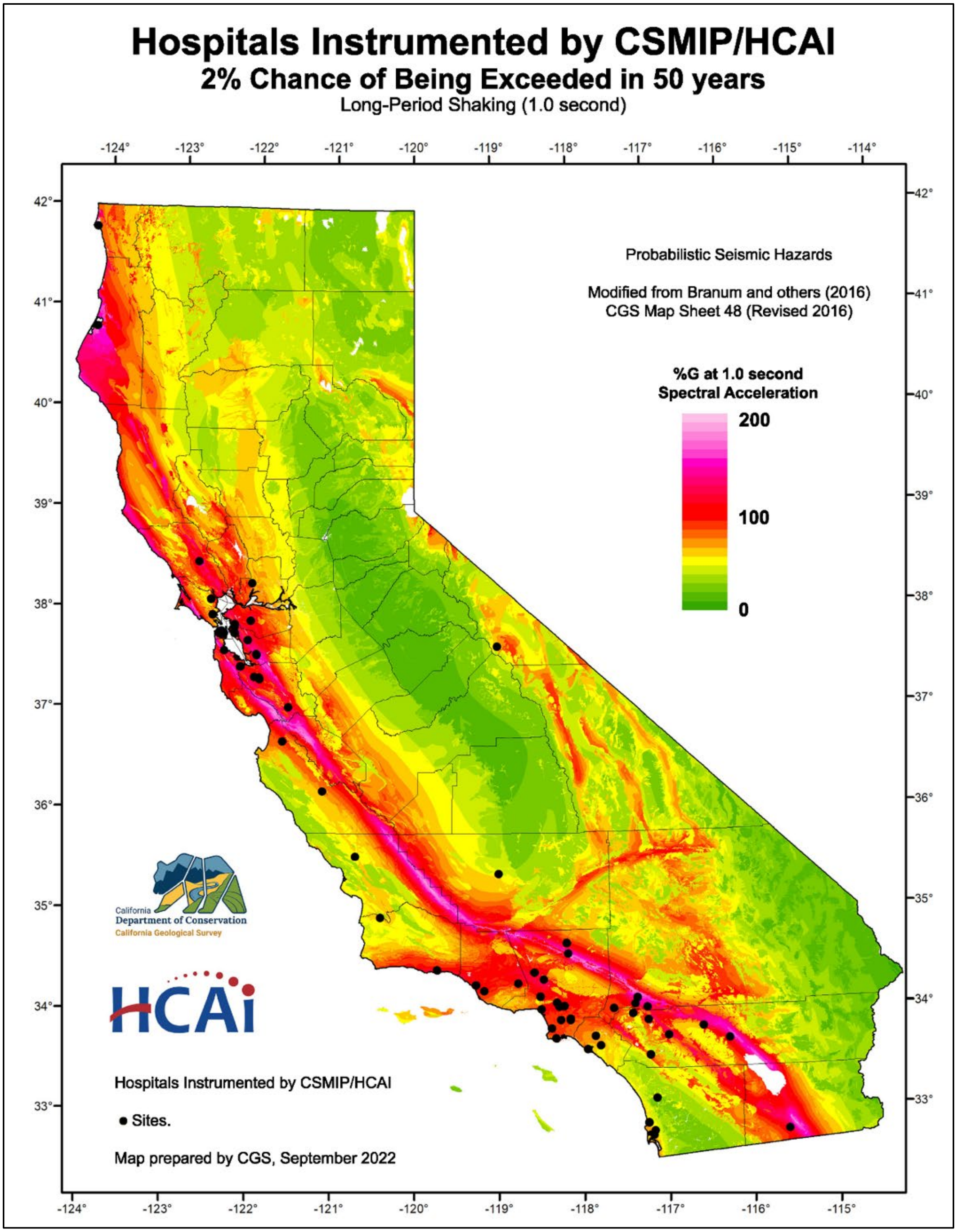


Figure 9. *Locations of the instrumented hospital buildings (black dots). The base map is the seismic hazard map of the California. Colors on this map display the levels of horizontal shaking that have a 2 percent probability of exceedance in a 50-year period.*

Chapter 3 – Benefits of Hospital Instrumentation

There are two distinct benefits which can be obtained by seismic instrumentation of hospital buildings. The first is understanding building seismic responses and improving hospital design codes and practices. This objective can only be achieved by installation of high-resolution sensors and recording equipment of the type CSMIP utilizes for instrumentation of a selected number of hospital buildings. Currently, there are about 90 hospital buildings which are instrumented in such a manner in California. The second, which is the primary focus of this white paper, is that seismic instrumentation combined with adaptation of existing hardware/software/Internet technologies can make the instrumented data recorded during earthquakes, by either high-resolution or low-resolution sensors, almost immediately available for safety assessment of hospital buildings and their content. Ideally with cooperation of hospital owners and managers, design professionals, and private sector sensor manufacturers and service providers, all California hospitals can be instrumented to achieve this second and extremely important objective.

The utilization of seismic instrumentation for identifying and understanding structural damage to hospital buildings from an earthquake or its aftershocks have been demonstrated for a period of more than 20 years by various researchers. Furthermore, the importance and value of instrumentation for identifying the hazards from nonstructural building elements (such as partitions, hung ceilings, and piping), as well as stationary and movable equipment inside and outside of the hospital buildings have been demonstrated by several investigators.

The following simple example of such utility illustrates the need for wide distribution and enhancement of seismic instrumentation of hospital buildings and integrating instrumentation into seismic health monitoring systems for California hospitals. At the time of the 1994 Northridge earthquake, the new Sylmar County Hospital (Figure 10) was one of the hospitals instrumented by CSMIP for HCAI. This hospital building replaced the earlier Sylmar County Hospital that was heavily damaged and had partial collapses by the 1971 San Fernando earthquake (see Figure 4) and had to demolished. The records obtained at this newer facility during this earthquake were presented in Figure 8. This building was specifically designed using a new structural system to resist major earthquakes without significant structural damage which was the objective of building codes enacted after the 1971 San Fernando earthquake and this objective was achieved during the Northridge earthquake. However, the damage to nonstructural components and contents was quite extensive during the Northridge earthquake and resulted in closure of this hospital for an extended period (Figure 11). The major lesson learned from the performance of this hospital was that design for structural integrity by itself does not necessarily provide for continued operation of a hospital because nonstructural elements of a hospital facility also must be designed and installed to resist earthquake forces. This lesson led to new building code regulations regarding design and installation of nonstructural elements. The records obtained from the hospital instrumentation provided valuable insight to draft these provisions.

Figure 10. *An outside view of the new Sylmar County Hospital Building (now Olive View-UCLA Medical Center) the day after the 1994 Northridge earthquake.*[11]

[11] Naeim, F. Hagie, S. Alimoradi, A. and Miranda, E. 2005, Automated Post-Earthquake Damage Assessment and Safety Evaluation of Instrumented Buildings, Proceedings of SMIP05 Seminar, Strong Motion Instrumentation Program, California Geological Survey, Sacramento, CA.

***Figure 11**. Examples of nonstructural damage at the new Sylmar County Hospital during the 1994 Northridge earthquake.*[12]

[12] Naeim, F. Hagie, S. Alimoradi, A. and Miranda, E. 2005, Automated Post-Earthquake Damage Assessment and Safety Evaluation of Instrumented Buildings, Proceedings of SMIP05 Seminar, Strong Motion Instrumentation Program, California Geological Survey, Sacramento, CA.

With the technology available in 1994, the recordings from the seismic instrumentation required collection and processing which was some weeks and months after the earthquake. The analysis of the data would take more time also. The maximum floor accelerations and story drifts interpreted from the instrumentation data are presented in Figure 12.

If the data summarized in Figure 12 were available immediately after the earthquake and the instrumentation system were connected to a simple application on a computer or a cell phone or tablet application, the data could be processed as shown in Figure 12. The processed data can be passed through some very basic fragility functions (that predict damage), such as those embedded in HAZUS-MH[13] or FEMA P-58[14] documents, then an estimate of the status of the building's structural and nonstructural performance would have been almost immediately available as shown in Figures 13 to 16.

It is important to note that although the simple HAZUS-MH or FEMA-P58 fragility functions used for illustration in this paper were not specifically developed for hospitals as they were mostly generated to estimate damage to structural and nonstructural components of ordinary buildings, application of even these simple fragility functions provide very useful information. Therefore, if hospital building and content specific fragility functions are developed and utilized, an even more accurate picture of the status of the building, its structural, nonstructural, and content conditions can be obtained rapidly after an earthquake.

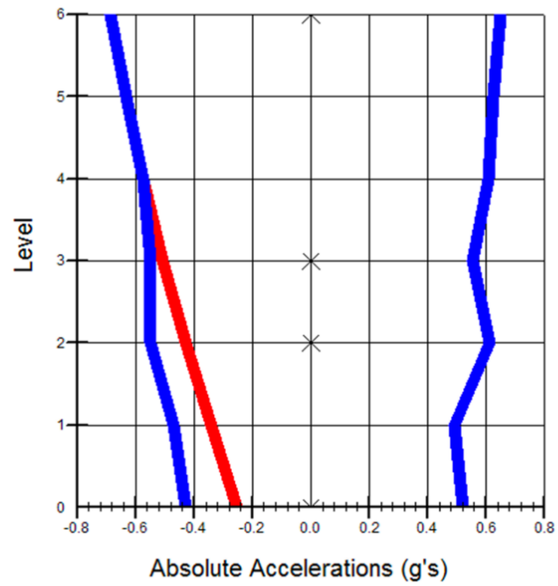
Applications of newer approaches and technologies have the potential of providing even more accurate, timely and useful information regarding the status of the hospital buildings and their contents. This timely and almost immediate estimation of the structural and nonstructural performance from the instrumentation data will immensely facilitate more timely and more informed post-earthquake response in hospital buildings.

As illustrated in Figures 13 through 16, simple fragility functions which were not specifically developed for hospital buildings were able to confirm the observations of both structural and nonstructural performance of the Sylmar County Hospital in the 1994 Northridge earthquake. Therefore, utilization of newer and building-specific fragility functions and methodologies can result in even more accurate evaluation of the status of the structural and nonstructural systems and components of a properly instrumented hospital building during or rapidly after an earthquake.

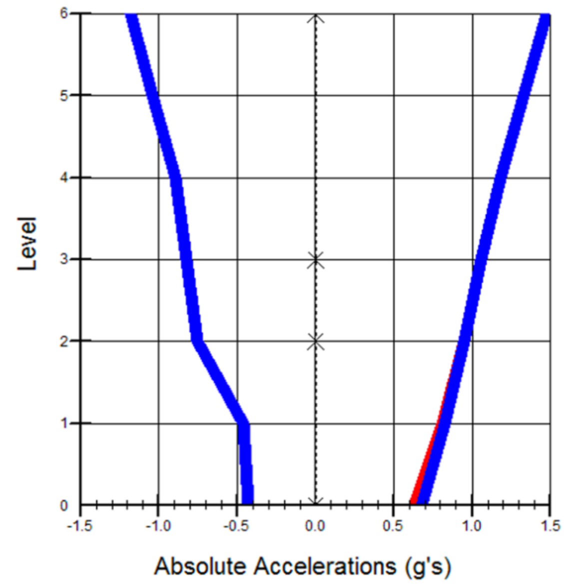
---

[13] Federal Emergency Management Agency (FEMA) 2022, HAZUS Earthquake Model Technical Manual, Version 5.1, https://www.fema.gov/sites/default/files/documents/fema_hazus-earthquake-model-technical-manual-5-1.pdf.

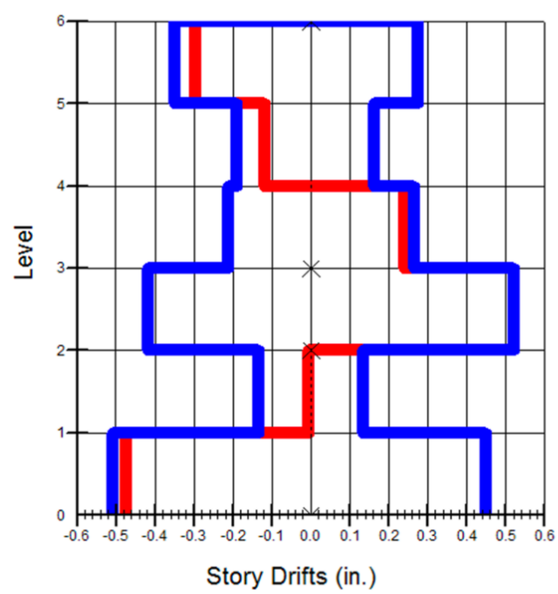
[14] Federal Emergency Management Agency (FEMA) 2018, Seismic Performance Assessment of Buildings, Volumes 1 to 7, https://femap58.atcouncil.org/reports.



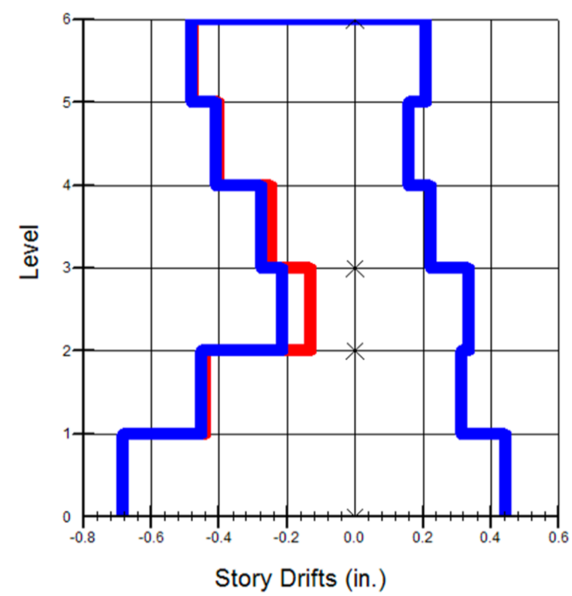
(a) Envelope of E-W floor accelerations (the maximum occurs at 7.72 seconds indicated by red line)



(b) Envelope of N-S floor accelerations (the maximum occurs at 4.22 seconds indicated by red line)



(c) Envelope of E-W story drifts (the maximum occurs at 6.78 seconds indicated by red line)



(d) Envelope of N-S story drifts (the maximum occurs at 4.24 seconds indicated by red line)

Figure 12. *Structural response quantities interpreted from the sensors installed at the new Sylmar County Hospital for the 1994 Northridge earthquake.*[15]

[15] Naeim, F. Hagie, S. Alimoradi, A. and Miranda, E. 2005, Automated Post-Earthquake Damage Assessment and Safety Evaluation of Instrumented Buildings, Proceedings of SMIP05 Seminar, Strong Motion Instrumentation Program, California Geological Survey, Sacramento, CA.

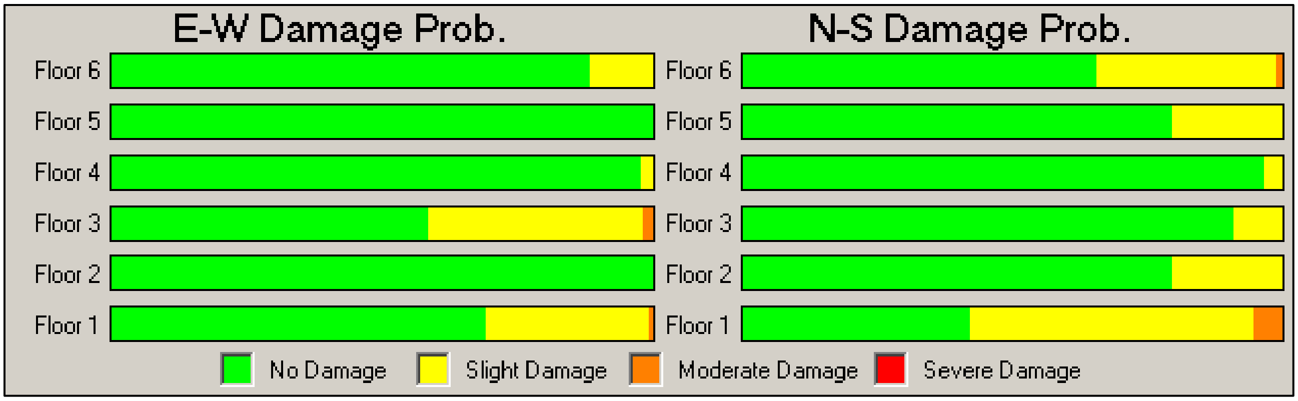


Figure 13. *Instrumentation indicates no damage to slight damage status of the Sylmar County Hospital structural system following the 1994 Northridge earthquake using a relevant and readily available HAZUS-MH fragility function.*[16]

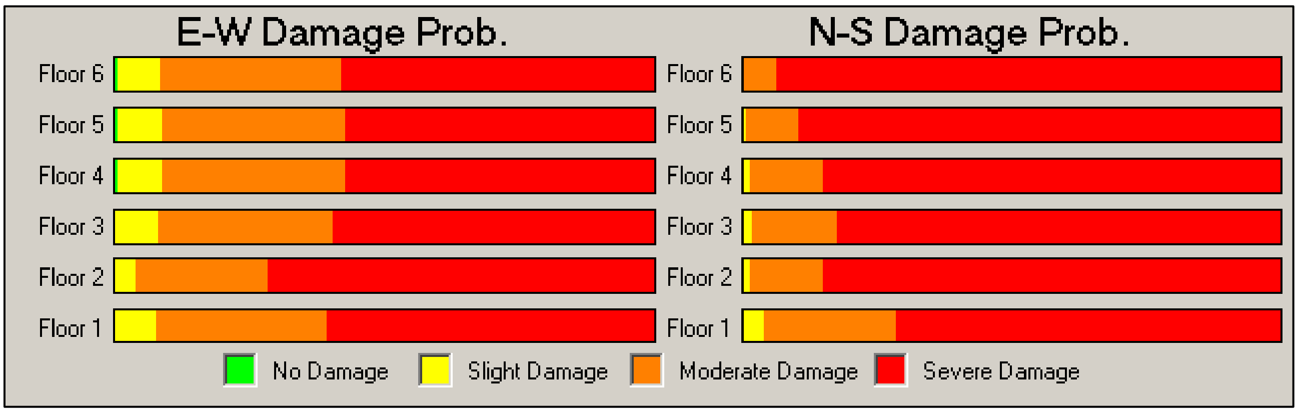


Figure 14. *Instrumentation indicates moderate to severe damage status for the nonstructural systems of the new Sylmar County Hospital following the 1994 Northridge earthquake using a relevant and readily available HAZUS-MH fragility function.*[17]

[16] Naeim, F., Kanda, K., Ventura, C. and Biro, T. 2021, Roadblocks and Incentives for Worldwide Adaptation and Implementation of Seismic Structural Health Monitoring (S2HM), Special Session at 17th World Conference on Earthquake Engineering, Sendai, Japan.

[17] Ibid.

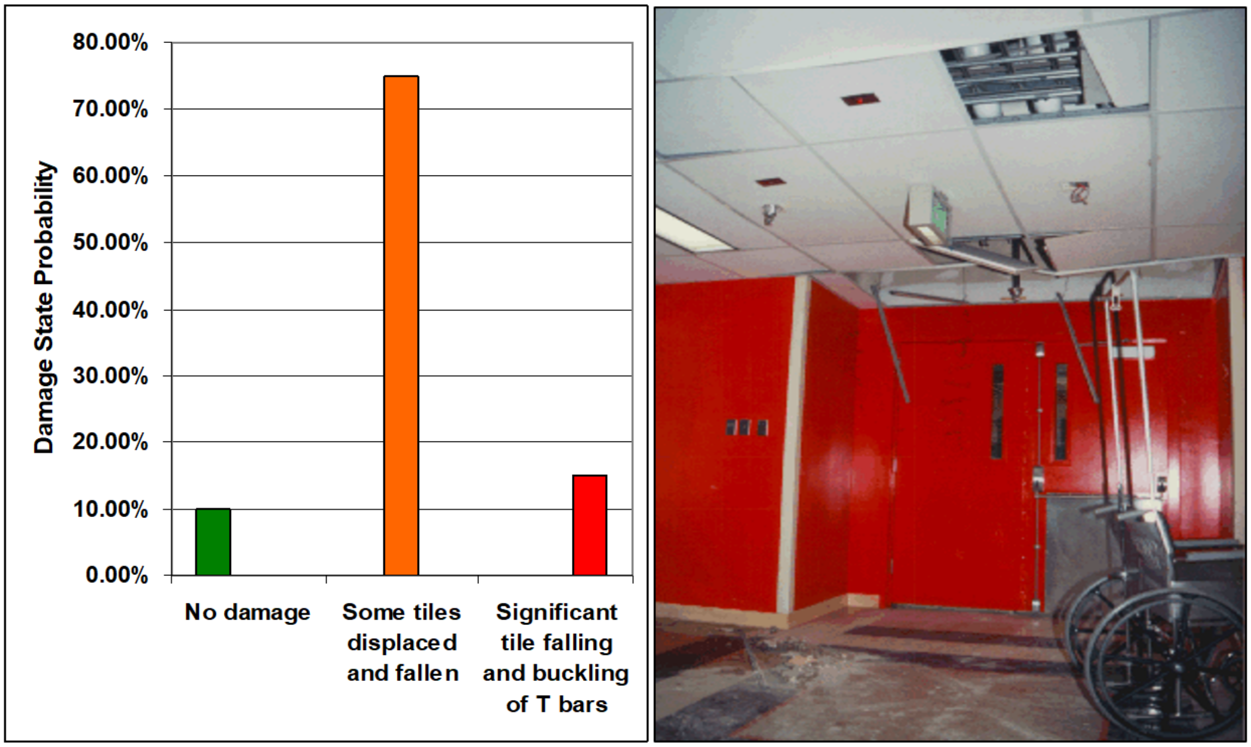


__Figure 15.__ Instrumentation indicates displaced suspended ceiling tiles on the first floor of the new Sylmar County Hospital following the 1994 Northridge earthquake using a relevant and readily available FEMA-P58 fragility function.[18]

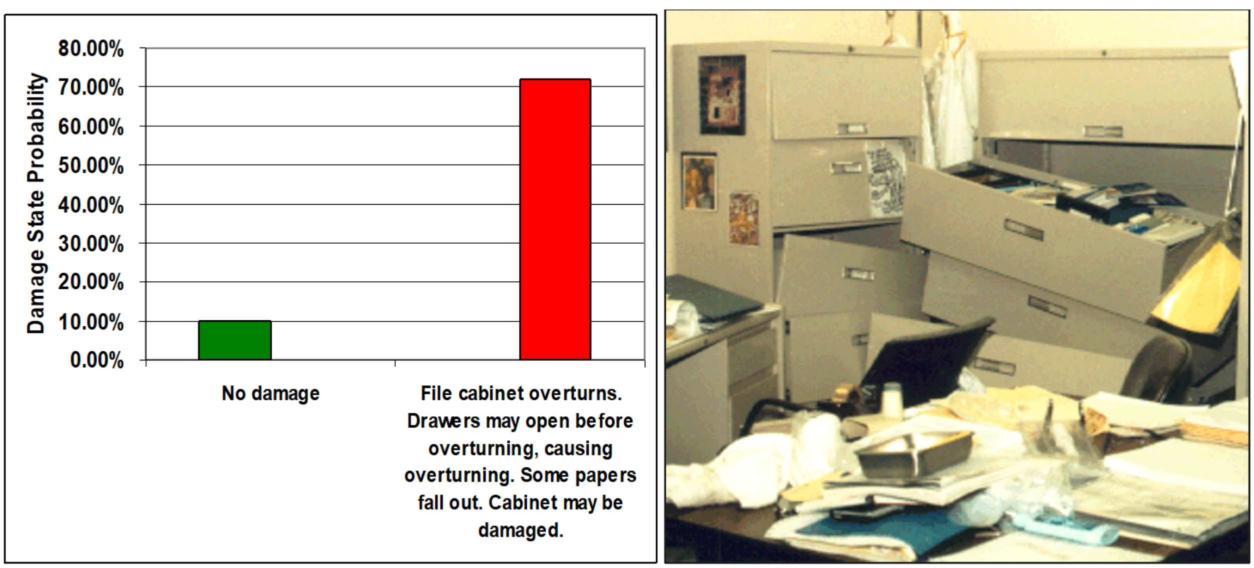


__Figure 16.__ Instrumentation indicates overturning of file cabinets on the 6th floor of the new Sylmar County Hospital following the 1994 Northridge earthquake using a relevant and readily available FEMA-P58 fragility function.[19]

[18] Naeim, F., Kanda, K., Ventura, C. and Biro, T. 2021, Roadblocks and Incentives for Worldwide Adaptation and Implementation of Seismic Structural Health Monitoring (S2HM), Special Session at 17th World Conference on Earthquake Engineering, Sendai, Japan.

[19] Ibid.

Chapter 4 – Increasing the Usefulness of the Strong Motion Data and Networks

As it was mentioned in Section 2, high-resolution strong motion instrumentation has been installed in about 90 hospital buildings in California. There are about 415 hospital campuses with over 3,000 hospital buildings throughout the state. The actual percentage of hospital buildings with strong motion instrumentation is less than 5 percent because most hospital campuses have multiple buildings.

As described in Section 3, advances in technology and communication now may enable strong motion instrumentation data to be available in real or near-real time which will provide more timely feedback on the structural and nonstructural performance of buildings and systems and potentially identify key indicators of distress or concern regarding the structural and nonstructural integrity of a building or facility.

The speed of transmission of the strong motion data from the various instruments will depend on the availability and capacity of the telecommunication channels which may be affected by earthquake and post-earthquake events. If the processed data can become more readily accessible in real or near-real time, the strong motion data can be used to assess damage and provide a more scientific basis for quick decision making regarding continuing occupancy and services in buildings. More rapidly available data can also be used to prioritize resources for recovery and restoration of services.

There needs to be a shift from simple instrumentation to a concept like that of a "Black Box" which is implemented in airplanes and cars (Figure 17). The "black box" could be a physical recorder located in the building or a virtual one in the Internet cloud. If the building "black box" is functional for an instrumented building at the time of an earthquake, the data from sensors are processed by the black box and results will be made available almost instantaneously. After the event, the data are transmitted to a central data center where it is received and processed and then posted to local data centers, followed by notification of the facility contact for some facilities. All the functions of data retrieval, data processing, and notification could be done on-site, very rapidly, with timely notification to key people. The black box would retain all the data from the sensors and the calculated motions and responses.

This approach would remove the vulnerability to loss or low speed of the communication between the hospital and the offsite data centers, since the information would be available either onsite and/or on the Internet cloud version of the "black box." It is likely that such a system could also be developed by and purchased from the instrumentation manufacturers.

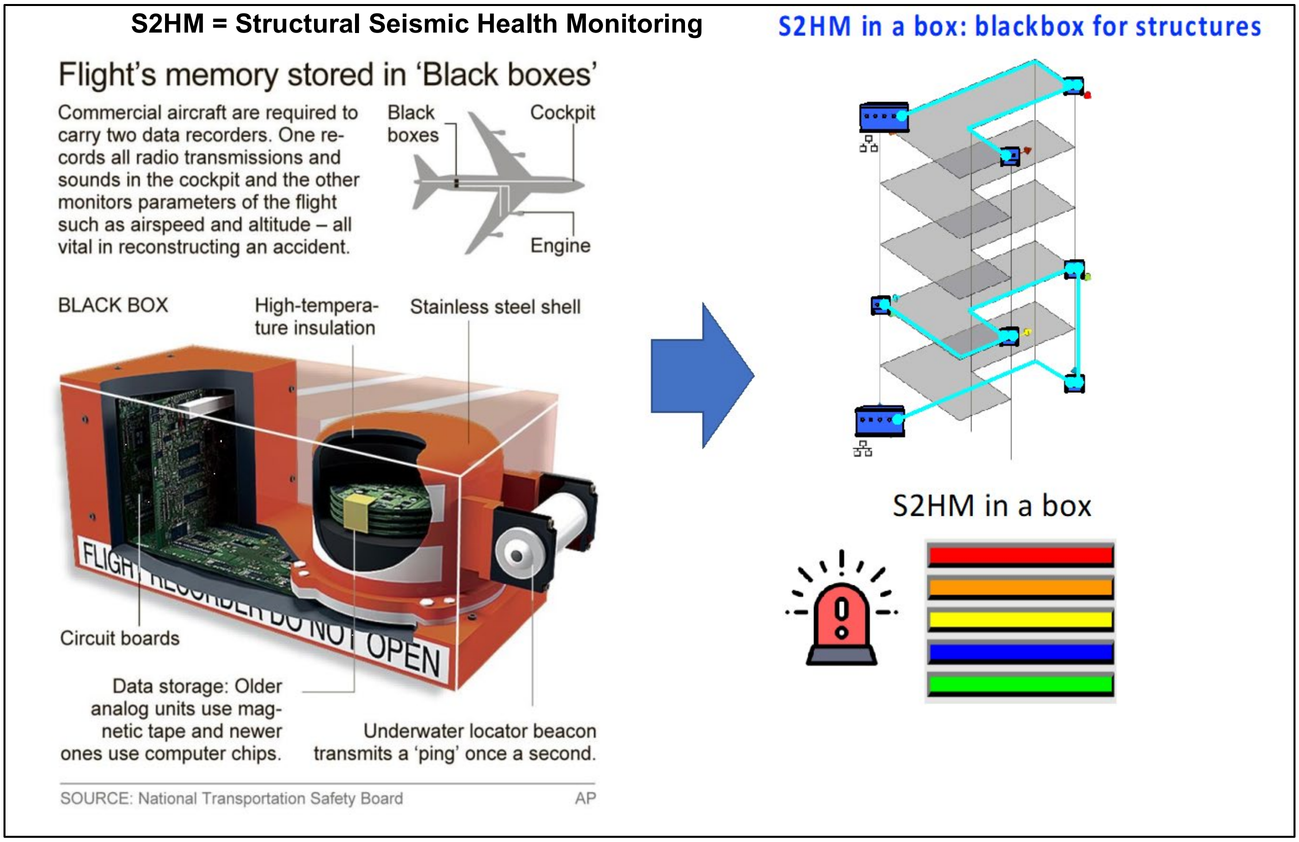


Figure 17. The concept of "black boxes" for buildings (Courtesy of Talhan Biro).[20]

There is no doubt that the existing seismic instrumentation network will record strong motion data from the inevitable future earthquakes. With advances in technology and communications, these data can be used more extensively and effectively to provide very useful information to owners and operators of hospital facilities regarding the structural health of their facilities on a timely basis and help them to make informed decisions regarding operations, occupancy, and allocation of resources after significant earthquake events.

Some facilities may need additional instrumentation to provide the necessary resolution of data to identify some key indicators of damage. However, there may also be more low-cost instrumentation that could provide these data that may be commercially available that need not be part of HCAI's instrumentation program. Individual or corporate hospital operators may find that investment in private seismic health monitoring systems will be beneficial and financially sound. If the recorded data would become available for curation and subsequent analysis by HCAI and engineering researchers, even more value and advances in understanding structural and nonstructural behavior can be learned and improvements can be made.

[20] Naeim, F., Kanda, K., Ventura, C. and Biro, T. 2021, Roadblocks and Incentives for Worldwide Adaptation and Implementation of Seismic Structural Health Monitoring (S2HM), Special Session at 17th World Conference on Earthquake Engineering, Sendai, Japan.

Chapter 5 – Future of Alternative Instrumentation and Data Analytics

This section introduces the potential role that alternative instrumentation technology and the application of data analytics can play in expanding the number of instrumented hospital buildings for the purpose of determining the safety status of hospital buildings during and immediately after earthquakes.

Lower cost and lower resolution sensors such as Class C MEMS[21] (micro-electromagnetic systems) accelerometer sensors (Figure 18) are becoming widely available and could be one of the sensor types that could help more widespread instrumentation of hospital buildings for the post-earthquake safety assessment purposes. Site and building specific real time data that would be highly valuable in the post-earthquake response environment. Other technologies such as the USGS ShakeAlert Earthquake Early Warning System, Community Seismic Network (Figure 19), displacement and velocity measurement devices (Figure 6), airborne and spaceborne remote sensing devices, and artificial intelligence based tools for damage assessment (Figure 20) are all potential tools that could be implemented in hospital facilities now or in the future, once they have been studied and their ranges of accurate response and limitations are clearly established, to assist with post-earthquake status evaluation of hospital buildings.

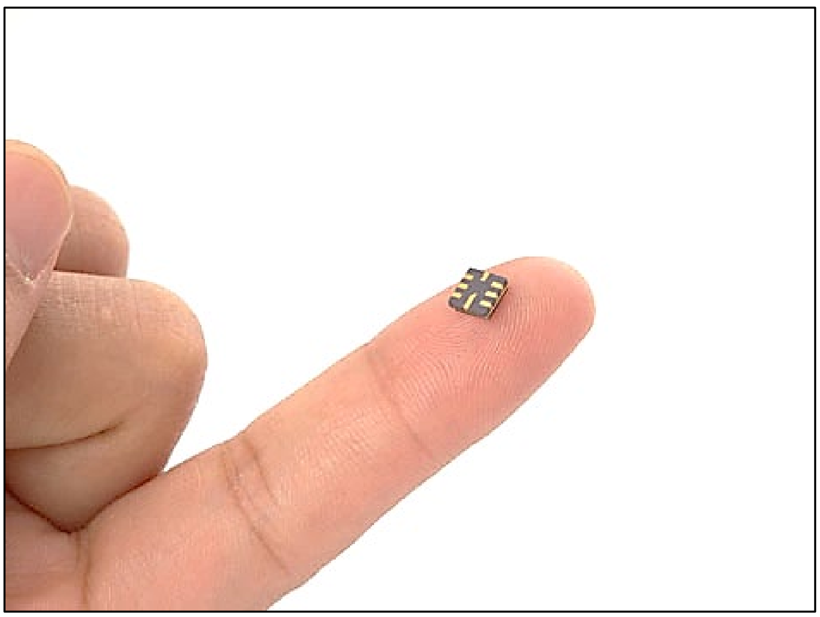


Figure 18. *A typical MEMS sensor which can be used to measure acceleration, tilt, pressure, and humidity. Many of these sensors are installed in every modern cell phone in use today.*[22]

---

[21] Evans, J.R., Allen, R.M., Chung, A.I., Cochran, E.S., Guy, R., Hellweg, M. and Lawrence, J, F. (2014), Performance of Several Low-Cost Accelerometers, Seismological Research Letters Vol. 85, No. 1 January/February.

[22] https://www.winsen-sensor.com/sensors/mems-gas-sensor/

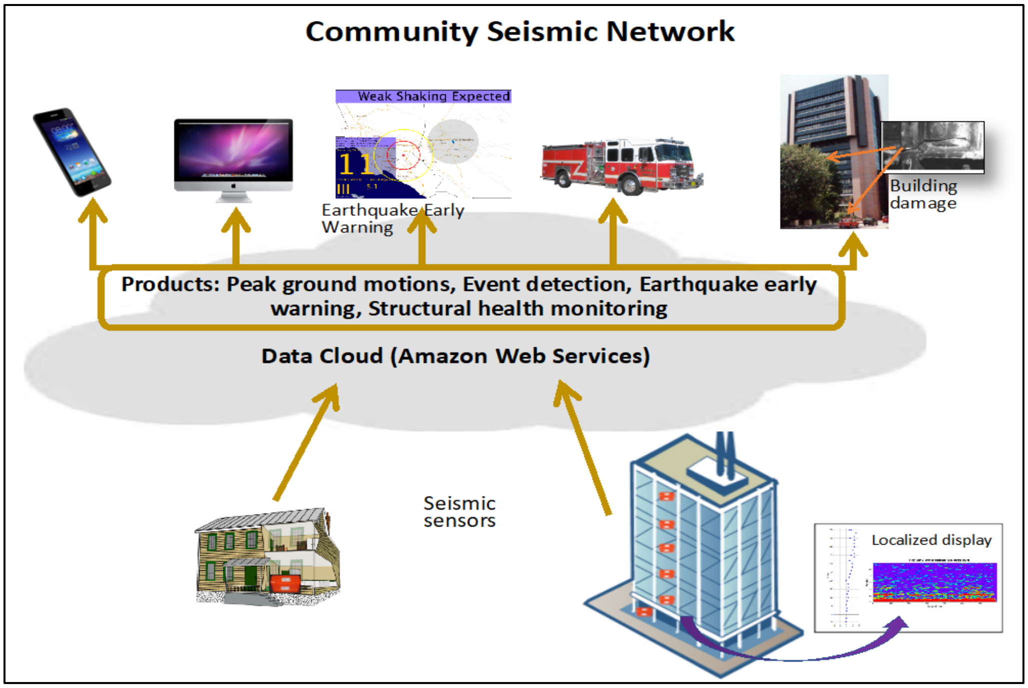


Figure 19. The Community Seismic Network implemented and managed by California Institute of Technology and UCLA provides a low-cost alternative for instrumentation of school campuses and other buildings with limited budget for instrumentation.[23]

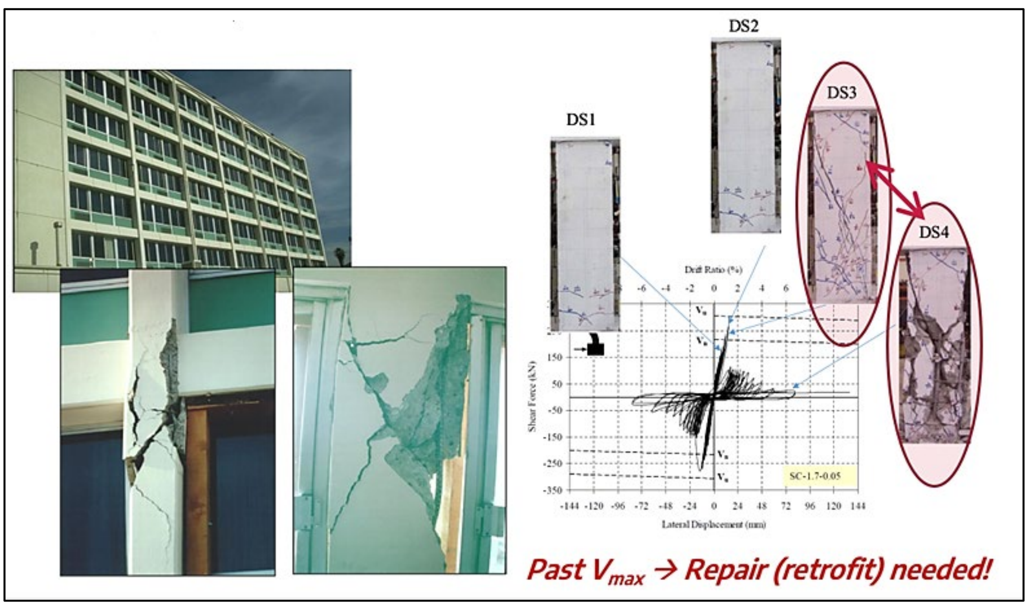


Figure 20. Integrating artificial intelligence, machine learning, and photographic tools creates yet another opportunity for immediate post-earthquake assessment of buildings as demonstrated by the ATC-145 project currently underway and sponsored jointly by FEMA and the New Zealand Earthquake Commission.[24]

[23] http://csn.caltech.edu/pdf/Function_Schematic.pdf

[24] Elwood, K.J. and Moehle, J.P. (2021), ATC-145 Update: Draft Guideline for Post-Earthquake Assessment, Repair, and Retrofit of Buildings, Proceedings of the 2021 Los Angeles Tall Buildings Structural Design Council Conference, Pages 86-94.

Adding Class C MEMS or similar sensors to existing instrumentation of instrumented hospital buildings or installing them in the vast number of hospital buildings that are not instrumented can provide situational awareness of an earthquake within the hospital environment to facility managers.

The efficient post-earthquake operation of a hospital facility will also be dependent on the performance of the many support buildings surrounding the acute care hospital. These include central utility plants, medical office buildings, parking structures, records storage, imaging centers, etc. Use of lower cost sensors will make it more affordable for hospitals to install sensors in all important buildings on their campus.

ShakeMap and ShakeCast may provide shaking intensity information and inspection priority but are not specific to an individual structure. CSMIP waveform data may be difficult to interpret by non-technical users.

A web-based platform that gathers sensor data and puts it into context would greatly aid emergency response. The platform would:

a. be accessible to each hospital,

b. gather data from multiple building sensors (high fidelity or MEMS-based) and compare it to building specific vulnerability functions,

c. display easy-to-understand damage estimates; and

d. be available to structural engineers inspecting the buildings.

Historically, HCAI/CSMIP hospital instrumentation projects have predominantly used accelerometers, whereas displacement transducers have only been utilized in limited applications. Another alternative technology is a laser-based optical sensor for measuring building displacement that is now available (see Figure 6). This technology appears promising for obtaining direct measurements of relative displacements of the floors of buildings (story drifts) which are generally a very good indicator of the expected level of damage in various floors of the building. The optical sensors do require a clear line of sight between the laser source and position-sensitive detector.

Chapter 6 – Improving Community Awareness of the Value of Strong-motion Instrumentation

It is a frequent observation that most people in the state of California have little knowledge of strong motion instruments, what they measure, or why they are important to public safety. As a result, public support for this vital element of earthquake safety may inhibit long-term funding for hospital instrumentation and maintenance. The life-safety benefit of robust hospital instrumentation is the ability to quickly identify any hidden structural problems in the affected hospitals that might make them unsafe to occupy. At the current level of hospital instrumentation, the instruments by themselves are not generally adequate to allow HCAI to fully assess damage to hospitals rapidly and accurately after a large urban event or for a large event in rural parts of the state where alternative hospital facilities are limited. HCAI engineers need to conduct an in-person assessment and review of damage at a site to evaluate whether a hospital is deemed to be fit for immediate occupancy (Green Tag), restricted occupancy (Yellow Tag), or unsafe (Red Tag). Until such evaluations are completed, the hospital facility is generally self-reliant in the determination of whether to continue or curtail health care services. In-person evaluations by qualified engineering professionals may take days to accomplish, during which time large aftershocks are likely to occur that could potentially further damage earthquake-weakened structures.

The purpose of this section is to provide HCAI with advice on how to develop and implement an effective outreach program to educate targeted audiences and promote instrumentation of acute care and skilled nursing facilities throughout the state.

HCAI should consider three audience groups for outreach and education efforts. These are:

1. Decision-makers, hospital owners, emergency responders
2. Professional engineering and scientific communities
3. Interested members of the public

Each of these groups should have a tailored informational message distributed within its ranks. The makers and users of this instrumentation should be getting regular messages that explain what is being measured, how it affects their well-being and why it is important, especially after a significant earthquake.

The first group includes elected officials, facility owners/operators, and emergency managers and responders. This group needs to have access to good explanations of the information that they are relying on to make decisions that affect the hospital community. Because of the range of specializations in this group, they may be more difficult to reach as a group and require different outreach approaches for subgroups. For example, elected officials at the state level cannot be contacted directly by unelected civil service employees. Such contacts need to be arranged by legislative liaisons at the state department or agency levels. However, state agencies such as HCAI and CSMIP need to prepare informative presentations and illustrated reports that explain what the instrumentation programs do for hospital buildings. Those reports can also form the basis for HCAI staff and their consultants to interact with city and county officials, first responders, and emergency planning personnel, as the need for the information arises. For decision-makers, hospital building owners, and emergency responders, the message is that their building is instrumented and the strong-motion records from inside the building can go a long way toward determining whether the building remains safe to occupy after the earthquake.

The second group primarily includes licensed civil/geotechnical/structural engineers, seismologists, and other geoscientists who are involved in the design and review of hospital and health care delivery development and construction projects. This group also includes university researchers who advance the tools used to produce earthquake-resistant structures. The message to this group should be technical and explain in detail the benefits of seismic instrumentation, and how it can be designed, implemented, and utilized. Examples of the ability to identify potential areas of structural and nonstructural distress from earthquakes, such as those given in Section 3 of this white paper, should be showcased.

The third group, consisting of the general public, should be made aware that technology exists today that seismic instrumentation when coupled with appropriate analysis packages can provide near real-time indications of structural and nonstructural distress in the hospitals that they rely upon to be available when “The Big One” occurs. They can have some confidence that in times of need, the hospitals they go to or are taken to have been evaluated for safety with reliable data and can be a safe harbor during periods of emergency following an earthquake. The message might be that the areas of greatest damage can be identified right after the earthquake so that they can stay away from those areas and identify areas where family and friends might need help. They also should understand that strong motion data are critical to the earthquake early warning system so that it can help to identify when severe ground shaking will arrive where they are located.

In addition to HCAI, other state agencies, organizations, and entities engage in outreach efforts related to seismic safety, such as:

- The California Geological Survey Strong Motion Instrumentation Program (CSMIP)
- The California Governor’s Office of Emergency Services (CalOES)
- The California Integrated Seismic Network (CISN)
- The Alfred E. Alquist Seismic Safety Commission (SSC)
- The California Department of Public Health (CDPH)

HCAI should build on partnerships with these and other state agencies and together they should engage their Public Affairs Officers to develop a coordinated outreach effort that prepares materials and strategies to send group-specific messages that remind them of the value of earthquake instrumentation and inform them about new advances in the field. Outreach can use websites, social media platforms, science podcasts, and/or traditional television, radio and print media methods. Technical staff input from HCAI and CGS will be necessary to make sure the messaging is accurate and at the right technical level for the targeted audience. HCAI should also consider setting up a partnership between the Legislative Liaison Officers from these and other agencies to develop outreach materials and strategies for engaging California legislators and local government elected officials.

Triggers for frequent, simple messaging to these groups should be identified along with prepared language so that messages can be produced and disseminated quickly. Examples of message triggers might include:

- Small but felt earthquakes anywhere in California or in bordering states.
- Damaging earthquakes anywhere in the United States or North America.
- Introduction of new instrument technologies or processing capabilities.
- Significant new instrumentation projects.

Technical staff (engineers, geologists, and seismologists) from all these agencies should identify professional organization publications and meetings and coordinate the preparation of technical papers and presentations that promote instrumentation and new applications.

Chapter 7 – Summary, Recommendations and Conclusions

Seismic instrumentation of buildings, and hospitals in particular, have provided important data regarding the response and behavior of structures in earthquakes for the purpose of seismic hazard mitigation. These data have been used by HCAI along with architects, engineers, and contractors that design and build health care facilities to design and construct better and safer hospitals. The data from seismic instrumentation have been used to improve the building codes as more is learned from the performance of hospital facilities and structures in general from every earthquake. The data are also useful in verifying the performance of new innovative technologies and building materials. The data have also been important in identifying potential problems in hospital construction and in the nonstructural components that are important to the continued operation of these critical facilities during and after large earthquake events. However, these benefits from seismic instrumentation are not fully realized until sometime after the earthquake occurs.

Technological advances in recent years now give us the opportunity to better use the data from seismic instrumentation to potentially provide essentially real-time understanding of the behavior of structural and nonstructural systems when strong earthquake shaking occurs. Through a combination of the seismic instrumentation, fast modern communications, efficient computing equipment, and curated software applications, we now can identify areas of concerns in the structural and nonstructural systems within a very short time after the earthquake occurs. This can be accomplished with relatively modest cost using economical Class C MEMS or similar technologies and WIFI connections, and personal computers.

Why would a hospital facility want to do this? A hospital administrator will need to make many important decisions about the operations of the facility after a strong earthquake occurs. The most important questions include but are not limited to:

- How safe is the hospital structure?
- How safe are the nonstructural components, such as mechanical, electrical, and plumbing systems?
- Is it safe to use medical equipment now?
- Can we continue to keep the hospital operational?
- Can we keep part of the facility operational?
- Do we need to evacuate?
- Do we need to curtail certain services?

As mentioned earlier, HCAI will send out engineers to evaluate hospital facilities after an earthquake which triggers building inspections, however, if the earthquake affects a large area, these evaluations will take time to complete. In the meantime, a hospital administrator may be forced to address the critical questions above without being a design, construction, or mechanical professional.

If the hospital facility had a seismic instrumentation system, the administrator in consultation with his or her design professionals would be able to make informed decisions and be more confident on these and other critical issues regarding the continued operation of the hospital very shortly after the earthquake occurs. It is advisable for the hospital to retain the services of a qualified engineer that can evaluate the data and output from the seismic instrumentation and provide more expert advice on those issues. There are commercial entities that can provide installation of such systems and technical support to interpret the results after an earthquake occurs. In addition, having such data and professional evaluation available will also aid HCAI in its evaluation of the facility and determination of the hazards and risks at that facility.

In conclusion, although there are some expenditures needed, a seismic instrumentation system for a hospital in California is a wise investment and provides some key insights into the structural health of the hospital structure and its supporting systems when an earthquake occurs. Hospital administrators, with the assistance of qualified experts, will have a very powerful tool that will aid in making some very important and timely judgments and decisions regarding continuing or discontinuing some or all healthcare functions at the facility. This is important for the safety of the patients and staff and the physical plant. Having such a system can also reduce the possibility of suspending health care services unnecessarily due to inadequate information and knowledge. The unnecessary loss of health care services after a major earthquake is never desirable and can cause loss of life or significant deterioration to the health of patients. Timely and wise decisions based on reliable data can avoid or minimize the financial impacts resulting from uninformed decisions and actions after an earthquake.

The Hospital Building Safety Board is encouraged by the advancements in technology and the role that increased use of seismic instrumentation beyond what is required by the Building Code can do to provide health care in times of emergency caused by earthquakes. It is our hope that hospital owners and administrators will consider seismic instrumentation as a wise investment to protect their patients and staff as well as their physical plant.

Appendix

Table A1. List of instrumented hospital buildings under the HCAI jurisdiction

No	HCAI Region	Facility Name	Building Name	Number of Sensors
1	Central	Alameda Hospital	South Wing	12
2	Central	Alta Bates Summit Medical Center-Alta Bates Campus	1985 Building	12
3	Central	California Pacific Medical Center - Mission Bernal Campus	New Hospital	16
4	Central	California Pacific Medical Center - Van Ness Campus	New Acute Care Hospital	24
5	Central	Eden Medical Center	Replacement Hospital	19
6	Central	George L. Mee Memorial Hospital	New Hospital	10
7	Central	Good Samaritan Hospital	Main Hospital	15
8	Central	Kaiser Foundation Hospital - Fremont	Hospital Patient Wing North	3
9	Central	Kaiser Foundation Hospital - Fremont	Hospital North	12
10	Central	Kaiser Foundation Hospital - Oakland/Richmond	Hospital	18
11	Central	Kaiser Foundation Hospital - San Francisco	North Wing	18
12	Central	Kaiser Foundation Hospital - Walnut Creek	Phase II Hospital	16
13	Coastal	Kaiser Foundation Hospital-Santa Clara	Hospital - Phase I	18
14	Coastal	Kern Medical Center	Wing D	11
15	Coastal	Lucile Packard Children's Hospital Stanford	New LPCH Expansion Building	21
16	Coastal	Mammoth Hospital	New Wing	10
17	Coastal	Marian Regional Medical Center	New Hospital Expansion	12
18	Coastal	MarinHealth Medical Center	06 - West Wing	12
19	Coastal	Mills-Peninsula Medical Center	New Hospital	24
20	Coastal	Natividad Medical Center	Acute Care (Building 500)	15
21	Coastal	Northbay Medical Center	Phase 1 Replacement Building	12

No	HCAI Region	Facility Name	Building Name	Number of Sensors
22	Coastal	Novato Community Hospital	Hospital	12
23	Coastal	O'Connor Hospital	Replacement Facility	16
24	Coastal	Priscilla Chan and Mark Zuckerberg San Francisco General Hospital and Trauma Center	Replacement Hospital	24
25	Coastal	Santa Barbara Cottage Hospital	Centennial Wing (Building I) (Arlington Pavilion)	9
26	Coastal	Santa Clara Valley Medical Center	West Wing K Nursing (6006)	15
27	Coastal	Santa Clara Valley Medical Center	Replacement Bed Building (Sobrato Pavilion) (6011)	20
28	Coastal	St. Louise Regional Hospital	Hospital Building Area A	10
29	Coastal	Stanford Health Care	Diagnostic Treatment Center	12
30	Coastal	Stanford Health Care	New Stanford Hospital	36
31	Coastal	Tenet Health Central Coast Twin Cities Community Hospital	Main Hospital	9
32	Coastal	UCSF Medical Center	Long Hospital	16
33	Coastal	UCSF Medical Center at Mission Bay	UCSF Benioff Children's Hospital	18
34	Coastal	Washington Hospital	Main Building	21
35	North	Kaiser Foundation Hospital - Santa Rosa	Hospital	13
36	North	St. Joseph Hospital	Phase III Addition Building	11
37	North	Sutter Coast Hospital	Hospital Building	10
38	North Los Angeles	Adventist Health Simi Valley	Main Hospital Building	12
39	North Los Angeles	Adventist Health White Memorial	Specialty Care Tower	9
40	North Los Angeles	Antelope Valley Hospital	Hospital Tower Addition	12
41	North Los Angeles	Children's Hospital Los Angeles	Anderson Pavilion	12
42	North Los Angeles	Community Memorial Hospital - San Buenaventura	New 6 Story Hospital Tower - West	24
43	North Los Angeles	Encino Hospital Medical Center	Main Tower / Basement / Mech Building	12
44	North Los Angeles	Henry Mayo Newhall Hospital	Main Hospital - Original Building	12

No	HCAI Region	Facility Name	Building Name	Number of Sensors
45	North Los Angeles	Hollywood Presbyterian Medical Center	South Wing	12
46	North Los Angeles	Hollywood Presbyterian Medical Center	D & T Tower	15
47	North Los Angeles	Huntington Memorial Hospital	West Tower	9
48	North Los Angeles	Kaiser Foundation Hospital - Downey	Main Building	9
49	North Los Angeles	Kaiser Foundation Hospital - Los Angeles	LAMC Hospital - Phase I	9
50	North Los Angeles	Keck Hospital of USC	Main Hospital	24
51	North Los Angeles	LAC/Olive View-UCLA Medical Center	Main Hospital Building	13
52	North Los Angeles	LAC+USC Medical Center	Inpatient Tower	12
53	North Los Angeles	LAC+USC Medical Center	New Diagnostic and Treatment	20
54	North Los Angeles	Martin Luther King, Jr. Community Hospital	Trauma Center	21
55	North Los Angeles	Palmdale Regional Medical Center	Main Building	16
56	North Los Angeles	PIH Health Hospital - Downey	Original Nursing Tower	12
57	North Los Angeles	Providence Saint John's Health Center	North Pavilion Inpatient Tower	24
58	North Los Angeles	St John’s Regional Medical Center	Patient Tower	17
59	North Los Angeles	Ventura County Medical Center	Hospital Replacement Wing	24
60	North Los Angeles	Ventura County Medical Center	Fainer Wing - Building 304	12
61	South	Arrowhead Regional Medical Center	Diagnostic & Treatment Bldg.	8
62	South	Arrowhead Regional Medical Center	Nursing Tower	19
63	South	Arrowhead Regional Medical Center	Central Plant	3
64	South	Community Hospital of San Bernardino	North Hospital	12
65	South	Desert Regional Medical Center	East Tower	13
66	South	El Centro Regional Medical Center	North Wing	5
67	South	El Centro Regional Medical Center	Lab Building	7
68	South	Hemet Global Medical Center	Tower I	10

No	HCAI Region	Facility Name	Building Name	Number of Sensors
69	South	Hoag Memorial Hospital Presbyterian	East Wing	27
70	South	Hoag Memorial Hospital Presbyterian	Inpatient Tower - 1974	18
71	South	John F. Kennedy Memorial Hospital	West/South Wing	8
72	South	Kaiser Foundation Hospital - Ontario	Main Hospital	15
73	South	Kaiser Foundation Hospital - Orange County - Irvine	Main Building	15
74	South	Orange County Global Medical Center	Administration	6
75	South	Palomar Medical Center	Hospital	12
76	South	Palomar Medical Center	Central Plant	6
77	South	Providence Little Company of Mary Medical Center San Pedro	Central Wing Tower	12
78	South	Providence Little Company of Mary Medical Center San Pedro	West Wing & Entrance Canopy	12
79	South	Providence Little Company of Mary Medical Center Torrance	Original Hospital	21
80	South	Redlands Community Hospital	Radiology Addition	9
81	South	Riverside Community Hospital	Building B	12
82	South Los Angeles	Riverside University Health System - Medical Center	Ancillary Building	15
83	South Los Angeles	Scripps Memorial Hospital - La Jolla	Transition Tower (& 5A)	12
84	South Los Angeles	Sharp Memorial Hospital	South Tower	15
85	South Los Angeles	Southwest Healthcare System	Women's Center and Emergency Room	9
86	South Los Angeles	UC San Diego Health Hillcrest - Hillcrest Medical Center	Main Hospital Building	12
87	South Los Angeles	UC San Diego Health La Jolla - Jacobs Medical Center & Sulpizio Cardiovascular Center	Main Hospital	12
88	South Los Angeles	UC San Diego Health La Jolla - Jacobs Medical Center & Sulpizio Cardiovascular Center	Bed Tower	24