Seismic Instrumentation of Healthcare Facilities

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

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Hospital Building Safety Board
Instrumentation Committee

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Contents

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 and 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 that 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]

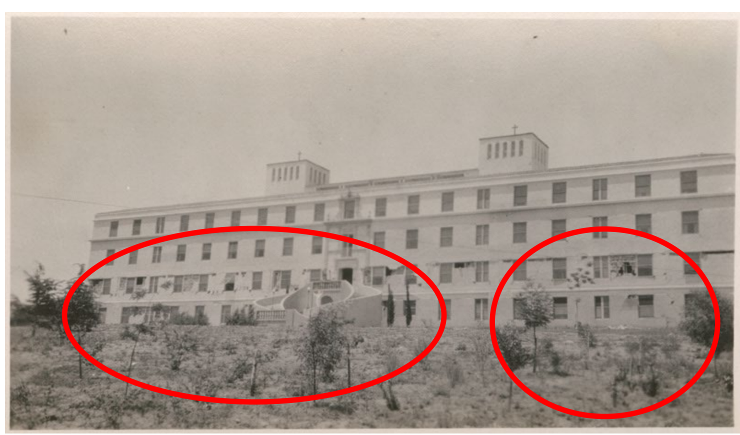

Figure 2. Damage to the Santa Barbara St. Francis hospital during the 1925 Santa Barbara earthquake[2]

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

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

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

Figure 4. Damage to the Olive View Hospital during the 1971 San Fernando earthquake[4]

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

[4]https://library.usgs.gov/photo/#/?category1=earthquakes&collection2=san%20fernando%20earthquake,%20february%201971)

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

After the 1971 San Fernando earthquake, the California legislature passed the 1972 Hospital Seismic Safety Act (HSSA). This Act 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. The intent was to bring any building whose useful life was being extended by a modernization program up to the modern seismic standards.

In 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 act experienced major structural damage and had to be evacuated. It must be noted that certain nonstructural components of the hospitals did incur significant damage, even in facilities built in accordance with the structural provisions of the HSSA Act.

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 have the tools and information necessary to make a rapid decision 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 the

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

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 (Figures 6 and 7) 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, or whether it should remain in service or be evacuated until repairs are made.

The target audience for this white paper are hospital owners, manages, and operators as well as public officials and the general public. More detailed technical information and references intended for design professionals are contained in a separate document available from HCAI (provide reference/hyperlink).

(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 health monitoring.

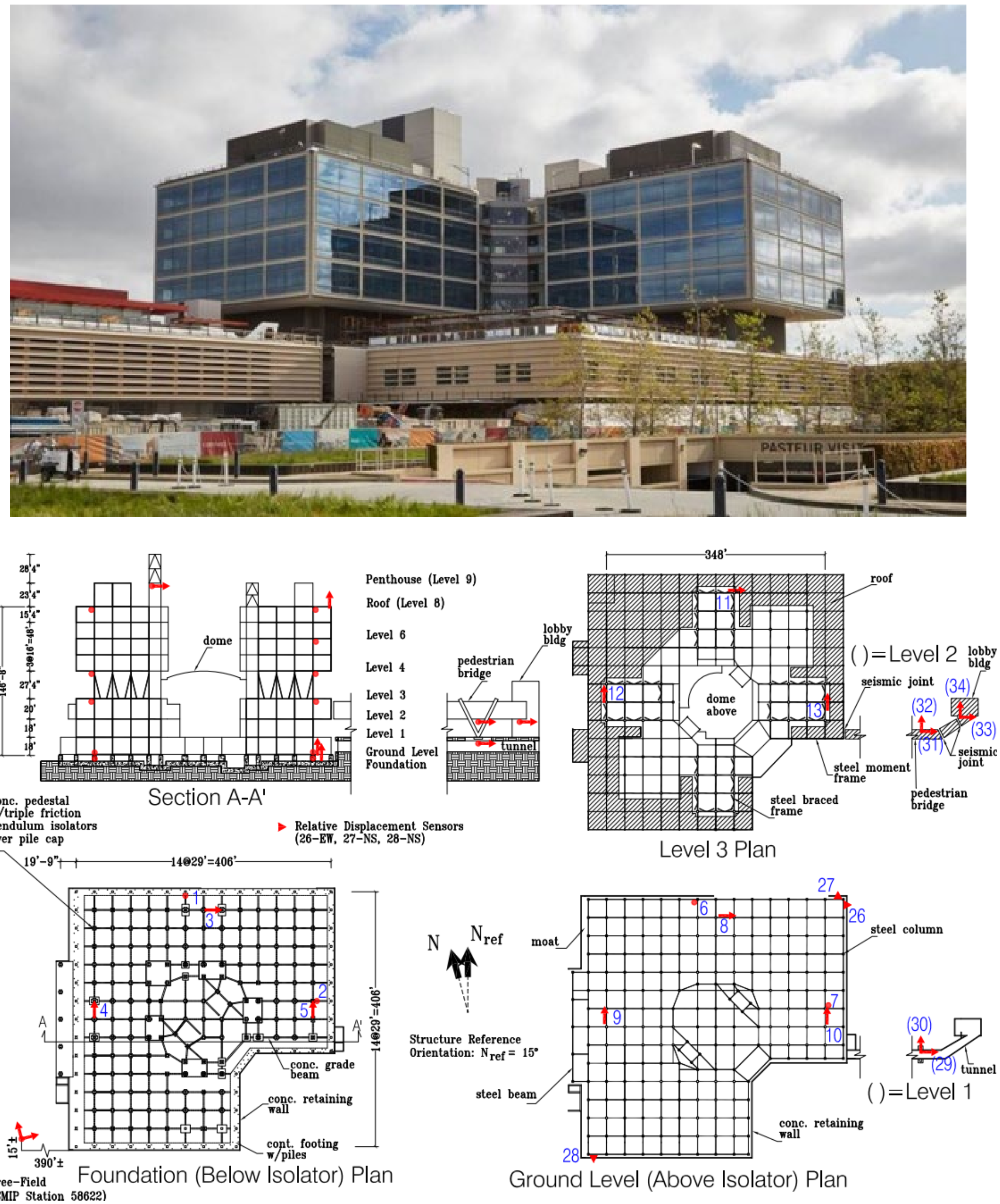

Figure 7[6, 7]. Photo (top) and sensor lay out diagram (bottom) of the seven-story hospital building at the Stanford Medical Campus. Red arrows in the schematic diagram show the locations and indicate the directional sensitivity of the strong-motion sensors (accelerometers). The sensors are connected to a central data acquisition system in the building.

[6] https://med.stanford.edu/news/all-news/2019/05/new-stanford-hospital-nearing-completion.html
[7] https://www.strongmotioncenter.org/NCESMD/photos/CGS/bldlayouts/bld58623.pdf

2 – Current Status of HCAI Instrumentation

In response to these needs explained in the previous section, for a long time now, the Department of Health Care Access and Information (HCAI – formerly the Office of Statewide Health Planning and Development or OSHPD) has 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 the hospital buildings when earthquakes occur and are useful and 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 may 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 (see Figure 8 and Appendix A Table). It should be noted that 90 instrumented hospital buildings represent a very small percentage of total hospital buildings in California and therefore more widespread instrumentation of hospitals is needed in order to immediately 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 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 behaviour. However, designs of hospitals buildings submitted for review that use such seismic resistance systems (deemed as experimental) may not yet be permitted by the CBC because the building code has not caught up with the latest technology. In those cases, HCAI under the provisions of "alternate means of compliance" permits such systems for hospital construction provided that such buildings are instrumented prior to the issuance of the certificate of occupancy. Examples include structures with Buckling Restrained Braced Frames, Steel Plate Shear Walls, Special Steel Moment Frames with SidePlate connections, 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 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 selects at least 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 characterizes the response of the subject buildings.

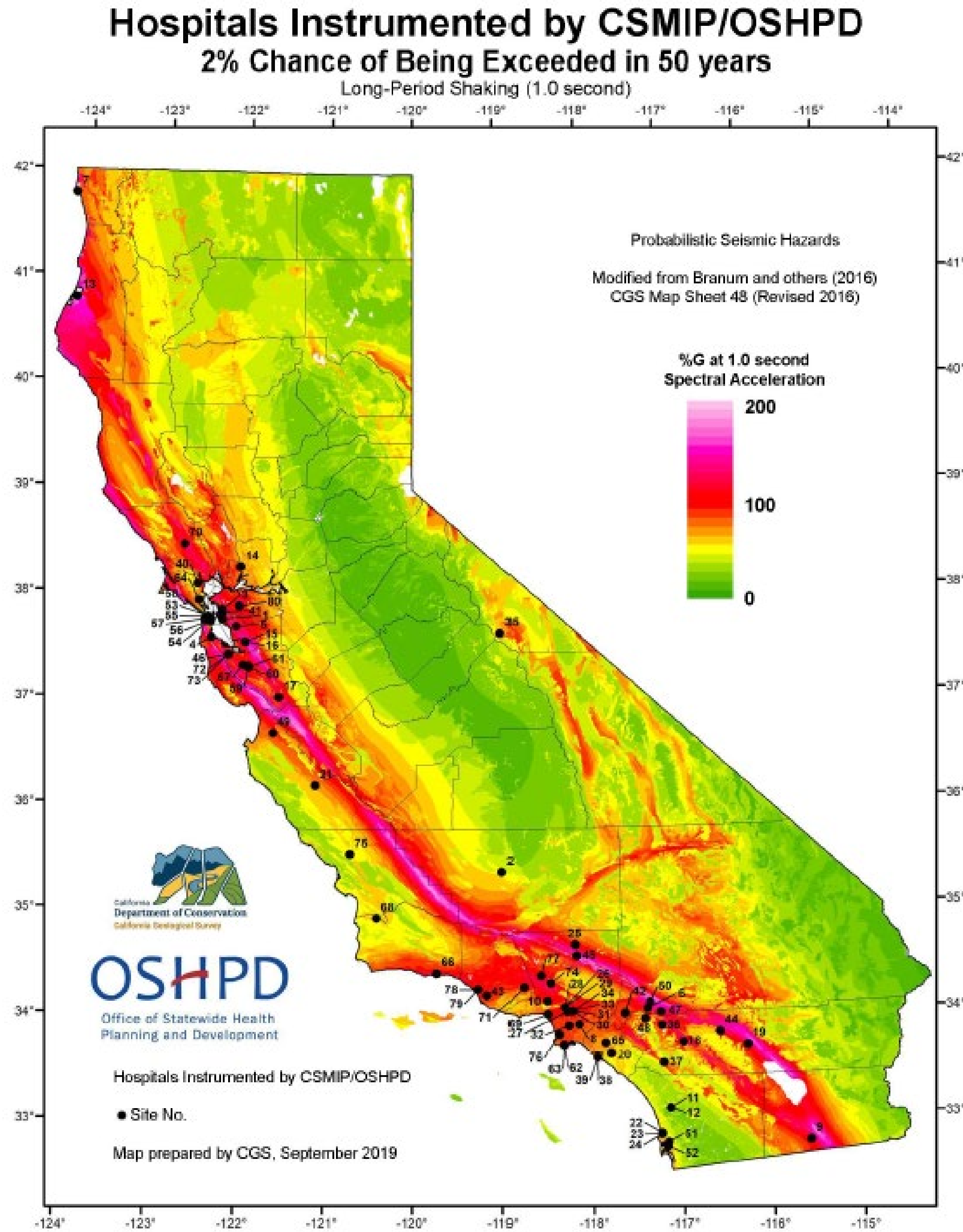

Figure 8. Locations of the instrumented hospital buildings (black dots). The base map is the seismic hazard map of the California. Colors on this map display the levels of horizontal shaking that have a 2 percent probability of exceedance in a 50-year period.

3 – The Utility of Hospital Instrumentation

Seismic instrumentation is vital tool that can provide for timely safety evaluation of hospitals and their contents following earthquakes. Unfortunately, as described in the previous section, there are only about 90 hospital buildings which are currently instrumented in California. Adaptation of some rather simple hardware/software/Internet technologies can make the instrument data recorded during earthquakes almost immediately available for safety assessment of hospital buildings and their contents. In addition, over the period of the past three decades, seismic instrumentation and evaluation of the response of instrumented buildings has resulted in significant changes and updates in seismic building design codes and practice. These include, but are not limited to, the following building code changes and improvements:

- Updating design ground motions and lateral force procedures
- Improvements of site response provisions in building codes
- Updating seismic design requirements for various building types and their structural and nonstructural components.
- Better understanding of soil-foundation-structure effects, and
- Improvements in building code formulas for estimating torsional effects and natural periods of buildings.

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 a number of 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 Olive View Medical Center hospital located in Sylmar (Figure 9) was one of the hospitals instrumented by CSMIP for HCAI. 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 performance of nonstructural components and contents was quite extensive during the Northridge earthquake and resulted in closure of this hospital for an extended period of time (Figure 10). The major lesson learned from the performance of the Olive View Medical Center 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 9. An outside view of Olive View Hospital Building the day after the 1994 Northridge earthquake.[8]

Figure 10. Examples of nonstructural damage at Olive View Hospital in the 1994 Northridge earthquake[8].

[8] 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 time after the earthquake. The analysis of the data would take more time also. Today, if the instrumentation of the building was connected to simple application on a computer or to a cell phone or tablet application that could process the sensor data and pass them through some very basic fragility functions (that predict damage), such as those embedded in HAZUS-MH (FEMA 2020) or FEMA P-58 documents (FEMA 2018), then a fairly accurate estimate the probability of the status of the building's structural and nonstructural performance would have been almost immediately available as shown in Figures 11 to 14.

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 would immensely facilitate more timely and more informed post-earthquake response in a hospital building.

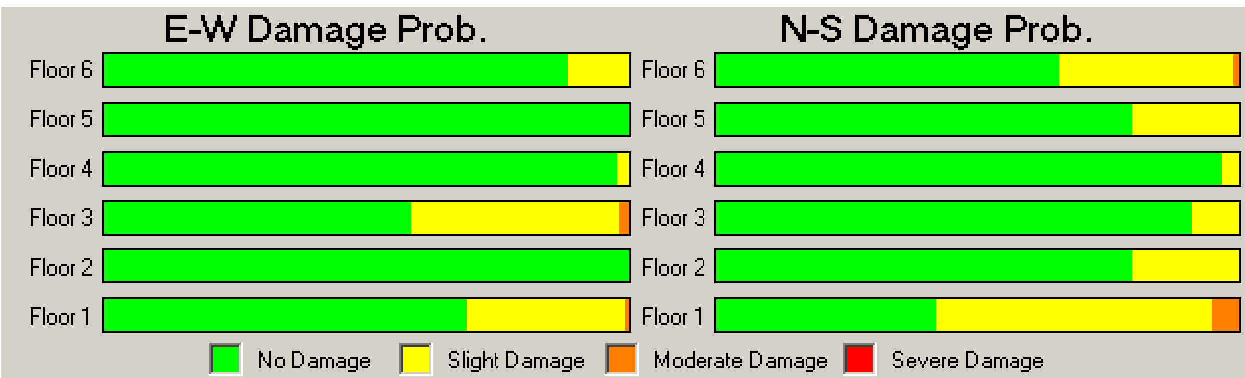

Figure 11. Instrumentation indicates no damage to slight damage status of the Olive View Hospital structural system following the 1994 Northridge earthquake using a relevant and readily available HAZUS-MH fragility function[9].

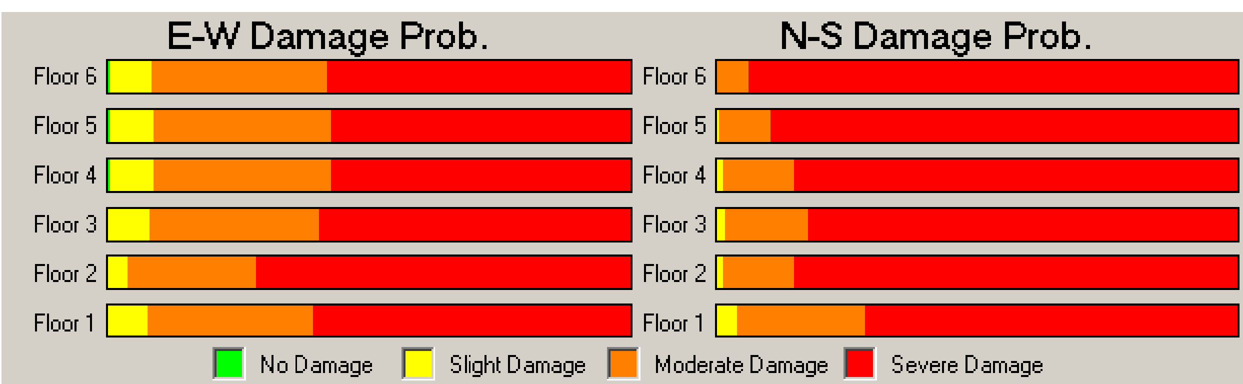

Figure 12. Instrumentation indicates moderate to severe damage status for the nonstructural systems of the Olive View Hospital following the 1994 Northridge earthquake using a relevant and readily available HAZUS-MH fragility function[9].

[9] 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

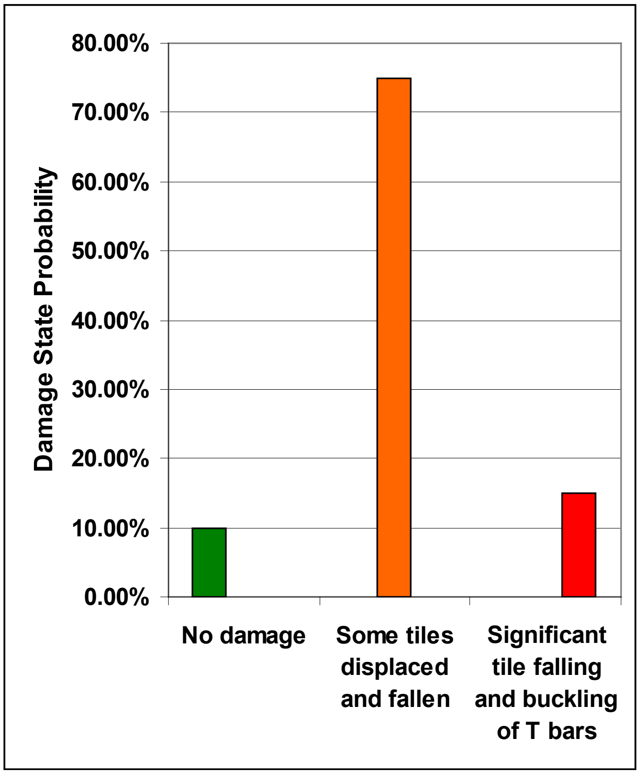

Figure 13. Instrumentation indicates displaced suspended ceiling tiles on the first floor of the Olive View Hospital following the 1994 Northridge earthquake using a relevant and readily available FEMA-P58 fragility function[9].

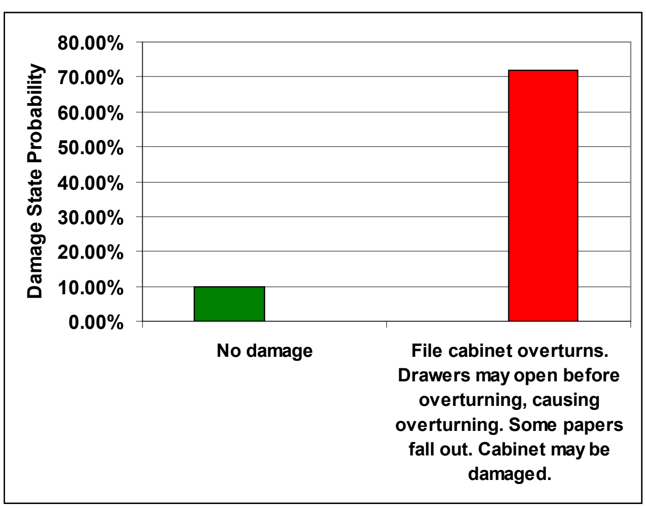

Figure 14. Instrumentation indicates overturning of file cabinets on the 6th floor of the Olive View Hospital following the 1994 Northridge earthquake using a relevant and readily available FEMA-P58 fragility function[9].

As illustrated in Figures 11 to 14, the fragility functions available in FEMA-P58 were able to confirm the observations of both structural and nonstructural performance of the Olive View Hospital in the 1994 Northridge earthquake. This same technology can be used today to have almost real-time evaluation of the structural and nonstructural conditions just after the earthquake event if the building has the appropriate seismic instrumentation.

4 – Improving the usefulness of our current Strong Motion data and network

As it was mentioned in Section 2, 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 likely 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 nostructural 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.

As mentioned earlier, HCAI required seismic instrumentation data is collected by CSMIP. The data recorded at each hospital building is transmitted to CSMIP as raw data that must be processed to be in a uniform standard format that can be readily used by researchers and other analysis platforms. CSMIP has a network of thousands of strong motion instruments in California that include non-hospital buildings, bridges, lifeline facilities and other types of installations. The availability of the processed data may be delayed because of the sheer amount of data to be processed. Also review of the processed data by CSMIP may be needed for quality control and assurance purposes.

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 decision making regarding continuing occupancy and services in buildings more quickly. More rapidly available data can also be used to prioritize resources for recovery and restoration of services.

We need to move from simple instrumentation to a concept similar to the concept of "Black Box" which is implemented in airplanes (Figure 15). If a building "black box" is located and functional in an instrumented building, at the time of an earthquake, the data from sensors are processed by the box and results will be made available almost instantaneously. After the event, the data is transmitted to the data center in Sacramento where it is received and processed and then posted to the data center at www.strongmotioncenter.org, 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 immediate notification of key people. The 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 data center in Sacramento, since the information would be available onsite in the "black box," at its URL (web address) on the Internet. It is likely that such a system could also be developed by and purchased from the instrumentation manufacturers. The software loaded in the box could be as specified by CSMIP and HCAI, and the software could also be modified by

CSMIP as needed for specific situations. For example, the data from certain sensors could be defined as key, and the box would process these and report them out immediately.

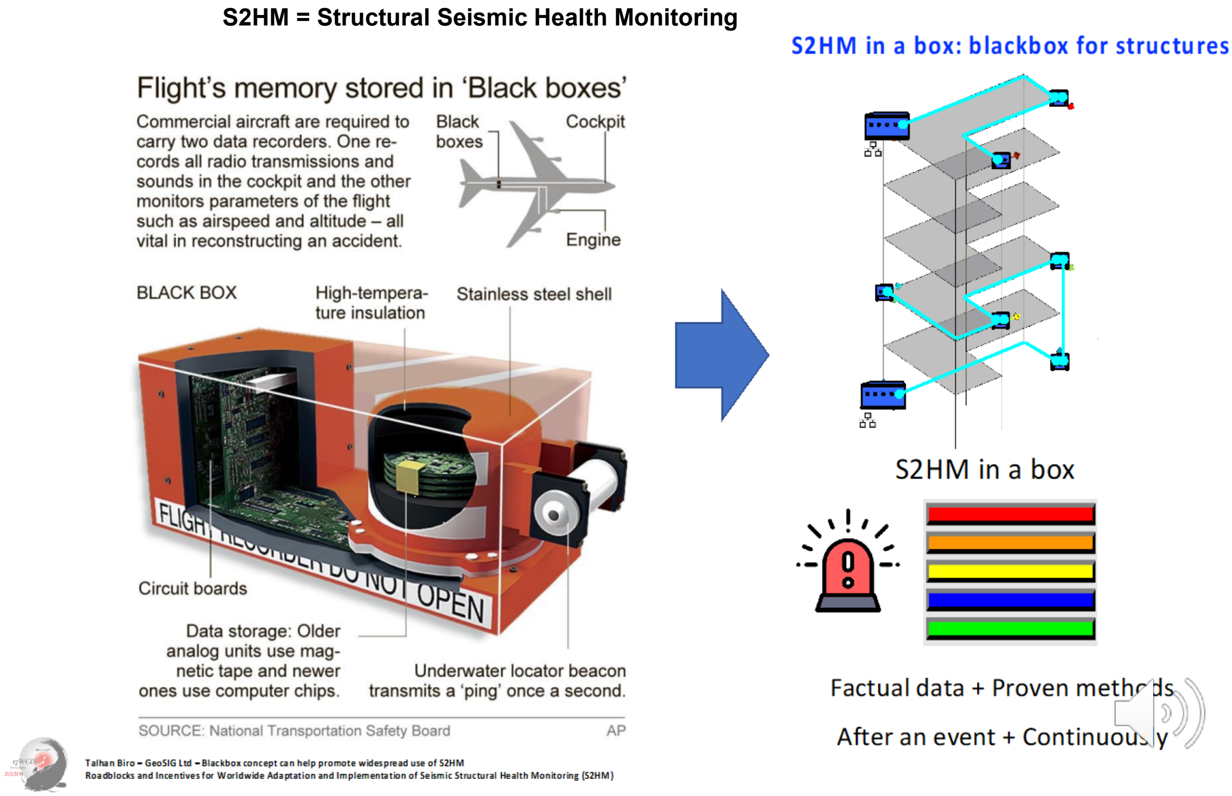

Figure 15. The concept of block boxes for buildings
(Courtesy of Talhan Biro, GeoSeis Ltd)[9]

There is no doubt that the existing network will record strong motion data from the inevitable future earthquakes. With advances in technology and communications, this data can be used extensively and effectively to provide very useful information to owners and operators of hospital facilities regarding the structural health of their facilities 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 may be able to provide this data that may be commercially available that may not necessarily be part of HCAI's instrumentation program. Individual or corporate hospital operators may find that investment in private seismic health monitoring systems may be beneficial and financially sound provided that the recorded data will be available for curation, and for subsequent analysis by HCAI and engineering researchers.

5 – The role that alternative instrumentation and/or data analytics can play in the future

This section provides an introduction on the potential role that alternative instrumentation technology and the application of data analytics can play in augmenting data obtained from the instrumented hospital buildings in the existing HCAI/SMIP instrumentation program or providing data in hospital buildings that are not instrumented. Lower cost MEMS (micro-electromagnetic systems) accelerometer sensors (Figure 16) are becoming widely available and could help provide more widespread 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 17), displacement and velocity measurement devices (Figure 6), airborne and spaceborne remote sensing devices, and artificial intelligence based tools for damage assessment (Figure 18) are all potential tools that could be implemented in hospital facilities now or in the future to assist with post-earthquake response and to provide valuable information on building response for use in future studies that could lead to future design improvements. However, the ShakeAlert and the Community Seismic Networks will only provide estimates of the free-field ground motions at any particular site and not be able to provide estimates of the motions within buildings.

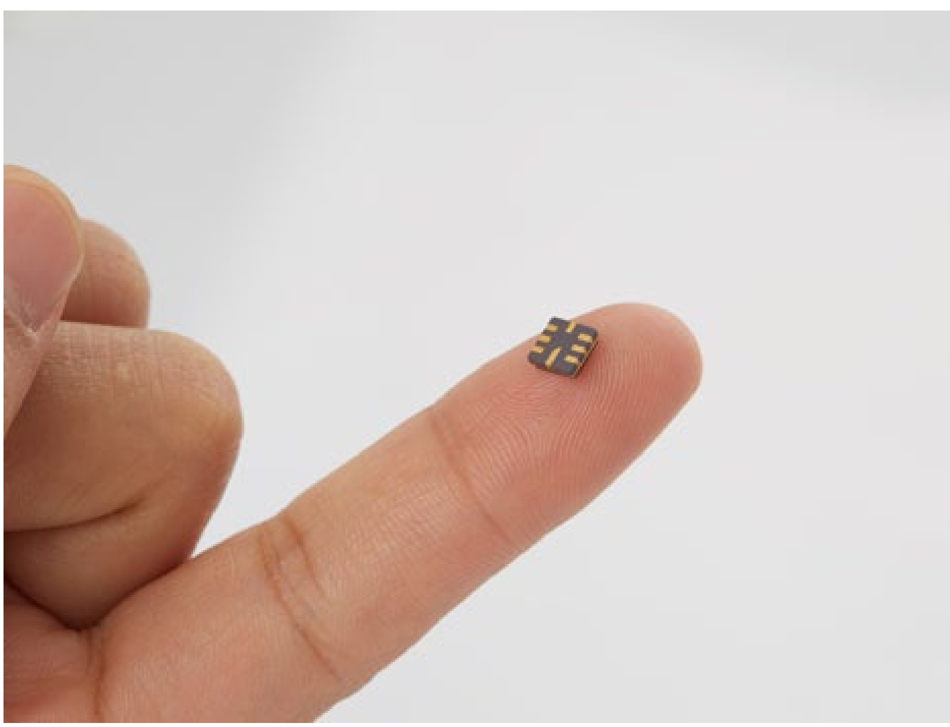

Figure 16. A typical MEMS sensor which can be used to measure accelerations, tilts, pressure, or humidity. Many of these sensors are installed in every modern cell phone in use today[10].

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

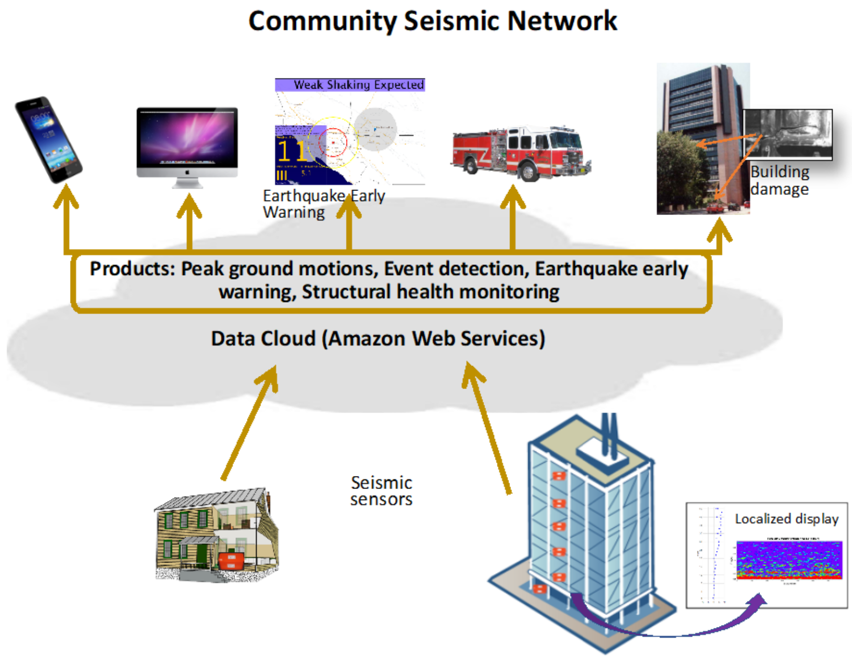

Figure 17. The Community Seismic Network implemented and managed by California Institute of Technology and UCLA provides a low-cost alternative for instrumentation of school campuses and other buildings with limited budget for instrumentation.[11]

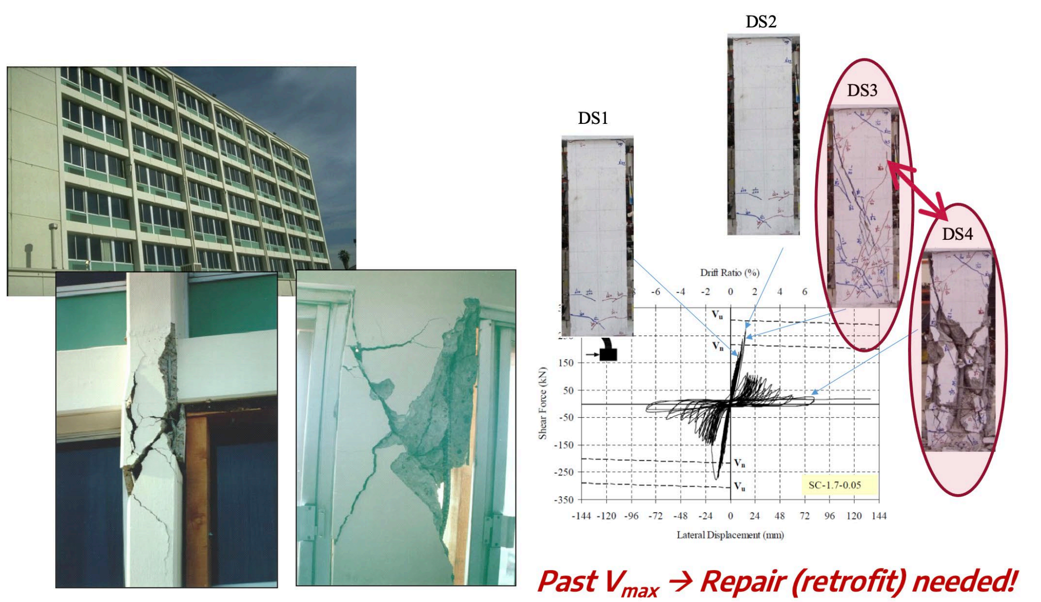

Figure 18. Integrating artificial intelligence, machine learning, and photographic tools creates yet another opportunity for immediate post-earthquake assessment of buildings as demonstrated by the ATC-145 project currently underway and sponsored jointly by FEMA and the New Zealand Earthquake Commission[12].

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

[12] 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 MEMS 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 surgeons, operators of sensitive imaging equipment, etc. Sensors placed in operating and imaging rooms could audibly alert doctors to stop what they are doing when shaking exceeds a threshold that is likely to indicate a high intensity event is occurring. Similar objectives could be achieved by implementation of low-cost Community Seismic Network-type sensors (consisting of MEMS).

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 a campus.

The current ShakeMap and CSMIP networks do not provide information that is readily accessible and meaningful to hospital staff in the seconds and minutes after an earthquake. ShakeMaps provide shaking intensity information, which is not specific to the vulnerability of an individual structure, nor always timely; in addition, 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.

A new laser-based optical sensor for measuring building displacement 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 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 which could make its application in existing hospital buildings difficult.

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 alternate hospital facilities are limited. HCAI engineers and inspectors 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 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 better instrumentation of acute care and skilled nursing facilities throughout the state.

HCAI might 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 general 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 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 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 in nature 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.

For the general public, the message might be that the areas of greatest damage are available to them 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 identify when severe ground shaking might arrive where they are located.

The third group, consisting of the general public, should be made aware that technology exists today that seismic instrumentation when coupled with even relatively simple 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" hits. The general public 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.

Currently there are other state agencies, organizations, and entities that 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)

HCAI should set up a partnership with other state agencies including the Department of Conservation (DOC), Alfred E. Alquist Seismic Safety Commission (SSC), and California Office of Emergency Services (CalOES). These agencies 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 HCAI, DOC, SSC, and CalOES 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 HCAI, CGS, SSC, and CalOES should identify professional organization publications and meetings and coordinate the preparation of technical papers and presentations that promote instrumentation and new applications.

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. This data has been used by HCAI along with architects, engineers and contractors that design and build hospital facilities to design and construct better and safer hospitals. The data from seismic instrumentation has 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 is also useful in verifying the performance of new innovative technologies and building materials. The data has 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 some time 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 if strong earthquake shaking occurs. Through a combination of the seismic instrumentation, fast modern communications, efficient computing equipment, and curated software applications, we now have the ability to 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 MEMS technology 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 may include:

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

As mentioned earlier, HCAI will send out engineers and inspectors to evaluate hospital facilities after an earthquake, however, if the earthquake affects a large area, these evaluations will take time to be undertaken. 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 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 of continued, partial, or suspension of occupancy and health care services at that facility or a portion of that facility.

In conclusion, although there are some expenditures needed, a seismic instrumentation system for a hospital in California may be a wise expenditure and provide 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 safety of the physical plant and the patients and staff at these facilities. 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 not desirable.

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 physical plants and their patients and staff.

Appendix A

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

No	Facility Name	Building Name	Number of Sensors
1	El Centro Regional Medical Center	North Wing	5
2	El Centro Regional Medical Center	Lab Building	7
3	UC San Diego Health La Jolla - Jacobs Medical Center & Sulpizio Cardiovascular Center	Main Hospital	12
4	Scripps Memorial Hospital - La Jolla	Transition Tower (& 5A)	12
5	Sharp Memorial Hospital	South Tower	15
6	UC San Diego Health La Jolla - Jacobs Medical Center & Sulpizio Cardiovascular Center	Bed Tower	24
7	UC San Diego Health Hillcrest - Hillcrest Medical Center	Main Hospital Building	12
8	Hemet Global Medical Center	Tower I	10
9	Desert Regional Medical Center	East Tower	13
10	John F. Kennedy Memorial Hospital	West/South Wing	8
11	Riverside University Health System - Medical Center	Ancillary Building	15
12	Hoag Memorial Hospital Presbyterian	East Wing	27
13	Kaiser Foundation Hospital - Orange County - Irvine	Main Building	15
14	Palomar Medical Center	Hospital	12
15	Palomar Medical Center	Central Plant	6
16	Hoag Memorial Hospital Presbyterian	Inpatient Tower - 1974	18
17	Southwest Healthcare System	Women’s Center and Emergency Room	9
18	Orange County Global Medical Center	Administration	6
19	Riverside Community Hospital	Building B	12
20	Providence Little Company of Mary Medical Center Torrance	Original Hospital	21
21	Providence Little Company of Mary Medical Center San Pedro	Central Wing Tower	12
22	Providence Little Company of Mary Medical Center San Pedro	West Wing & Entrance Canopy	12
23	PIH Health Hospital - Downey	Original Nursing Tower	12
24	Martin Luther King, Jr. Community Hospital	Trauma Center	21
25	Kaiser Foundation Hospital - Ontario	Main Hospital	15
26	Redlands Community Hospital	Radiology Addition	9
27	Community Hospital of San Bernardino	North Hospital	12
28	Arrowhead Regional Medical Center	Diagnostic & Treatment Bldg.	8
29	Arrowhead Regional Medical Center	Nursing Tower	19
30	Arrowhead Regional Medical Center	Central Plant	3
31	Adventist Health Simi Valley	Main Hospital Building	12
32	Providence Saint John's Health Center	North Pavilion Inpatient Tower	24
33	LAC+USC Medical Center	Inpatient Tower	12

No	Facility Name	Building Name	Number of Sensors
34	LAC+USC Medical Center	New Diagnostic and Treatment	20
35	Keck Hospital of USC		
36	Henry Mayo Newhall Hospital	Main Hospital - Original Building	12
37	Children's Hospital Los Angeles	Anderson Pavilion	12
38	Palmdale Regional Medical Center	Main Building	16
39	LAC/Olive View-UCLA Medical Center	Main Hospital Building	13
40	Keck Hospital of USC	Main Hospital	24
41	Antelope Valley Hospital	Hospital Tower Addition	12
42	Encino Hospital Medical Center	Main Tower / Basement / Mech Building	12
43	Hollywood Presbyterian Medical Center	South Wing	12
44	Hollywood Presbyterian Medical Center	D & T Tower	15
45	Good Samaritan Hospital	Main Hospital	15
46	Community Memorial Hospital - San Buenaventura	New 6 Story Hospital Tower - West	24
47	Ventura County Medical Center	Hospital Replacement Wing	24
48	Ventura County Medical Center	Fainer Wing - Building 304	12
49	Santa Barbara Cottage Hospital	Centennial Wing (Building I) (Arlington Pavilion)	9
50	St John’s Regional Medical Center	Patient Tower	17
51	Marian Regional Medical Center	New Hospital Expansion	12
52	Kern Medical Center	Wing D	11
53	Tenet Health Central Coast Twin Cities Community Hospital	Main Hospital	9
54	George L. Mee Memorial Hospital	New Hospital	10
55	Natividad Medical Center	Acute Care (Building 500)	15
56	Mammoth Hospital	New Wing	10
57	St. Louise Regional Hospital	Hospital Building Area A	10
58	Kaiser Foundation Hospital-Santa Clara	Hospital - Phase I	18
59	Kaiser Foundation Hospital - Fremont	Hospital Patient Wing North	3
60	Kaiser Foundation Hospital - Fremont	Hospital North	12
61	Santa Clara Valley Medical Center	West Wing K Nursing (6006)	15
62	Santa Clara Valley Medical Center	Replacement Bed Building (Sobrato Pavilion) (6011)	20
63	O'Connor Hospital	Replacement Facility	16
64	Washington Hospital	Main Building	21
65	Stanford Health Care	Diagnostic Treatment Center	12
66	Kaiser Foundation Hospital - Walnut Creek	Phase II Hospital	16
67	UCSF Medical Center	Long Hospital	16
68	Mills-Peninsula Medical Center	New Hospital	24
69	Alameda Hospital	South Wing	12

No	Facility Name	Building Name	Number of Sensors
70	Eden Medical Center	Replacement Hospital	19
71	Alta Bates Summit Medical Center-Alta Bates Campus	1985 Building	12
72	UCSF Medical Center at Mission Bay	UCSF Benioff Children's Hospital	18
73	Priscilla Chan And Mark Zuckerberg San Francisco General Hospital and Trauma Center	Replacement Hospital	24
74	Kaiser Foundation Hospital - Oakland/Richmond	Hospital	18
75	Lucile Packard Children's Hospital Stanford	New LPCH Expansion Building	21
76	Stanford Health Care	New Stanford Hospital	36
77	California Pacific Medical Center - Van Ness Campus	New Acute Care Hospital	24
78	California Pacific Medical Center - Mission Bernal Campus	New Hospital	16
79	Kaiser Foundation Hospital - San Francisco	North Wing	18
80	Marinhealth Medical Center	06 - West Wing	12
81	Northbay Medical Center	Phase 1 Replacement Building	12
82	Novato Community Hospital	Hospital	12
83	Kaiser Foundation Hospital - Santa Rosa	Hospital	13
84	St. Joseph Hospital	Phase III Addition Building	11
85	Sutter Coast Hospital	Hospital Building	10
86	Huntington Memorial Hospital	West Tower	3
87	Kaiser Foundation Hospital - Los Angeles	LAMC Hospital - Phase I	3
88	Adventist Health White Memorial	Specialty Care Tower	3
89	Kaiser Foundation Hospital - Downey	Main Building	3