

**RECORDED RESPONSE AND OBSERVED PERFORMANCE OF  
A WOOD-FRAME HOSPITAL BUILDING  
DURING THE 2003 SAN SIMEON EARTHQUAKE**

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**Abstract**

The Community Hospital in Templeton is a 1-story wood frame structure built in 1977 and instrumented by the California Strong Motion Instrumentation Program in 1994 as part of the OSHPD Hospital Instrumentation Project. During the M6.5 San Simeon Earthquake of December 22, 2003, maximum horizontal accelerations of 0.5 g and 1.3 g were recorded at the ground floor level and the roof, respectively. The hospital did not suffer structural or non-structural damage during the earthquake despite the strong ground shaking. This paper presents analysis results of the recorded response data and building performance observed after the earthquake. Some factors that can be attributed to the good performance of this hospital during the San Simeon earthquake are also discussed.

**Introduction**

The 84-bed acute care hospital in Templeton is a one-story wood frame structure built in 1977. The building was designed in 1975 as per the requirements of the California Code of Regulations, Title 17 (California Building Standards Code). The structure has an irregular plan with base dimensions of 336'x277' (Figures 1 and 2). Only the North Wing (111'x51') and the West Wing (72'x51') of the hospital are instrumented. These two wings are tied to other parts of the hospital without any seismic joints.

The essential character of the gravity load carrying system for the North and West Wings consists of 2x repetitive wood joists supported on 2x wood stud walls. The gravity loads are light and the spans are short. The interior bearing walls are framed with 2x wood studs and are sheathed with gypsum board on both sides. The story height is approximately 14'. The roof is

essentially flat and all the roof top equipment is arranged to be supported by the roof framing along the central corridors.

The lateral forces in the North and West Wings are transferred by the roof diaphragms to wood shear walls. The roof diaphragms are sheathed with ½" wood structural panels. The exterior shear walls are sheathed with ½" wood structural panels on 2x6 studs at 16" o/c with exterior stucco finish and gyp-board interior finish. There are a relatively small number of windows. Typical shear walls are 12 feet long and some are as long as 21.5 feet. Prefabricated proprietary tie downs have been provided in order to prevent shear wall uplift only for some interior shear walls. All walls are supported on 16" wide continuous concrete spread footings. The 5 inch thick concrete slab on grade is tied integrally to the footings.

According to the geologic and soil investigation report, the soils at the site are typically stiff clays underlain by the bedrock of the area, the Monterey shale. Below a depth of 29 feet in one of the borings the Monterey formation was encountered. The design soil bearing capacity is 3000 psf. The site is situated in seismic Zone 4 in an area surrounded by active faults. It is 26 miles west of the San Andreas Fault, 3 miles west of the Rinconada Fault, and 20 miles east of the Hosgri Fault Zone.



Figure 1. View of the 1-story Hospital in Templeton. The North Wing is on the left side of the photo, while the West Wing is on the right side.

### **Strong Motion Instrumentation**

The hospital in Templeton was instrumented in 1994 as part of the OSHPD/CSMIP agreement to instrument hospitals in California. It was recommended for instrumentation by the Instrumentation Committee of the Building Safety Board. The planning for the instrumentation of the hospital began in early 1993. The instrumentation was completed in June 1995. In general, instrumentation of a building involves the installation of accelerometers or other sensors at key locations throughout the structure. The number and location of sensors determines the amount of information that may be recovered about the response of the building after an

earthquake. Sensors installed at key structural members allow the important modes of vibration to be recorded and specific measurement objectives to be achieved. Optimal locations in a building were initially developed by CSMIP engineering staff after studying the lateral force resisting systems from the design drawings. Review of the candidate locations by the OSHPD structural engineer and a Strong Motion Instrumentation Advisory Committee member ensured an optimal layout of a limited number of sensors.

The final instrumentation plan includes 9 accelerometers in the building and three at a reference free-field site. The locations of these 9 sensors are shown in Figure 2. Each of these 9 sensors is connected via cabling to a central recorder located outside the building. The digital recorder coupled with a communication system allows the recording system to immediately send the data to the CSMIP office in Sacramento after the system is triggered by an earthquake. The ground response station was installed in the parking lot, about 200 feet northwest of the building, to measure the referenced ground motion for the building. Unfortunately, this station was removed due to hospital expansion construction before the 2003 San Simeon Earthquake. A new station was installed on January 27, 2004 at a location about 500 feet from the building.

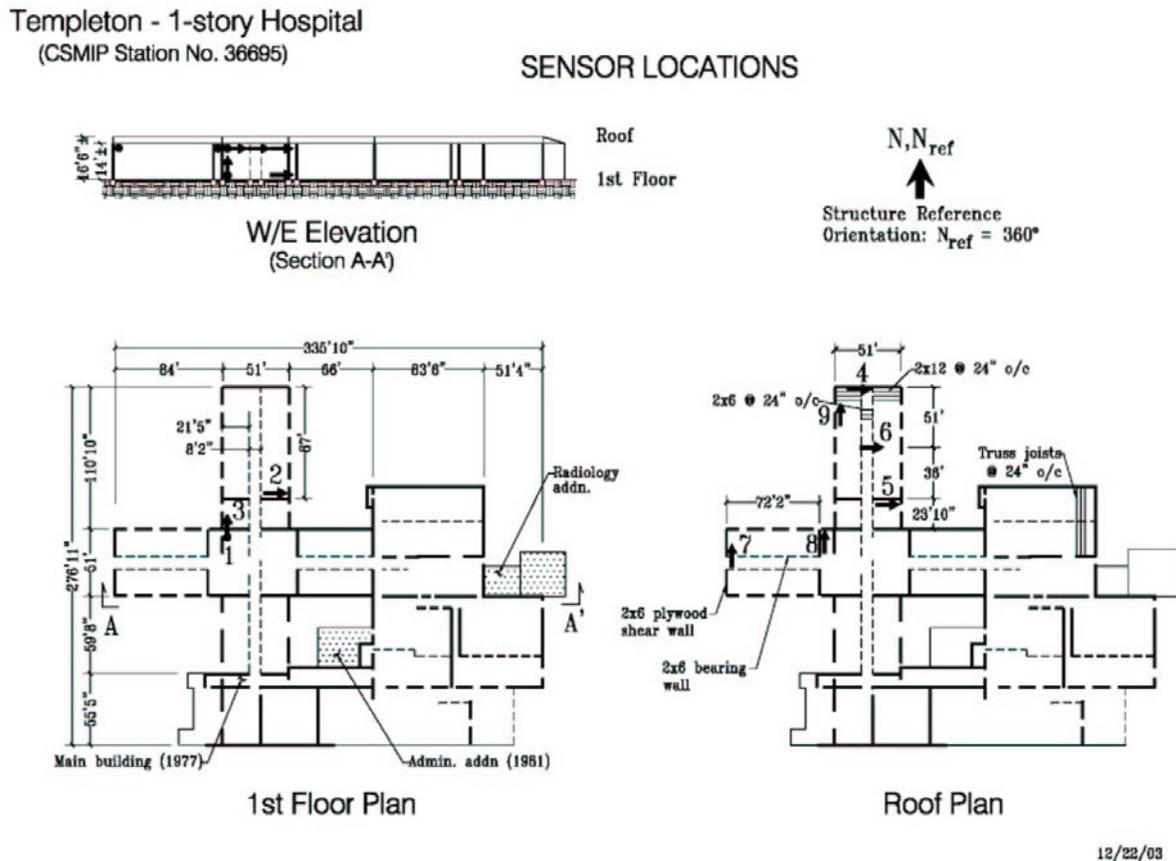


Figure 2. General plans of the 1-story Hospital in Templeton and locations of 9 sensors in the North and West Wings of the hospital.

The objective of instrumenting this hospital building is to measure its response during future earthquakes. Compared to the rest of the building, the distribution of the load carrying

system (both horizontal and vertical) is relatively regular in the North and West Wings of the hospital. Therefore, these two wings were selected for instrumentation. The input motion is measured at the ground floor level in three perpendicular directions. Since these two wings are 'light' wood frame structures, they are not likely to experience torsional base motion due to the inertial interaction effects. Therefore, the torsional input motion is not measured at the base of this building. The response of the structure is measured at the roof level of selected shear walls. Due to the flexible nature of the roof diaphragm the in-plane deformation was expected to be significant. The diaphragm in-plane motion is, therefore, measured by installing one sensor (i.e., Sensor 6) at a location almost midway between the north and south shear walls on the North Wing.

### Records from the 2003 San Simeon Earthquake

The magnitude 6.5 earthquake occurred near San Simeon on December 22, 2003. The epicenter was 11 km northeast of San Simeon, at a depth of about 8 km. Figure 3 shows a ShakeMap of contoured peak ground accelerations with the epicenter and inferred rupture fault indicated. Although the hospital is 38 km from the epicenter, it is only 12 km from the projected southern end of the rupture.

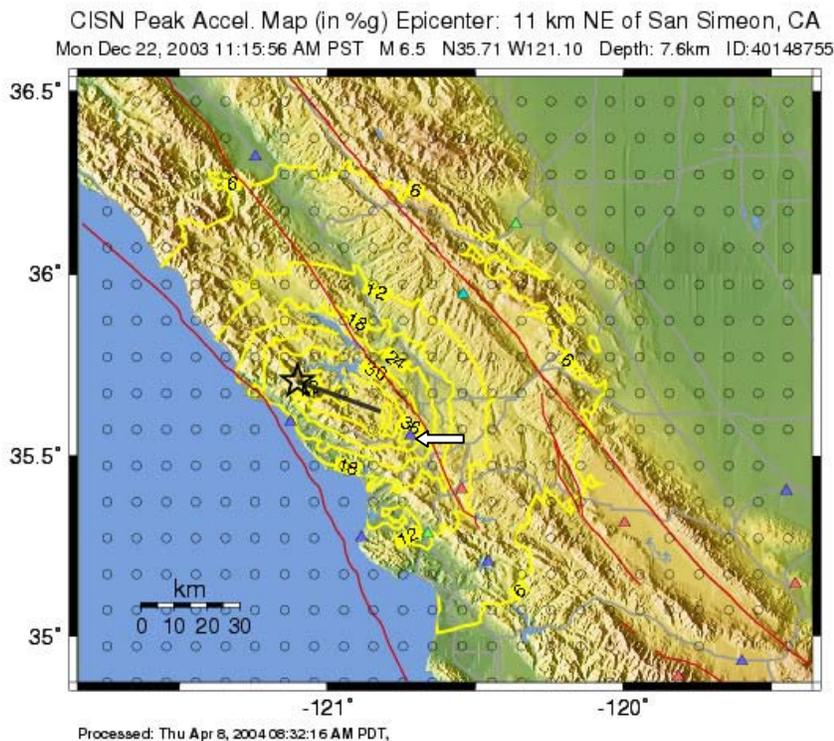


Figure 3. ShakeMap of the contoured peak ground accelerations for the San Simeon earthquake of December 22, 2003. The location of the hospital in Templeton is shown as a triangle indicated by an arrow.

The acceleration records from all 9 sensors in the building are plotted in Figure 4. These records as well as the velocities, displacements and response spectra were available to the users

right after the earthquake at the CISN Engineering Strong Motion Data Center (<http://www.cisn-edc.org>). The recorded maximum accelerations were 0.5 g at the ground level, 1.0 g on the top of the wall at roof level and 1.3 g on the roof diaphragm. This is the strongest record ever recorded in a wood frame building.

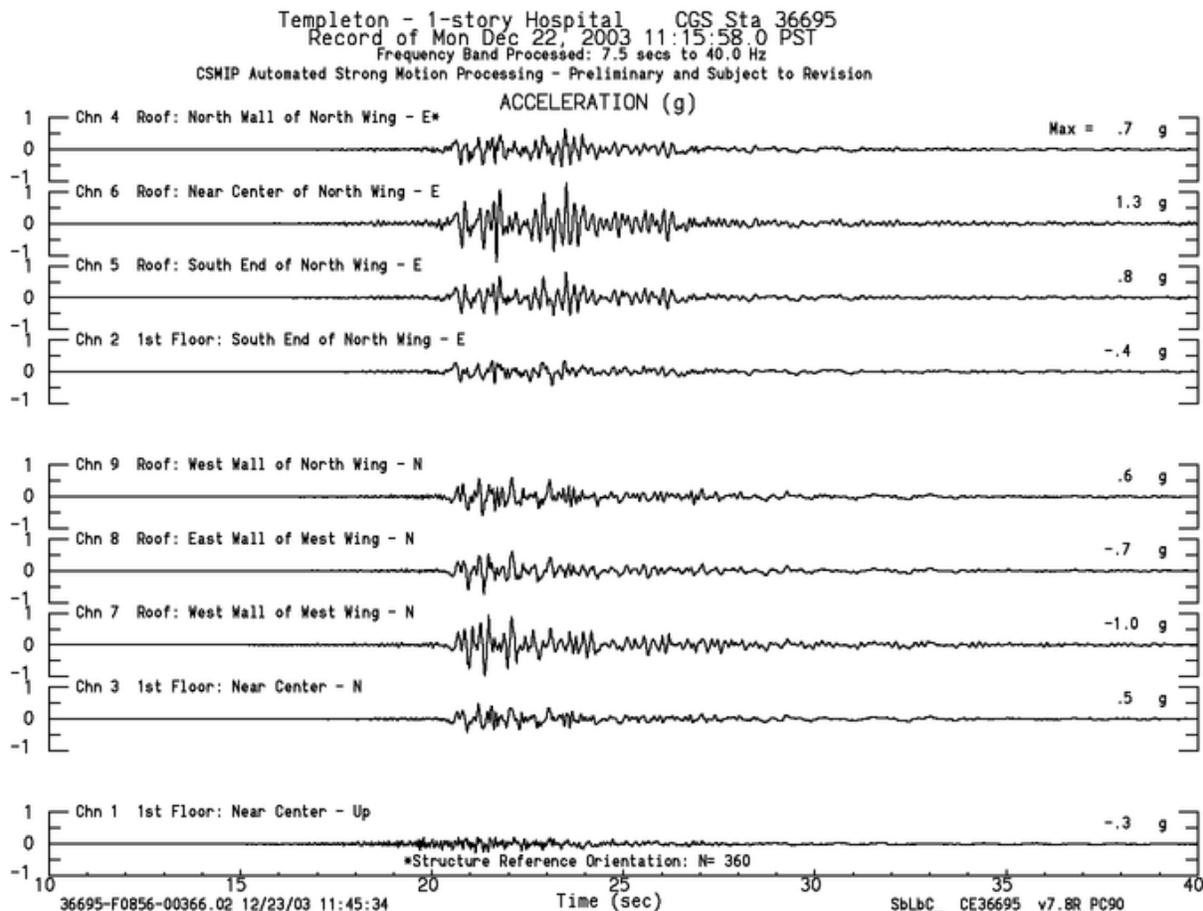


Figure 4. Recorded accelerations from the 1-story Hospital in Templeton during the San Simeon earthquake of December 22, 2003. (The usable data bandwidth for the processed data is from 40 Hz to 7.5 seconds.)

In general, the peak accelerations recorded on the ground floor of a low-rise building are smaller than those recorded at a free-field site due to the fact that the concrete slab foundation

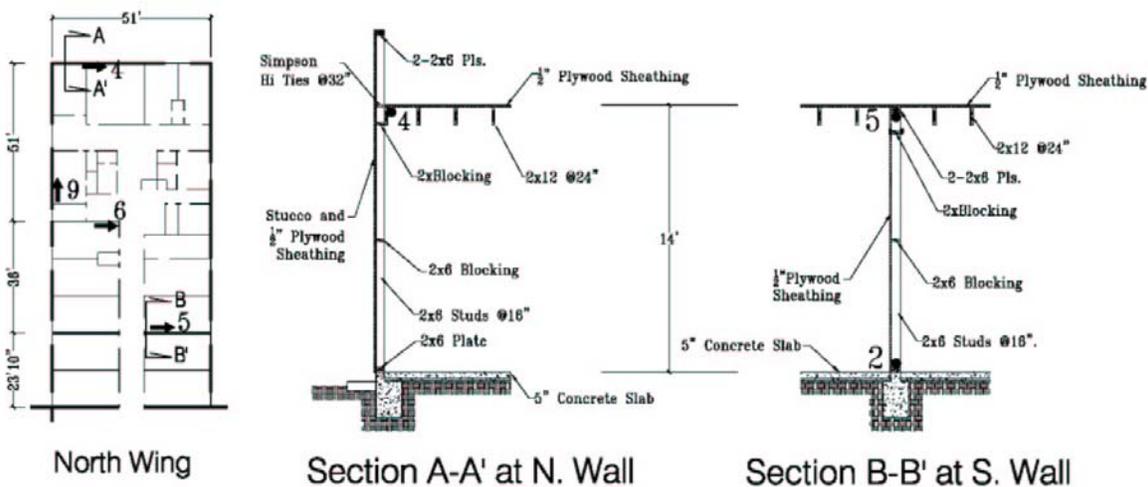


Figure 6. Structural details and sensor locations at the North Wing of the Templeton hospital.

Because the hospital building is a stiff structure and the San Simeon earthquake was close and relatively large, the building is expected to attract a high level of seismic forces. To examine this in more detail, the records from the North Wing are discussed here. The structural details of the North Wing and the sensor locations are shown in Figure 6.

Figure 7 shows a 5-second window of the accelerations recorded by Sensor 2 on the first floor (base) and three sensors on the roof, in the east-west direction. The maximum acceleration at the base is 0.43g. The maximum acceleration reached 0.65g on the top of north shear wall, 0.79g on the top of south shear wall, and 1.28 g near the center of the roof. The roof diaphragm motion is prominent in the acceleration records. One can estimate the period of vibration from the acceleration record or the corresponding response spectra shown in Figure 8. It can be seen from the spectra that both shear walls and the roof diaphragm have a period of about 0.2 second. In the other direction, the period of vibration is also at 0.2 second.

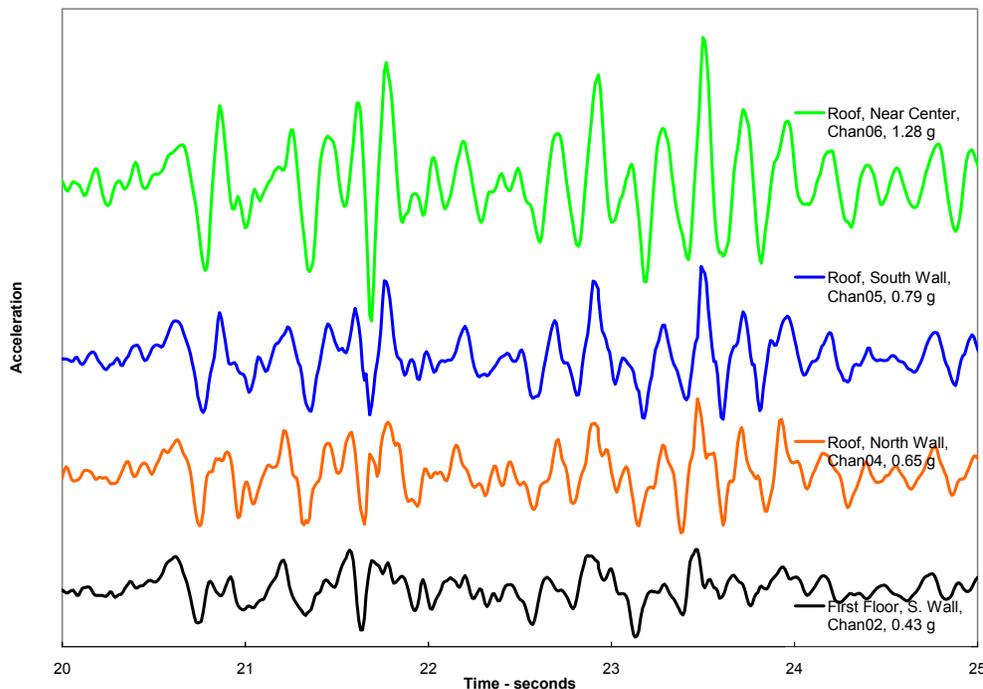


Figure 7. A strongest 5-second window of the east-west acceleration records obtained on the first floor and the roof of the North Wing of the hospital in Templeton during the San Simeon earthquake of December 22, 2003.

It is interesting to compare the period of this hospital building with those computed from the empirical formula given in the Uniform Building Code. In Figure 9, Camelo, Beck and Hall (2002) compare the building periods derived from the low-amplitude strong-motion data recorded at five CSMIP-instrumented wood frame buildings, forced vibration data from one building, and the period formula given in the 1997 Uniform Building Code. The Templeton

hospital has a story height of 14 feet. It is clear that its period is longer than what the UBC formula would predict.

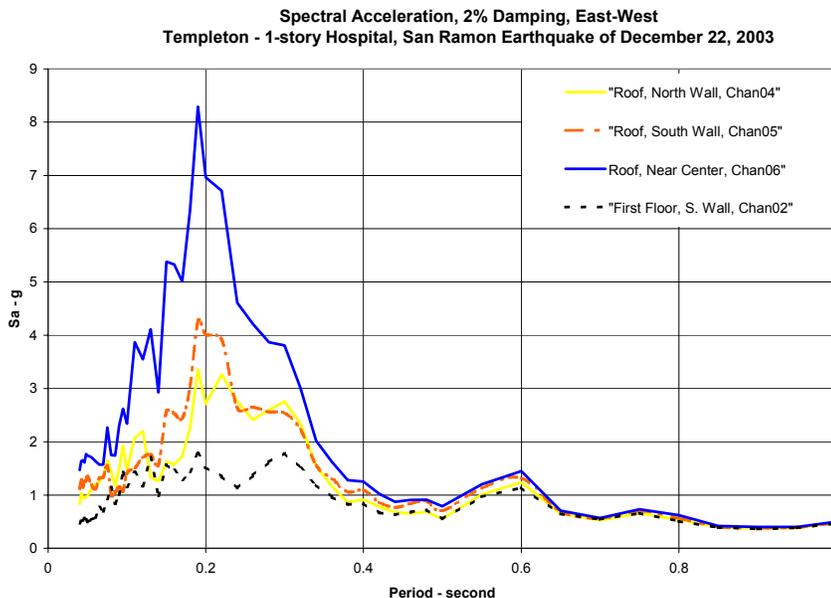


Figure 8. Acceleration response spectra (2% damping) of the acceleration records (shown in Figure 7) in the east-west direction from the North Wing of the hospital in Templeton during the San Simeon earthquake of December 22, 2003.

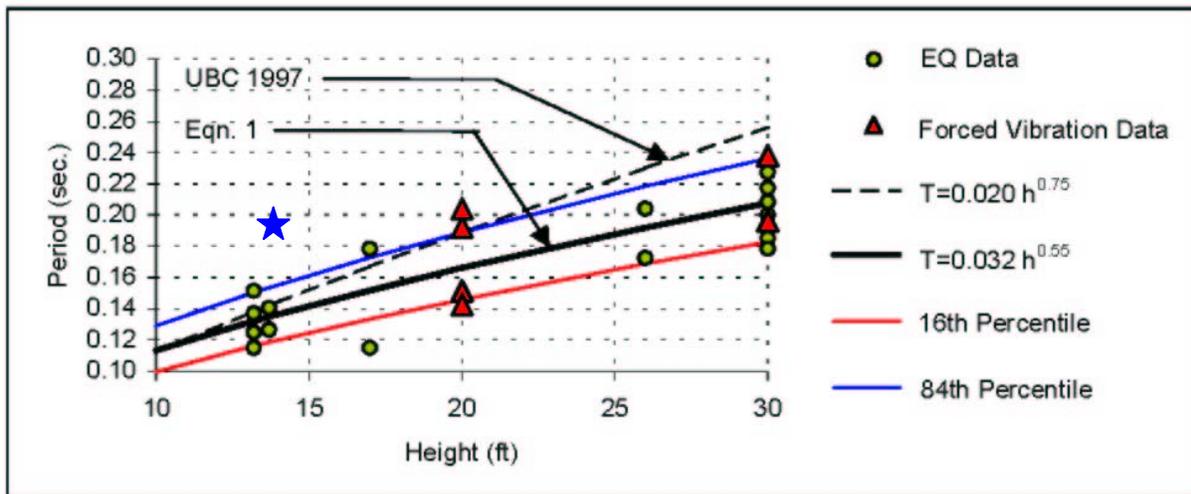
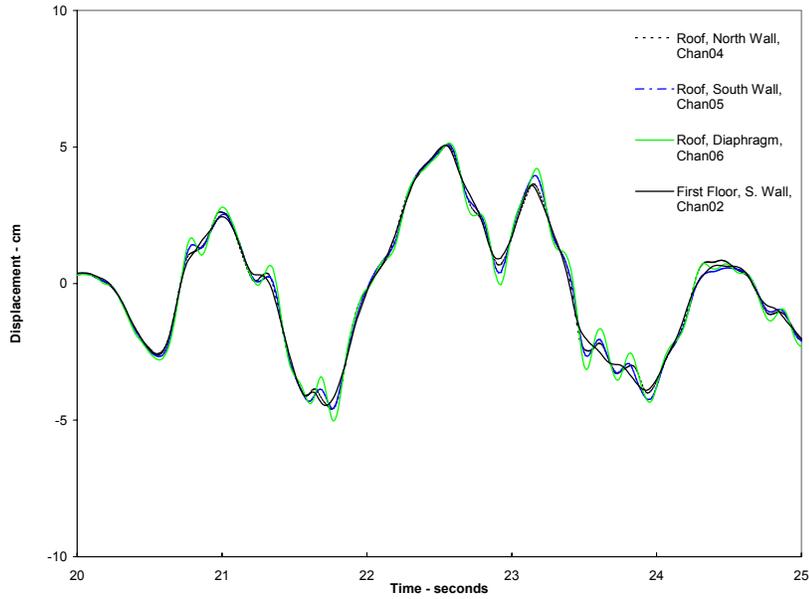


Figure 9. The period of the 1-story hospital in Templeton derived from the records of the 2003 San Simeon earthquake (shown as a star) is compared with periods of other wood frame buildings and the periods derived from the formula in the 1997 UBC. (Camelo, Beck and Hall, 2002)

The displacement records corresponding to the acceleration records in Figure 7 are plotted and overlaid in Figure 10. These absolute displacements at the roof are mainly from the



ground displacement. The response of the wall and the roof diaphragm are not obvious from the absolute displacement plots in Figure 10. The deformation of the walls and the roof diaphragm can be calculated by differencing the roof displacement records from the first floor record. They are plotted in Figure 11.

Figure 10. East-west displacements (absolute, integrated from the accelerations) corresponding to the acceleration records shown in Figure 7.

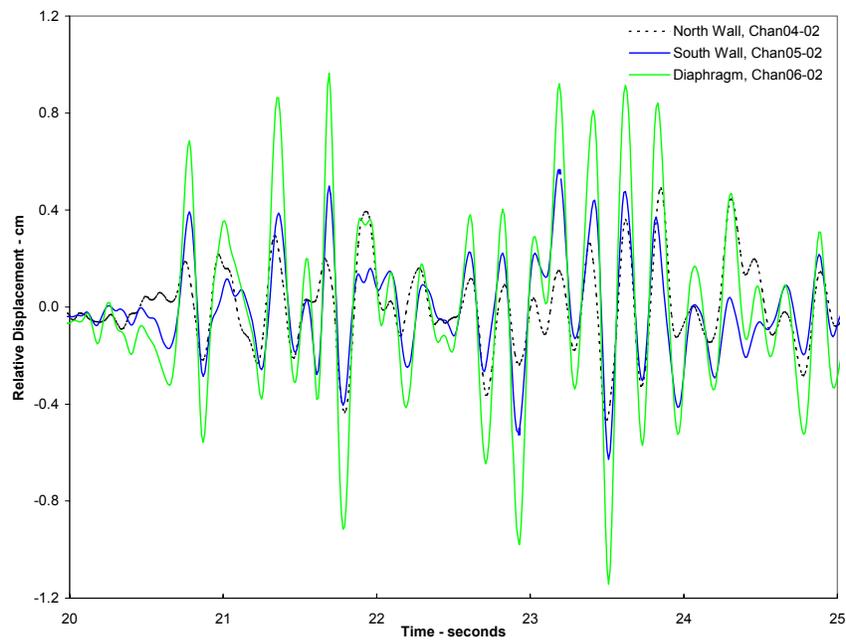


Figure 11. Deformation of the walls and the roof diaphragm, in a 5-second window corresponding to the strongest ground shaking, obtained by computing the relative displacement (east-west) between the roof and the first floor of the North Wing of the Templeton hospital during the San Simeon earthquake of December 22, 2003.

It can be seen from Figure 11 that the roof diaphragm and the wall deformations are in phase and have a period of 0.2 second. The maximum deformation of the walls is about 0.5 cm which corresponds to an inter-story drift ratio of 0.12%. The roof diaphragm had about 0.5 cm deformation relative to the top of the wall. These relative displacements are much smaller than the maximum ground displacement, which is larger than 6 cm.

### **Building Performance during the 2003 San Simeon Earthquake**

The hospital buildings at this site were designed to meet the requirements of the Alfred E. Alquist Hospital Facilities Seismic Safety Act (HSSA). The performance objective of the buildings, summarized in the HSSA is:

“...that hospital buildings that house patients who have less than the capacity of normally healthy persons to protect themselves, and that must be reasonably capable of providing services to the public after a disaster, shall be designed and constructed to resist, insofar as practical, the forces generated by earthquakes, gravity, and winds.”

Although designed circa 1975, an examination of the drawings indicates that in general, these buildings meet, and in some cases, actually exceed current seismic code requirements. The superior performance the structural and nonstructural systems in this earthquake bear witness to the effectiveness of the HSSA provisions, when applied by a skilled design professional.

### **Performance of the Structural System**

The damage observed in the structure as a result of the earthquake can be classified as very minor. The damage was essentially limited to minor cracking in the architectural finishes. Observable damage was limited to:

- Minor cracks were observed in the gypsum wallboard finish at the southeast side of the main hospital building. The cracks were limited to wall intersections, along gypsum wallboard seams, and door and window corners.
- At the north side of the main hospital building and at the interface with Radiology Addition damaged floor tiles were observed extending the width of the corridor. The vinyl floor tiles buckled and suffered minor hairline cracks. However, no corresponding cracks were observed in the adjacent corridor walls.
- Minor cracking and spalling of the plaster soffits was observed at the Emergency Room entrance where the canopy connects to the main building. The damage occurred at the architecturally furred columns and soffit along the canopy-building interface. The canopy

has been designed, detailed and built as a seismically separate structure, however, the architectural finishes span over the seismic separation without any special details to accommodate the seismic separation.

Based on the level of observed damage, it is apparent that the structural system remained essentially elastic during the earthquake.

### **Performance of Non-Structural Components**

The damage to nonstructural components and systems was also very minor, especially in contrast to the damage observed in the nonstructural components and systems of the skilled nursing facility building nearby. A power surge caused the emergency generator to go on line. It functioned as expected during the power disruption. The normal power was restored after a few hours.

The seismic safety shut-off valve for the natural gas system did function as expected for the level of ground motion recorded at the site. Fortunately, there was no need for the safety valve to operate.

The fire sprinkler system withstood the strong motion with minor damage. In one case, one of the branch lines was detached from its support and dropped down approximately 3 inches carrying with it the escutcheon (shield). In spite of that issue, no sprinkler heads were damaged to the point of causing water leakage.

In reviewing the drawings, the conservative nature of the anchorage and bracing design of the nonstructural components and systems is readily apparent. For example, bracing is provided for all piping, down to 1-inch diameter. In contrast, current code requires bracing only on pipes 2-½ inches or larger in diameter. The spacing between lateral pipe braces is also much smaller than that found in current practice. Duct bracing is also conservatively spaced and designed. Finally, flexible couplings are specified for pipe to component connections, a practice only recently required in Title 24.

### **Summary**

Large amplitude strong-motion record was obtained from a 1-story wood frame hospital building in Templeton during the 2003 San Simeon Earthquake. The record shows the ground shaking was very strong, especially at short periods. The response of the structure, which has a period of 0.2 second, was large in acceleration, but relatively small in displacement. Despite the strong demand from the ground motion, the structure apparently had enough strength and did not suffer any structural damage during the earthquake.

### **Acknowledgement**

The California Strong Motion Instrumentation Program and the Office of Statewide Planning and Development extend their appreciations to staff of the hospital in Templeton who

has permitted and cooperated in the installation and maintenance of strong-motion equipment in the hospital. CSMIP also extends its appreciation to members of the Instrumentation Committee of the Hospital Building Safety Board (HBSB) and the Buildings Subcommittee of the Strong Motion Instrumentation Advisory Committee in recommending the hospital for instrumentation. Don Jephcott of HBSB and Bhima Nagarajan of OSHPD reviewed and commented on the proposed sensor locations.

The instrumentation of the hospital in Templeton was made possible through the efforts of CSMIP engineers and technicians who planned and installed the instrumentation. Praveen Maholtra was the project engineer. The instrumentation was installed by Don Ridgley, Ron Ayala and Norman Ingram.

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