STRONG-MOTION INSTRUMENTATION OF THE OAKLAND CITY HALL

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Abstract

The Oakland City Hall was strengthened after the 1989 Loma Prieta earthquake and instrumented with 21 sensors by the California Strong Motion Instrumentation Program in 1995. This paper describes the sensor locations in the City Hall and the instrumentation objectives. Low amplitude strong-motion records that were obtained from the instrumentation at the City Hall during the magnitude 4.9 Gilroy earthquake of May 13, 2002 are also presented and discussed.

Introduction

The Oakland City Hall, constructed in 1914, is a historic landmark. It is an eighteen-story building, crowned with a decorative three-story clock tower. It was designed in 1911. In elevation the building can be divided into three sections: the podium, the office tower, and the clock tower (Figures 1 and 2). The podium is 124′ by 179′ in plan and rises to a height of 70′ above the ground. On top of the podium is a twelve-story office tower (66′ by 102′ in plan) that rises to a height of 206′. The building steps back once more above this level (14th Floor) and rises to the 16th Floor at a height of 232′. The 18th Floor is the base of the clock that rises to a final height of 305′. The building has a complete basement floor 14′ in height.

The load bearing system in the building consists of riveted steel frames made up of rolled shapes and built-up sections of angles and plates. For the purpose of fire-proofing, steel elements are enclosed in brick masonry, unreinforced concrete or hollow clay tiles (HCT). The exterior walls are the major lateral load resisting elements in the podium and the office tower. They are composed of infill unreinforced brick masonry faced with granite and terra cotta ornamentation. The interior partitions are hollow clay tiles, and the ceilings and walls are finished with plaster. A typical floor in the building consists of a 5″ thick reinforced concrete slab supported on steel frames.

The shear forces at the base of the office tower are transferred through the podium roof diaphragm to the exterior walls of the podium. The overturning moments at the base of the office

Figure 1. View of the Oakland City Hall from the Plaza.

Figure 2. View of the Oakland City Hall from the roof of an adjacent high-rise building.

tower are carried by axial forces in the columns aligned with the exterior walls of the office tower. These columns are continuous from the office tower through the podium and to the foundation. The building foundation consists of a 2′4″ deep concrete mat over the entire basement area. Building columns are supported on a framework of structural steel beams embedded within the concrete mat. The soil at the building site consists of sand and clay that becomes very dense and stiff below 100′. The bedrock is estimated at a depth of 400′ to 500′ (Dames & Moore, 1990).

Seismic Strengthening

During the 1989 Loma Prieta Earthquake, the clock tower and its supporting steel frame were severely damaged (Button, et al., 1991). The northern URM wall of the clock tower shifted almost one inch off its base at the 16th floor level. The floor beams supporting the clock tower had diagonal shear fractures through the web. These cracks were caused by the overturning forces of the clock tower. Cracking also occurred in the perimeter walls at the 16th floor. The terra-cotta ornamentation at the 16th floor showed evidence of spalling. The main steel frame in the podium and the office tower was not damaged. Many interior hollow clay tile partitions in the office tower and the podium suffered extensive cracking.

In strengthening the City Hall, 111 lead-rubber seismic isolation bearings were used to isolate the building at the top of the existing mat foundation (Honeck, et al., 1994; Walters, 2003). Simultaneously, new concrete shear walls and braced steel frames were added to strengthen and stiffen the existing lateral load resisting system for the superstructure (Figure 3). A system of 6′6″ deep steel outrigger trusses encased with concrete was added at the basement level to spread out the seismic overturning forces to isolator bearings mounted on concrete pedestals rising from the mat foundation. The trusses will limit the uplift at the isolators to 0.25 inch (Honeck and Walters, 1994). The isolators were designed to undergo a maximum horizontal displacement of approximately 11 inches.

In the podium and tower structure new concrete shear walls and steel braces were added. In the transverse direction, concrete shear walls were added up to the 7th floor level and concentric braced steel frames were added from the 7th to the 14th floors. These braced frames were designed to share loads with existing URM perimeter walls (Elsesser, 1993; Walters, 2003). In the longitudinal direction concrete shear walls were added up to the 4th floor level only. No braced frames were added in this direction.

The clock tower was strengthened by adding a steel 3-D space frame in its interior that rises from the 14th floor level. The original base of the clock tower was at the 16th floor level. At the 14th floor level, loads from the clock tower are transmitted to the exterior and interior columns below by new transfer trusses. The top chord of transfer trusses is just below the 14th floor level and the bottom chord is just below the 13th floor level.

The new seismic force resisting system, together with the existing structure, was designed to resist a base shear of 13% of the weight of the structure, as transmitted by the base isolators. The seismic repair design was in accordance with the 1991 City of Oakland Building Code (equivalent to 1988 UBC). The design of the base isolation system was in accordance with the appendix to Chapter 23 of the 1991 Uniform Building Code. The design was also based on the site-specific response spectra with 475-year return period (Dames and Moore, 1990). Dynamic response analyses of the structure using ETABS and ANSR programs were performed (Honeck and Walters, 1994). The input motions for the computer models were the strong-motion records from the Loma Prieta earthquake obtained by CSMIP at a nearby 2-story building and the artificial acceleration time histories generated from the design earthquake.

Strong-Motion Instrumentation and Records

Records from the 1957 San Francisco Earthquake

The Oakland City Hall was originally instrumented prior to the San Francisco earthquake of March 22, 1957. The accelerographs were installed at the basement and on the 16th floor. The recorded peak horizontal accelerations were 9.0% g on the 16th floor and 4.0% g at the basement from the main shock of the 1957 San Francisco earthquake (magnitude 5.3, distance 24 km). A magnitude 4.4 aftershock was also recorded at the City Hall (Caltech EERL, 1976)

During the 1957 San Francisco earthquake the structure exhibited a fundamental vibration period of 1.2 to 1.3 seconds. From the forced vibration tests conducted after the Loma Prieta earthquake the fundamental periods were determined to be 1.56 seconds (E-W), 1.32 seconds (N-S) and 0.74 seconds (Torsional) (ANCO, 1990). The period of the original structure was modeled by the computer at 1.6 seconds. According to the soil-structure interaction analysis by Dames and Moore (1990), the soil-structure interaction has essentially no effect on the fundamental period of the building. The fixed-base period of the structure was lowered to 1.25 seconds by addition of concrete shear walls and steel braces (Elsesser, 1993; Walters, 2003). The base-isolated structure has a period of 2.8 seconds. In summary, the building fundamental periods are:

1935 vibration tests	1.2 seconds
1957 earthquake	1.2-1.3 seconds
1990 ambient	1.45 seconds
1990 forced vibration	1.56 sec. (E-W), 1.32 sec. (N-S)
As-is model	1.6 seconds
Strengthened (fixed base)	1.25 seconds
Strengthened (base-isolated)	2.8 seconds

Strong-Motion Instrumentation in 1995

The planning for the instrumentation of the Oakland City Hall began in early 1992. The instrumentation was completed in June 1995 at the last stage of the seismic strengthening work. 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 structural engineer of record and a Strong Motion Instrumentation Advisory Committee member ensured an optimal layout of a limited number of sensors.

The final instrumentation plan includes 21 accelerometers in the City Hall. The locations of these 21 sensors are shown in Figure 3. Each of these 21 sensors is connected via cabling to a central recorder located on the first floor. This cabling was installed by the City's contractors for the strengthening work. 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. Due to the congested built environment around the City Hall, no instrument has been installed at a nearby site to measure the referenced ground motion for the building.

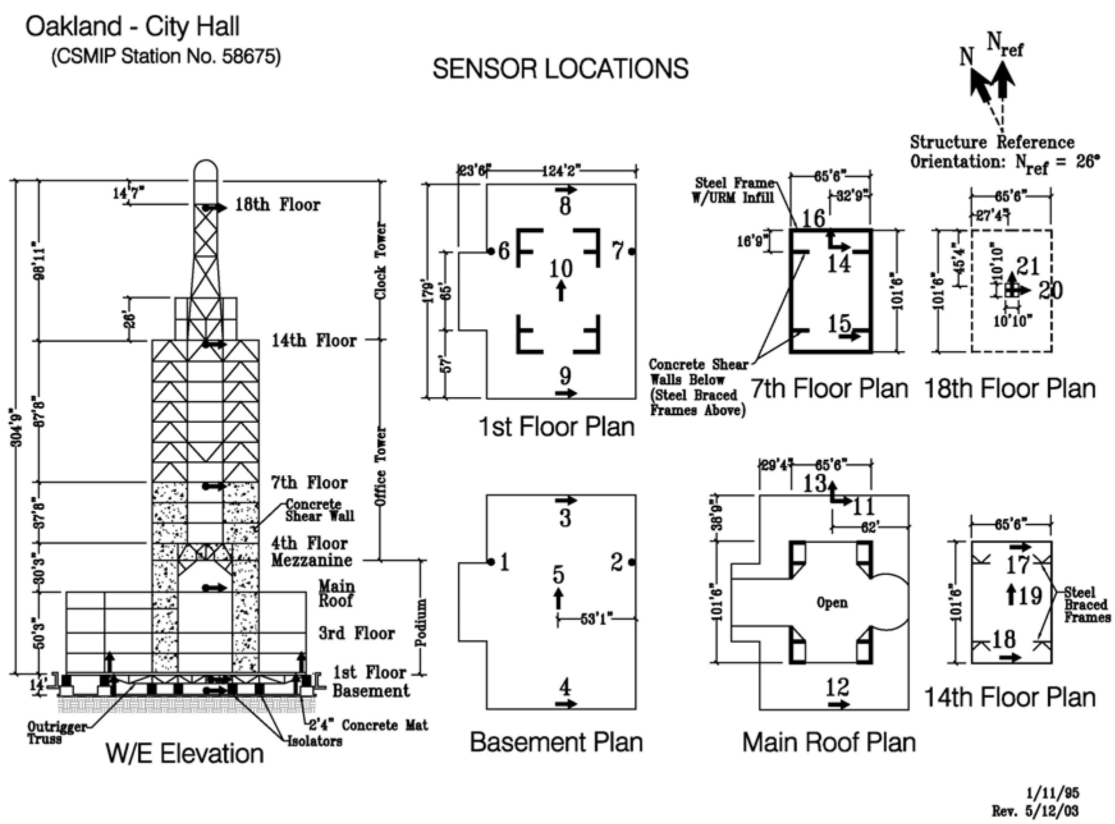

Figure 3. Locations of 21 sensors installed at the Oakland City Hall.

The primary objective of instrumentation for this building is to obtain sufficient seismic response data so that the effectiveness of the seismic strengthening using base isolation can be assessed. Strong-motion sensors were installed at strategic locations in the basement and the superstructure. In the basement and below the first floor of the building, six accelerometers were installed both below and above the isolators to measure the effects of isolation on the input horizontal motion to the structure (Figure 4). Four accelerometers sensors measure vertical motion and rocking motion of the superstructure in the transverse (east-west) direction (Figure 5). Eleven sensors installed in the upper stories of the superstructure measure the lateral motions at various floor levels. These sensors are located at the floors where seismic force resisting elements are changed or where the plan setbacks occur. Specifically, these floors are on the Main Roof, the 7th Floor, the 14th Floor and the 18th Floor (Figure 6).

Figure 4. (Left) Sensors 9 (above isolator) and 4 (below isolator) with protecting boxes and conduit installed on the south side of the basement at Oakland City Hall. The cabling has about 2 feet of slack to allow relative movement across the isolator. (Right) Close-up view of Sensor 9 with plumb bob indicating vertical direction.

In the transverse (east-west) direction on the 14th floor, the 7th floor, and the main roof and the first floor, a pair of accelerometers were installed on the north and south sides of the building to measure the torsional motion as well as the translational motion of the floor. Four vertical sensors were installed above and below two isolators on the west and east sides to measure the rocking motion of the superstructure about the North-South axis and detect possible uplift in a future major earthquake.

The records from this instrumentation will provide information on the input base motion and the response of the structure at different levels. Key parameters of the structural response, including modal periods and damping for the first few modes, the base shear, story drifts and isolator deformation can be computed from the records.

Figure 5. Sensors 7 (above isolator) and 2 (below isolator) with protecting boxes and cabling conduit installed on the east side of the basement at the Oakland City Hall to measure vertical motions.

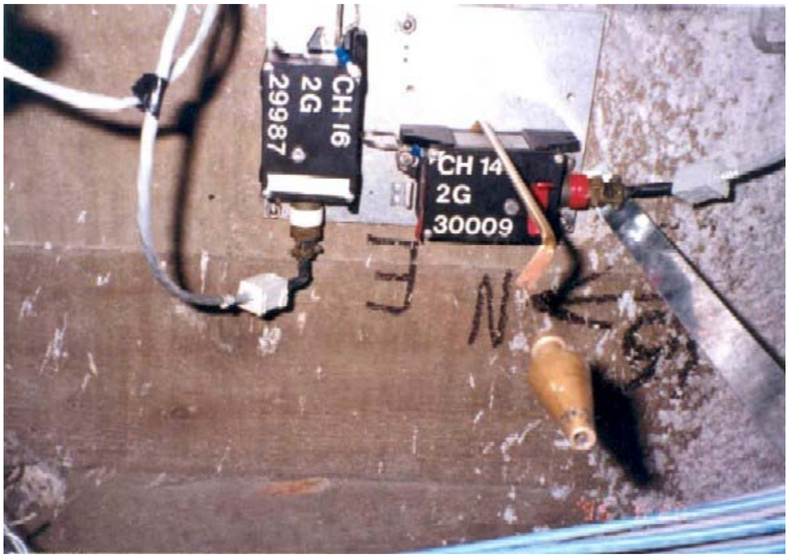

Figure 6 Sensors 14 and 16 installed on the underside of the 7th Floor slab at the Oakland City Hall to measure horizontal motions. The plumb bob in the photo indicates vertical direction.

Records from the 2002 Gilroy Earthquake

The magnitude 4.9 earthquake occurred near Gilroy on May 13, 2002 at a distance of 100 km from the Oakland City Hall. Figure 7 shows the small amplitude acceleration records obtained from the City Hall in the longitudinal (north-south) direction. The recorded maximum accelerations were 0.6 % g below the isolator, 0.7% g above the isolator, 0.8% g at main roof, 1.5% g on the 7th floor, 1.0% g on the 14th floor and 3.1% g on the 18th floor. Due to limited space, the records from the other 15 sensors in the transverse and vertical directions are not shown and discussed herein.

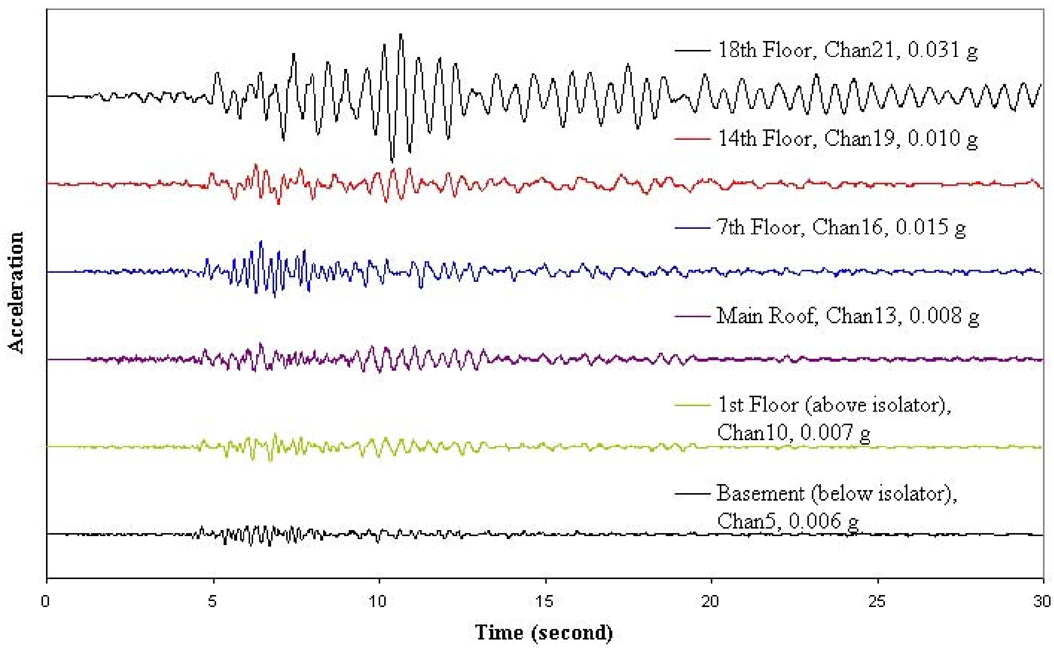

Figure 7. Recorded accelerations in the longitudinal (north-south) direction from the Oakland City Hall during the Gilroy Earthquake of May 13, 2002.

Because the Gilroy earthquake was small and distant from the City Hall, the building is expected to respond like a fixed-base structure and base isolators would have little effect on the building response. It can be seen from the acceleration records that the motion of the clock tower was significantly larger than the office tower (below the 14th floor) and the second mode motions are prominent in the records. The displacement records from the 18th, 14th and 1st floors are plotted and overlaid in Figure 8. The first mode can be clearly seen in the whole record, while the second mode is dominant between 10 and 13 seconds. Figure 9 shows the response spectra from the acceleration records of all six sensors in the longitudinal direction. It can be seen from the spectra for the 18th floor that the relatively large acceleration on the top of the clock tower is mainly due to the second mode response. Periods of the first and second modes can be derived from the spectra in Figure 9 or measured directly from the displacement records in Figure 8. They are 1.25 and 0.55 seconds, respectively. The first mode period from the record is very close to the period calculated for the fixed-base strengthened model.

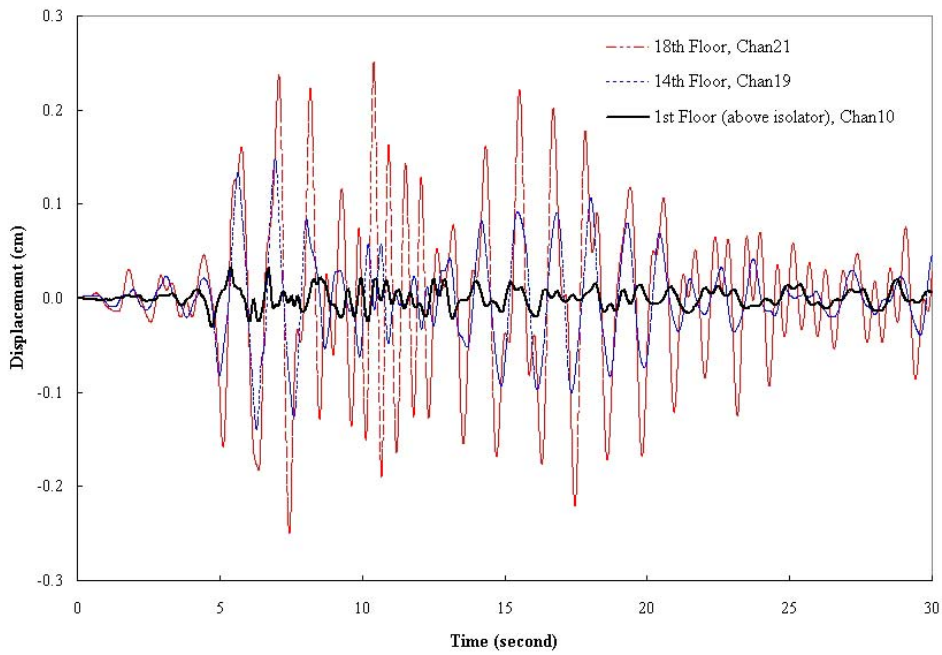

Figure 8. Displacements at the 18th Floor, the 14th Floor and the 1st Floor in the longitudinal (north-south) direction from the Oakland City Hall during the Gilroy Earthquake of May 13, 2002.

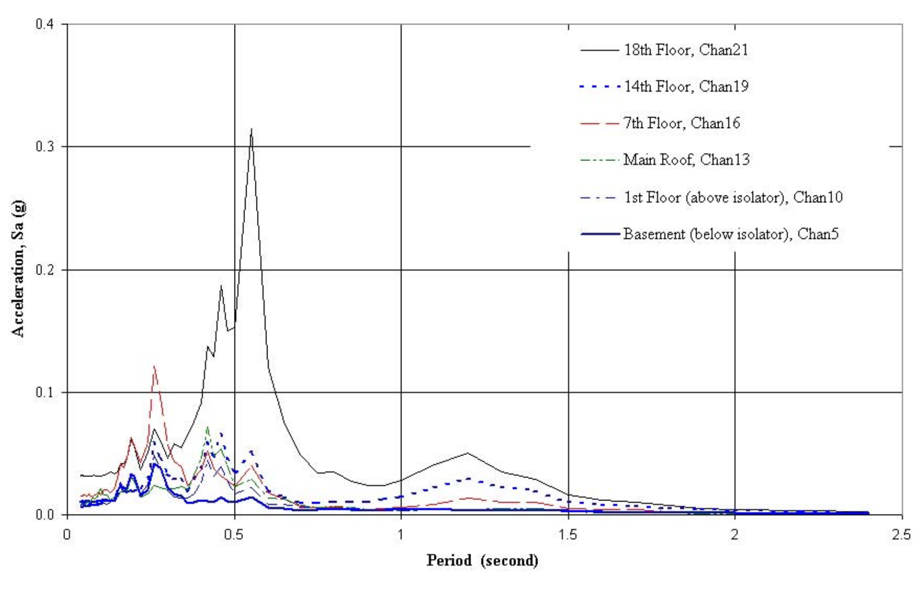

Figure 9. Acceleration response spectra (2% damping) of the records in the longitudinal (north-south) direction from the Oakland City Hall during the Gilroy Earthquake of May 13, 2002.

The displacement records from sensors above and below the isolator are plotted and compared in Figure 10. The deformation of the isolator can be calculated by differencing these two displacement records. The isolator deformation is smaller than 0.01 cm and much less than the design displacement of 28 cm or 11 inches.

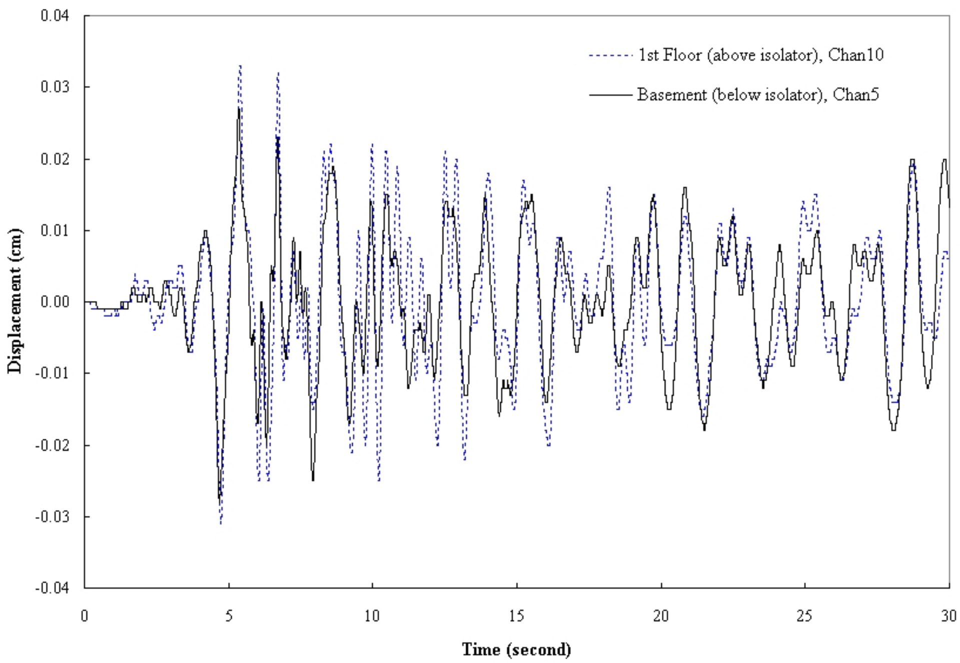

Figure 10. Displacements above and below the isolator in the longitudinal (north-south) direction from the Oakland City Hall during the Gilroy Earthquake of May 13, 2002.

Summary

The California Strong Motion Instrumentation Program installed strong-motion equipment at the Oakland City Hall during the seismic strengthening project in 1995 with assistance and cooperation from the City of Oakland. The instrumentation system will record building response data from which effectiveness of the seismic strengthening using base isolation, as well as the seismic safety, can be assessed after future significant earthquakes. The recorded data will be available so the near-real-time data can be used for post-earthquake evaluation of the building performance.

Acknowledgement

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The instrumentation of the Oakland City Hall 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 Steve Fife, Tom Pierce and Neil Adler.

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