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Case History of Seismic Base Isolation of a Building –The Foothill Communities Law and Justice Center

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Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 4.16

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SYNOPSIS: The Foothill Communities Law and Justice Center, located in seismically active Southern California, is the first building in the United States to be base isolated for seismic resistance. Natural rubber isolators with layers of steel plates were used to make the fundamental period of vibration of the base isolated building about twice as long as that for a comparable conventional fixed base building. Most earthquake energy is present in the shorter period ranges, and at longer periods, a building should be subjected to less earthquake input; this will allow buildings to be designed more economically and increase the likelihood of less damage, both structural and non-structural. The experience of the Law and Justice Center after three small earthquakes suggest that the concept is not only feasible, but may be the wave of the future for what would be relatively short period buildings.

INTRODUCTION

The Foothill Communities Law and Justice Center (FCLJC) is the first building in the United States of America to utilize the principle of base isolation to resist strong earthquake ground motions. The principle of base isolation is completely opposite to the conventional technique of earthquake resistance in structures, which is to strenthen (stiffen) the structure. In adding stiffness to a structure, the structure will attract more force, making it more difficult to resist the earthquake forces and adding to the cost of the structure. Most low- to medium-rise buildings have fundamental periods of vibration in the range of periods where the earthquake energy is the greatest. If the fundamental period of the building can be shifted to a higher period where the earthquake energy is less, the building should be subjected to less induced forces. Base isolation introduces flexibility at the foundation level of a structure to limit the accelerations at the higher floors. Thus the superstructure will attract less force during an earthquake; this should make design simpler and the cost of the structure more economical. By reducing the forces in the structure, the likelihood of damage to non-structural elements of the structure (including contents) would be diminished. This could also reduce the hazard to human occupants.

FCLJC BUILDING AND BASE ISOLATOR DESCRIPTION

The FCLJC building is four stories in height with a mechanical penthouse; the building also has a full basement and measures 417 feet by 110 feet in plan (Figure 1). The building is supported on 98 natural rubber isolators just above the foundations at a subbasement level. The basement of the building is actually a supported floor and required that there be two basement walls. There is an interior basement wall that is part of the base isolated building; there is also a separate retaining wall around the exterior of the building designed to accommodate a possible 16 inch deflection of the building during a earthquake event. Traction elevators were needed because hydraulic-type elevators would have required shafts extending into the ground. Utilities providing services to the building were specially designed with extra loops or flexible joints to allow for the deflections of the building.

The building is mainly of steel construction with braced frames providing the the lateral resistance (Way and Lew, 1986). At the basement level, the steel braced frames transfer lateral load to concrete shear walls which extend the full height of the basement; the basement of the building (from the basement floor to the ground floor) essentially acts as a large box girder to spread the lateral loads to the base isolators. A braced frame system was used instead of a moment frame to try to have rigid body motion of the building's superstructure.

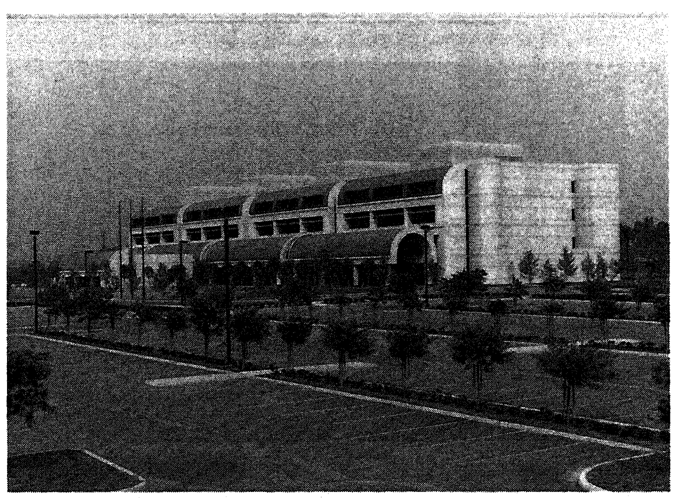

Figure 1. Photograph of Foothill Communities Law and Justice Center.

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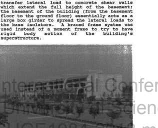


Figure 1. Photograph of Foothill Communities Law and Justice Center.

Figure 2. Cut-away view of natural rubber isolator used in the FCLJC Building.

The natural rubber base isolators selected for this project consisted of "high-damping" rubber isolators made up of alternating layers of rubber and steel plates (Figure 2). Although eight bearing types were actually utilized, all of the bearings had a diameter of 30 inches and height of 16 or 18 inches. During manufacture, additives were added to the natural rubber to improve ozone resistance, bond strength, tensile strength, stiffness, and damping. A description of the fabrication and quality assurance process for the bearings has been described by Tarics et al (1986).

GEOTECHNICAL SETTING

The FCLJC Building is located in seismically active southern California (Figure 3). The building is located about 40 miles east of downtown Los Angeles in the city of Rancho Cucamonga which is in the western part of the County of San Bernardino (Crandall, 1982). The site is within a region of large-scale crustal disturbance caused by faulting and is within the intersection of east-west trending Transverse Ranges Province, represented by the San Gabriel Mountains to the north, and the Peninsular Ranges Province, represented by the Puente Hills and Santa Ana Mountains to the south. The FCLJC building is located in the Chino Basin, which is an alluvium filled down-dropped fault block bounded by the San Jacinto fault zone on the east, the Chino-Elsinore fault zone on the west, and the Sierra Madre fault zone on the north. The famous San Andreas fault is located within 13.5 miles of the building; this is the portion of the fault that last ruptured in 1857 with about a Magnitude 8 earthquake and a similar event has been predicted by some seismologists and geologists within the next 30 to 50 years. Other major fault systems near the building are the San Jacinto, Elsinore, and Sierra Madre Faults which are located 11, 17, and 1.2 miles from the building location; these three fault systems are capable of up to Magnitude 7.5 events. An earthquake on any of these nearby faults or other of the numerous faults in southern California could produce significant ground motions at the building location.

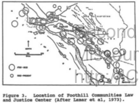


Figure 3. Location of Foothill Communities Law and Justice Center (After Lamar et al, 1973).

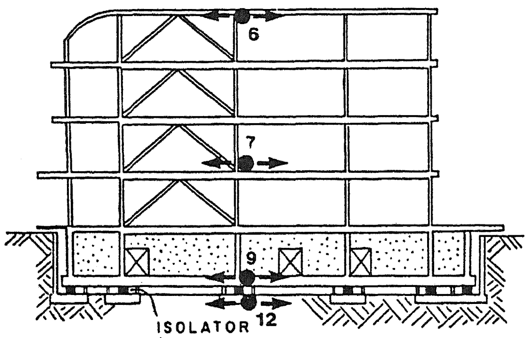
DESIGN CRITERIA AND EXPECTED RESPONSE

The FCLJC building was designed to remain essentially elastic under even the maximum credible earthquake events on the nearby faults; this criteria even exceeds the performance criteria that would be required for an essential facility designed by the Uniform Building Code. Under maximum credible earthquake conditions, a structure can not generally be designed to behave completely elastically; generally, it is only practical to design against collapse at these levels. With base isolation, it becomes practical to also protect the non-structural elements and the building contents as well as better protect the occupants.

By base isolation, the fundamental period of the FCLJC Building was made to be about 2.0 seconds; the fundamental period of an equivalent conventionally fixed-base building would be about 1.1 seconds. A thorough dynamic analysis of the base isolated building system was made to determine the expected response of the natural rubber isolators and the building superstructure to the seismic excitations from postulated earthquakes on the fault systems described earlier. With a base isolation system, the amplification of accelerations within the building from the base level to the roof level is expected to be nearly unity, implying rigid body motion above the base isolation level. The amplification factor for a fixed-base building would be expected to be about four times.

PERFORMANCE DURING SEVERAL SMALL EARTHQUAKES

The State of California Office of Strong Motion Studies has instrumented the FCLJC building with a total of 19 accelerometers as part of the California Strong Motion Instrumentation Program (Huang et al, 1986). Figure 4 shows a cross section through the center of the FCLJC building; also shown are the locations of four of the accelerometers which are oriented to record motions parallel to the minor axis of the building. Accelerometer No. 6 is located on the roof of the building, Accelerometer No. 7 is mounted on the second floor, Accelerometer No. 9 is located at the basement level (above the isolators), and Accelerometer No. 12 is mounted at the



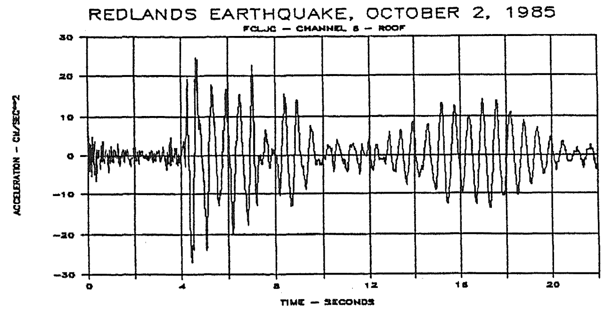
SOUTH/NORTH SECTION

Figure 4. Cross Section of the Minor Axis of the FCLJC and Locations of Accelerometers Nos. 6, 7, 9, and 12.

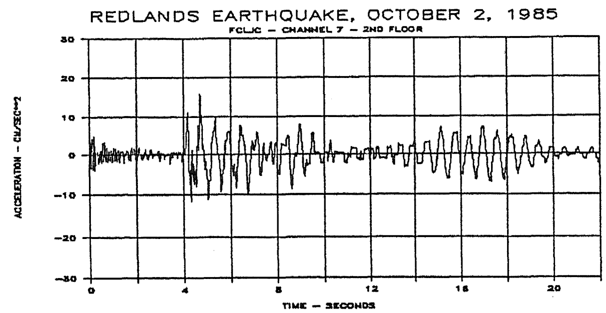
foundation level (within the subbasement and below the isolators).

Although only recently completed, ground and building motions caused by several small earthquakes have been recorded at the FCLJC building. The processed accelerograms for Accelerometer Nos. 6, 7, 9, and 12 recorded during the Redlands earthquake of October 2, 1985 (magnitude 4.8 ML) are shown in Figure 5; the epicenter of this event was about 30 kilometers from the building. It is obvious from a visual inspection of these four accelerograms that the high frequency horizontal motions present in the foundation recording have been filtered out by the isolators as these frequencies are not present in the records above the isolators; this can be clearly seen in the roof and second floor records and is even evident in the basement record. The maximum acceleration at the roof level was about the same as that recorded at the foundation level. The maximum acceleration levels in the basement and the second floor are less than that at the foundation level.

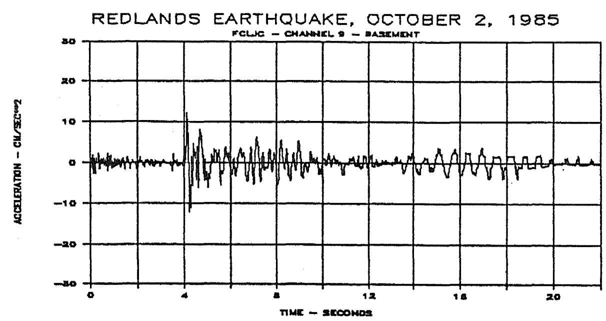
Processed accelerograms were also available from the Palm Springs earthquake of July 8, 1986 and the records from the same accelerometers are shown in Figure 6; the epicenter of this earthquake was about 100 kilometers from the building. As in the Redlands earthquake, the high frequency waveforms noted in the foundation level record are absent from the other three records. Unlike the Redlands earthquake, there is no reduction in the maximum acceleration level at the basement and there is some amplification of the maximum acceleration at the higher levels; the maximum acceleration at the roof level is about three times the maximum acceleration at the foundation level. Preliminary data from the recent Whittier Narrows earthquake of October 1, 1987 (magnitude 6.1 ML) indicate that a maximum acceleration of about 0.03g was measured at the foundation level and about 0.05g was measured at the roof level (Shakal, 1987);the epicenter was about 55 kilometers from the FCLJC building.



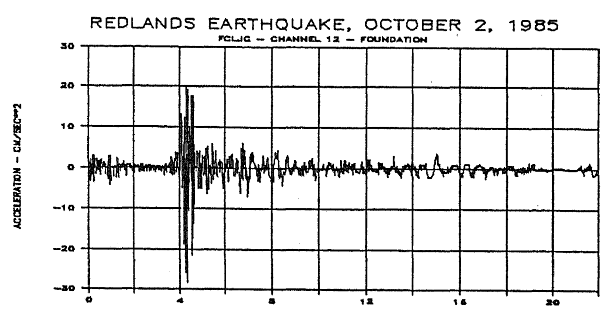
(a) Channel 6 - Roof



(b) Channel 7 - 2nd Floor



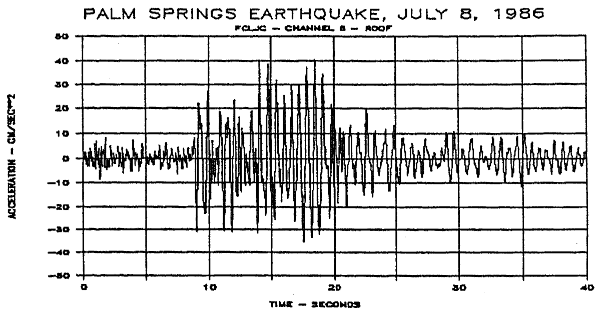
(c) Channel 9 - Basement



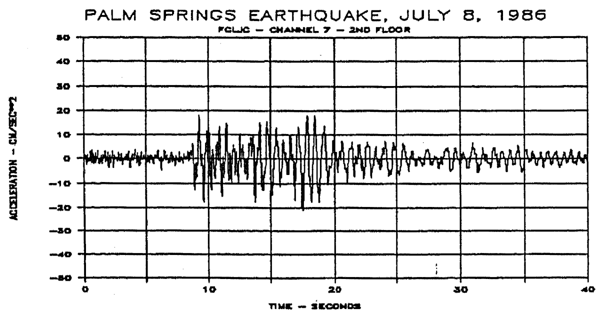
(d) Channel 12 - Foundation

Figure 5. Acceleration-Time Histories Recorded During the Redlands earthquake of October 2, 1985.

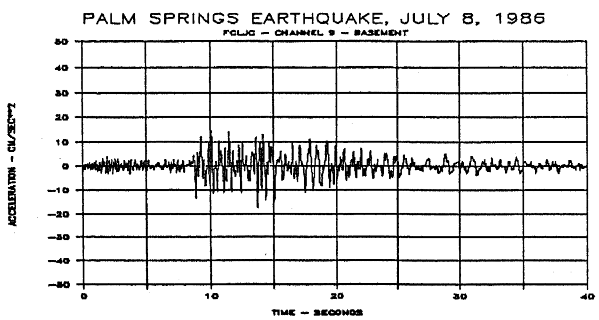
Spectral analyses were also performed for these accelerogram records from the two earthquakes. The Fast Fourier Transform (FFT) of each record was computed and smoothed once. Spectral ratios or transfer functions between the three upper building level records and the foundation level record were computed; the transfer functions are shown in Figures 7 and 8. The transfer functions from both earthquake events are very similar. High frequencies above about 10 Hertz are greatly deamplified above the isolators in the building. The fundamental



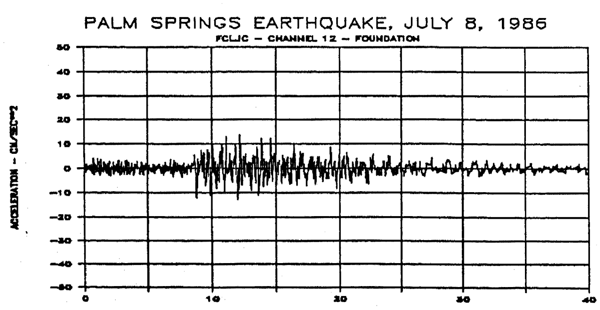
(a) Channel 6 - Roof



(b) Channel 7 - 2nd Floor

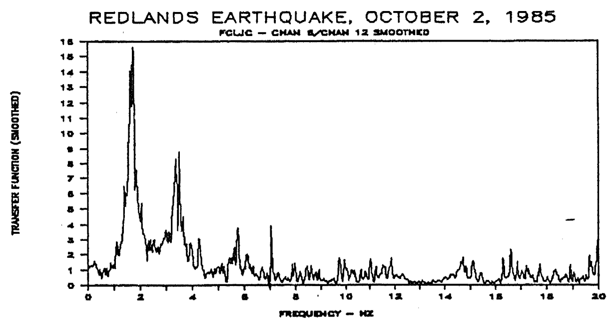


(c) Channel 9 - Basement

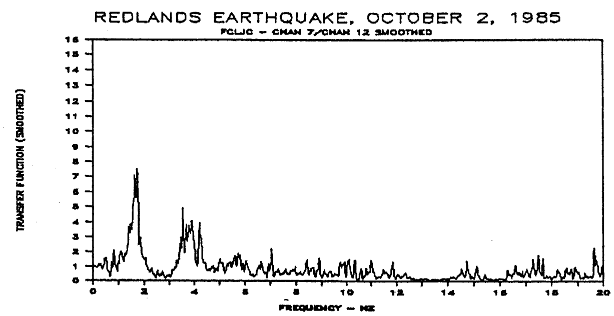


(d) Channel 12 - Foundation

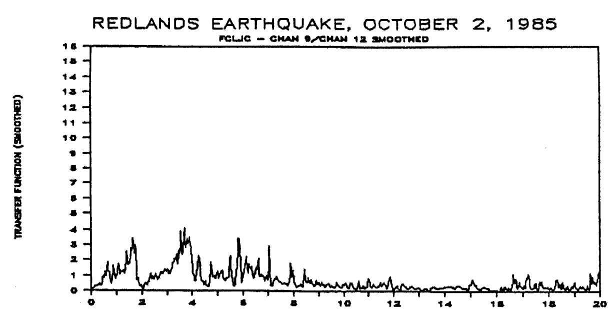
Figure 6. Acceleration-Time Histories Recorded During the Palm Springs earthquake of July 8, 1986.



(a) Ch. 6 to Ch. 12 - Roof to Foundation

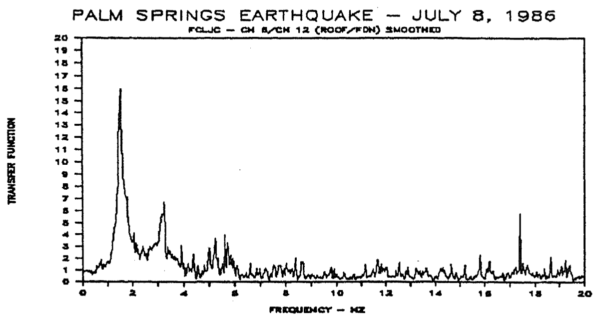


(b) Ch. 7 to Ch. 12 - 2nd Floor to Foundation

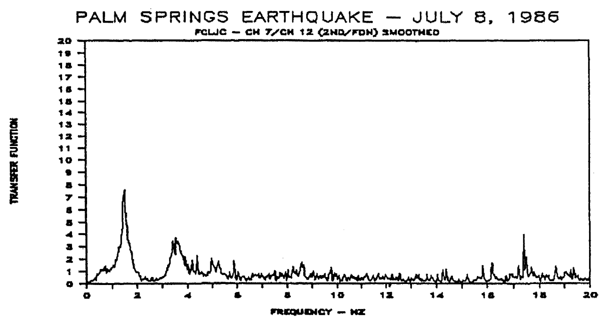


(c) Ch. 9 to Ch. 12 - Basement to Foundation

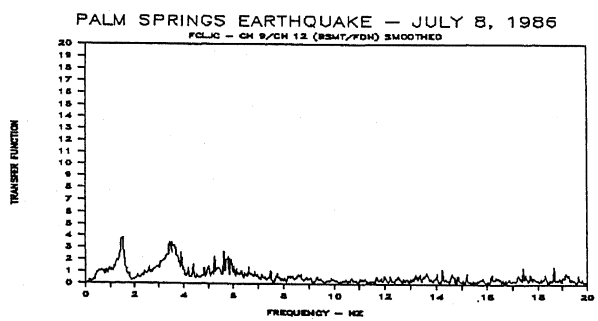
Figure 7. Fourier Transfer Functions - Redlands Earthquake.



(a) Ch. 6 to Ch. 12 - Roof to Foundation



(b) Ch. 7 to Ch. 12 - 2nd Floor to Foundation



(c) Ch. 9 to Ch. 12 - Basement to Foundation

Figure 8. Fourier Transfer Functions - Palm Springs Earthquake.

period of vibration appears to have been about 0.6 seconds (corresponding to a frequency of 1.7 Hz) in the Redlands earthquake; it appears that the second period of vibration is about 0.3 seconds (3.5 Hz). For the Palm Springs earthquake, the fundamental period of vibration appears to be about 0.7 seconds (1.5 Hz) and second period of vibration is about 0.3 seconds (3.5 Hz).

CONCLUSIONS

The report card on the base isolation system for the Foothill Communities Law and Justice Center is still incomplete. The performance of the building during the Redlands and Palm Springs earthquakes is somewhat mixed. There was no amplification of acceleration in the building relative to the foundation level during the Redlands event; however, there was amplification during the Palm Springs event. There also seems to have been some amplification of the maximum accelerations in the Whittier Narrows earthquake. In the frequency domain, the transfer functions of the motions at the higher building levels compared to the foundation level are very similar for both the Redlands and Palm Springs events. The base isolators are very effective in filtering out the higher frequencies above 10 Hertz.

Of course, the measured responses of the building were in three distant and rather moderate earthquakes. With higher excitation levels, it would be expected that higher damping of the isolators would be developed. The observed filtering effect of the isolators for the higher frequencies is encouraging and at higher acceleration levels, it is hoped that the filtering effect would be observed at lower frequencies. In less than three years, three earthquakes have been recorded at the FCLJC building. There is no doubt that many more earthquake records will be available in the future that will help the engineering profession understand the behavior and performance of base isolation.

ACKNOWLEDGMENTS

Mr. Robert Rigney, former County Administrator of the County of San Bernardino, had the insight and courage to commit himself to building the first base isolated building in the United States of America. The design architects for the building were HMC Architects and Hellmuth, Obata & Kassabaum. The structural engineer was Taylor and Gaines and the base isolation consultant was Reid and Tarics.

Appreciation is extended to the Dr. Tony Shakal of the California Strong Motion Instrumentation Program (CSMIP) for providing earthquake time histories recorded at the FJLJC building.

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