

THE JUNE 28, 1991 SIERRA MADRE CALIFORNIA EARTHQUAKE

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ABSTRACT

Although not a major event compared with the 1989 Loma Prieta one, the Sierra Madre earthquake of June 28, 1991 served to remind Californians that seismic hazard mitigation programs require constant monitoring to ensure their effectiveness and that the stock of precode, high risk buildings continues to prove difficult to eliminate. In this paper aspects of damage suffered by constructed facilities are summarized, specific examples of the behaviour of selected structures are reported and ongoing problems with earthquake insurance and the enforcement of state law requiring cities to identify buildings particularly prone to earthquake damage are described.

THE EARTHQUAKE

The thrust-fault motion, consistent with the north side of the Sierra Madre fault sliding up and over the south side and an epicentre some 12 km below the San Gabriel Mountains, 19 km northeast of Pasadena (see Figure 1), was initially assessed as a Richter magnitude 6 event. Subsequently, it was reassessed to be of magnitude 5.8. Timed at 7:43 a.m. local time, perceptible shaking lasted some fifteen seconds in neighbouring communities of Altadena, Pasadena, Sierra Madre and Monrovia. General motion was detected from the California Central Valley in the north to the Mexican border in the south.

Strong motion instruments provided evidence of peak ground accelerations of around 0.20g (horizontal) and 0.13g (vertical) in Altadena, 13 km from the epicentre. The duration of strongest shaking was less than four seconds. Several aftershocks noted included a Richter magnitude 4.3, approximately two hours after the main event.

Two fatalities were ascribed to the earthquake and approximately 100 people were treated for injuries. Some 26,000 customers lost electric power for a few minutes and the telephone system was overloaded for several hours.

BUILDING DAMAGE

Apart from the inevitable fracturing of shop windows and the depositing of contents of supermarket shelves onto the floor, the most

obvious damage was sustained by several historic buildings in Pasadena. The east wall of the Spanish-style City Hall (Figure 2) was cracked and the dome was tilted. Hollow clay tiles forming a veneer over a concrete masonry wall fell from the 1924 vintage Pasadena Playhouse (Figure 3) onto an adjoining property. Several churches suffered damage, including the 60-year old Westminster Presbyterian Church in Pasadena (Figure 4). Stained glass windows collapsed (Figure 5) and architectural components fell off the structure (Figure 6). Typical of the unreinforced masonry building damage was that sustained by 877 Colorado Boulevard (Figure 7) where lack of anchors contributed to severe cracking of the walls (Figure 8). Many brick chimneys collapsed (Figure 9) and even a few code-compliant buildings were rendered uninhabitable, including a 1963 design Motel-6 structure adjacent to the Santa Anita racetrack (Figure 10). Windows were broken, wastewater pipes were fractured, bottom plates parted from the concrete slab, and much structural cladding was shattered. One of the two fatalities resulted from an angle section falling from the steel truss covering the racetrack grandstand onto a woman working an early-morning exercise session.

Overall, the damage sustained estimated at \$35,000,000, much was predictable and certainly of a form likely to be repeated until hazard mitigation programs have been completed.

HIGH RISK BUILDING HAZARD REDUCTION

The Sierra Madre earthquake focused attention on the lack of consistency with which the various California city and county authorities have tackled the hazard reduction of high risk buildings. In June 1991 approximately three-quarters of

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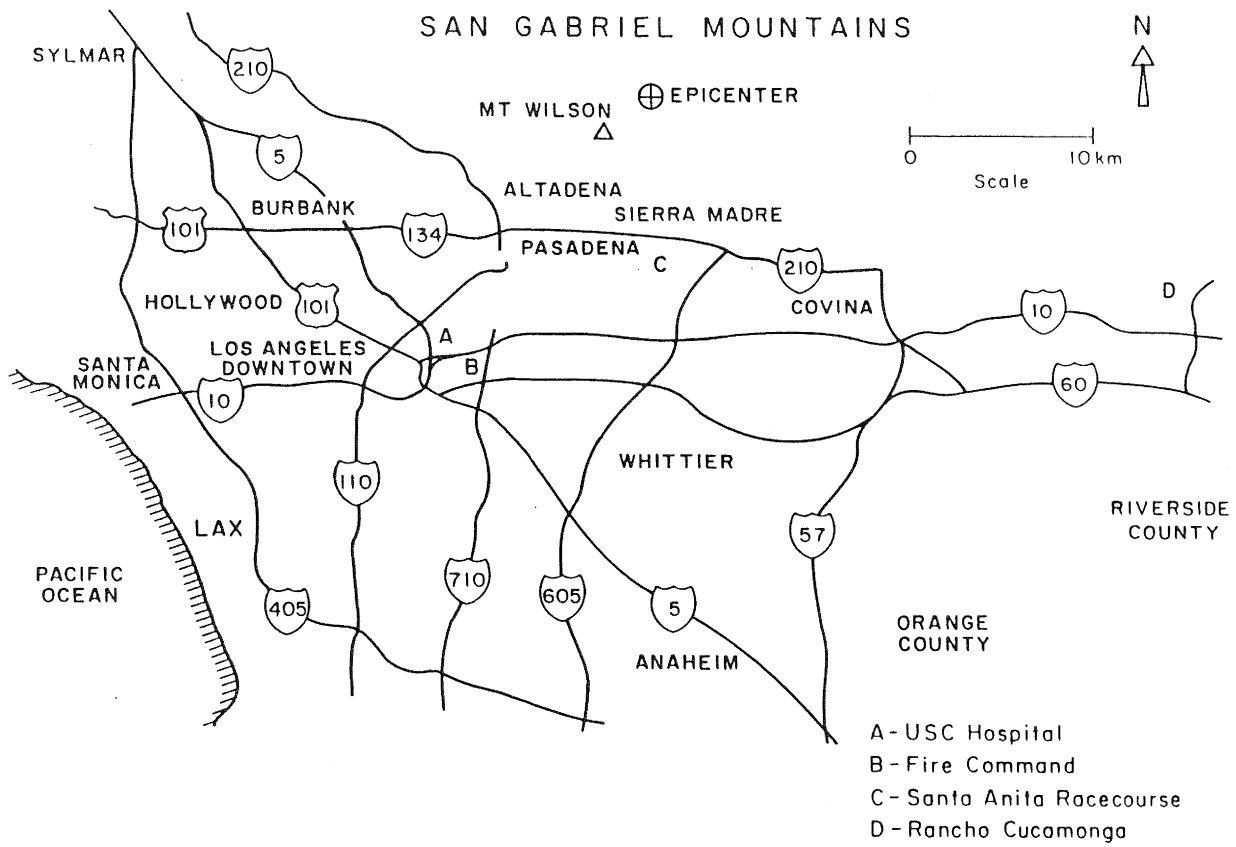


FIGURE 1. LOCATION MAP

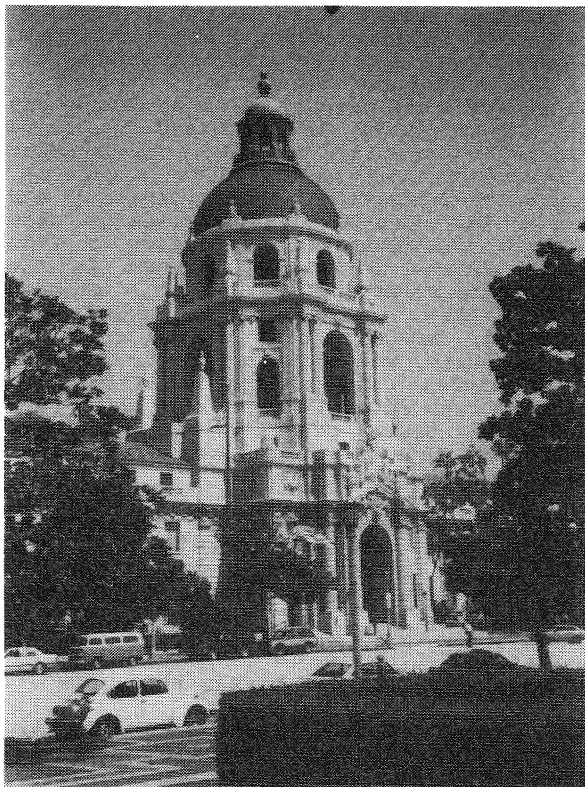


FIGURE 2. PASADENA CITY HALL



FIGURE 3. REAR OF PASADENA PLAYHOUSE



FIGURE 4. WESTMINSTER PRESBYTERIAN CHURCH,
NORTH LAKE AVENUE, PASADENA

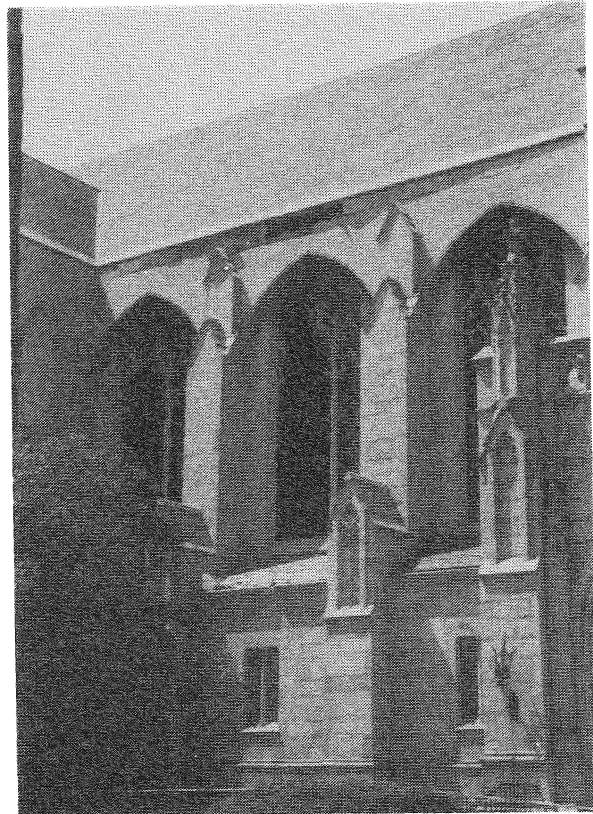


FIGURE 5. SOUTH ELEVATION OF WESTMINSTER
PRESBYTERIAN CHURCH

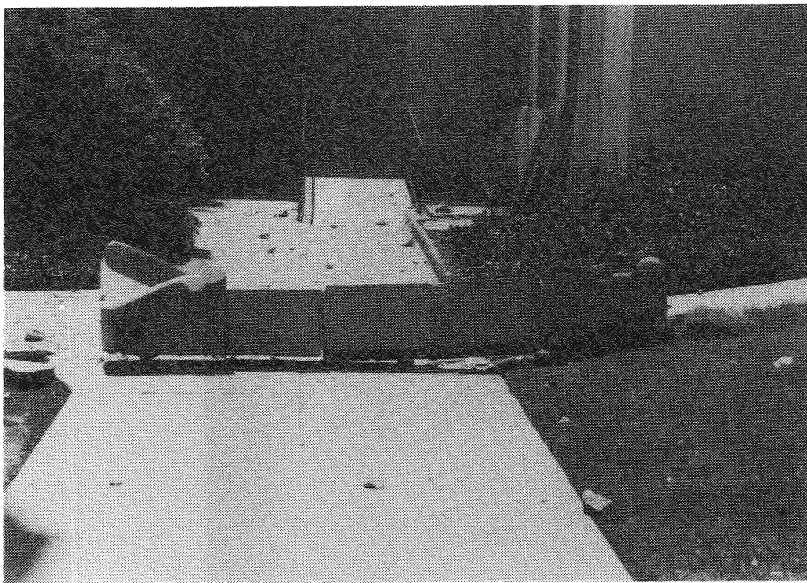


FIGURE 6. TOPPLED PINNACLE, WESTMINSTER PRESBYTERIAN CHURCH



FIGURE 7. 677 COLORADO BOULEVARD, PASADENA

FIGURE 9. FALLEN BRICK CHIMNEY, SIERRA MADRE

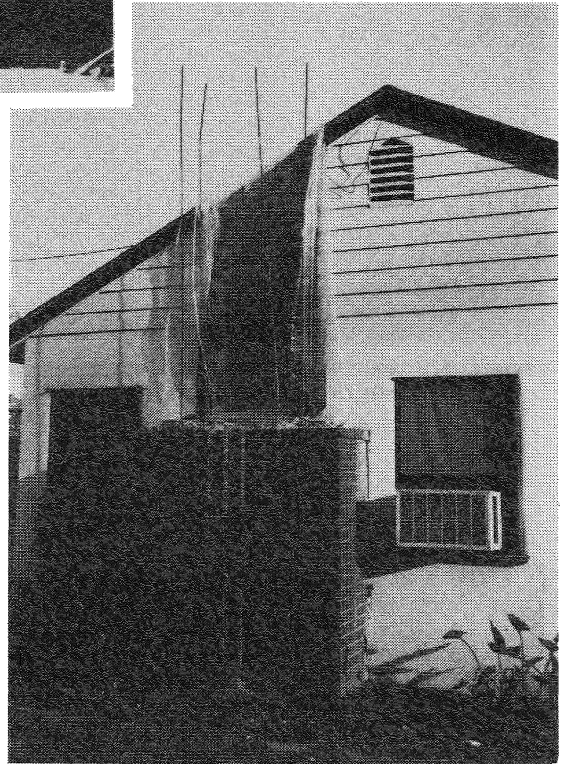
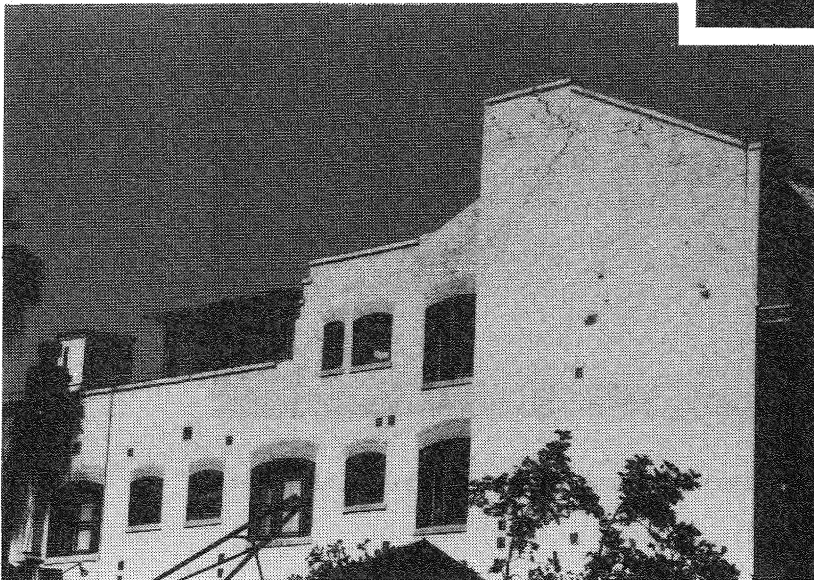


FIGURE 8. CRACKED WALLS IN FIGURE 7 BUILDING



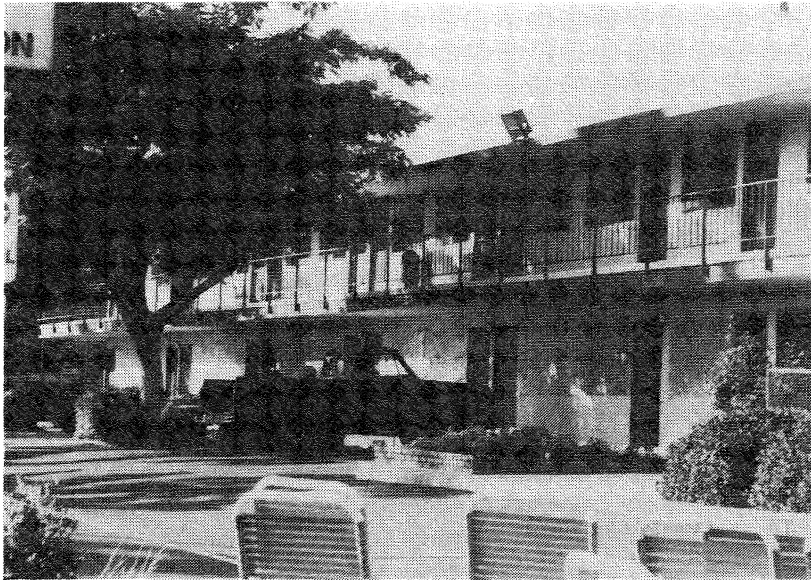


FIGURE 10. BOARDED-UP MOTEL 6 BUILDING, ARCADIA

California cities and counties were in substantial compliance with the 1986 Unreinforced Masonry Building Law which calls for the establishment of effective mitigation programs for high risk buildings. The areas controlled by these authorities include almost 90% of the total buildings which fall under the law. Over half the adopted mitigation programs involve mandatory strengthening and approximately two-thirds of the total number of appropriate buildings are included in these mandatory programs. Most programs provide for retrofitting within a three to seven year time span. A notification-only approach, considered the least effective of the various alternatives cover about 18% of the URM buildings in the state. A few cities have adopted a form of voluntary strengthening compliance.

More than one-quarter of the local governments in California have yet to comply with the URM building mitigation requirements, but only about 12% of the total of appropriate structures are in these jurisdictions. Surprisingly, in view of the fact that half of the eligible buildings in the San Gabriel Valley are in Pasadena, prior to the Sierra Madre earthquake the City of Pasadena had not satisfied the State that those buildings within the city especially vulnerable to seismic damage had been identified, yet alone been strengthened.

The disproportionate damage sustained by Pasadena, estimated at \$10M to 200 commercial and residential properties, undoubtedly reflects the local attitude to seismic hazard abatement which has received much more serious attention by the City of Los Angeles. This city's seismic safety ordinance (1), adopted ten years ago, requires retrofitting or removal of more than 8,000 unreinforced masonry precode buildings. Exempt from the requirements are

single-family homes and apartment houses of four units or less. To date, some 4,600 eligible structures have been strengthened, about 800 are currently being retrofitted and almost 2,000 have been demolished or vacated.

It is likely that the Sierra Madre event will prompt action by those jurisdictions which have been tardy in attempting to comply with the 1986 law. Cities such as San Francisco and Pasadena, which have only required serious compliance with seismic strengthening requirements when remodelling is undertaken as part of a building use change, are likely to move much closer to the City of Los Angeles position. It is recognized that this process would be expedited by more readily available financing for upgrading and by standardization of codes governing retrofitting.

In some instances, voluntary seismic upgrading had been undertaken by property owners with notable success. An example is the Crown City Hardware store in Duarte (Figure 11). This more than fifty-year old single storey unreinforced masonry building of approximately 6,500 square feet footprint had been seismically upgraded in 1990 at a cost of \$50,000 (Figure 12) essentially by tying the parapet back to the bowstring roof trusses at two levels. It survived the June 28 shaking unscathed, whereas the building directly across the street (Figure 13) suffered significant damage.

FREEWAY STRUCTURES

After the serious damage sustained to freeway structures in the 1987 Whittier (2) and 1989 Loma Prieta (3) earthquakes, it was not surprising that considerable concern was exhibited by those caught in morning rush-hour traffic on June 28, 1991. Reports were



FIGURE 11. CROWN CITY HARDWARE BUILDING,
1047 NORTH ALLEN, PASADENA

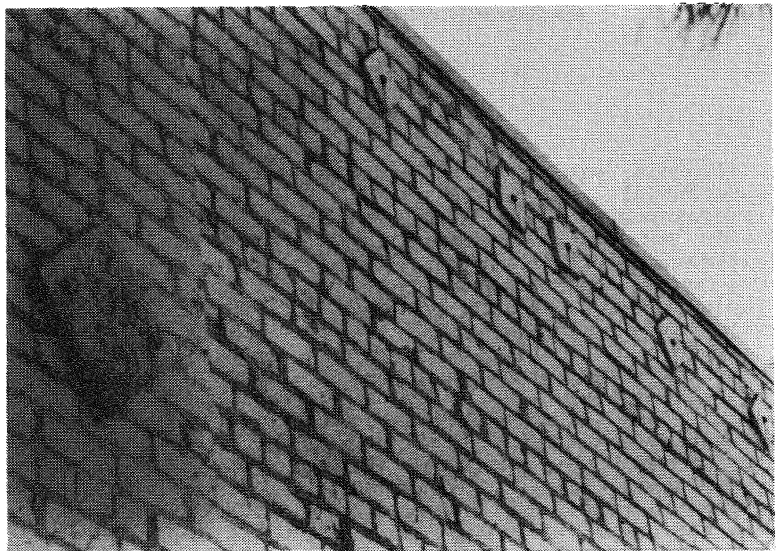


FIGURE 12. WALL ANCHOR, REAR OF CROWN CITY
HARDWARE BUILDING

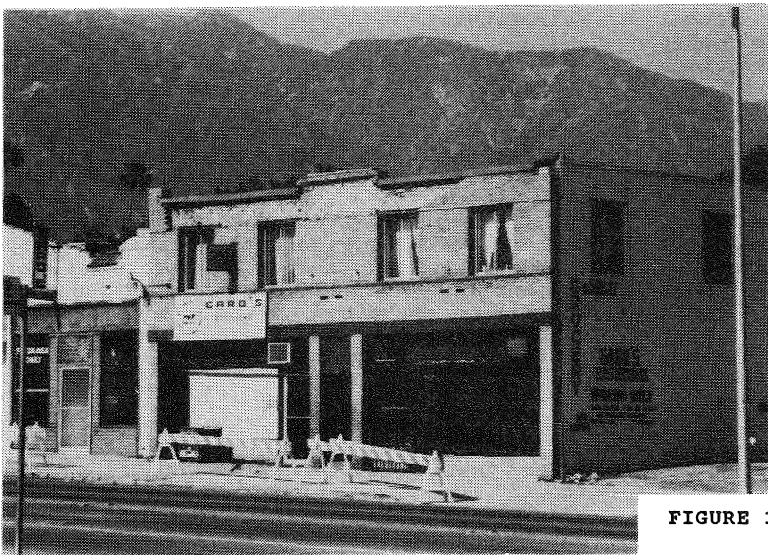


FIGURE 13. BUILDING DIRECTLY ACROSS STREET
FROM CROWN CITY HARDWARE

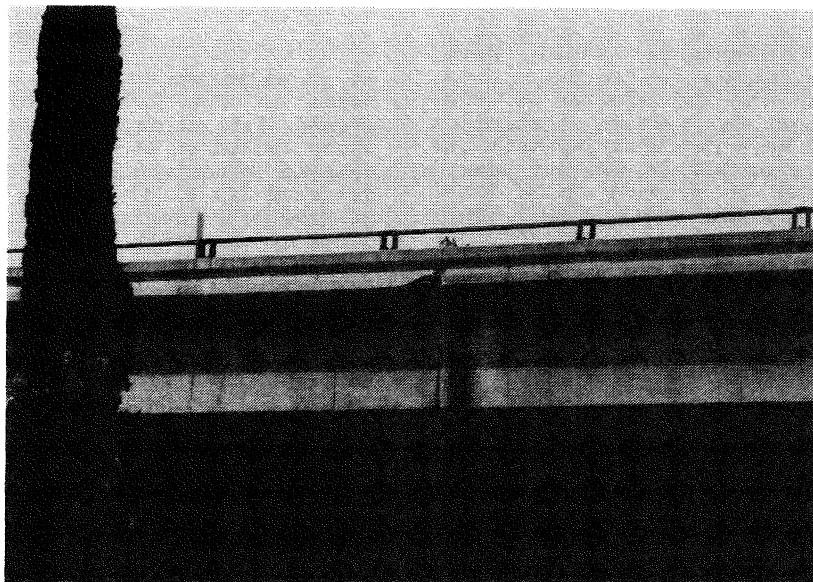


FIGURE 14. 210 FREEWAY OVERPASS AT SECOND AVENUE, ARCADIA

made of drivers leaving their vehicles and contributing to the exceptional gridlock conditions in the San Gabriel Valley immediately after the shaking was felt.

Very little structural damage occurred to the freeway system and no routes were affected other than by short-term restrictions to allow inspections to be made. Typical of the minor damage recorded was that observed on the 210 Freeway overpass at Second Avenue in Arcadia (Figure 14) where longitudinal compression at a joint caused spalling of some concrete.

BASE ISOLATED STRUCTURES

After a relatively slow start in California, base isolation as a means of limiting seismic response is gradually gaining acceptance. Records were obtained at these base isolated structures in the Sierra Madre earthquake (4).

The Los Angeles County Fire Command Center, a recently completed two-storey base-isolated braced steel frame building, is 28 km from the epicentre. Freefield peak accelerations of 0.12g horizontally and 0.03g vertically were measured as were values of 0.08g horizontally and 0.05g vertically on the base of the steel structure and 0.09g horizontally and 0.09g vertically at second floor level.

The Los Angeles, University of Southern California Hospital, a base-isolated, eight-storey braced steel frame is currently under construction 29 km from the epicentre. Some sensors had been installed and records were obtained. The peak accelerations were 0.12g horizontally and 0.03g vertically freefield, 0.06g horizontally and 0.04g vertically at the base of the steel frame and 0.09g horizontally and 0.05g vertically on the upper part of the frame itself.

At the Rancho Cucamonga Law and Justice Center, a base-isolated braced steel frame, 43 km from the epicentre, low amplitude records smaller than those made in the 1990 Upland earthquake were obtained. Peak accelerations recorded were 0.04g horizontally and 0.03g vertically, freefield, 0.03g horizontally and 0.02g vertically at the steel frame base and 0.08g horizontally and 0.02g vertically on the upper part of the frame.

Although critical examination of the response of a prototype base-isolated structure to strong ground motion still awaits the occurrence of such excitation close to an instrumental building, the records obtained in the Sierra Madre earthquake are likely to prove useful in calibrating the behaviour of these three southern California base-isolated buildings.

INSURANCE

The Sierra Madre earthquake has once again directed attention to California's earthquake insurance provisions. Traditionally, coverage has been a matter of individual choice. Private insurance companies typically charge annual premiums of \$2 to \$3 per \$1,000 of coverage with a 10% or 15% deductible applied separately to the structure and the internal contents. It is estimated that only a small proportion of property owners carry earthquake insurance, many being deterred by the high deductibles. Of the 25,000 houses damaged in the Loma Prieta earthquake, 96% suffered damage less than a corresponding 10% deductible. After the Loma Prieta disaster, the state instituted a temporary increase in the sales tax, raising about \$800 million to fund an earthquake recovery program.

The June 28, 1991 event occurred three days before a state initiative was scheduled to

have become effective in which mandatory home earthquake insurance would have provided coverage of up to \$15,000 in an attempt to bridge the gap created by the deductibles applied by private insurers. The program would have required payments of premiums ranging from \$12 to \$60 per year. These were expected to provide about \$250 million annually to the state fund. The success of the proposal depended largely on infrequent claims on the fund in the first few years to allow a significant accumulation to occur before a major event results in many claims being made. The state insurance commissioner supported delay of implementation of the new scheme for six months to allow review and possible revision of the proposal. In particular, it appears likely that the average premium of \$30 per year will be judged inadequate to ensure adequate funding of the program. A revised figure of about \$120 has been aired together with a deductible of 5% of the insured value of the structure, applicable to the state insurance.

Although the June 28 damage, estimated to total \$33.5 million, is relatively insignificant compared with the \$7 billion cost of the Loma Prieta event or the \$10 billion estimate attributed to a future catastrophic California earthquake, it has served to focus scrutiny on the apparently flawed proposals which were about to be enacted to establish a state insurance fund. Hopefully a viable proposal will be developed within the next few months.

STATE OF EMERGENCY DECLARATION

A week following the Sierra Madre earthquake, State of California Governor Wilson declared a state of emergency in Los Angeles County, the main effect being that owners of houses and businesses damaged on June 28 may qualify for low interest loans.

To qualify for state loans, homeowners must show evidence of having been rejected for financing by private lending institutions, including banks. The California Natural Disaster Assistance Program provides loans at 3% interest, with payments deferred for up to 30 years, but such assistance is only available if all other possibilities have been exhausted.

Some state funds will be provided for repair to public facilities as a result of the declaration, although the problems currently being experienced with the state budget may result in any allocation being judged inadequate.

CONCLUSION

It is estimated that the cost of damage to homes in the Sierra Madre earthquake is around \$15 million, covering some 1,600 units including 13 destroyed and 58 severely damaged structurally. Some 500 business suffered \$11 million in losses and the cost of damage to public buildings and property owned by nonprofit organizations is believed to be \$7 million.

Many of the lessons learned in previous earthquakes have been reinforced by the results of this one. A few new aspects have unfolded including the uneven concern exhibited by individual cities for the hazard buildings mitigation program and the unsatisfactory nature of earthquake insurance provisions. Continued effort is clearly needed if these defects in the earthquake hazard mitigation provisions are to be overcome.

ACKNOWLEDGEMENTS

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REFERENCES

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