deteriorated on account of the civil war, this moderate-magnitude EQ had devastating consequences: more than $1.5 billion in losses (more than one fourth of the gross domestic product of El Salvador) and 100,000 homeless. The following are the main lessons that have been learned from this EQ.

Recorded EQGMs. A total of nine strong-motion records, each consisting of 3 components, were recovered from the accelerographs installed at seven stations. The stations were all within 6 km of the epicenter. The PGAs of the recorded horizontal ground motions ranged from 0.32g to 0.72g. The vertical components of the ground acceleration were very high, and varied from 0.15g to 0.46g. Shakal et al. [26] have presented a detailed evaluation and discussion of the recorded data. The recorded accelerations at the Geotechnical Investigation Center (CIG) are shown in Fig. 25. The horizontal PGA at 90° (E00W) was 0.69g. The calculated PGV and PGD for this record are 80 cm/sec and 11.9 cm, respectively. The maximum calculated PGD is 17.8 cm for the record obtained at the National Geographic Institute. The CIG record will be used later to show that PGA is not a reliable parameter by which to judge the damage potential of an EQ. It will be shown that the damage potential of this recorded EQGM was small because the duration of strong motion was very short, about three seconds. The EQGMs recorded during this EQ are very important, because the provide information about the characteristics of strong shaking at very small distances from the source of the EQ. The availability of close-in strong-motion data is very limited.

Geotechnical Effects. The main shock caused several hundred landslides in an area of at least 200 km^2 This EQ also produced rockfalls. Other types of observed ground failures included lurching, cracking, and differential fill compaction and settlement. Local geological and soil conditions (soil profile and topography) affected the severity of the EQGMs, and consequently the damage throughout the city. The predominant site period ranged from about 0.5 to 1.0 second.

Performance of Buildings. Damage to buildings was major and widespread in the city. Although no new lessons were learned, the observed damage emphasized the following lessons, which have been learned before.

- Faulty construction, consisting of poor quality control of material, poor workmanship, and deficiencies in detailing and placement of reinforcement, was the common cause of severe damages.
- It is important to consider the probable predominant period of the EQGMs in the design of a building, and to try to prevent the response of the building from entering into resonance with the EQGMs.
- It is necessary to avoid torsional effects as much as possible (Fig. 26).

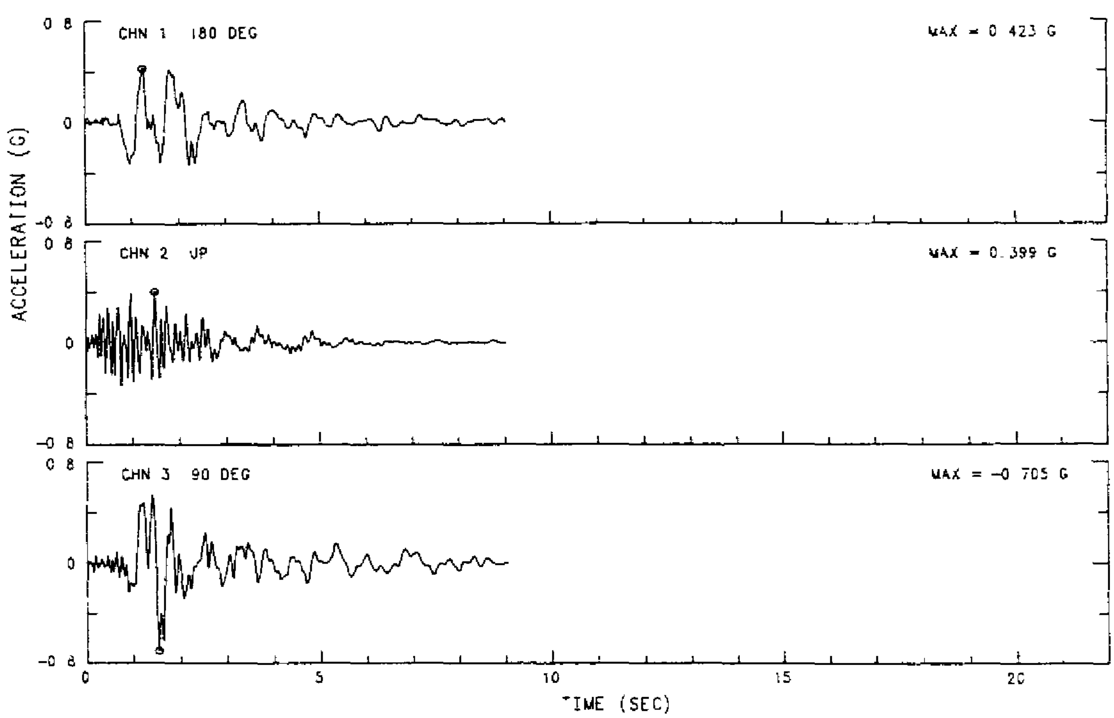

Fig. 25 THE 1986 SAN SALVADOR EQ: ACCELEROGRAMS RECORDED AT THE GEOTECHNICAL INVESTIGATION CENTER (CIG) (Shakal et al. [26])

- Buildings with structural systems based on the use of shear walls behave better than buildings which use MRSF systems (Fig. 27).
- It is important to avoid creating short-column conditions in MRSFs by avoiding the use of partial-height infill masonry panels.
- It is necessary either to upgrade or demolish buildings that have been condemned because of poor performance in previous EQs.

Fig. 26 PHOTO ILLUSTRATING COLLAPSE OF ONE STORY DUE TO TORSIONAL EFFECTS

THE WHITTIER NARROWS EARTHQUAKE OF OCTOBER 1, 1987 [27]. Although the numbers of killed (3) and injured (about 1,350) were relatively small, this moderate magnitude (M_L=5.9) EQ generated the largest set of strong-motion data ever before obtained. It also created significant social disruption. The EQGMs originated by this EQ tested and supplied important information about the seismic performance of unreinforced masonry buildings in the City of Los Angeles. The buildings had been upgraded in accordance with an ordinance enacted in February 1981 regarding such buildings. Approximately 1,100 such buildings had been upgraded by the time of the EQ, which, in spite of the fact that the EQGMs it generated were considered moderate, damaged several of them. A study reported by Deppe [27] indicates that 85 fully strengthened buildings were damaged, of which 15 were severely damaged. The observed damage indicates the need to improve certain aspects of the code design standards for upgrading such masonry buildings. As reported by Moore et al. [27], no loss of life or major injuries were attributed to the damage suffered by the upgraded masonry buildings (nor to those that were not upgraded), but the falling bricks associated with the observed damage did present an injury hazard.

The main features of this EQ, which will be used later in assessing the implications of the lessons learned, are the following.

Recorded EQGMs. This EQ triggered more than 250 strong motion recorders. The maximum horizontal acceleration recorded was 0.63g, in the basement of the 10-story building shown in Fig. 28, which was located near Uptown Whittier at an epicentral distance of 10 km. The station at the Cedar Hill Nursery in Tarzana, which is

Fig. 27 VIEW OF A HOSPITAL COMPLEX CONSISTING OF AN 11-STORY TOWER (RC FRAME WITH COUPLED SHEAR WALLS), WHICH SURVIVED THE 1986 SAN SALVADOR EQ, AND A 3-STORY ANNEX (RC FRAME) WHICH DID NOT [26].

located 44 km from the epicenter, recorded a horizontal PGA of 0.62g. This large value is considered to be anomalously high. It does not fit any of the available attenuation curves.

7215 Bright Avenue, Whittier Records. Figure 29 shows the three records from accelerographs at the basement of the 10-story RC building. In spite of the high intensity of the two horizontal acceleration components (0.63g and 0.40g), the building suffered no visible damage. Figure 29 also shows the acceleration spectra for the recorded 90° horizontal component. From analysis of these spectra and comparison with the design spectra required by code (see Fig. 10), it would appear that any structure with a fundamental T=0.4 sec would have to suffer severe damage. The lesson relearned from these analyses of the recorded EQGMs and the observed seismic performance clearly confirms once more that PGA and linear elastic design spectra are not reliable indices for judging the damage potential of EQGMs. As will be discussed later, an analysis of the Input Energy, E_I, and the Hysteretic Energy, E_H, input for this apparently very severe EQGM acceleration shows very clearly that, due to the very short duration of the strong motions for this recorded EQGM, less than four seconds, these energies are very small and thus the damage potential should be small.

Recorded Response of a 10-Story RC Building. The 10-story building located at 7215 Bright Avenue in Whittier (Fig. 28) was designed and constructed in 1972 according to the 1970 UBC. The structural system in the transverse (EW) direction is a RC dual system, composed of a very flexible frame and shear walls, designed by a factored (yielding) base shear strength of 0.073W. In the longitudinal (NS) direction, the structural system comprises a MRSF system where lateral forces are resisted by the perimetral frame designed for a factored shear strength of 0.052W. The building was instrumented with 3 SMA-1 analog accelerographs (each capable of recording 3 components of motion. These accelerographs were located at the basement and on the 5th and 10th floors. The largest acceleration was recorded at the 5th floor, rather than at the roof, indicating a possible strong participation of the second translational mode. The recorded accelerations indicate that the structure was subjected to strong shears, considerably higher than those required by the 1970 UBC, which was used in its design. In view of the very minor damage that this building suffered under the 1987 EQ, it appears that the real yielding strength of this building is significantly larger than that required by the code for which it was designed.

Performance of Highway Bridges. As reported by Gates et al. [27], a total of 24 bridges were found to have some damage or suffered some movement or both. Only one bridge suffered moderate damage, and was described as having some significant damage in the columns of one bent (Fig. 30). All of the columns of the center bent suffered shear failures. The structure was built in 1964 and retrofitted for seismic failure with the addition of longitudinal cable restrainers on the three bents in 1981. Priestley [27] describes the structural characteristics and estimates the level of lateral response. The PGA at the bridge site has been estimated at about 0.20 to 0.25g.