Fig. 3. Remains of Ruben Dario Building.

Fig. 4. Freemason's Lodge.

made. The motion lasted for about six seconds, consisting of two cycles of strong horizontal motion with a frequency of about 2 Hz combined with a significant vertical motion with a much higher frequency of about 10 Hz. The peak values recorded were 0.78 g horizontally and 0.47 g vertically; the maximum values of ground acceleration recorded at each station are shown in Fig. 2. It can be seen that the ground accelerations were generally higher on the east side of the city than on the west although the focal distances are similar. This may, in part, be due to the thicker deposits of volcanic ash on the east side. However, observations of damage cannot really be used to support such a theory since the majority of the damage was concentrated in a band around the main fault line and in isolated pockets of extremely poor housing.

EARTHQUAKE DAMAGE

Although the areal extent of the damage produced by the earthquake was fairly small, the effects were surprisingly damaging for such a small earthquake. Table 2 compares the damage resulting from this earthquake with seven other similar near-field events. The figures, particularly for the numbers of homeless and the total damage, are at best very approximate, but nonetheless provide an interesting comparison. Undoubtedly the very severe damage caused by this relatively small earthquake is in large part due to its very shallow focus.

The total damage, including lost production, has actually been estimated at between U.S.$1.5—2.0 billion, about 10% of which was insured. An indication of how devastating this damage is for El Salvador can be gained by examining the ratio of the material loss per affected person to the GNP/capita for the country; for the San Fernando earthquake this ratio was 0.2, for Popayan 2.3 and for San Salvador 3.6. This disaster comes on top of crop failures due to drought in recent years and six years of civil war in El Salvador which has claimed 60,000 lives. In 1985, inflation in El Salvador stood at 22%; in the first six months of 1986 it rose to 34% and the consequences of the earthquake will undoubtedly cause further increases.

The earthquake caused considerable damage to business and industry, the largest private loss being La Constancia Brewery with losses broken down as follows:

Building	U.S.$1.6 million
Equipment	U.S.$0.5 million
Stock	U.S.$0.25 million
Lost business	U.S.$2.0 million
Total	U.S.$4.35 million

The worst hit sector was that of small businesses and workshops. This has resulted in a large increase in the number of unemployed in the city; before the earthquake urban unemployment already stood at 19% with a further 58% chronically underemployed.

The earthquake also caused widespread damage to the capital's infrastructure. Damage to roads resulted from small slides on steep cuttings although in general transport was operating throughout the city. A great deal of disruption was caused by more than 500 burst water pipes, of which 287 were primary distribution lines. The production of potable water was not affected but the damage to the distribution system left many people without running water, which was being distributed in tankers.

The electricity supply system was disrupted by damage to two of the four substations that serve the capital, at Soyapango and San Antonio Abad, as well as to transformers and cables; nonetheless, rapid repair work restored 80% of the city's supply within 26 hours of the disaster. The telecommunications system suffered very badly and the state company, ANTEL, suffered the largest single loss due to the earthquake with damages totalled at U.S.S17.6 million. ANTEL reported that 30,000 telephone lines were put out of service and the system was still running at a greatly reduced capacity a month after the earthquake.

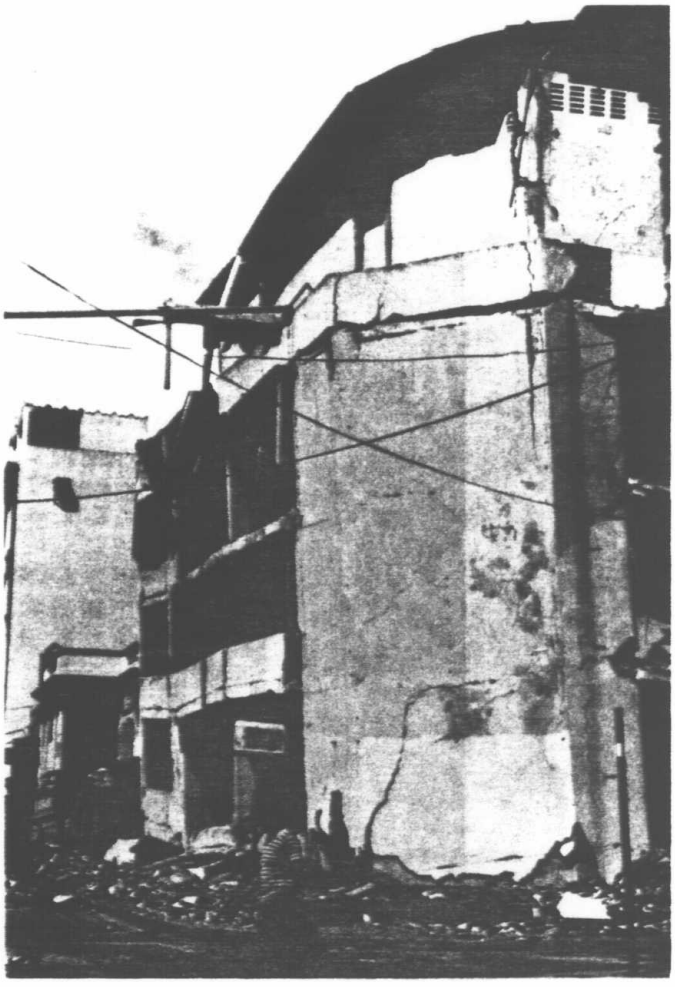

Fig. 5. Freemason's Lodge.

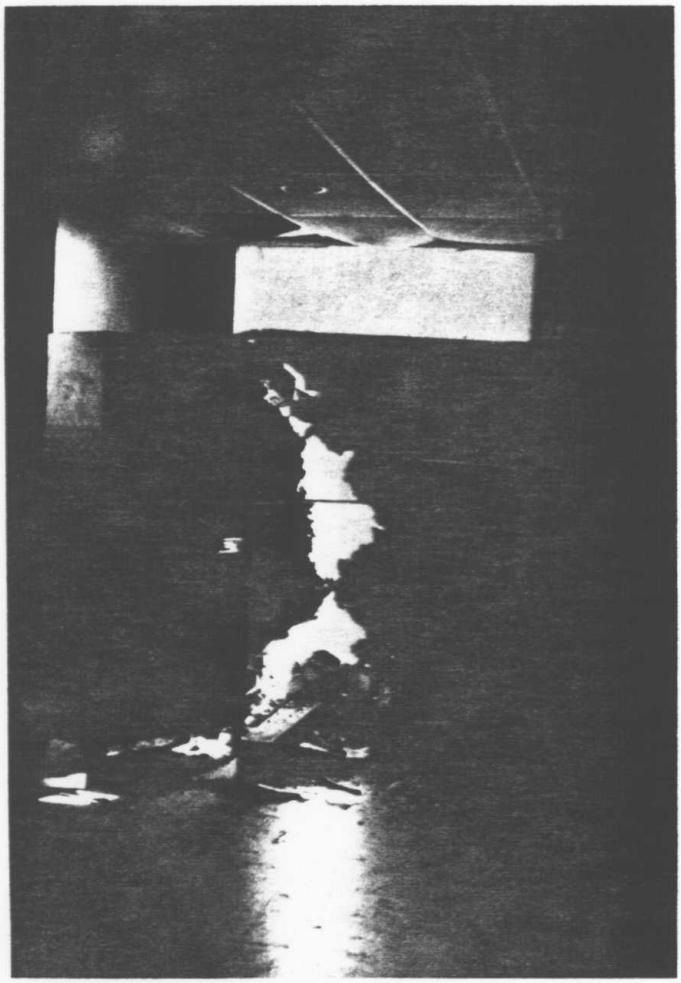

Fig. 6. Cracked brick infill panel in Benjamin Bloom Hospital.

ENGINEERED STRUCTURES

The predominate form of engineered construction in San Salvador is reinforced concrete frames and the majority of buildings are of less than ten storeys. Three days after the earthquake the Salvadoran Construction Association (CASALCO) reported that it had registered considerable damage to seventy-five buildings of three or more storeys, which is consistent with the authors' observations. There was one case of complete collapse when the six-storey Ruben Dario building in the downtown area was reduced to a close packed stack of floor slabs (Fig. 3). A number of buildings failed at their ground floors; some like the Freemasons' Lodge (see Figs. 4 and 5), Pete's Bar and the Papeleria Centroamericana were heavily damaged at other floors as well, whilst other buildings like the Hotel San Salvador and the Edificio Duenas remained intact above the damaged levels. One ten-storey structure suffered total failure at its third storey but showed no signs of distress above or below this level.

The U.S. Embassy, built to four storeys in 1967 with a fifth added in 1982, suffered damage at its first floor to shear walls and the perimeter columns ranging from minor damage to complete shear failure. Repairs were being carried out to allow safe access to the building for the removal of its contents; it was announced that the Embassy would be relocated at a total cost of U.S.$70 million.

Amongst the damaged engineered structures there was evidence of damage due to horizontal movement of buildings forming hinges at the tops and bottoms of columns. Severe spalling of columns remote from their ends indicates that many buildings were harmed by the large number of cycles of vertical loading that caused deterioration of the concrete and in places this led to compression failures.

In some cases blockwork infill panels were used in the reinforced concrete frames; these provided little horizontal resistance as they simply buckled under the increased vertical load. Reinforced concrete shear walls were rarely used, but where they were adopted they generally performed well. An example of this was the ten-storey Benjamin Bloom Children's Hospital constructed in 1969 which comprises a massive central lift shaft and two large shear walls at either end. The building suffered no structural damage except that the small brick infill panels between the shear walls and a brick services shaft adjacent to the lift tower both cracked (Fig. 6). Nonetheless, the hospital was not operational as a result of damage to services and equipment, coupled with the total loss of one of the three annex buildings (Fig. 7). The medical staff had established a field hospital under canvas as they had at most of the other medical centres in the city (Fig. 8).

An issue that the earthquake brought to the forefront was the question of repair and demolition of damaged structures. An interesting example is that of the National University, where 30% of the concrete framed buildings were damaged. The three- and four-storey buildings of the engineering and architecture faculties had been damaged at their lower storeys in the 1965 earthquake. These damaged floors had been reparied and stiffened by greatly increasing the size of the columns at these levels; this increased stiffness simply allowed the lower storeys to transfer the seismic forces upwards to where they caused damage at the upper levels. It is interesting to note that in his report to UNESCO Rosenblueth said that this would be the likely result if such repairs were carried out.

Another building that was damaged in 1965 and repaired and then failed in the 1986 earthquake was the Hotel San Salvador. The same is true of the Ruben Dario building which has caused considerable controversy since it was apparently condemned to demolition after the 1965 earthquake.* Immediately after the 10th October disaster

*A woman who worked in one of the offices housed in the Dario who had left the building minutes before the earthquake told us that all those who worked there knew that the building was unsafe and that they often felt the building shake when heavy vehicles went past.