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D. H. Weichert

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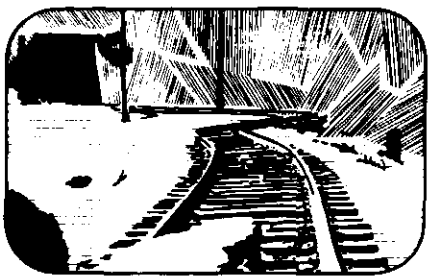
Articles



Earthquake Reconnaissance: Guatemala, February 1976

D.H.Weichert
Division of Seismology & Geothermal Studies
Earth Physics Branch
Department of Energy, Mines & Resources
Ottawa, Ontario K1A 0Y3

Introduction

Seismological knowledge often advances discontinuously after the occurrence of a major earthquake and much can be learnt from field investigations. In Canada, magnitude 7 to 8 earthquakes have occurred in the past, in both the east and west, and are likely to recur. The Seismological Service of Canada has, therefore, contingency plans for fast deployment of manpower and instruments following a large Canadian earthquake.

Within the framework of these plans, arrangements had been made with the Earthquake Engineering Research Institute (EERI) of the U.S. to participate in one of their post-earthquake expeditions. When the magnitude 7.5 earthquake struck Guatemala on 4 February 1976, the writer followed the EERI invitation and joined their reconnaissance team. This paper is basically an account of this earthquake, its seismic effects and the early investigations, but it is also meant as an illustration and reminder of the tasks that would face the Canadian seismological community and especially the Seismological Service in the case of a significant Canadian earthquake.

The Global Tectonic Context

Earthquakes do not come as a surprise in Guatemala. Since the old capital was destroyed by an earthquake in 1541, destructive tremors have been recorded at least every few decades, and small-scale seismic activity is frequent along a belt parallel to the Pacific. This is, of course, part of the well-known Pacific rim of fire. The active volcanic chain, extending from Mexico with several offsets and gaps along the whole of Central America, together with the deep Middle America oceanic trench are now understood as manifestations of the underthrusting of a part of the Pacific ocean floor under the Americas, as shown in Figure 1. The Cocos plate, welling up from the East Pacific Rise and descending again a little more than 1000 km to the east, is the immediate cause for the high seismicity parallel to the coast. Locations and depths of most big shocks prevent major damage: the shallow earthquakes are usually near the trench and off the coast, while near the main population centres the Cocos plate is already at depths of 50 to 150 km, and earthquakes within or near the cold and brittle plate at this depth cause little damage at the surface. On the other hand, shallow activity associated with the volcanism, connected perhaps with ascending magma, is relatively weak.

The epicenter for the magnitude 7.5 earthquake of 4 February was given by the U.S. National Earthquake Information Service as 15.27° N and 89.25° W, in the Motagua valley, as shown in Figure 2, about 160 km northeast of Guatemala City at a shallow focal depth of perhaps 5 km. The great damage and location of this earthquake suggested a different global tectonic mechanism, also shown in Figure 1. Although the details of current and past plate motions in the Caribbean area are still controversial, a cursory inspection of the coastal outlines of the Antilles arc, the Puerto Rican trench and its continuation into the Cayman trench after passing between and shearing off Cuba and Haiti, gives a rather vivid indication of the present-day boundary between the North American and Caribbean plates. Towards the southwest the Cayman trough continues into the Gulf of Honduras, cleaving Central America between the Yucatan and Honduran peninsulas. On land this tectonic boundary continues and is recognized as the Polochic-Chixoy and Motagua fault systems (Figs. 1 and 2). This structural feature may originally have been formed by plate collision in the Lower Cretaceous (110 million years ago), while the left lateral motion indicated by the offset of Cuba against Haiti may have started in the Tertiary (55 million years ago). The Caribbean plate may then have collided with and been held back by the Cocos plate, while the North American continent continued to move in a westerly direction.

Reconnaissance Teams

I found a distinct lack of awareness in Guatemala of the potential danger from earthquakes along the North America-Caribbean plate boundary. This was expressed, for instance, by the fact that a week after the event, local papers st ll connected the earthquake with the volcanoes southwest of the capital, although there was little damage

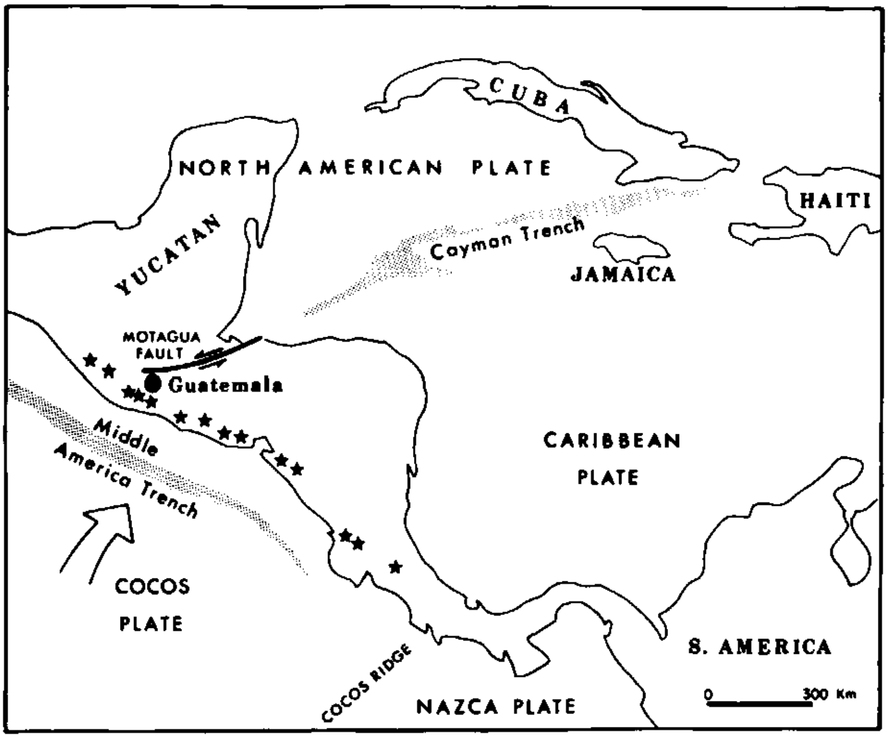


Figure 1
Schematic tectonic map of the Caribbean and Central America.

in that direction. This lack of public information is easily understood when one realizes that no seismological service as such exists. Its functions are maintained at a low level by the Meteorological Observatory of the Ministry of Agriculture, aided to some extent by the U.S. Geological Survey which has installed a six-station telemetered network near Guatemala City, mainly for monitoring the volcanic seismicity. Participation in, or coordination of seismological investigations was therefore not provided by the Guatemaltecs, but the National Observatory served as a hospitable rallying point for the arriving foreign teams, especially since it is located within easy walking distance of the airport.

As expected, the strongest contribution to immediate scientific reconnaissance came from the U.S. with independent representation from at least three organizations. The U.S. Geological Survey was well represented very soon after the quake, being involved in geological reconnaissance, in attempts to obtain strong motion records, in isoseismal and engineering damage surveys, as well as in recording of aftershocks. This strong

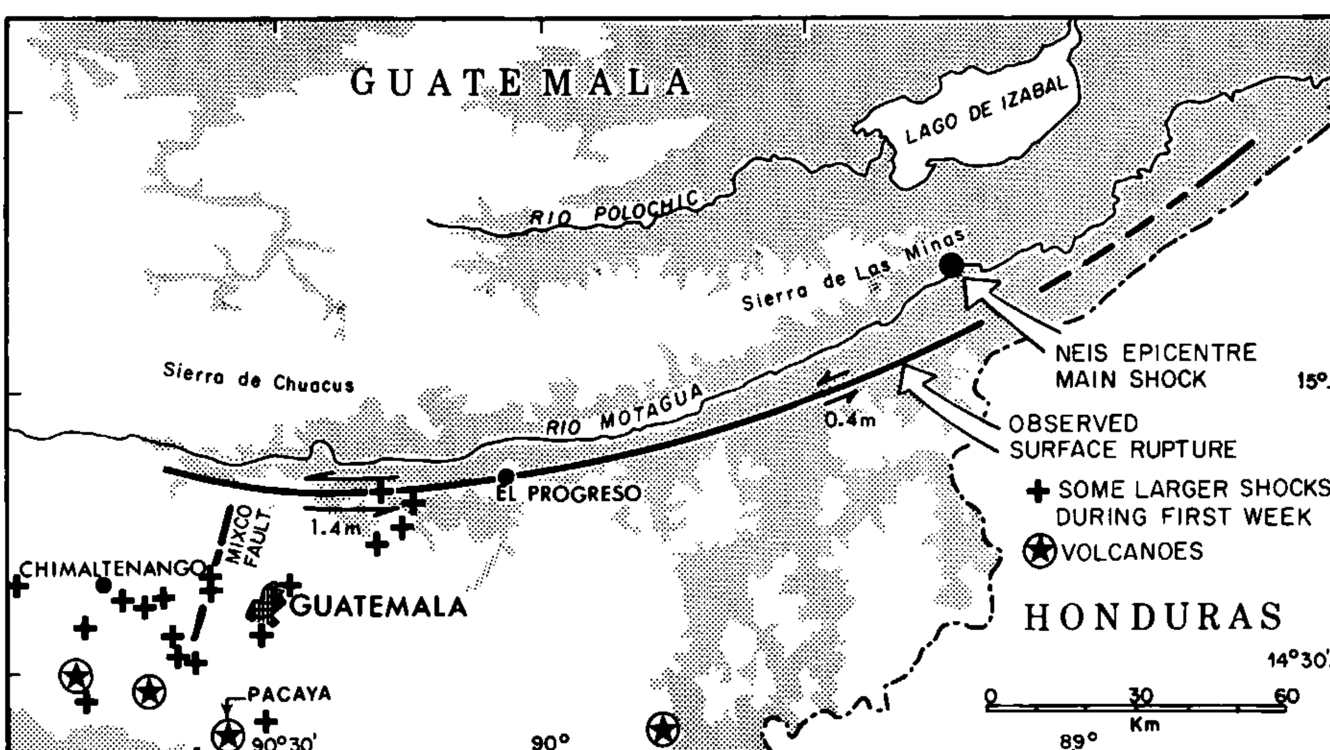


Figure 2
Diagram of Guatemalan earthquake setting.

representation was not surprising since the Survey has been involved in observational aspects of international seismology for about two decades, resulting in the World-Wide Standard Seismic Network. Moreover, they have installed strong-motion accelerographs, which are now the property of the host countries, in many foreign countries including Guatemala.

The EERI immediately fielded a six-man reconnaissance team, which was quickly followed by several other individual observers associated with the institute. The task of this reconnaissance team, quickly and informally dispatched, was to survey the situation, collect the most fragile evidence and then make recommendations for later in-depth studies of worthwhile aspects by specialists. After this earthquake, the EERI team became informally associated with the Guatemalan Department of Public Works. In assisting this department's damage survey of public buildings, the team also achieved its own purpose smoothly and efficiently.

The University of Texas and two Mexican universities fielded early observer teams who set up instruments for aftershock recording, and one team from Venezuela arrived a little later with the same objective.

Geological Investigations

Since large parts of the Motagua valley and adjoining hills were only sparsely covered with vegetation, surface faulting was located and could be followed for a considerable distance within the first few days. An EERI geologist had carried out extensive field investigations in the area during the previous summers, and was therefore able to pinpoint the active fault trace of the Motagua fault zone on aerial photographs, which led to the immediate discovery of the surface rupture. The main fault trace could be followed almost continuously for 240 km, from about 60 km east of the epicenter, along the south side of the Motagua valley, to well northwest of Guatemala City, into the vicinity of Mixco Viejo, as shown in Figure 2. A surface rupture was not observable in the river alluvium east of the town of Los Amates, where the weak surface either could not sustain cracking at all or the trace had already disappeared. In this area some sand boils were reported, but no other evidence for liquefaction was cited. The writer and some engineering colleagues found it difficult to convince themselves by air observation of the "continuity" of the fault trace in an area where our geologist friends had already established its existence. Figures 3 and 4 show examples of easily visible surface offset and cracking.

The closest approach of the fault rupture to Guatemala City was about 25 km due north. The main crack zone of deformed ground varied in width from about 2 m to 5 m, but occasionally appeared as wide as 9 m. Several slip measurements were made by USGS and EERI geologists, ranging from a minimum 0.4 in the epicentral area to a maximum of 1.4 m directly north of Guatemala City. This increase of offset from the epicentral area towards the west appeared to be confirmed by other intermediate measurements. It is also consistent with seismograms recorded in Canada, which show a gradual build-up of amplitude over the first 50 to 70 seconds, corresponding to the time of propagation of the fault break. No vertical component of slip was observed for the main fault. Some secondary faulting was reported from about the centre of the main fault, paralleling it about 0.5 km to the south. Like the main fault, it appears as a series of right-stepping en echelon cracks, extending for about 3 km. Secondary faulting was

Figure 3
Faultbreak, easily visible as it crosses a dirt road, note the right-stepping en enchelon pattern, which was generally observed.

Figure 4
Road crossing of the fault, looking north. The far side has moved left, as confirmed by the offset in the white centreline of the road.

also reported for the Mixco fault, a N-NE trending structure (see Fig. 2).

In view of the common statement that northeastern American earthquakes (eastern Canadian) do not break the surface, it should be useful to relate here the opinion that past searches after the infrequent magnitude six or greater eastern quakes may not have been thorough enough to offset the disadvantages of our heavily wooded terrain and often snow-covered ground.

More easily observed but less exciting ground failure phenomena were very extensive landslides and slumping. With much of the surface material consisting of pumice deposits and other volcanic material, sliding of the very steep hillsides was inevitable. The often minimal roadcuts and narrow fills across gulleys were an invitation for disaster, and they impeded emergency relief operations very severely.

Contrary to what this writer would have expected, the geological survey turned out to be a good example of the need for speedy action. Obviously, large-scale slumping of hill sides or similar effects will not normally disappear overnight, but had the earthquake in Guatemala occurred during the rainy season, the finer details of the surface fault rupture could have been obliterated or disappeared within days, according to the geologists involved.

Instrumental Surveys

Big earthquakes are usually followed by many smaller tremors. Registration of these aftershocks can yield valuable information about the earthquake source region and mechanism. Elementary statistical analysis relating the drop-off in number of shocks, their magnitude and their time can give some insight into the state of stress and stress relief within the source region. Determination of epicenters and depths may improve the definition of the source volume and its relation to fault lines or other tectonic features, or it may indicate the presence of unrelieved stress in neighboring areas. Finally, the additional instruments may give sufficient data for good determination of source mechanisms and regional peculiarities of wave propagation. Thus, for the seismologist, recording of aftershocks is one of the most immediate and time-critical concerns. This explains the earlier observation that at least four independent teams set up operations in the country within about two to ten days. Considering the length of the main fault area, it is perhaps unfortunate that most instruments were initially located too close together, near the capital, but because of the road damage only helicopter-assisted operations could have done better. Priority for helicopters was a continuous ferrying operation of food and supplies into the hinterland and the evacuation of wounded to the hospitals in the capital.

The locations of the larger aftershocks that occurred during the first week, shown in Figure 2, are only a preliminary and incomplete sample of the many hundreds of shocks during that time. These locations were obtained by our Mexican colleagues, who operated their smoker seismographs out of the observatory as headquarters (smokers are seismograph systems recording on paper smoked over a sooty flame: still considered as best quality recording by many). The epicenters in Figure 2 do not clearly define any particular tectonic structure. There is a weak suggestion of activity extending to the southwest in the general location of secondary faulting along the Mixco fault near the volcanic line. Renewed smoke eruptions of Pacaya volcano bore witness to some interaction, and seismograph systems to study this area were set up by the Venezuelan group. The severe aftershock that followed the original earthquake within two and a half days, causing wide-spread damage by knocking down previously weakened structures, was probably located there.

A much more detailed knowledge of the characteristics of strong and destructive ground motion is highly desirable for engineering design of complex modern structures. This has led to the estabishment of extended networks of strong motion accelerometers in many earthquake-prone areas of the world, though predominantly in North America. Yet, until the 1971 San Fernando earthquake produced an abundance of strong motion records in that region, these records were rare. In Guatemala, several strong-motion accelerometers had also been installed, but none of these units recorded the main shock or were triggered by any of the strong aftershocks of the first week. This emphasizes again the difficulties in maintaining such delicate instrumentation in a long continuous state of readiness, for an event that one hopes will not occur during one's lifetime. Actually there were two instrumental records of strong motion of the main shock, but they came from seismoscopes in the same building and may be hard to interpret because they contained two years of superimposed data. Seismoscopes record horizontal ground motion by scribing the two-dimensional motions of a pendulum on to a smoked spherical watch glass.

Qualitative surveys

Historically, detailed surveys of damage have helped both to define the epicentre and give some measure of magnitude. Contours of earthquake intensity, i.e., of observed damage and other ground motion effects reported by the population, have been drawn. Their diameter, shape and maximum intensity have allowed conclusions as to focal depth and length of fault breakage, although regional variations of wave propagation characteristics and attenuation complicate such interpretation.

Lacking adequate near-focus instrumental records, strong motion information about the Guatemalan earthquake comes from intensity (isoseismal) surveys with their inherent subjectivity and dependence on local types of construction. There are two areas of interest in qualitative investigations, seismological and engineering. Seismologists take into account ground motion effects of all types, including the impressions related by eyewitnesses, and then attempt to assign an intensity value to these observations. The scale now normally used in North America is the Modified Mercalli scale, ranging from Intensity I - ground motion not normally perceived by humans - to Intensity XII - total damage. Definitions for the intermediate grades rely heavily on observations such as "masonry class 'C' damaged, heavily damaged, or destroyed", but such definitions obviously depend on local construction practices and are difficult to apply in areas like Guatemala where most of the indigenous "masonry" consists of air-dryed clay bricks reinforced with straw. Empirical relations between intensity and quantitative measures of ground motion are therefore notoriously poor.

This type of detailed but rather qualitative intensity survey was done in Guatemala City and environs by two Spanish speaking USGS seismologists. Their results and conclusions are unknown to this writer and the following is therefore based on personal observations, supplemented by some second-hand information.

After reading the sensational damage reports in Canadian newspapers, the first reaction was a relief. The main airport building was open and had no structural damage. An aqueduct near the airport that had survived from Spanish colonial days had lost some bricks, but only the occasional arch had completely collapsed. Most middle-class brick and concrete residences in this area had survived without significant damage. However, this area is in the south, away from the fault. Further north, the modern downtown skyline still did not reveal extensive external damage, although plaster and brick damage especially in older buildings turned out to be considerable. A few kilometres north in the older and poorer areas, frequency of damage increased with the number of adobe structures and was more severe. Typically, the frame and adobe corners of street blocks had been thrown out, with considerable damage to the house, while most of the row houses in the street had lost only parapets and other poorly secured roof structures.

The city is built in the plains of a graben, right on the continental divide, filled with loose to well-cemented volcanic material. It is surrounded by deeply eroded canyons, the sides of which are occupied by "squatters", the poorest social strata, living in badly constructed huts on the poorest imaginable real estate. This is where the major loss of life in the city occurred, not because of severity of ground motion but because of social and geologic factors.

Earthquake intensity is very difficult to judge under these circumstances and it may be illuminating to relate how one experienced investigation team in the city changed its consensus on the intensity at a certain point from VI to VII, but "certainly not VIII". This occurred because this author succeeded in re-classifying the particular type of damaged masonry one class higher. Examples like this emphasize that this is no more than an ordinal or ranking scale, and cannot really be expected to correlate well with measured ground motion parameters.

Reconaissance into the fault area revealed much more extensive, but still not consistent damage. Adobe type construction very near the fault itself was almost totally destroyed, but in many cases whole blocks of it were left standing only a few hundred metres away. A different type of housing survived well - perhaps not surprisingly: huts with light thatched roofs on wooden post frames directly standing on the fault were distorted, but many did not fall. The Guatemaltecs have taken note of this and are asking for light building materials for reconstruction aid. In one case, a woman was said to have slept across the fault and survived, with one leg of her bed in the fault crack. I did not see the location nor talk to her.

This is a good further example to emphasize speed and timeliness of this type of investigation. During the first few days people are communicative, but soon they return to everyday life, or to the grim task of reconstruction. Outsiders become intruders unless they offer help. Clean-up operations make fresh evidence illegible, or barricades prevent access to private property altogether. Despite government instructions to wait for proper inspection and permits, repairs were rapidly progressing in some places.

The province and capital of Chimaltenango was the, or one of the, most heavily suffering areas, off the southwest end of the surface fault break. This is on the Altiplano, the Highland, where the usual ground amplification effect, often observed along ridges and slopes, may have contributed to destruction on a large scale. However, even here damage appears very inconsistent. Figure 5 shows a typical view in the provincial capital with street after street of destroyed adobe houses. The number of dead quoted was between 9000 and 14000 out of 16000, but this may be for the whole province. Turning towards the market square, one finds the modern bank building without glass damage. The decorative slender concrete column has not suffered, nor has the brick wall in front of the property. The old church needs repairs, but the one-story solid-brick municipal building (vintage mid-1930) and the masonry jail on the other side of the square show no externally visible damage.

Mindful of classical reports of motion of monuments in graveyards, the author visited local cemeteries. This was almost completely useless because the dead are laid to rest above ground in small mausoleums built of brick and concrete, which survived the quake with practically no damage.

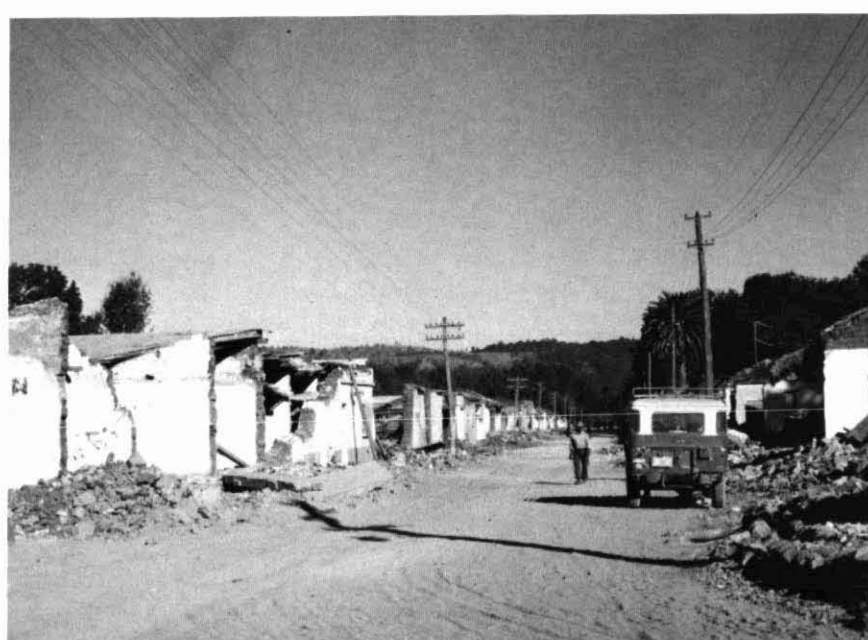


Figure 5
Chimaltenango: typical adobe damage, about 20 km from surface break.

Water supply for Guatemala City comes from several surrounding reservoirs. These did not seem to be damaged, but enough underground pipes within the city were broken to result in water cutoff, and supply was short at least for the first week. According to the Mercalli intensity scale this would rate an intensity of IX, but is inconsistent with other definitions for this intensity. In general, Guatemala City suffered no more than intensity VII, with some arguments for VIII, especially in the north.

The other important line of qualitative investigation is damage surveys of specially designed structures. Although of only peripheral interest to the seismologist, it is this type of damage that is often spectacular and economically significant. The engineering profession in Guatemala has long been well aware of the earthquake danger and are using building recommendations similar to the Californian codes for engineering structures. There are only about 30 modern highrise buildings in the city and most survived with little structural damage. Architectural damage on the other hand was widespread and often severe. A great danger to occupants was the spalling and cracking of brick partitions and shearwalls caused by insufficient isolation of these rigid units from the more ductile structural frame. The building that housed the Canadian consulate was an example of this: although no structural damage could be found, the building was vacated and barred after a few days, presumably because of the dangerous look of exposed separation joints between structural units and the general interior damage from failure of brick partitions, especially on the upper floors.

Complete collapse of heavy concrete canopies supported by rather fragile looking reinforced concrete columns was widespread, but not surprising. Collapses of engineered buildings were rare and usually attributable to doubtful design. Figure 7 shows a view of a collapsed second story of a school: it contained no shear walls. Collapse of some columns caused the Terminal Hotel to break in half. At the Camino Real Hotel, an unusual architectural effect was achieved by a supporting X-type outside frame. Here, many of the eastern legs in the ground floor were shattered

Figure 6
Chimaltenango: modern bank building and decorative brick wall remained standing.

Figure 7
Collapsed second floor of a school in southeast Guatemala City, about 30 km from fault.

and the reinforcement bars slightly buckled.

Closer to the fault zone, within about 10 km, a highway bridge had collapsed - the only one to my knowledge. Although spectacular, the simple sideways (north-south) sliding of the bridge decks can easily be explained by an acceleration of only a few per cent of gravity, leading to the failure of insufficient welds that held shear keys in place. A number of railroad bridges right along the fault showed no apparent damage from the air. About five m away from the main fault crack, no damage could be seen in a transformer substation.

These examples must suffice to illustrate the considerable inconsistency of damage patterns and the general feeling shared by experienced "earthquake chasers" that intensity of shaking was lower than expected from early newspaper reports.

Conclusions

This seismological observer mission has complemented routine efforts of readiness within the Canadian Seismological Service, by serving as the basis for discussions about the Canadian scene. Probably the most impressive lesson learnt is the need for timeliness of operations, not only to catch possible aftershocks, but equally to collect other often fragile evidence. While ground cracking may last longer in different environments, the psychology of people will generally demand quick action in collecting detailed and accurate isoseismal information.

Without in the least wishing to predict an earthquake for Canada, we must stress that earthquakes of the same damage potential as the Guatemala quake have occurred in Canada and are likely to recur. This one was a killer quake - mainly because of poor construction and high population density. However, its magnitude was only about seven and a half, maximum intensity was maybe VIII or IX, and only VII to VIII within the capital city.

For comparison, the maximum intensity of the magnitude 7 earthquake northeast of Quebec City in 1925, was estimated as IX, and the intensity VII area extended for over 200 km along the St. Lawrence River. Although its mechanism is not known, the ground motion of this earthquake may have been quite comparable to that of the Guatemalan event, but different indigenous construction methods and sparse population may have prevented it from being remembered as the Guatemala 1976 killer will be.

Acknowledgements

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