THE GUATEMALAN EARTHQUAKE OF FEBRUARY 4, 1976, A PRELIMINARY REPORT

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A preliminary report of a series of closely related studies of the destructive Guatemalan earthquake of February 4, 1976

This study was conducted by the U.S. Geological Survey in cooperation with the Government of Guatemala and with partial support from the Organization of American States

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GLOSSARY

Accelerogram. A record made by an accelerometer, showing the amplitude of acceleration as a function of time.

Accelerometer. An instrument designed to record ground accelerations

Aftershock. Secondary small magnitude earthquakes which follow the main event.

Amplification. Seismic-wave amplification is a relative measurement of the ratios of seismic waves recorded on alluvium to those recorded on crystalline rock. In the frequency domain is the ratio obtained from two stations for a selected spectral component.

Bar. 10^6 dyne cm^{-2}.

Body-wave magnitude (m_b). A measure obtained from the amplitude and period of P- or S-waves at teleseismic distances.

Colegio. School.

Deconvolved. Division of a time series into a new time series plus a shorter wavelet. Usually the wavelet has a physical significance such as the impulse response of a system.

Departamento. A subdivision of the Republic of Guatemala geographical territories. Similar to States in the United States.

Department. See Departamento.

Energy (E). A measure of the seismic energy released by an earthquake. Dimensions are in ergs. This quantity E is often given in empirical relationships as functional dependent on magnitude.

Epicenter. The point on the Earth's surface vertically above the hypocenter or point of origin of an earthquake.

Fracture zone. An elongated complex of geologic features, mostly faults, thought to represent the contact between major geologic units which are moving relative to each other.

G-waves. Seismic surface waves impulsive and slightly dispersed are called G-waves (mantle Love waves). The suffix 2, 3, 4, and so on indentifies the great circle path of propagation. Odd numbers identify the short great circle path from epicenter to station G1; G3 is that epicentral distance plus 360°. Even numbers identify waves that propagate in opposite azimuths.

Hazardous structure An unsafe structure because of poor design, poor construction, defects in foundations, or damaged due to faulting or vibrational effects of an earthquake.

HYPO71. The identification of a software package which computes the hypocenter parameters of an earthquake.

Hypocenter. The point of origin of an earthquake, where rupture begins and from which seismic waves originate.

Intensity. A numerical subjective index describing the effects of an earthquake on man, on structures, and on the Earth's surface. The Modified Mercalli scale of 1931 with ratings from I to XII, as defined below, is used in the United States (modified from Richter, 1958):

Modified Mercalli intensity scale

I. Not felt, except by a very few under specially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing truck. Duration estimated.

IV. During the day, felt indoors by many; outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.

V. Felt by nearly everyone, many awakened Some dishes, windows, and so on broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everyone runs outdoors. Damage negligible in buildings of good design and construction; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars.

VIII. Damage slight in specially designed structures: considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground.

Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Isoseismals. Contour lines of equal intensity.

Left-lateral movement. A horizontal movement in which the block across the fault from the observer has moved to the left.

Love waves. A type of surface wave.

Magnitude (M_L, m_b, M_s). A quantity characteristic of the total energy released by an earthquake. The "intensity" rating, as contrasted to magnitude, describes its effects at a particular place. Richter (1958) devised the logarithmic magnitude scale, which is in terms of the motion which would be measured by a standard type of seismograph located 100 km from the epicenter of an earthquake. M_L is the magnitude determined from local recordings, m_b is known as body-wave magnitude, and M_S as a surface-wave magnitude.

Main event. Refers to the main earthquake.

Meizoseismal area The area within the isoseismals of higher Modified Mercalli intensity ratings.

Modified Mercalli. See Intensity.

Particle displacement. The difference between the initial position of a soil particle and any later position.

Particle velocity. The time rate of change of particle displacement.

Phase. Any change of frequency in the seismogram of an earthquake. The seismograph responds to the motion of the ground and makes a seismogram. The seismogram is a line that is related to the motion of the Earth in any one chosen direction. The principal phases are called P, S, and L phases.

Plate One of the mechanically independent lithospheric segments comprising the outermost layers of the Earth.

Right-lateral movement. The contrary of left-lateral movement See Left-lateral movement

Sand mounds. The deposits resulting from turbid upward flow of water and some sand to the ground surface from increased ground-water pressures when saturated cohesionless materials are liquefied by earthquake ground motions.

Sedimentation tank. A large reinforced concrete tank designed to house large amounts of water.

Seismogram. A record of ground motion caused by an earthquake.

Seismograph. A system for amplifying and recording the signals from a seismometer.

Seismometer. A device that detects vibrations of the Earth, and whose physical constants are known for calibration to allow calculation of the actual ground motion from the seismograph.

Seismoscope. An instrument that inscribes on a glass plate a permanent record of an earthquake. This instrument is an unconstrained pendulum that records strong ground motions.

Seismoscope plate. A record of ground motion caused by an earthquake.

Station code. Abbreviation of seismological stations: (1) of the WWNSS, (2) of stations in Guatemala prior to the February 4 earthquake, and (3) of field portable seismograph stations in Guatemala.

1. WWNSS stations mentioned in this report:
   - ALQ, Albuquerque, New Mexico
   - BRK, Berkeley, California
   - COL, College, Alaska
   - DUG, Dugway, Utah
   - GEO, Georgetown University, Washington, D.C.
   - GIE, Galapagos Island
   - GOL, Golden, Colorado
   - GUA, Guam
   - KIP, Kipapa, Hawaii
   - LON, Longmarie, Washington
   - PAS, Pasadena, California
   - PAL, Palisades, New York
   - PTO, Pôrto, Portugal
   - PRE, Pretoria, South Africa
   - SJG, San Juan, Puerto Rico
   - WES, Weston, Massachusetts

2. Stations in Guatemala:
   - ARC, Quiriguá, Department of Izabal
   - BVA, Buena Vista, Department of Guatemala
   - CHI, Chimachoy, Department of Sacatepéquez
   - FGO, Volcán de Fuego, Department of Escuintla
   - MMA, Magdalena Milpas Altas, Department of Sacatepequez
   - REC, Recreo, Department of Guatemala
   - TER, Terranova, Department of Escuintla

3. Field stations in Guatemala:
   - ARC, Quiriguá, Department of Izabal
   - CCO, Chichicastenango, Department of Quiché
   - CHM, Chimaltenango, Department of Chimaltenango
   - CML, Chiquimula, Department of Chiquimula
   - ELC, El Chol, Department of Baja Verapaz
   - FFF, La Piña, Department of Izabal
   - GCG, Guatemala City, Department of Guatemala
   - JAP, Jalapa, Department of Jalapa
   - JOY, Joyabaj, Department of Quiché
   - PAL, Palencia, Department of Guatemala
   - PTO, Puerto Barrios, Department of Izabal
   - RIO, La Esmeralda, Department of Izabal
   - SAN, Sanarate, Department of El Progreso
   - SJE, San Jeronimo, Department of Baja Verapaz
   - TEC, Tecpan, Department of Chimaltenango
   - TEL, Teleman, Department of Alta Verapaz
   - VIT, Vitalis, Department of Izabal

Stereographic projection A coordinate system or network of meridians and parallels, projected from a sphere at suitable intervals, used to plot points whose coordinates are known and to study orientation and distribution of planes and points.

Strike. Angle between true north and the trace or projection of a geologic surface or lineation on the horizontal plane.

Strike-slip fault. Fault in which movement is principally horizontal.

Strong motion. Ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage due to earthquakes. This type of motion is usually recorded on seismoscopes and accelerographs.

Surface-wave magnitude (M_S). A measure obtained from the amplitude and period of surface waves at teleseismic distances.

Teleseismic. Refers to distances in the far field

Thrust fault. A steeply or slightly inclined fault in which the block above the fault has moved upward or over the block below the fault.

Trench. Elongated bathymetric depression of the sea floor. Thought to be areas where oceanic crust is subducted into the upper mantle.

Universidad. University.

Wavelet. A short time series used in the deconvolution of a longer time series. It refers also to a time pulse.

Zone. Suburbs or districts in Guatemala City.

SYMBOLS AND ABBREVIATIONS

[See the Glossary also]

A	area of dislocation.
°C	degrees Celsius.
cm	centimetre.
cm/rad	centimetres per radian.
cm–s	centimetres-second.
cm/yr	centimetres per year.
$\overline{D}$	average fault displacement
dyne-cm	dyne-centimetre.
dyne cm^{-2}	dyne per square centimetre.
Δ	epicentral distance.
$\Delta\sigma$	stress drop.
E	energy. See Glossary.
E_s	seismic energy.
G2, G3, G4	G-waves See Glossary.
g	acceleration due to gravity (980 cm-s^{-2}).
H	height.
Hz	Hertz (cycles per second).
h	focal depth.
I_{mm}	Modified Mercalli intensity rating.
ICAITI	Instituto Centroamericano de Investigacion y Técnologia Industrial.
kg	kilogram.
km	kilometre.
km^2	kilometre squared.
km^3	kilometre cubed
km/s	kilometres per second.
L	fault length.
m	metre.
M	magnitude.
m_b	body-wave magnitude.
M_L	local magnitude.
M_o	seismic moment.
M_S	surface-wave magnitude.
min	minute.
mm/min	millimetres per minute.
ms	millisecond.
ms/day	milliseconds per day.
m.y.	million years.
μ	rigidity around faulted medium.
NEIS	National Earthquake Information Service.
Q	seismic quality factor.
r	radius of a circular dislocation.
RMS	root-mean-square.
ROCAP	Regional Office for Central America Programs
s	second.
S	sensitivity of seismoscope.
S_d	relative ground displacement.
SQ	solution quality in computer program for calculating hypocenters.
σ	effective shear stress.
T_1	natural period of seismoscope.
T_2	second harmonic of seismoscope.
θ	azimuth.
$\bar{u}$	average horizontal fault displacement.
USAID	U.S. Agency for International Development.
UTC	Universal Coordinated Time.
WWV	Call letters for National Bureau of Standards time and frequency radio broadcast station, Fort Collins, Colorado.
WWNSS	Worldwide Network of Standard Seismographs.
w	fault width.
$\dot{x}$	horizontal particle velocity

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ABSTRACT

The Guatemalan earthquake of February 4, 1976, with a surface-wave magnitude of 7.5, was generated by left-lateral slippage on the Motagua fault and was felt over an area of at least 100,000 km². This earthquake claimed more than 22,700 lives and injured more than 76,000 people. The preliminary estimate of losses is about $1,100,000,000.

Ground breakage was observed and mapped for a distance of nearly 240 km along a segment of the fault. It is the longest surface rupture to have occurred in America since 1906. The inferred total length of faulting is nearly 300 km, postulated on the basis of small aftershocks and high damage concentration west of Guatemala City. Maximum horizontal slippage as measured on the fault, about 25 km north of Guatemala City, was 325 cm. The average horizontal displacement is approximately 100 cm. Slippage also occurred on a number of secondary faults and caused damage to houses and other structures in the vicinity of Guatemala City.

The February 4 earthquake caused extensive landsliding along the highway that leads from Guatemala City to the Pacific and Atlantic Oceans. Landslides also blocked many railroads and destroyed many communication routes in the highlands of Guatemala. A large landslide near Tecpan covered two small villages and dammed a river. Additional landslides were triggered by aftershock activity.

Guatemala contains three major earthquake-generating zones. The first zone, which has the highest level of seismicity, is the Benioff zone that dips northeastward beneath Guatemala and is due to the Cocos plate being thrust beneath the Caribbean plate. The second lies at shallow depths along the chain of active volcanoes; the third is the fault system that bisects Guatemala from east to west. It is in this third zone that the February 4 earthquake occurred.

The preliminary fault plane solution is consistent with almost pure sinistral slip on a nearly vertical fault striking about N. 65° E. This solution agrees with the geologically mapped fault trace. The seismic moment was determined to be 2.6×10^{27} dyne-cm from the amplitude of mantle Love waves (G-waves). A fault depth of 29 km was calculated from the seismic moment and the field observations of fault length and fault displacement. The earthquake was a low-stress-drop event, $3\leq\Delta\sigma\leq18$ bars. The energy release was 1.1×10^{24} ergs.

Thousands of aftershocks followed the main earthquake. Epicenters for 78 small aftershocks determined from locally recorded data delineate the Motagua fault and several secondary faults. A number of epicenters in the eastern part of Guatemala follow the general trend of the inferred extension of the Motagua fault. A large number of events that occurred south of the Motagua fault and west of long 90.3°W. at depths of less than 14 km are associated with secondary faults, such as the north-south faults that bound the Guatemala City graben.

The maximum Modified Mercalli intensity was IX in the Mixco area, in some sections of Guatemala City, and in Gualán. The Modified Mercalli intensity reached VI over an area of 33,000 km². The concentration of high intensities observed near the western end of the Motagua fault suggests the influence of a westward-propagating fault rupture.

Communities and small towns that suffered 100 percent damage covered an area of 1,700 km². At some localities, adobe structures near the causative fault (within 10 km) were essentially undamaged; at greater distances from the fault in the highlands, there was widespread collapse of adobe buildings. Modern earthquake-resistive structures in Guatemala City were damaged, including several hospitals. Several water tanks and corrugated-steel grain silos and numerous heavy parapets collapsed.

The information compiled in this study will be useful in assessing and delineating earthquake hazards in Guatemala to reduce the potential for loss of life and property in future earthquakes. The information in this study is also important in evaluating the effects to be expected from large strike-slip earthquakes elsewhere, such as those that occur in coastal California. A more detailed study of the distribution of intensities in Guatemala City could provide the basis for delineating variations in the hazards due to ground shaking and ground failure throughout the city and could assist in developing land-use policies.

INTRODUCTION

The Republic of Guatemala in Central America suffered extensive loss of life and severe damage to its economy from the February 4, 1976, earthquake. A request by the Guatemalan government to the Organization of American States prompted the U.S. Geological Survey to send a team of scientists and engineers to Guatemala to investigate the cause of the earthquake, the geologic, seismologic, and engineering effects, and the hazards resulting from the earthquake. U.S. Geological Survey Open-File Report 76–295, which was released in March 1976, provided a brief interim summary of the activities

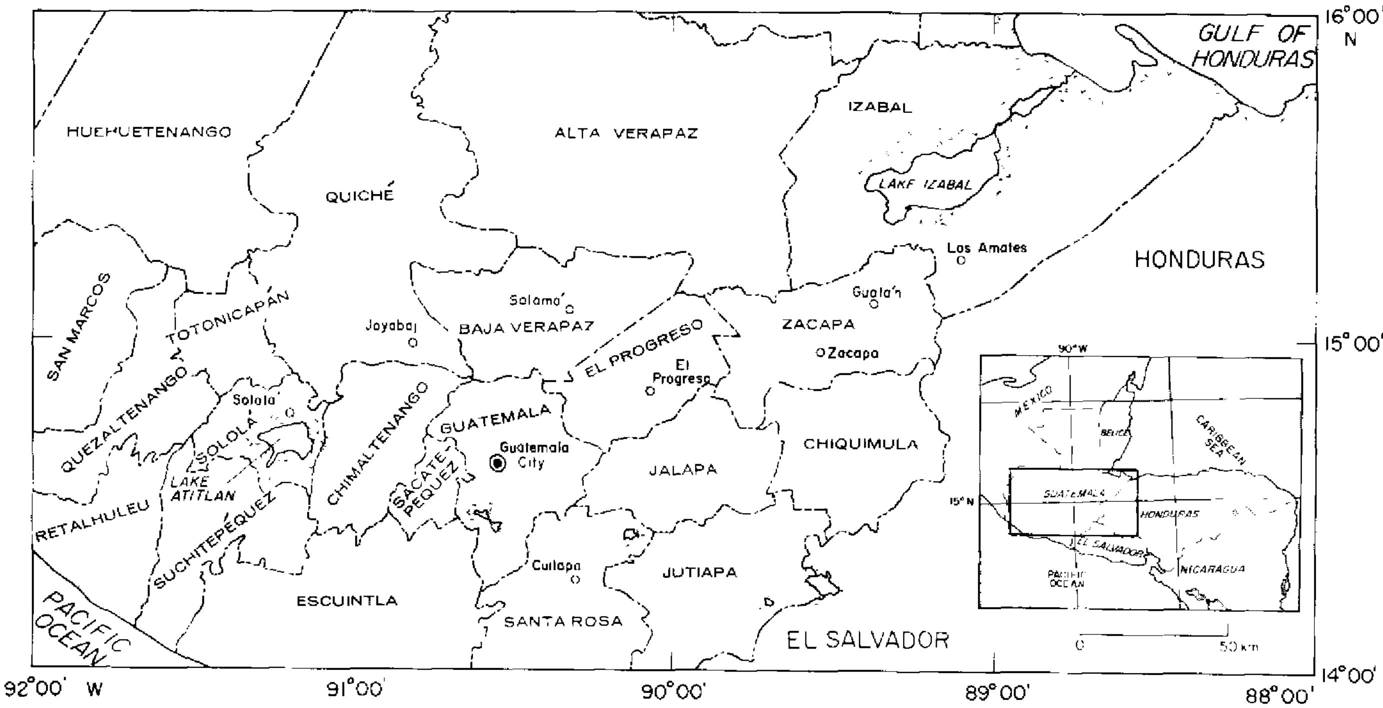

FIGURE 1.—Guatemala and its Departments (States), including its general location in Central America. Base map modified from Guatemala, Instituto Geográfico Nacional, 1974, 1:500,000.

of the earthquake investigation team. The open-file report and this publication represent the immediate response by our agency to the request of the Guatemalan government.

Guatemala has a long history of damaging earthquakes. Historic chronicles date earthquake occurrences in Guatemala from the period of the Spanish conquest. The chronicles indicate that the cities of Antiqua and Guatemala City have been badly damaged by earthquakes more than 15 times since the early 16th century. The most damaging earthquakes to have occurred before the February 4 event were on December 25, 1917, and on January 3, 1918. These earthquakes and their aftershocks claimed numerous lives and partially destroyed Guatemala City.

The February 4 earthquake caused extensive damage, as the following statistics from a few of the cities and Departments (States) show: 88,404 houses were destroyed and 434,934 people left homeless in the Department of Guatemala, about one-half that number in the Department of Chimaltenango (fig. 1), and all houses were destroyed in the towns of San Pedro Sacatepéquez, El Jicaro, Sumpango, Tecpan, and Gualán.

From the above, it is obvious that the principal hazard to life from earthquakes in the Republic of Guatemala is the collapse of manmade structures because of ground shaking. There are, in addition, other serious earthquake hazards, especially landslides in the highlands and surface breakage along active faults. Landslides can interrupt lifelines, in particular, roads, railroads, and communication networks, and they can dam streams and cause lakes that are subject to sudden release upon failure of the dam.

There is much to learn from this earthquake that is directly relevant to the problem of reducing earthquake hazards in the United States. The fault that produced the earthquake is the boundary between two crustal plates and is tectonically similar to the San Andreas fault in California and to the Fairweather fault in southeastern Alaska. Many of the modern buildings in Guatemala City are similar to structures in the United States and in particular to those in cities in coastal California.

The different papers of this report present (1) the tectonic setting and the seismicity of the region; (2) the local seismic activity before the February 4 earthquake; (3) the main event and principal aftershocks as recorded at teleseismic distances; (4) the source parameters of the main event and possible future earthquakes on the fault that slipped on February 4; (5) estimation of strong ground motion due to the main event; (6) aftershocks from local data and their relation to primary and secondary faulting; (7) the geologic effects, including primary and secondary faults, landslides, and relation of faulting to damage; (8) the intensity of shaking and its distribution, casualties and damage, ground-motion parameters at intermediate distances, and source parameters from field observations; (9) damage and engineering implications and earthquake-resistant design code; and (10) design, construction practice, and general observations on damage to high-rise structures.

The results from this collective investigation will aid in the reduction of earthquake hazards in Guatemala and in the United States, but the material presented in this report should be considered as preliminary. Some of the details may change, and the conclusions may be modified upon further scrutiny of existing data and upon analysis of new data gathered in later geologic field studies.

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