UNITED STATES EARTHQUAKES 1933

SERIAL No. 579

U. S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY - WASHINGTON

U. S. DEPARTMENT OF COMMERCE
Daniel C. Roper, Secretary

COAST AND GEODETIC SURVEY
R. S. PATTON, Director

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UNITED STATES EARTHQUAKES
1933

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INTRODUCTION

This publication is a summary of earthquake activity in the United States and the regions under its jurisdiction for the calendar year 1933. The period up to 1927 for the United States is covered (for all except minor earthquakes) by Special Publication No. 149 of this Bureau, "Earthquake History of the United States Exclusive of the Pacific Region", and by several publications for the Pacific region. These include the Holden and McAdie catalogs [1] and a forthcoming publication of the Seismological Society of America which will extend the record through 1927. The period from 1928 on is covered by the series to which the present publication belongs. United States Coast and Geodetic Survey Special Publication No. 191 entitled, "Destructive and Near Destructive Earthquakes in California and Western Nevada, 1769–1933", was issued early in 1935.

Earthquakes of volcanic origin in the Hawaiian and Philippine Islands are not included, and only severe shocks are included in the case of the Philippine Islands, as complete reports are published by the Manila Central Observatory. Earthquakes adjacent to the United States and felt within its borders are described only in a general way when detailed descriptions are published elsewhere. The instrumental results are given for the principal earthquakes of the year regardless of location.

The noninstrumental information has been furnished by a large number of individuals and organizations whose voluntary cooperation has made it possible to prepare descriptions of the earthquakes of this country with a completeness and accuracy never before attained. Lack of space prohibits giving individual credit to all of these cooperators. The principal sources of information are as follows:

United States Weather Bureau.

Division of geology and geography of the National Research Council.

Central office of the Jesuit Seismological Association at St. Louis, Mo.

The San Francisco Field Station of the Coast and Geodetic Survey, cooperating with the Seismological Laboratory of the Carnegie Institution and California Institute of Technology (H. O. Wood, research associate, in charge), University of California (Perry Byerly in charge of the seismological station), and Stanford University. These persons are usually responsible for instrumental determinations of epicenters in California when given. Among the commercial agencies in this section there are a number of cooperators, including the Pacific Telephone & Telegraph Co., Great Western Power Co., National Board of Fire Underwriters, Southern California Telephone Co., Standard Oil Co. of California, Associated Oil Co., Southern Pacific Railroad, San Diego & Arizona Railway Co., Associated Factory Mutual Fire Insurance Cos., Clay Products Institute of California, Board of Fire Underwriters of the Pacific, with more than 20,000 correspondents, the Southern Sierras Power Co., also a large number of other organizations and individuals. In the State of Washington the Supervisor of Geology (H. E. Culver), Department of Conservation and Development, Pullman, actively cooperates.

[1] Smithsonian Miscellaneous Collections, 1089. A Catalog of Earthquakes on the Pacific Coast, 1769–1897. Edward S. Holden. Smithsonian Miscellaneous Collections, 1721. Catalog of Earthquakes on the Pacific Coast, 1897–1901. Alexander G. McAdie.

The large number of reports received from Alaska in 1933 is due largely to the successful efforts of Dr. C. E. Bunnell, president of the Alaska Agricultural College and School of Mines, in organizing a corps of volunteer observers.

Press dispatches (received through the courtesy of Georgetown University).
Telegraphic reports collected by Science Service, Washington.
Reports from individuals.
Bulletin, Seismological Society of America, 1933.

In addition to the above sources of information, the Coast and Geodetic Survey, or its field station at San Francisco, canvasses areas affected by shocks of unusual intensity. In this way the extent and the maximum intensities of all heavy shocks are determined and the data are usually sufficient to construct isoseismal maps. The destructive features of these shocks are enumerated in the abstracts, but otherwise the descriptive matter is reduced to a minimum. The original reports are open for inspection by anyone interested in unpublished details. For 1933 more detailed descriptions of earthquakes on the west coast will be found in mimeographed reports issued at the San Francisco Field Station.

Beginning with the 1931 number of this series, Serial No. 553, the Coast and Geodetic Survey has used and will continue to use, the modified Mercalli intensity scale of 1931, in place of the Rossi-Forel scale, to designate the intensity of earthquake activity. All intensity numbers therefore refer to the new scale. The reasons for this change are set forth in an article entitled "Modified Mercalli Intensity Scale of 1931", by Harry O. Wood and Frank Neumann, in the December 1931, number of the Bulletin of the Seismological Society of America, volume 21, no. 4. This article contains the original unabridged scale and also an abridged scale. The latter is given here together with equivalent intensities according to the Rossi-Forel scale.

MODIFIED MERCALLI INTENSITY SCALE OF 1931

[Abridged]

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. (IV to V Rossi-Forel scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale.)

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars. (VIII Rossi-Forel scale.)

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. Disturbs persons driving motor cars. (VIII+ to IX to Rossi-Forel scale.)

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. (IX+ Rossi-Forel scale.)

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. (X Rossi-Forel scale.)

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines 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.

In the noninstrumental reports an asterisk (*) indicates that the time is taken from an instrumental report and is reliable. In other instances quite large deviations are frequently reported. In the case of California, earthquakes reported as feeble at only one point are not plotted on the epicenter map of the United States, nor are minor aftershocks plotted for heavy earthquakes in California or any other region. The reader should bear in mind that the information service in California has been developed to a point not approached in any other section of the country. Attention is again called to the fact that more detailed information on California earthquakes of 1933 has been published in mimeograph form at the San Francisco Field Station of the Coast and Geodetic Survey. As the Pacific coast epicenters obtained from instrumental data have not been published in their entirety, the forthcoming publications of the Research Laboratory at Pasadena, and the seismological station at Berkeley should be consulted for a complete record of the year's activities.

Time is indicated as continuous from 0 to 24 hours, beginning and ending with midnight. In noninstrumental reports local standard time is indicated. In the summary of instrumental results Greenwich civil time is used.

Within the United States the same regional arrangement has been followed as in Special Publication No. 149, previously mentioned, except that Washington and Oregon have for convenience been treated separately from California.

The published epicenters have been determined at the Washington office unless otherwise stated. Quite often they represent the mean of the positions determined by the bureau and the central station of the Jesuit Seismological Association cooperating with Science Service. Immediate epicenter determinations from telegraphic reports are frequently made through the cooperation of these institutions and individual seismograph stations and the results broadcast without delay to Europe and points in the Pacific. As the published epicenters are based on only a portion of the available data, they must be considered provisional.

COOPERATION OF INVESTIGATORS SOLICITED

In order that these publications may be as complete as possible in the more important details of earthquakes and in references, it is desired that investigators cooperate to the fullest extent. Such cooperation will be to the mutual advantage of everyone concerned.

The Bureau is willing to furnish investigators all information at its disposal consisting principally of seismographic records and post card questionnaries obtained in many instances through special canvassing of affected areas. In return it is requested that preferably advance notices be furnished of results obtained so that abstracts and references may be inserted with due credit, of course, given the sources. An advance notice of a planned investigation might save considerable overlapping of effort and would give wider publicity to the work of the investigator.

STRONG MOTION SEISMOGRAPH RESULTS

In 1932 the Coast and Geodetic Survey inaugurated a program of strong motion seismological work designed to furnish the engineer and others interested with data considered essential to the design of earthquake resistant structures. Although some reports have been published in mimeographed and other form it is the consensus of opinion that such reports should be published in more permanent form. This number therefore contains the first reports to be issued in permanent form covering this activity from the time the work began in 1932 until the end of 1933.

NONINSTRUMENTAL RESULTS

EARTHQUAKE ACTIVITY IN THE VARIOUS STATES

Arizona: Slight shock in central part on November 27.
Arkansas: Moderately strong shock in northeastern part on December 9.
California: The Long Beach earthquake of March 10 was the outstanding shock of the year. Two others of near destructive intensity were those of May 16, in the San Francisco Bay region and October 2, near Los Angeles. The western Nevada earthquake of June 25 was felt widely throughout the State. The remaining activity was normal in type.
Georgia: Slight shock of doubtful character on June 9.
Idaho: One moderate shock in western part on April 20 and three in eastern part ranging from slight to moderately strong on October 31, November 2, and November 3.
Kansas: Moderate shock in northern part on February 20.
Kentucky: Slight shock in northern part on May 28.
Massachusetts: Slight shock January 17 in eastern part.
Michigan: Weak shock on peninsula January 29.
Missouri: Slight shocks in eastern part on March 11, July 13, August 3, and November 16.
Montana: Shocks from slight to moderately strong intensity in western portion on February 10, May 4, June 5, June 10, August 19, November 19, and December 20.
Nebraska: Tremors of doubtful character in northern part on August 8. Meteor?
Nevada: The shock of June 25 in the western central part of the State was outstanding. That of June 23, was widespread but of low intensity.
New Jersey: Slight shock January 24.
New York: Slight shocks in northern part on May 20, June 26, and October 29.
Ohio: Slight shock in western part on February 22.
Oklahoma: Moderately strong shock felt in central part on August 19.
Oregon: Slight shock in western part on November 23, and disturbance by meteor in western part on January 17.
South Carolina: Two slight and one moderate shock in southeastern part on July 25, December 19 and December 23.
Utah: Slightly destructive shock in southwestern part on January 20.
Virginia: Slight shock in eastern part on January 26 and central part on July 23.
Washington: Weak to moderate shocks on January 2 and 29, March 18, April 29, May 29, May 31, and August 22. All but three in Puget Sound area.
Wisconsin: Slight shock in southern part on December 6.
Alaska: The Kenai Peninsula area experienced sharp but nondestructive shocks on January 3 and April 26, the latter being followed by a large number of aftershocks. A large number of smaller shocks were reported.
Hawaii: No earthquakes of importance except those of volcanic origin. Those of December 2 were the strongest.
Puerto Rico: Practically no activity.
Philippine Islands: No shocks of outstanding importance.
Canal Zone: No shocks of outstanding importance.

NORTHEASTERN REGION

[75th meridian or eastern standard time]

January 17: 0:30. Fall River and New Bedford, Mass. Severe earth tremors lasting a few seconds were felt; no serious damage reported.
May 20: 14:57. Lawrenceville, N. Y. All awakened by northeast to southwest motion lasting 30 seconds; accompanied by roaring sounds.
June 26: 9:10. Scarsdale, N. Y. Felt by many in Port Chester, White Plains, Mamaroneck, Rye, Purchase, Mount Vernon, and Ossining. Southwest to northeast bumping motion lasting 6 seconds, accompanied by thunderous sounds.
October 29: P. M. Johnsville, N. Y., IV. Felt over the western half of Fulton and Montgomery Counties. Windows rattled, objects on shelves were jarred, and one window was broken. A slight rumbling accompanied the tremor.

EASTERN REGION

[75th meridian or eastern standard time]

January 24: Shortly before 21:00. Near Trenton, N. J., V. Sharp jolt felt over central New Jersey from Lakehurst to Trenton. Although doubtful

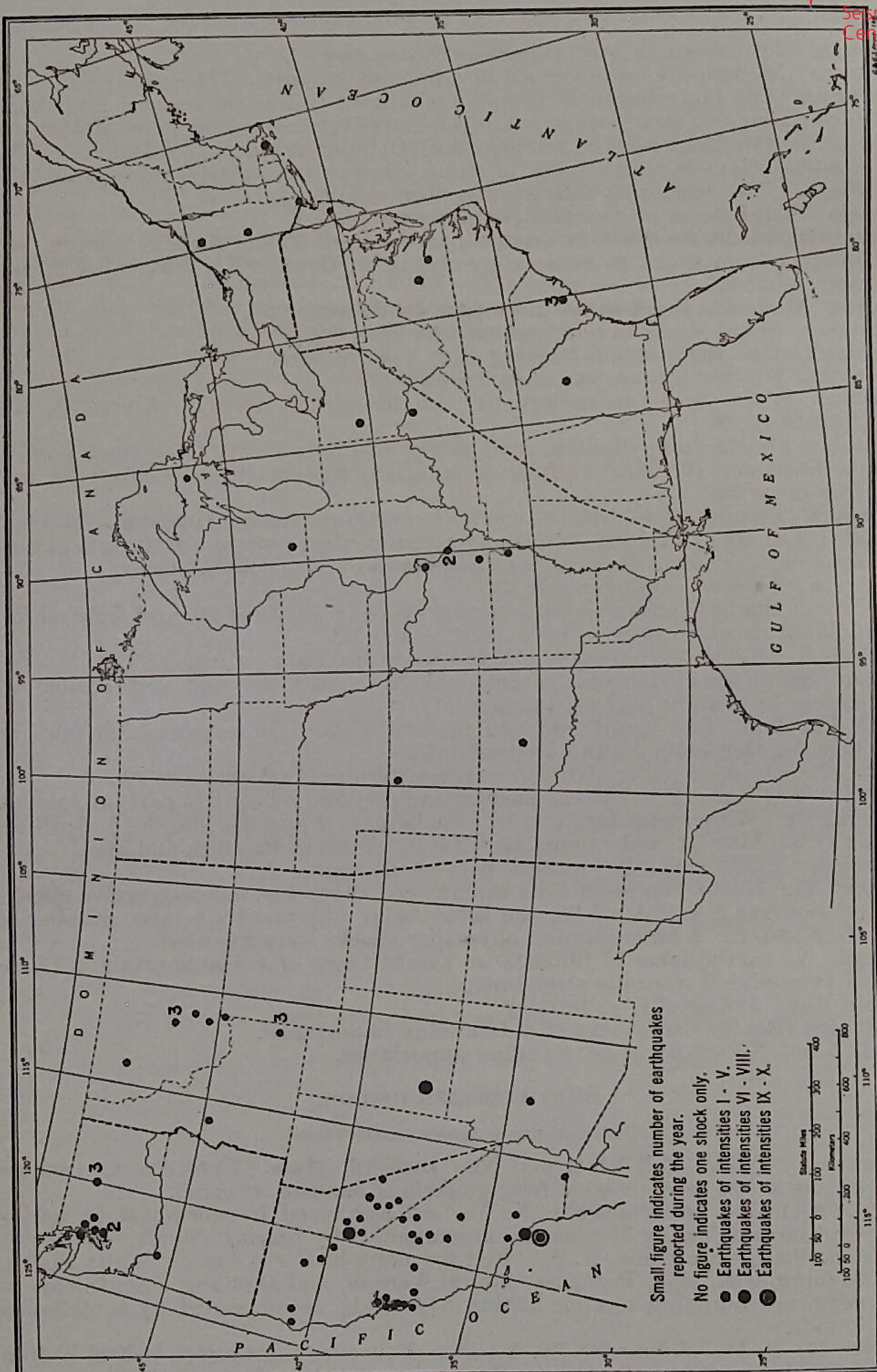

FIGURE 1.—Earthquake epicenters, 1933.

as to whether or not it was an earthquake, it was felt most strongly at Lakehurst, where people reported that they were rolled out of bed. Other people reported pictures shaken from walls. Reported felt at Robbinsville, White Horse, Hightstown, Bordentown, Columbus, Burlington, Freehold, Englishtown, and New Egypt. Felt over 600 square miles.

January 26: 22:00. Near Petersburg, Va., III. Intermittent shocks lasting from 10 p. m. until 2 a. m., were strong enough to rattle doors and windows loudly and cause building to shake.

May 28: 10:10. Maysville, Ky., IV. A severe earth tremor apparently centering in Mason County was felt over Mason, Fleming, and Bracken Counties, in Kentucky and at many points in Ohio. Logs were shaken in a log house and windows, dishes, and cooking utensils rattled over a wide area. A child was reported thrown from a swing at Ripley, Ohio.

June 9: 6:30. Eatonton, Ga. Several persons reported sounds resembling heavy explosions and one reported plaster being shaken down. Two distinct shocks. Seismic?

July 23: 10:—.New Canton, Va., III. Many felt rapid southwest to northeast motion accompanied by loud rumble. No damage.

July 25: 21:34. Summerville, S. C., III. Rapid trembling motion traveling from west to east, felt by several.

December 19: 9:12. Summerville, S. C., IV. Bumping north to south motion felt by and frightened many and lasted about 1 second. Windows rattled and children ran from schoolhouse; no damage.

December 23: 4:40. Summerville, S. C. Many persons awakened and frightened by two decided bumps, the first at 4:40 a. m. and the second about 4:55 a. m. Windows rattled, dogs barked, no damage.

CENTRAL REGION

[90th meridian or central standard time]

January 29: 5:00. Newberry, Mich., II. Distinct vertical movement noticed by two persons.

February 20: 11:00. Norton, Kans., IV. Distinct shock felt by many over Norton and Decatur Counties in Kansas and the southern part of Furnas and Harlan Counties in Nebraska. Windows and dishes rattled, telephone bells jingled, and houses and buildings swayed. Some were frightened and ran from buildings. Many reported feeling the shock in Oronoque, and Norcatur, Kans.; and Beaver City, Hendley, Oxford, and Stamford, Nebr. No damage reported. Seismic origin of the disturbance doubted by some who advance the opinion of an exploding meteor.

February 22: 22:20. Sidney, Ohio, III. An earthquake of moderate intensity was felt over four counties, Shelby, Logan, Darke, and Auglaize. Many persons in New Bremen, Anna, Quincy, Versailles, Fort Laramie, and Bellefontaine reported the disturbance but as there was a severe electrical storm at the time most persons attributed it to the storm and not to a seismic disturbance. It apparently was strongest at Sidney, Ohio, where windows rattled and houses shook. The disturbance was accompanied by a low rumbling sound.

March 11: 6:48. Poplar Bluff, Mo., III. Two distinct earth tremors occurred at 6:48 and 7:04. Windows rattled and pictures shook.

July 13: 8:43. St. Marys, Mo., felt.

August 3: 22:35. St. Marys, Mo. "Preceded by sound like distant thunder and wound up as loud crash when building seemed to rise up and shake." No damage.

August 8: Time uncertain. Scottsbluff, Nebr. Vibrations which caused buildings to shake over a wide territory in western Nebraska and eastern Wyoming believed to have been caused by a fallen meteor. Residents in the vicinity of Henry, Nebr., reported a great explosion. Seismic?

August 19: 13:30. El Reno, Okla., V. Severe earthquake felt by all and caused general alarm. Buildings trembled for 3 or 4 seconds, hanging objects swung, dishes and pictures were broken, chimneys, walls, and ornaments were cracked slightly, but damage to buildings was negligible. Minco and Union City, Okla., reported it felt less severely.

November 16: 3:29. St. Louis, Mo., local shock. Franklin, Jefferson, and St. Louis Counties, Mo.; and St. Clair and Monroe Counties, Ill. Epicenter near Grover, Mo. Recorded instrumentally at St. Louis.

December 6: 23:55. Stoughton, Wis., III. A sharp shock felt by many over the southern half of Dane County. Windows rattled, houses shook, hundreds ran to their basements to see if furnaces had exploded. Also felt at Rutland.

December 9: 2:40. Manila, Ark., V. Many awakened by two distinct earth shocks which broke windows in several homes.

WESTERN MOUNTAIN REGION

[105th meridian or mountain time]

January 20: 6:05. Parowan, Utah, VI. Plaster cracked, slight damage to brick, masonry, and concrete. There was a distinct and longer tremor at 6:07 or 6:08. Two distinct shocks felt slightly at Minersville, Utah.
February 10: 18:15. Rollins, Mont., IV. Two sharp shocks about 5 seconds apart, felt by many. Windows, doors, and dishes rattled, walls creaked. Several slight aftershocks followed throughout the night. Also felt slightly at Kalispell, Mont.
April 20: 13:25. Donnelly, Idaho, IV. Many frightened by rapid motion lasting 4 seconds. Windows, doors, and dishes rattled, walls creaked.
May 4: 11:54. Helena, Mont., III. A slight vertical jolt, felt by many.
June 5: 4:15. West Yellowstone, Mont. Slight shock awakened few.
June 10: 22:59. Helena, Mont., IV. A sudden jar felt by and awakened some. Many alarmed, dishes rattled. Strongest earth tremor felt in Helena for several years. No damage.
August 19: 3:13. Logan, Mont., V. Felt by majority of population, alarmed few. Buildings swayed, loose objects were disturbed and plaster cracked slightly. Registered on the seismograph in Bozeman.
October 31: 8:55. Gray, Idaho, III. Felt by many, alarmed few. Loose objects disturbed, trees and buildings swayed slightly. Slight shocks also at 9:30 and 9:45.
November 2: 9:26. Gray, Idaho, V. Trembling motion accompanied by subterranean sounds felt by all and frightened several. Trees and buildings swayed and one wall in the schoolhouse was reported cracked.
November 3: 3:00. Gray, Idaho, aftershock of quake on November 2.
November 27: Hillside, Ariz., III. Trembling motion accompanied by subterranean sounds felt by 75 percent of population. Buildings swayed, rattled, and creaked. Also felt at Wikieup, Ariz.
November 29: 10:00. Virginia City, Ennis, and Laurin, Mont., IV. East to west bumping motion felt by many. Apparently strongest in Ennis where buildings shook, loose objects were disturbed, and pop bottles rattled in case. Accompanied by faint roar.
December 20: 17:33. Helena, Mont., III. Many felt east to west trembling motion. Believed to have been stronger 8 miles west of Helena.
During 1933. Durango, Colo. Because of the unusualness of the phenomena, mention is made here of Durango's "moving mountain." Beginning in December 1932, and lasting through most of 1933 the activities of this mountain were commented on frequently in the press and hundreds of people visited the region. Deep subterranean rumblings were heard and explosions caused millions of tons of dirt and rock to slide down the mountain. It belched forth fire and gas and smoke at times which hung over the valley. The disturbances were reported to have been due to the burning of coal in the numerous coal veins which penetrate the mountain.

CALIFORNIA AND WESTERN NEVADA

[120th meridian or pacific standard time]

All places are in California unless otherwise stated

January 4: 22:10. Wabuska and Potts, Nev., IV. Sonora, Calif., III.
January 9: 6:10. Los Angeles, IV and V. Some plaster cracked. Moreno, IV. Also felt at Pasadena, Placenta, and Ramona.
January 12: 22:20. Mount Hermon, Olympia, San Francisco, Soquel, and Wrights (Santa Cruz Mountains), IV. Weaker at Aptos, Oakland, and Saratoga.
January 19: 16:24. Kern River No. 3 and Kernville, III.
January 20–27. Simon, Nev. Five earthquakes strong enough to shake houses and furnishings felt from January 20 to 27. Each preceded by a deep rumble.
January 21: 5:30. Calexico and El Centro, III.
January 21: 9:34. Kern River No. 3, III. Also felt at Ducor (Vestal substation).
January 21: 10:00. Calexico and El Centro, III.
January 26: 0:26. Gardena (La Fresa substation) and Lomita, III.
January 27: 22:38. Santa Cruz, felt.
January 30: About 9:00. Lompoc, rattled windows.

February 2: 17:45. Laws, IV. Also felt at Benton, Bigpine, Bishop, Deep Springs, and Mocalno.

February 2: 19:23. Benton, Big Creek and Laws, IV. Also felt at Bass Lake, Bigpine, Bishop, Deep Springs, Florence Lake, Huntington Lake, Mocalno, Navelencia, Shaver Lake, Squaw Valley, and Visalia.

February 13: 14:15. Benton, Calif., IV. III and under at Austin, Nev., Mina, Nev., and Reno, Nev.

February 25: 22:25. Brown, IV. III and under at Onyx and Sand Canyon.

February 26: 1:30. Hollister, IV. III and under at Salinas and Spreckels.

March 4: 21:27. Humboldt Bay Fog Signal Station, IV.

March 9: 1:12. Huntington Beach, IV. Originated very near source of Long Beach earthquake (Pasadena).

March 9: 17:52. Sattley, II. Felt by two people.

March 10: 17:54*. The Long Beach Earthquake. Intensity VII–IX. Epicenter 33°34′.5 north, 117°59′ west, about 3.5 miles southwest of Newport Beach, according to Pasadena. 120 killed, hundreds injured. Damage estimated at $41,000,000. Land area affected 75,000 square miles. See map.

The Long Beach earthquake was not of major magnitude from the seismological point of view but because of its location in a thickly settled region with many poorly constructed buildings, it ranks as one of the most destructive earthquakes in the history of the United States. If damage by fire is excluded in the case of the California earthquake of 1906, the Long Beach shock may be considered the most destructive, because more than 90 percent of the damage in the 1906 earthquake was through fire, whereas, at Long Beach the fire loss was almost negligible because of protective measures taken beforehand. The greatest damage occurred in the more thickly settled district from Long Beach to the industrial section just south of Los Angeles proper where water soaked alluvium and other unfavorable geological conditions were predominant. The shock was of submarine origin. Slight slumps and distortion of made and unconsolidated ground occurred in the region from Compton to Long Beach but there was no visible evidence of faulting.

As the Coast and Geodetic Survey had no parties in the field to make intensive surveys of the affected area, the more detailed descriptions of the earthquake will be left to quotations from other authoritative sources. Because of their length they comprise a special section of this publication entitled "The Long Beach Earthquake." See page 25. For that material the Coast and Geodetic Survey is especially indebted to the Seismological Laboratory of the Carnegie Institution of Washington at Pasadena, The National Board of Fire Underwriters, and the Los Angeles Weather Bureau office. The Bureau is also indebted to many other organizations and individuals for additional information, most of which has already appeared in mimeographed form under the title of Abstracts of Reports Received Regarding the Earthquake Which Occurred in Southern California on March 10, 1933. This was issued by the San Francisco Field Station of the Coast and Geodetic Survey and copies are still available.

Although the volunteer information service directed by the San Francisco Field Station was inadequate to satisfactorily cover the larger centers of population much valuable information concerning density distribution throughout the affected area was obtained. This is abstracted below according to the intensities appraised in the Washington office, following the usual practice of publishing such material.

Further details must await reports on a number of investigations still under way. The Seismological Laboratory at Pasadena is making a thorough study of the scientific aspects including the interpretations of a vast amount of instrumental data; the California Institute of Technology, cooperating with the Coast and Geodetic Survey, is making a survey of the strongly affected areas to study the effects of the earthquake on various types of buildings. Further on in this publication will be found the preliminary results of the Coast and Geodetic Survey's strong motion seismograph observations which are to be revised and treated more thoroughly in "United States Earthquakes, 1934." In view of the studies mentioned and others now in progress which are not related directly to the work of the Bureau the reports on the Long Beach earthquake in this publication must not be accepted as final.

The following abstracts of reports on the main shock are taken from individual reports and press clippings collected by the San Francisco Field Station of the Coast and Geodetic Survey.

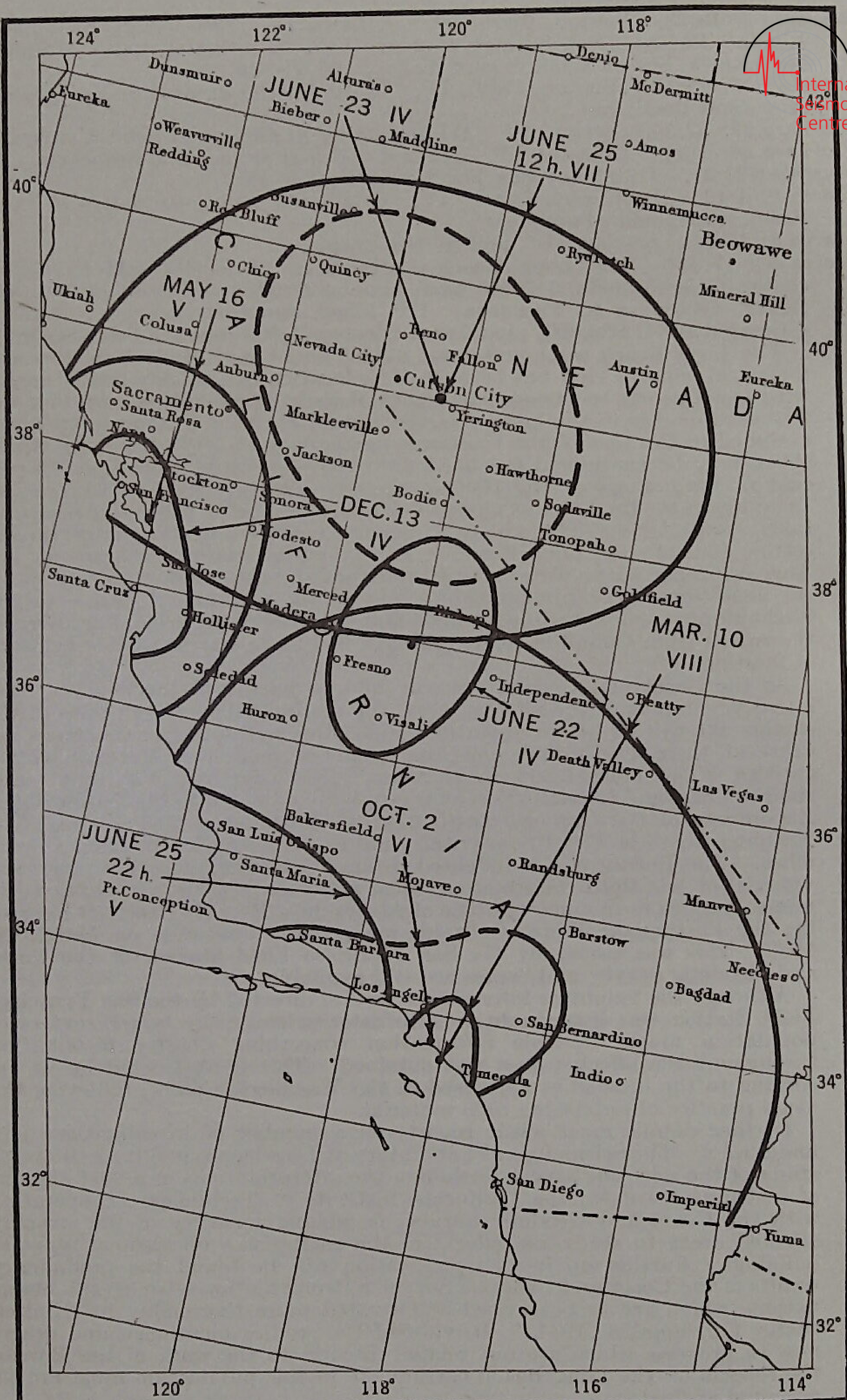

FIGURE 2.—Areas affected by the California and Western Nevada shocks of March 10, May 16, June 22, 23, 25, 25, October 2, December 13.

INTENSITY VII–IX:

Compton.—Practically every building within a 3 block radius was demolished or badly damaged. A number of automobiles were buried beneath the debris. See general description of earthquake for further details.

Long Beach.—Intensity varied from VII to IX over the city. Walls caved in, buildings collapsed, tanks fell through roofs, houses displaced from foundations. Pavements displaced and roads cracked, communication with city disrupted; oil derricks caught fire. Automobiles unmanageable during shock. See general description of earthquake for further details.

INTENSITY VIII:

Anaheim.—Damage great to brick and masonry; several buildings condemned; many chimneys damaged; automobiles damaged by falling bricks.

Balboa Island Bridge.—Shock preceded by noise like broadside from a battleship. Expansion joints of bridge separated like rifle shots. Tons of dirt from bluffs slid down on road.

Bellflower.—Damage great in wood, brick, and masonry. Chimneys fell.

Bolsa Chica Gun Club.—Crevices and cracks appeared in fields and highway. Pavement displaced.

Costa Mesa.—Two brick business buildings completely wrecked, all others lost fronts. Few chimneys escaped having tops knocked off.

Cypress.—Damage great in brick buildings. Walls and chimneys fell.

Garden Grove.—Brick walls tumbled into streets from many buildings—other buildings collapsed, water mains cracked. Electric service interrupted.

Huntington Beach—2½ miles toward Newport.—Extreme shock. Three-lane highway spread about 8 inches apart between each lane for about 150 feet. Lane on northeast side settled 15 inches.

Huntington Beach.—Most of the fronts of brick buildings in business section in the streets. A number of cement bridges and cement foundations under steel derricks were "squashed" several inches up out of ground. Radiators in post office thumped loudly on floor, clerk unable to stand. Five hundred-foot extension of steel and concrete pier separated from main section by 2-foot break.

Newport Beach.—Small cracks in ground, and some small landslides. About 800 chimneys broken at roof line; 30 buildings partially damaged or destroyed; few leaks in water mains and relatively little plaster fell.

Santa Ana.—Martial law. Not one brick building in business section escaped partial damage. Public buildings badly damaged. Streets filled with debris. People spent night in automobiles.

Near Santa Ana Bridge.—Highway, before arriving at bridge from Santa Ana, buckled in two places and for 1,000 feet had dropped about 4 inches.

Seal Beach.—Damage great in brick and concrete. Walls, chimneys, and plaster fell. Furniture broken. Section of pier collapsed. Several injured.

Signal Hill.—Derricks twisted, a number burned. Tanks and buildings collapsed. Oil line broken.

South Gate.—Store fronts collapsed in business district. Elevated tank and steel tower collapsed.

Watts.—Stores seriously damaged, water mains broken. Casualties from falling bricks.

Willowbrook.—Damage great in brick and masonry; furniture broken; ground cracked. Chimneys and columns fell.

INTENSITY VII:

Anacapa Island.—Coast Survey party approaching shore off south side saw two landslides, about a quarter mile apart, occur simultaneously. Several hundred tons in larger slides. Not felt in launch which was under way.

Artesia.—Casualties caused by building collapse and falling debris.

Bell.—Cracked plaster, windows, walls, and chimneys. Spilled liquids, indoors and outdoors. Considerable damage to buildings.

Buena Park.—Cracks in brick buildings, schools badly hit; goods fell from shelves, windows broken, coping fell.

Corona del Mar.—Damage considerable in brick, masonry, concrete. Windows and furniture broken. Chimneys fell.

Dominguez.—Oil refinery badly damaged. Dishes broken. Damage otherwise slight.

Downey.—Plaster cracked, windows and dishes broken. Chimneys fell.

Fullerton.—Three brick buildings seriously damaged. Chimneys, plaster, and dishes fell. Structural steel building undamaged.

Graham.—Front of bank building reported fallen.

Hermosa Beach.—Walls of some large buildings badly damaged. Globes knocked off street lamps.

Huntington Park, central section.—Severe damage to business buildings and to poorly constructed brick buildings. Chimneys down. High school destroyed by fire.

Laguna Beach.—Windows broken, glassware knocked off shelves, some heavy furniture moved 2 inches. Some top walls fell. Leaks in water and gas mains. City without lights 1 hour.

Lomita.—School chimneys fell; considerable damage. Merchandise shaken from shelves. Books, pictures, and plaster fell; windows and dishes broken.

Los Angeles County, central section.—Many tons of rocks loosened and rolled into canyons. Violent swaying of trees. Liquids in dishes splashed east.

Los Angeles, eastern section.—Cornices, tops of chimneys, dishes, and plaster fell. Gas mains damaged.

Los Angeles, southern section.—Damage heavy.

Los Angeles, west-central section.—Many buildings slightly damaged; some, poorly constructed, destroyed. North to south walls cracked; some plaster thrown down.

Lynwood.—Houses thrown from foundations, theater collapsed, bank building damaged; gas, light, and water facilities cut off.

Manhattan Beach.—Plate-glass windows broken, walls cracked, some chimneys down.

Newport.—Top walls of six brick buildings fell. Few chimneys escaped. Damage not severe. Hundreds of people left town because of unfounded rumors of tidal wave.

Norwalk.—Considerable damage to brick and masonry. Chimneys fell, heavy furniture moved, stock fell from shelves. Communication service disrupted. One killed, several injured.

Redondo Beach.—Fire walls jarred loose, fronts of stores damaged, objects broken in stores, two schools damaged.

San Pedro.—Damage confined to brick walls above roofs. Plaster and pictures fell. Numerous leaks in gas lines. Water mains and telephone lines broken, service lines to ship terminals broken.

Somis (near).—Chimney thrown from ranch house.

Torrance.—One-hundred-thousand gallon tank cracked open; 80,000-gallon tank damaged. Buildings damaged, chimneys fell.

Venice.—High school damaged. Chimneys fell, plaster cracked, dishes broken.

Intensity VI:

Alhambra.—Plaster, pictures, knick-knacks fell, windows and dishes broken, water spilled, some chimneys cracked.

Beverly Hills.—Marked damage to chimneys, fire walls, tile partitions on a northwest line, Bedford Drive, Olympic Boulevard to Santa Monica Boulevard. Slight damage. Store windows and dishes broken, merchandise upset, trees and bushes shaken strongly.

Covina.—Plaster cracked, water spilled, small objects overturned.

Culver City.—Slight cracks in several buildings. Chimneys and fireplaces damaged, street lights broken. Chimney and fireplace in two houses shifted several inches.

Fillmore.—Two big mountain slides. Damage slight, cracked plaster and broke dishes.

Gardena.—Stores damaged.

Glendale.—Large plate-glass window and electric-light domes broken.

Harbor City.—Chimneys fell, windows broken.

Huntington Park.—Damage slight. Knick-knacks and books fell. (See Huntington Park, central section under VII.)

Laguna Bell Substation.—Damage slight. Cracked plaster and walls, overturned small objects. Spilled liquids from tanks.

Lake Arrowhead.—Moved small objects and cracked plaster.

La Verne.—Damage slight. Plaster cracked; pictures and books fell. Furnishings moved.

Lighthipe Substation.—Cracked plaster, windows, walls, and chimneys. Considerable damage to electrical equipment.

Los Angeles, central section.—Many windows broken. Many east-to-west walls cracked. Slight damage to chimneys.

Los Angeles, northwest section.—Damage slight. Plaster cracked in north-to-south walls.

Los Angeles, west section.—Bricks from chimneys fell toward the north. Many became dizzy, a few nauseated.

Montebello.—City hall damaged.

Oxnard.—Hanging objects swung northeast. Books and pictures fell, telephone lines broken; damage slight.

Palos Verdes Estates.—Buildings cracked, no injuries.

Pasadena, Lamanda Park.—A few articles fell from shelves. Some walls cracked. Crockery broken. Little damage reported.

Placentia.—No serious damage to buildings; chimneys, plaster, pictures, and books fell.

Pomona.—A few chimneys cracked. Some plaster fell.

Orange.—Chimneys fell, plaster cracked, clocks stopped.

Santa Monica.—North-to-south motion. Moved small objects and overturned small vases. Windows broken, chimneys shaken and bricks dislodged High school and city hall damaged slightly.

Saugus, Southern California Edison Co. Substation.—North-to-south motion. Large transformers moved. Plaster cracked.

Simi.—Knickknacks fell and vases overturned. Chimneys cracked.

Summit.—Plaster, chimneys and ground cracked. Slight damage to masonry and concrete.

Tustin.—Building reported damaged.

Ventura.—Some plaster, windows, walls, and chimneys cracked. Dishes broken. Overturned vases, spilled water. A few brick walls damaged slightly.

Whittier.—Plate glass windows shattered. Brick cornices thrown down.

INTENSITY V:

Arcadia.—Cracked plaster. Damage slight. Spilled water indoors.

Avalon.—Slight plaster cracks in two buildings. Trees and bushes shaken strongly. Fall of knickknacks in one instance.

Azusa.—Slight damage.

Bloomington.—Small objects moved, spilled water, cracked plaster. Damage slight.

Eagle Rock.—Some plaster cracked.

El Segundo.—Damage slight.

El Toro.—Damage slight. Plaster cracked; vases overturned.

Escondido.—Very slight damage. One chimney cracked and some plaster fell, stock thrown on floors in stores.

Fullerton, Stewart Station.—Broke dishes and windows.

La Crescenta.—Cracked windows; plaster, pictures and books fell.

Los Angeles Harbor.—Lighthouse tower swayed east to west. Considerable mercury shaken out of lens base.

Maywood.—Windows broken.

Monrovia.—Dishes broken, bottles knocked from shelves.

Moreno.—Overturned small objects. Suspended objects swung, water spilled.

North Hollywood.—Moved car several inches; trees and bushes shaken strongly. No damage.

Ontario.—Chimneys and plaster cracked, clocks stopped.

Riverside.—Damage slight.

San Fernando.—Small objects overturned.

San Juan Capistrano and San Clemente region.—Some buildings suffered slight damage.

San Pedro, half-way between San Pedro and Redondo.—Plaster cracked.

Santa Paula.—China and glassware in store window broken.

Sierra Madre.—Plaster cracked in some buildings. Electric light poles swayed through 18 inches.

South Pasadena.—Small objects overturned, water spilled; damage slight.

Topanga.—Store goods fell from shelves. Rock fell into road.

Westminster.—Stock in stores thrown to floor.

Woodcrest.—Small objects moved and overturned.

INTENSITY IV:

Acton, Altadena, Atwood, Bakersfield, Banning, Beaumont, Brea, Brown, Burbank, Cajon, Camarillo, Cardiff-by-the-Sea, Carlsbad, Carriso Gorge, Charter Oak, Chatsworth, Chino, Claremont, Colton, Corona, Devore, Eagle Rock Substation, El Mirage, El Modena, Elsinore, Etiwanda, Fallbrook, Fellows, Fontana, Guasti, Helendale, Highgrove, Irwindale, Jamul, Keen Kamp, Kernville, La Canada, La Crescenta, La Mesa, Lancaster, La Vina, Llano, Los Alamitos, Maricopa, McKittrick, Mecca, Mentone, Mojave, Monolith, Monterey Park, Montrose, Nestor, Oceanside, Oildale, Palmdale, Pasadena, Pine Knot, Piru, Point Loma Light Station, Point Vicente Light Station, Ramona, Riverside, Rosamond, San Bernardino, San Dimas, San

Gabriel, San Marcos, San Nicholas Island, Santa Ana River S. C. E. Station No. 1, Santa Barbara, Solana Beach, Stanton, Sunnymead, Triunfo, Trona, Tujunga, Upland, Victorville, and Yucaipa.

INTENSITY III AND UNDER:

Aberdeen, near Adelaida, Arroyo Grande, Atascadero, Atolia, Avila, Bass Lake, Big Creek, Blythe, Bradley, Brawley, Buttonwillow, Calexico, Caliente, Campo, Casmalia, Catalina Island, Cedarpines Park, Delano, Dos Cabezas, El Centro, Exeter, Fairmont to Little Lake, Fresno, Garnet, Glennville, Halcyon, Hanford, Hayfield Camp, Hipass, Hollister, Inyokern, Jacumba, La Habra, Lemoore, Lindsey, Little Lake, Lone Pine, Ludlow, McFarland, Muroc, Needles, Newberry, Newhall, Paso Robles, Pine Canyon Dam, Pixley, Point Conception, Point Fermin Light Station, Point Hueneme Light Station, Porterville, Prado, Redlands, San Fernando, San Diego, San Miguel Island, San Luis Obispo, Santa Maria, Santa Fe Springs, Santa Rosa Island, Sequoia National Park, Seven Oaks, Springville, Tipton, Tulare, Visalia, Warner Springs, Wheeler Ridge, Woodlake; Las Vegas, Nev.; Prescott, Ariz.

Aftershocks followed the main shock at intervals so short that it seems impossible to correctly separate the large number of noninstrumental report cards received. More than 500 reports are available covering about 100 aftershocks. As the aftershocks often occurred only a few minutes apart and the times reported on the cards are sometimes uncertain by that amount, it seems that tabulation of these reports might be made to better advantage after the study of instrumental results at the Seismological Laboratory at Pasadena is completed. For this reason they are not published here.

There was apparently no shock of major importance following the main shock. This accords with the conclusion drawn by Mr. Wood from the amplitudes registered on the Pasadena seismographs. A list of 80 of the stronger aftershocks recorded is published in Mr. Wood's article from which quotations are made in this report. The noninstrumental reports indicate that two shocks were felt previous to the first one on Mr. Wood's list. It seems quite probable that they were masked on the seismograms by the prolongation of the main shock.

March 12: 14:00. Reese River, IV.

March 13: 5:19. Colton and San Dimas, IV. Also felt at Guasti and La Crescenta.

March 15: 3:13. San Dimas, IV. Duration 45 seconds.

March 24: 17:32. San Diego, barely perceptible.

March 27: 2:45. Candelaria, Nev., and Redding, Calif., IV. Also felt at Auberry, Laws, Oakhurst, and Mocalno.

March 27: 5:01 and 5:06. Benton, Big Creek, Oakhurst, and Paynes' Creek, IV. At Big Creek the first shock caused many residents to leave their beds. Also felt at Auberry, Laws, Manton, and Mocalno.

March 30: 4:20. Lennox, moved small objects. Felt at Long Beach and Los Angeles.

March 31: 3:00. Los Angeles, sharp.

April 2: 1:00. Seal Beach, V. Chimneys cracked. Newport Beach, IV. Los Angeles felt three minor shocks.

April 6: 4:00. Long Beach, V. Books and pictures fell; pendulum clock facing east stopped.

April 6: 8:12. Caribou, felt. Also felt at Caribou Power House Camp.

April 6: 22:30. Newport Beach, IV. At 22:26 Huntington Beach felt a weak shock.

April 12: 2:03. Porterville and Visalia, IV. Felt at Delano, Ducor, and Tipton.

April 15: 4:20. Alameda, Oakland, and Piedmont, III. Also felt at Berkeley, East Oakland, and San Francisco.

April 15: 7:55. Newport Beach, IV.

April 19: 6:20. Huntington Park, V. Slight damage. Willowbrook, IV.

April 29: 7:00. Hynes, IV. Felt at Los Angeles.

April 30: 1:55. Hynes, IV.

May 4: 19:00 to 20:00. Hynes and Long Beach. A serious landslide occurred at San Clemente at 19:15 which may have been precipitated by an earthquake.

May 5: 5:00. Hynes and Long Beach, felt.

May 8: 2:34. Kern River No. 3, IV. Earthquake in Mexico at 2:34 possibly acted as trigger force.

May 9: 13:00. Silver Peak and Tonopah districts, Nev., light.

May 9: 13:05. Hynes, Los Angeles and San Dimas, light.

May 16: 3:47*. San Francisco Bay region, V. Southern Alameda County, according to provisional statement by University of California. Felt over 8,000 square miles. See map.

INTENSITY V:

Hayward.—Clocks stopped, chimneys moved.

Martinez.—Terrazzo floor of Hall of Records cracked.

Niles Canyon.—Landslide, plaster cracked, windows broken, goods thrown from shelves.

Oakland.—Fire extinguishers thrown from walls of Ford plant.

Oakland Harbor Light Station.—Water spilled east to west.

Pleasanton.—Windows cracked, merchandise fell from shelves.

San Francisco.—Practically everyone awakened, telephone operators left switchboards, a few cases of broken windows and cracked plaster reported. Intensity low in grade V.

Santa Cruz.—Knickknacks moved, small objects fell.

INTENSITY IV:

Ano Nuevo Island Lighthouse, Antioch, Centerville, Fort Barry, Fort Point Light Station, Inverness, Livermore, San Jose, San Mateo, San Rafael, Santa Clara, Santa Rosa, Saratoga, Soquel, Stanford University, Stockton, Tracy, Vallejo, Watsonville, Wrights, and Yerba Buena Light Station.

INTENSITY III AND UNDER:

East Brother Island Lighthouse, Merced, Modesto, Mount Hamilton, Sacramento, San Pedro, Spreckles, and Wallace.

Reported "severe" at Alameda, Berkeley, Gilroy, Petaluma, and Richmond.

NOT FELT AT THE FOLLOWING PLACES:

Arbuckle, Auberry, Blocksburg, Corning, Covels, Elk Creek, Forest Glen, Fort Brag, Garberville, Jamesburg, Laytonville, Madera, Mariposa, Mendocino, Orland, Paskenta, Point Arena, Red Bluff, Robbins, Rockport, Roseville, Ruth, San Benito, Scotia, Snelling, Soledad, Waterford, Weaverville, Weott, Williams, Willits, Willows, and Woodland.

May 16: About 13:00. Compton, Downey, Huntington Park, and Maywood, V. Also felt at Long Beach and vicinity and at Los Angeles.

May 18: 1:15. San Bernardino, felt.

May 19: 8:27. Calexico and Imperial, IV.

May 24: 20:05. Fortuna, Holmes Flat, Pepperwood, Scotia, and Whitlow, felt.

June 3: 18:43. Redwood City and San Francisco, IV. Also felt at Mount Hamilton and San Jose.

June 4: 6:10. Luning, Nev., V. Also felt at Hawthorne, Nev., Pilot Mountain, Nev., and at Benton, Calif.

June 7: 6:00. Smoky Valley, Nev., IV.

June 10: 0:30. Round Mountain, Nev., IV. Felt at Smoky Valley, Nev.

June 10: 22:28 Compton and Huntington Park, IV. Also felt at Hynes.

June 11: 11:25. Compton, IV. Also felt at Huntington Park and Hynes.

June 11: 11:40. Compton, IV. Felt at Hynes.

June 12: 7:00. Mineral, IV.

June 14: 6:58. Brawley, slight.

June 22: 4:36 and 4:41. See map.

INTENSITY IV AT THE FOLLOWING PLACES:

Benton, Big Creek, Fresno, Huntington Lake, Kingsburg, Laws, Parlier, Sanger, Sequoia National Park, Tollhouse, Tulare, and Visalia.

INTENSITY III AND UNDER:

Bishop, Corcoran, Crooked Creek, Friant, Lindsay, Monson, Navelencia, Planada, Porterville, Squaw Valley, Tipton, and Wood Lake.

NOT FELT AT THE FOLLOWING PLACES:

Delano, Ducor, Exeter, and Independence.,

June 23: About 6:00. Twenty miles south of Mammoth Lakes, IV. Rock slides were caused by an earthquake.

June 23: 11:55. A low intensity but widespread shock centering at or near the epicenter of the heavier shock of June 25. Intensity IV. Affected area approximately 30,000 square miles. See map.

INTENSITY IV:

Camino, Courtland, Fallen Leaf, Portola, and Quincy, Calif.; Candelaria, Gold Hill, Ione, Nixon, Reno, and Roderick, Nev.

INTENSITY III AND UNDER:

Alamo, Bagby, Benicia, Challenge, Diablo, Markleeville, Northfork, Ripon, Santa Rosa, and Wawona, Calif.; Broken Hills, Golconda, Hawthorne, Nyala, Schurz, Simon, Sparks, Tonopah, and Virginia City, Nev.

Not felt at the following places in California:

Adams, Aetna, Ahwahnee, Alameda, Albion, Alder Springs, Altaville, Alturas, Antelope, Aptos, Arbuckle, Auberry, Auburn, Bayles, Beckwourth, Bieber, Big Pine, Big Sur, Biola, Bloomfield, Boulder Creek, Bowman, Bridgeport, Broderick, Calexico, Calhey, Calistoga, Calpella, Campo Seco, Carmel, Cassel, Chowchilla, Clearlake, Coalinga, Columbia, Colusa, Contolesse, Cordelia, Corte Madera, Cressey, Cupertino, Davis Creek, Diamond Spring, Dos Rios, Downieville, East Nicolaus, Eldridge, Elk Creek, El Nido, Elverta, Folsom City, Fort Bragg, Freestone, French Camp, French Gulch, Friant, Glenn, Gonzales, Grass Valley, Greenwood, Gridley, Gustine, Hazel Creek, Hilton, Hood, Idria, Independence, Ione, Jackson, Johnstonville, Keddy, Kelseyville, Kennett, Kirkwood, Knights Landing, Laton, Lincoln, Litchfield, Livermore, Livingston, Los Banos, Marina, Meeks Bay, Mendota, Millville, Minarets, Mitchell Mill, Mocalno, Monterey, Napa, Nevada City, Niles, Oilfields, Old Station, Orland, Owenyo, Palo Cedro, Paskenta, Perkins, Petaluma, Placerville, Pleasant Grove, Point Arena, Point Reyes, Port Chicago, Prather, Princeton, Rackerby, Raymond, Red Bluff, Redding, Riverdale, Salinas, San Martin, Sattley, Selma, Sloat, Smartville, Soquel, Spreckels, St. Helena, Sunol, Sutter, Tahoe, Taylorsville, Topaz, Truckee, Vacaville, Vallicita, Walnut Creek, Westhaven, Westwood, Williams, Willow Ranch, Willows, Woodland, Woodleaf, Ydalpom, Yolo, and Yosemite National Park.

Not felt at the following places in Nevada:

Alamo, Arden, Austin, Baker, Battle Mountain, Beatty, Beowawe, Bullion, Dixie Valley, Elko, Ely, Gardnerville, Gerlach, Goldfield, Hiko, Las Vegas, Lima, Lower Rochester, Metropolis, Orovada, Overton, Pioche, Potts, Rawhide, Shafter, Sharp, Steptoe, Stewart, Stillwater, Tuscarora, Tybo, Valmy, Verdi, Winnemucca, and Yerington.

June 25: 0:05. Zephyr Cove, Nev., IV.

June 25: 12:45*. Western Nevada, near Wabuska and Yerington. Intensity VII. 39°05′ N., 119°20′ W. Felt over approximately 40,000 square miles and well recorded on European seismographs. See map.

Intensity VII at the following places in Nevada:

Virginia City.—Catholic church badly damaged, a number of chimneys down, many windows broken, some walls cracked.

Wabuska.—Upper range of VII. All brick chimneys down, dishes broken in large quantity and merchandise thrown from shelves.

Yerington.—Courthouse wall separated 2 inches from rest of building; 1 concrete building thrown askew, 1 chimney down, canned goods thrown from shelves, some cracks in ground from which water shot for a time.

Intensity VI at the following places in Nevada:

Carson City.—Severe cracks in Federal building, 2 old chimneys down, plaster fell in 1 or 2 cases.

Dayton.—Plaster fell, chimneys cracked.

Fallon.—Some cracks in walls and plaster.

Fort Churchill.—Some bricks dislodged from old buildings.

Lahontan.—Landslides in hills south of dam, front shaken out of stone building on near-by ranch.

Manhattan.—Post office badly cracked.

Mason.—Plaster cracked, vases overturned.

Minden.—Plaster cracked, small objects overturned.

Schurz.—Cliff slid into road about 18 miles west of town.

Stewart.—Plaster and windows cracked, dishes broken, vases overturned.

Intensity VI at the following places in California:

Lodi.—Some plaster cracked, merchandise thrown from store shelves, automobiles moved.

Markleeville.—Cracked plaster, threw down small objects and books, overturned vases.

Tahoe City.—Plaster cracked in some walls, glassware broken.

Intensity V at the following places in Nevada:

Gold Hill, Hawthorne, Hazen, Rawhide, Reno, Roderick, and Verdi.

Intensity V at the following places in California:

Grass Valley, Lockeford, Log Cabin, Mount Gregory, Nevada City, Omo Ranch, Santa Rosa, Varner, and Volcanoville.

Intensity IV at the following places in Nevada:

Austin, Broken Hills, Dixie Valley, Eureka, Flanigan, Gardnerville, Gerlach, Imlay, Ione, Lodivale, Lovelock, Luning, Mina, Nixon, Oreana, Phonolite, Pyramid, Round Mountain, Smoky Valley, Sparks, Stillwater, Thorne, Wellington, and Wichman.

Intensity IV at the following places in California:

Acampo, Ahwahnee, Amador City, Auburn, Beckwourth, Bethany, Bridgeport, Broderick, Brooks, Brown's Valley, Byron, Camptonville, Carquinez Strait Lighthouse, Chico, Coleville, Colgate, Columbia, Colusa, Courtland, Diamond Springs, Douglasflat, Douglas Resort, Dunnigan, East Nicolaus, El Capitan, Eldridge, Emerald Bay, Esparto, Fairfield, Fair Oaks, Fiddletown, Firebaugh, Forest, Freeport, French Camp, Fresno, Galt, Georgetown, Graniteville, Gridley, Herald, Hobart Mills, Homewood, Hood, Ione, Jackson, Janesville, Knights Landing, Kyburz, Lake Alpine, Lake Tahoe, Legrand, Lincoln, Liveoak, Livingston, Long Barn, Martell, Marysville, Meeks Bay, Merced, Meridian, Milton, Modesto, Moores Flat, Newcastle, North Bloomfield, North Sacramento, Oakdale, Paradise, Perkins, Petaluma, Placerville, Planada, Pleasant Grove, Portola, Princeton, Rio Vista, Ripon, Robbins, Roseville, Ryde, Sacramento, Sattley, Sierraville, Smithflat, Stockton, Storrie, Summit Soda Springs, Sutter, Tahoe Pines, Taylorsville, Topaz, Tracy, Truckee, Vacaville, Valley Springs, Vallicita, Verona, Wallace, Weimar, Wheatland, Williams, Willows, Winters Island, Woodland, Wolf, Yola, Yosemite National Park, and Yuba City.

Intensity III and under at the following places in Nevada:

Battle Mountain, Big Meadows, Candelaria, Eastgate, Elko, Golconda, Lahontan, Lake Rochester, Mill City, Simon, Tonopah, Unionville, and Winnemucca.

Intensity III and under at the following places in California:

Antelope, Antioch, Arbuckle, Bagby, Bakersfield, Benicia, Big Creek, Big Oak Flat, Bowman, Campo, Challenge, Clarksville, Clipper Mills, Cordelia, Diablo, Downieville, Fallen Leaf, Folsom City, Fresno, Gerber, Glenn, Graeagle, Gustine, Jamestown, Johnstonville, Laton, Livermore, Los Banos, Madera, Manteca, Mendota, Mitchell Mill, Navelencia, Niles, Oakland, Orland, Oroville, Port Chicago, Quincy, Red Bluff, Riverdale, Roseville, San Andreas, San Francisco, Sanger, San Jose, San Migeul, Sloat, Smartville, Soda Springs, Sonora, Susanville, Virgilia, Vorden, Waterford, Wawona, and Woodleaf.

The earthquake was also felt with intensity not reported at the following places: Altaville, Bakersfield, Elverta, Gerber, and Greenwood, Calif.

Not felt at the following places in Nevada:

Alamo, Baker, Beatty, Beowawe, Bullion, Carlin, Currant, Ely, Goldfield, Hiko, Las Vegas, Lind, Metropolis, Mount Montgomery, Orovada, Overton, Potts, Preston, Shafter, Steptoe, Sulphur, Tubo, and Valmy.

Not felt at the following places in California:

Adams, Aetna Springs, Alamo, Albion, Anderson, Aptos, Auberry, Bayles, Bieber, Big Pine, Big Sur, Bloomfield, Boulder Creek, Calistoga, Calpella, Camp Rodgers, Carmel, Cassel, Cathay, Chowchilla, Coutolenco, Cressey, Cupertino, Dana, Davis Creek, Ducor, Elk Creek, El Nido, Fort Bragg, Freestone, Friant, Fulton, Gonzales, Hazel Creek, Hilton, Idria, Independence Keddie, Kelseyville, Kennett, Kerman, Kirkwood, Lawrence, Litchfield, Lookout, Los Molinos, Marina, Mocalno, Monterey, Mount Hermon, Napa, Oilfields, Old Station, Palo Cedro, Paskenta, Point Arena, Point Reyes, Prather, Rockerby, Ravendale, Raymond, Redding, St. Helena, Salinas, San Martin, San Rafael, Soquel, Spreckels, Sunol, Trigo, Upper Lake, Walnut Creek, Westhaven, Westwood, Willow Ranch, and Ydalpom.

June 25: 13:30. Beckwourth, IV. Also felt at Merrimac and Southampton Shoals Light Station.

June 25: 22:26 and 22:29. Off Point Conception, V. Two separate shocks occurred centering at sea a short distance off Point Conception. The second shock was the stronger and attained a maximum intensity of V on land. It was felt over a land area of about 4,000 square miles and was recorded on nearby seismographs. See map. Shocks were reported as early as 22:21 and as late as 22:35.

Intensity V:

Buellton and Point Conception Light Station.

Intensity IV:

Casmalia, Halcyon, Hueneme Light Station, Lompoc, Los Alamos, Santa Barbara, Santa Maria, Santa Paula, Santa Ynez, Solvang, Surf, and Ventura.

Intensity III and under:

Arroyo Grande, Bakersfield, Fillmore, and Goleta.

July 4: (—). Lassen Volcanic National Park. Eight earth shocks severely shook buildings in the eastern section. The Lassen Volcanic Observatory has recorded 17 earthquakes since July 1.

July 5: 22:25. Long Beach and Norwalk, IV.

July 16: 16:32. North shore of Monterey Bay, V.

INTENSITY IV:

Aptos, Gilroy, Olympia, Santa Cruz, and Watsonville.

INTENSITY III AND UNDER:

Morgan Hill, Pacific Grove, Salinas, San Francisco, Soquel, and Spreckels.

July 16: 20:30. South Gate, IV. Huntington Park, III.

July 18: 1:10. Newark, IV. Niles, Redwood City, and San Francisco, III.

July 20: 18:55. Luning, Nev., IV. Slight at Mina, Nev., at 19:07.

August 3: 20:18. Long Beach and Seal Beach, IV. Also felt at Anaheim, Huntington Beach, and Santa Ana.

August 4: 0:50. Seal Beach, IV. Felt at Anaheim and Huntington Beach a few minutes earlier.

August 5: 15:34. Santa Ysabel, IV. Also felt at Mecca and San Diego.

August 5: 19:30. Camp Angelus, Mecca, San Diego, and Santa Ysabel, IV.

August 10: 15:41. Newark, IV. Felt at Corte Madera, Niles, Oakland, San Francisco, and San Rafael.

August 12: 8:48. Long Beach and Seal Beach, IV.

August 27: 5:35. Anaheim and Huntington Beach, light shock.

August 28: 14:05. Luning, Nev., IV.

August 28: 20:16. Seal Beach, V.

INTENSITY IV:

Downey, Huntington Beach, and Hynes.

Reported felt at approximately the same time at Long Beach and Norwalk.

August 30: 6:30. Schurz, Nev., IV.

September 24: 16:45. Newport Beach, two hard shocks. Felt also at Huntington Beach and Santa Ana.

September 26: 22:06. Huntington Park and Hynes, IV.

September 28: 3:55*. Benbow, Briceland, Cape Mendocino Light Station, Ettersburg, Scotia, Shively, and Upper Mattole, IV. Felt at Eureka and Humboldt Bay Fog Signal Station.

October 2: 1:10*. Near Los Angeles, VI. Epicenter according to Pasadena 33° 47′, north, 118°08′ west. See map. This is close to Signal Hill and about 3 miles northeast of Long Beach. It was felt over a land area of approximately 6,000 square miles. The shock was quite sharp but damage was rather superficial. It was recorded on eight strong motion seismographs, the results appearing in another part of this publication.

INTENSITY VI:

Bell.—Dishes, windows and knickknacks broken, some bricks fell.

Huntington Park.—Many windows broken and a brick building damaged.

Los Angeles.—Intensity varied between IV and VI but it was greatest in the business section; plaster was cracked in some walls, dishes and windows broken, books, pictures and knickknacks thrown down. Some street lamps were badly damaged.

INTENSITY V:

Anaheim, Bloomington, Chatsworth, Glendale, Hollywood, Huntington Beach, Hynes, Long Beach, Los Angeles, Moreno, Placentia, Pomona, Redondo Beach, and San Pedro.

INTENSITY IV:

Acton, Beverly Hills, Carpinteria, Colton, El Modeno, Etiwanda, Irwindale, La Canada, La Crescenta, La Verne, Lomita, Norco, North Hollywood, Oxnard, Point Vicente Light Station, Pasadena, Reseda, Rosamond, San Dimas, San Fernando, San Gabriel, Santa Ana, Santa Barbara, Santa Monica, Saugus, Summit, Tujunga, Upland, Venice, Ventura, and Yorba Linda.

INTENSITY III AND UNDER:

Baldwin Park, Claremont, Chino, Llano, Mentone, San Bernardino, San Diego, and Victorville.

NOT FELT AT THE FOLLOWING PLACES:

Carmel, Ducor, and Piedras Blancas Light Station.

October 2: 1:21. Hynes, Long Beach, and Pasadena, felt.

October 2: 2:33. Hynes and Los Angeles, felt.

October 2: 4:00. Hynes, Long Beach and Los Angeles, light.

October 2: 5:26. Huntington Beach, Hynes, Long Beach, Los Angeles, Pasadena, and San Gabriel, mild.

October 2: 5:54. Imperial Valley, felt.

October 2: 7:41. Hynes, Long Beach and Los Angeles. Earthquake in Ecuador at 7:29 probably acted as trigger force.

October 2: 8:54. Imperial Valley, slight tremor.
October 2: 18:45. Brawley, felt.
October 5: 2:50. Riverside, San Bernardino and Victorville, IV. Felt at La Verne, Mentone, and Seven Oaks. A shock was felt at Acton sometime in the early morning.
October 5: 12:35. Huntington Park, Hynes, Long Beach, and Los Angeles, felt.
October 5: 20:52. Almanor Dam, near Caribou, IV.
October 19: 10:36. Balboa, IV. Two distinct tremors at Santa Ana.
October 24: 23:01. Huntington Park, VI. Felt over land area of 2,300 square miles. At Huntington Park there was slight damage in brick, some chimneys fell and a few windows were broken; small objects were moved and vases overturned.

INTENSITY V:

Altadena, Bell, Burbank, Glendale, and Sierra Madre.

INTENSITY IV:

Acton, Beverly Hills, Hollywood, La Canada, Los Angeles, Montebello, North Hollywood, Pasadena, Placentia, and San Fernando.

INTENSITY III AND UNDER:

Santa Ana and South Pasadena.

October 27: 3:00*. Ione, Nev., V. Austin, Broken Hills, Dayton, Mina, Tonopah, and Yerington, all in Nevada, IV.
November 13: 13:29. Seal Beach, IV. III and under at Huntington Beach, Long Beach, Los Angeles, and Pasadena.
November 20: 0:45. Los Angeles, IV. Also felt at Bell and Huntington Park.
November 20: 1:10. Balboa, IV. Felt at Glendale.
November 20: 2:31. Huntington Park, V. Downey, IV. Also felt at Bell, Glendale, and Los Angeles.
November 22: 18:25. Caribou, IV. Also felt at Almanor Inn, Butte Valley, and Prattville.
November 28: 6:15. California-Nevada border. Slight at Coleville, Markleeville, and Topaz, Calif., and Minden, Nev.
December 2: 15:19. San Jose, scarcely perceptible.
December 11: 1:50. Watsonville, IV. Also felt at Spreckels and Wrights.
December 11: 2:01. Hollister, IV. Also felt at Aptos, Morgan Hill, Ross, San Francisco, and Santa Crus.
December 11: (—). San Jose, felt.
December 13: 7:34. San Francisco Bay region, IV. Felt over 5,000 square miles. See map. Epicenter uncertain without instrumental data. May have been off shore.

INTENSITY IV:

Carmel, Gilroy, Hollister, Monterey, Morgan Hill, San Francisco, San Jose, Santa Cruz, Soquel, and Watsonville.

INTENSITY III AND UNDER:

Aptos, Benicia, Corte Madera, Pacific Grove, Redwood City, Ross, Salinas, San Martin, Spreckels, Stanford University, Sunol and Wrights.

December 15: 0:55. Broken Hills, Nev., IV. Also felt at Brucite, Ione, and Granite, Nev.
December 15: 15:16. Seal Beach, IV.
December 19: 21:28. Huntington Beach and Mile Rocks, felt.
December 30: 10:00. Seal Beach, IV. Also felt at Huntington Park.

WASHINGTON AND OREGON

120th meridian or Pacific standard time]

January 2: 17:20. Seattle, Wash., IV. Many felt houses sway, furniture was shaken and pictures moved on walls. Two tremors, first at 5:20 p. m., the second occurring at 10 p. m.
January 17: 22:—. Burns, Oreg. Meteor fell causing shock like an earthquake.
January 29: 1:45. Port Townsend, Wash., III. Few awakened by rapid east to west motion, windows and doors rattled.
March 18: 1:01. Sultan, Wash., II. Slight but distinct shock felt by observer.
April 29: 1:05. Chelan and Pateros, Wash., III. Felt by many. Windows and doors rattled, trees and bushes shaken slightly. Lasted several seconds.
May 29: 12:30. Chelan, Wash., III. Light shock felt by many caused windows, doors and dishes to rattle.
May 31: 12:20. Chelan, Chelan Falls, and Lakeside, Wash., IV. Two shocks, one at 12:20, the second at 12:30. Apparently strongest at Chelan Falls where it was felt by all and caused windows, doors, and dishes to rattle, and moved small objects. Trees and bushes shaken slightly.

August 22: 3:35. Everett, Wash., IV. Strong shock awakened many at Everett, Hartford, and Hansville. Strongest at Everett where houses were shaken, windows, doors, and dishes rattled, and small objects moved. Another shock at about 3:37.

August 22: 4:30. Bothell, Wash., IV. Several awakened as dishes, doors, and windows rattled and walls creaked. Shock lasted 5 seconds.

August 22: 4:35. Seattle, Wash., IV. Strong, vertical, highly localized shock awakened hundreds and "all but tossed us out of bed." Windows and dishes rattled in scores of homes but there was apparently no damage.

November 23: 6:25. Portland, Oreg., III. Several awakened by trembling motion lasting a few seconds.

ALASKA

[150 meridian time]

NOTE.—Instrumental epicenters are obtained from teleseismic data and subject at times to errors of a degree or more.

January 3: 18:00*. Instrumental epicenter 61° north, 147° west. Seward. A severe earth shock of 20 seconds duration sent people running into the streets. Ground cracks appeared at several Alaskan points and even in the streets of Seward, the fissures running north and south. The valley leading north from Seward was markedly disturbed; cracks appeared in the Forestry Bureau road for a distance of 20 miles to Kenai Lake and the effects of the quakes were noticeable along the Turnagain Arm route of the Alaska Railroad.

Anchorage reported "an earthquake of greater intensity than any previously recorded here." It shook the city for 45 seconds. Fairbanks and Cordova reported quakes of brief duration and slight intensity. At Horner the shock lasted over 2 minutes, and at Ellamar, about 50 seconds. It was felt by many at McCarthy, Susitna, and Wasilla. Chickaloon reported a shock at 18:30. No property damage was reported at any point.

January 17: 0:08. Homer; "just noticeable."

March 2: 12:30. Yakutat.

March 2: P. M. Susitna.

March 17: 5:20. Yakutat; lasted 45 seconds.

March 17: 22:30. Susitna.

March 18: 22:20. Juneau, III. Recorded instrumentally at Sitka.

March 20: 21:45. Valdez; slight.

March 27: 18:21. Whale Island, Afognak. Felt by observer. Recorded instrumentally at Sitka.

April 2: 8:26. Homer, III.

April 18: 20:40. Whale Island, Afognak; light earth tremor.

April 22: 7:17. Whale Island, Afognak; felt by several.

April 26: 10:28. Dutch Harbor, Aleutian Islands. Slight earthquake, no damage.

April 26: 16:36*. Instrumental epicenter 62° north, 151° west. Anchorage, VI. Telegraph lines were down for a distance of 50 miles from Anchorage. The shock lasted about 3 minutes. Plate glass windows in several stores were broken and stocks of goods tumbled from their shelves. This earthquake was considered by residents as the worst in 30 years.

The quake was felt severely on Kodiak Island and along the Aleutian Islands. It was felt strongly at Curry, McGrath, Seward, and Wasilla; Dillingham (Kanakanak), IV; reported light at Healy. The shock was felt also at College, Fairbanks, Susitna, Valdez, and Whale Island.

Because of difficulty in correlating the times of occurrence of the following aftershocks it has been considered best to list them all as individual shocks, even though it is evident that this is not always true.

April 26: Homer; earthquake and following tremors.

April 26: Kasilof; cracks in ice 3 feet thick running east and west.

April 26: Big Susitna River District, VII.

April 26: Old Tyonek, VII. Houses shaken off foundations.

April 26: 16:45. Whale Island, Afognak; fairly heavy shock. Felt also at Seward.

April 26: 17:03. Homer, V; worst in 15 years.

April 26: 17:13. Seward. Slight shocks felt occasionally until after midnight.

April 26: 17:29. McCarthy, IV. Susitna, III.

April 26: 17:37. Homer, Mile Seven (Cordova), and Susitna, III.

April 26: 17:50. Mile Seven (Cordova) and Susitna, III.

April 26: 18:10. Homer; mild; 76 seconds duration.

April 26: 18:50. Anchorage, V. Time questionable; possibly 16:37 or 17:50.

April 26: 23:00. Homer, III.

April 27: 12:20. Dutch Harbor. Buildings shaken; no damage reported.

April 27: 21:35. Homer, mild.

April 27: Time uncertain. Whale Island, Afognak. Two light shocks.

April 27: Anchorage. Fifty-four aftershocks were noted; the major shocks occurred at 3:30, 4:30, 11:55, 16:55, and 21:15. Clocks were stopped but no damage reported. The shocks felt at Anchorage at 16:55, 20:40, and 21:15 were recorded instrumentally at Sitka.

April 27: Susitna. Continual earthquake all day.

April 28: Time uncertain. Whale Island, Afognak. Two light tremors.

April 28: Anchorage. Nine aftershocks, the most prominent one occurring at 2:32.

April 28: Susitna. Aftershocks; occurred at 0:05, 9:06, 9:12, 10:27, 14:25, and 16:04.

April 29: Anchorage. Thirteen aftershocks were noted; two major ones occurred at 2:30 and 17:43. Shocks felt at 0:45, 8:34, and 17:43 were recorded instrumentally at Sitka.

April 29: Susitna. Aftershocks; occurred at 4:05, 7:20, 10:10, 13:07, 15:25, 15:45, 15:51, and 16:22.

April 30: Anchorage. Eight aftershocks. The principal one occurred at 1:30.

April 30: 2:20. Susitna, felt.

May 1: 0:06. Susitna. Strong aftershock. It was recorded ins rumentally at Sitka. Smaller aftershocks occurred at 12:05, 14:45, 18:00, nd 21:00.

May 1: 5:15. Seward. Also some during night.

May 1: 11:53. Anchorage, two aftershocks. The principal sho occurred at 11:53.

May 1: 20:32. Whale Island, Afognak. Light shock.

May 2: Anchorage, five aftershocks.

May 2: 23:00. Seward, felt.

May 3: 2:30. Anchorage and Susitna, aftershock.

May 3: 2:35. Anchorage and Susitna, aftershock. It was reported heavy at Anchorage and was recorded instrumentally at Sitka.

May 3: Anchorage. Ten aftershocks. Those at 2:30, 2:35, and 16:15 were most noticeable.

May 3: Susitna. Four aftershocks occurred at 2:30, 2:35, 14:35, and 16:25.

May 4: Anchorage. Four aftershocks.

May 4: Kasilof, two small quakes.

May 4: 3:01. Susitna, felt.

May 5: Time uncertain. Anchorage, one aftershock.

May 5: Susitna. Four aftershocks occurred at 7:55, 18:40, 19:40, and 20:15.

May 6: Susitna. Two aftershocks occurred at 8:40 and 13:30.

May 7: 19:00. Susitna. Four aftershocks occurred at 8:35, 13:05, 19:00, and 19:25. The one at 19:00 was reported strong.

May 13: P. M. Seward, felt.

May 13: Time uncertain. Old Tyonek, severe; some damage.

May 14: 17:00. Seward, felt.

May 15: 6:35. Susitna, felt.

May 15: 22:30. Seward, felt.

May 18: Anchorage. A number of minor shocks have been felt from May 13 to May 18.

May 19: 12:10. Allakaket, shock lasted 2 minutes.

May 22: 21:10. Seward, two shocks, 4:04 and 21:10. The second shock was felt at Anchorage and was recorded instrumentally at Sitka.

May 25: 6:25. Anchorage and Seward. Sharp at Anchorage.

June 11: 15:50. Homer, mild.

June 12: 5:06. Homer, mild.

June 12: 5:23*. Instrumental epicenter, approximately 61° north, 155° west. Homer, Seward, and Susitna. Reported as felt by observer from each place.

June 13: 6:07. Seward, felt by observer. Recorded instrumentally at Sitka.

June 13: 12:20*. Instrumental epicenter, 61° North, 151° West. Chickaloon, Homer, and Seward, earthquake of moderate intensity. Lesser shocks were felt for a day before main shock.

June 13: Time uncertain. Homer; lasted about 1 minute.

June 14: Anchorage. Two shocks felt; no damage reported.

June 15: 12:40. Anchorage, moderate intensity. Several minor shocks felt. Susitna, felt by observer. Recorded instrumentally at Sitka.

June 16: 22:55. Seward, slight.

June 16: Time uncertain. Kasilof, felt.
June 17: 12:11. Seward, rather severe.
June 17: Time uncertain. Kasilof, felt.
June 19: 8:30. Homer, felt by all.
June 19: 8:48*. Instrumental epicenter 60° North, 150° West. Seward and Susitna, felt.
June 19: Time uncertain. Kasilof, felt.
June 19: 9:02. Seward, very slight.
June 28: 0:25. Seldovia, felt.
June 28: 2:05. Homer, III.
June 28: Instrumental epicenters placed at 53° north, 165° west, near the Alaska Peninsula; and at approximately 53° north, 163° west, according to St. Louis. Islands in the vicinity of Dutch Harbor reported a series of earthquakes of considerable intensity. Shocks were recorded instrumentally at Sitka at 10:01.6 and 23:39.0, June 28, and at 2:30.7, June 29, Greenwich civil time.
July 28: 1:49. Dutch Harbor. "A violent earthquake of 15 seconds duration was felt in this vicinity at 3:49 a. m., Pacific standard time." Damage not determined. It was recorded instrumentally at Sitka.
August 30: 16:52*. Instrumental epicenter 60° north, 137° west. Haines and Skagway, V. Juneau, IV. Three heavy shocks reported at Skagway.
August 31: 4:00. Eagle, felt.
September 19: 13:40*. Instrumental epicenter 58° north, 137° west, approximately. Juneau and Skagway, IV. Pictures and chandeliers swayed, clocks stopped; no damage reported.
September 19: 18:55. Homer, very light shock.
September 24: 7:43. Anchorage, a slight earthquake reported felt. Also, big game hunters who had been at Post River Lake, 175 miles northwest of Anchorage, reported nightly earthquakes followed by thunderous roars and booming explosions.
September 26: 19:20. Anchorage, lasted 5 seconds.
September 26: 23:00. Anchorage, lasted 15 seconds.
September 28: 17:00. Anchorage, felt.
October 11: 8:25. Homer, III.
November 5: 23:15. Seward, felt.
November 7: 5:30. Cordova, slight tremor.
November 11: 11:15. Homer, III.
November 23: 23:55. Homer, felt.
November 27: 23:25. Homer, felt.
December 5: 7:25. Seward, felt.
December 17: 19:27. Juneau, III. Recorded instrumentally at Sitka.
December 29: 11:55. Homer, "just noticeable."

VOLCANIC ACTIVITY IN ALASKA

There have been several reports of volcanic activity in Alaska. May 13, it was reported that an unnamed peak west of Tyonek, an apparently long extinct volcanic crater, was throwing out smoke. May 23, Mount Redoubt, 10,000-foot volcano, dormant for years, was reported to be throwing smoke. December 1, Kanaga Island reported that the Great Sitkin volcano was erupting.

HAWAIIAN ISLANDS

[157½ meridian (West) time]

NOTE.—In the case of these islands with their many earthquakes of volcanic origin, only the more severe ones are listed. Reports of the Volcano Research Laboratory under the jurisdiction of the United States Geological Survey and the Hawaiian Research Association give all details. The epicenters of 92 local shocks have been published by A. E. Jones, in the journal of the Washington Academy of Sciences, vol. 24, no. 10, October 15, 1934.

October 21: A nearby shock was recorded instrumentally at Honolulu at 9:11.
December 2: 6:00. Hilo. The entire island of Hawaii was shaken by earthquake shocks preceding the eruption of the Mauna Loa Volcano. Press reports stated that this eruption was "the greatest eruption of a Hawaiian volcano since 1903."

PHILIPPINE ISLANDS

[120th meridian (East) time]

NOTE.—Only the more important shocks are included in this report. See reports of Weather Bureau, Manila Central Observatory, for complete data.

February 19: 12:36. Instrumental epicenter located in region 14°.2 north, 122°.7 east, according to Manila. Felt in southeastern Luzon, at Daet, VIII.

April 26: 18:50. Anchorage, V. Time questionable; possibly 16:37 or 17:50.

April 26: 23:00. Homer, III.

April 27: 12:20. Dutch Harbor. Buildings shaken; no damage reported.

April 27: 21:35. Homer, mild.

April 27: Time uncertain. Whale Island, Afognak. Two light shocks.

April 27: Anchorage. Fifty-four aftershocks were noted; the major shocks occurred at 3:30, 4:30, 11:55, 16:55, and 21:15. Clocks were stopped but no damage reported. The shocks felt at Anchorage at 16:55, 20:40, and 21:15 were recorded instrumentally at Sitka.

April 27: Susitna. Continual earthquake all day.

April 28: Time uncertain. Whale Island, Afognak. Two light tremors.

April 28: Anchorage. Nine aftershocks, the most prominent one occurring at 2:32.

April 28: Susitna. Aftershocks; occurred at 0:05, 9:06, 9:12, 10:27, 14:25, and 16:04.

April 29: Anchorage. Thirteen aftershocks were noted; two major ones occurred at 2:30 and 17:43. Shocks felt at 0:45, 8:34, and 17:43 were recorded instrumentally at Sitka.

April 29: Susitna. Aftershocks; occurred at 4:05, 7:20, 10:10, 13:07, 15:25, 15:45, 15:51, and 16:22.

April 30: Anchorage. Eight aftershocks. The principal one occurred at 1:30.

April 30: 2:20. Susitna, felt.

May 1: 0:06. Susitna. Strong aftershock. It was recorded ins rumentally at Sitka. Smaller aftershocks occurred at 12:05, 14:45, 18:00, nd 21:00.

May 1: 5:15. Seward. Also some during night.

May 1: 11:53. Anchorage, two aftershocks. The principal sho occurred at 11:53.

May 1: 20:32. Whale Island, Afognak. Light shock.

May 2: Anchorage, five aftershocks.

May 2: 23:00. Seward, felt.

May 3: 2:30. Anchorage and Susitna, aftershock.

May 3: 2:35. Anchorage and Susitna, aftershock. It was reported heavy at Anchorage and was recorded instrumentally at Sitka.

May 3: Anchorage. Ten aftershocks. Those at 2:30, 2:35, and 16:15 were most noticeable.

May 3: Susitna. Four aftershocks occurred at 2:30, 2:35, 14:35, and 16:25.

May 4: Anchorage. Four aftershocks.

May 4: Kasilof, two small quakes.

May 4: 3:01. Susitna, felt.

May 5: Time uncertain. Anchorage, one aftershock.

May 5: Susitna. Four aftershocks occurred at 7:55, 18:40, 19:40, and 20:15.

May 6: Susitna. Two aftershocks occurred at 8:40 and 13:30.

May 7: 19:00. Susitna. Four aftershocks occurred at 8:35, 13:05, 19:00, and 19:25. The one at 19:00 was reported strong.

May 13: P. M. Seward, felt.

May 13: Time uncertain. Old Tyonek, severe; some damage.

May 14: 17:00. Seward, felt.

May 15: 6:35. Susitna, felt.

May 15: 22:30. Seward, felt.

May 18: Anchorage. A number of minor shocks have been felt from May 13 to May 18.

May 19: 12:10. Allakaket, shock lasted 2 minutes.

May 22: 21:10. Seward, two shocks, 4:04 and 21:10. The second shock was felt at Anchorage and was recorded instrumentally at Sitka.

May 25: 6:25. Anchorage and Seward. Sharp at Anchorage.

June 11: 15:50. Homer, mild.

June 12: 5:06. Homer, mild.

June 12: 5:23*. Instrumental epicenter, approximately 61° north, 155° west. Homer, Seward, and Susitna. Reported as felt by observer from each place.

June 13: 6:07. Seward, felt by observer. Recorded instrumentally at Sitka.

June 13: 12:20*. Instrumental epicenter, 61° North, 151° West. Chickaloon, Homer, and Seward, earthquake of moderate intensity. Lesser shocks were felt for a day before main shock.

June 13: Time uncertain. Homer; lasted about 1 minute.

June 14: Anchorage. Two shocks felt; no damage reported.

June 15: 12:40. Anchorage, moderate intensity. Several minor shocks felt. Susitna, felt by observer. Recorded instrumentally at Sitka.

June 16: 22:55. Seward, slight.

March 3: 10:20. Instrumental epicenter placed in Zambales Mountains, according to Manila. Felt throughout western Luzon; Manila, IV.
March 22: 19:42. Daet, southeastern Luzon, VI.
May 27: 12:43. Borongan, Samar Islands, VI; Tacloban, Leyte Island, V.
June 6: 10:29. Instrumental epicenter estimated at 14°.3 north, 121°.6 east, according to Manila. Manila, IV. Provinces of Rizal, Laguna, Batangas, Bulacan, Cavite, and Tayabas, felt. There was some damage to brick work in sugar central at Nasugbu, Batangas.
August 20: 19:46. Instrumental epicenter located in region 13°.6 north, 124°.8 east, according to Manila. Southeastern Luzon, VI.
December 2: 16:45. Instrumental epicenter located in region 20°.3 north, 121°.9 east, according to Manila. Basco, Batan Island, VII.
December 26. A volcanic eruption, a typhoon and a tidal wave occurring in the Philippine Islands took a toll of at least nine lives and caused much property damage.

PUERTO RICO

[60th meridian time]

March 19: 13:07. Santurce, felt.
October 23: 23:18. San Juan, felt.
November 9: 19:47. San Juan, felt.

PANAMA CANAL ZONE

[75th meridian time]

February 19: 18:28. Balboa, reported felt by a few people.
February 21: 11:45. Balboa, reported felt by a few people.
March 12: 2:43. Balboa, felt by one.
May 6: 0:34*. Instrumental epicenter 6° north, 83° west, off west coast of Panama. Balboa, III.
May 30: 6:44 to 6:57*. Instrumental epicenter 8° north, 83° west, off west coast of Panama. Balboa, felt by few.
June 19: 4:48 and 4:51. Two quakes superimposed. First quake stronger, intensity IV. Balboa, first quake alarmed several.
June 25: 22:53. Balboa, II, felt by few.
July 7: 16:11. Balboa, felt by few. Origin doubtful, may have been dynamite explosion.
July 9: 17:13. Similar to preceding quake. Shock very sharp and rapid, lasted about 2 seconds. Balboa Heights, felt by observer.
August 12: 5:12. Balboa, felt by observer.
September 22: 11:41. Balboa, IV. Some people reported hearing a sharp noise similar to an explosion; felt by many.
November 21: 18:49. Instrumental epicenter approximately 8° north, 83° west, Balboa, I. Chiriqui and Bocas del Toro Provinces, R. P., felt.
November 21: 23:53. Balboa I. Chiriqui, R. P., felt.
November 22: 0:08. Balboa, I. Chiriqui, R. P., felt.
November 22: 1:58. Balboa, I.
November 22: 3:12. Balboa, I.
November 22: 3:45. Balboa, I.
November 22: 5:14. Balboa, I.
November 23: 13:58*. Instrumental epicenter 8° north, 84° west. Balboa, I. Chiriqui, R. P., felt.
November 29: 0:03*. Instrumental epicenter 8° north, 84° west, off west coast of Panama. Balboa, I.
December 1: 11:29. Balboa, I.
December 1: 22:02. Balboa, II.
December 5: 23:58. Balboa, IV, felt locally by many.
December 6: 1:36. Balboa, III, felt locally by many.
December 6: 5:25. Balboa, IV, felt.

MISCELLANEOUS ACTIVITIES

GEODETIC WORK

During the year 1933 one arc of triangulation was completed for the investigation of earth movement in California. This work was a reoccupation of the stations of an arc originally executed in 1928–29 from Newport Beach to Riverside, Calif., to determine the amounts of horizontal movements in this area caused by the Long Beach earthquake. However, the differences between the original observed angles and the angles observed in 1933 were too small to indicate that any movement of the stations had occurred.

The following lines of levels were run during the calendar year 1933 for the purpose of investigating earthquakes or detecting earth movements:

Dumbarton Bridge, via Palo Alto, to Skyline Boulevard, Calif.
Santa Ana to San Diego and Fall Brook, Calif. (Releveled.)
San Jose to Santa Margarita, Calif. (Releveled.)
San Francisco to Niles to Oakland, Calif. (Releveled.)
Mina to Battle Mountain, Nev.
Cairo-Hoxie Area (Arkansas, Kentucky, and Tennessee).
Harbor City to Redondo Beach, Calif. (In progress at the end of the year.) (Releveled.)
Long Beach Area, Calif. (In progress at the end of the year.) (Releveled.)

The lines from San Jose to Santa Margarita, Calif., and from San Francisco to Niles to Oakland, Calif., were rerun because of abnormal settlement of San Jose, which may not be attributable to earthquakes.

The first 5 lines in the above list have been fitted to the first-order level net and the results published in mimeographed form. The remaining lines have not been fitted to the first-order net.

TIDAL OBSERVATIONS

The great seismic sea wave resulting from the submarine earthquake originating off the Sanriju coast of Japan on March 2 was recorded on the tide gages at Honolulu, Territory of Hawaii, and at Santa Monica, Calif. Official reports state that 1,560 were killed, 956 missing, and 354 wounded; 2,878 houses were washed away, 1,458 thrown down, and 211 burned. The locally affected territory lay along the northeast coast of the main island centering around Ryori Bay. The waves were 96 feet high at the head of the funnel-shaped bay, 45 feet at Sasu and in proportion elsewhere.

The first wave arrived at Honolulu at 14:35, 157½ meridian time, indicating an average velocity from the origin of 480 miles per hour. At Santa Monica the arrival time was 20:30, 120th meridian time, corresponding to a velocity of 475 miles per hour. At Santa Monica the time is somewhat indefinite due to interference of the seiche movement generally present.

On the Island of Hawaii a wave rising 9½ feet above mean tide was reported from Napoopoo. Further details can be found in the Volcano Letter for March.

No other tidal disturbances of seismological interest were noted on the tidal records of the Bureau.

HYDROGRAPHIC WORK

Vessels of the Bureau are directed to make reports of visible and felt effects of earthquakes. Parties engaged in surveys near Los Angeles submitted reports on the Long Beach earthquake and reference is made to them in the description of that shock elsewhere in this publication.

THE LONG BEACH EARTHQUAKE OF MARCH 10, 1933

This supplements information given in the preceding pages of this publication where the usual practice of abstracting post-card reports was followed. Those pages as well as the strong motion seismograph results following should be consulted for further information which this publication contains on the Long Beach earthquake.

As previously stated the Coast and Geodetic Survey had no party in the field to prepare a detailed report on events in the epicentral area, but such reports have been published by other organizations, and the Bureau is indebted to them for the material which follows. The scientific aspects have been thoroughly covered by H. O. Wood of the Pasadena Seismological Laboratory; the engineering phases by the report of the National Board of Fire Underwriters prepared under the direct supervision of Robert E. Andrews. Of general interest is the description of the shock as reported by Lawrence Daingerfield of the Los Angeles Weather Bureau office; also a statement of Prof. Charles C. Conroy, cooperating with that office on meteorological conditions at the time of the shock. The reports mentioned should be consulted for further details. The object in extracting their more important features is to embody under one cover the essential facts of the earthquake in order that they may always be readily accessible to those who may wish to refer to them in connection with the non-instrumental and the seismographic results of this Bureau.

The following quotations are taken from Mr. Wood's article entitled, "The Long Beach Earthquake of March 10, 1933", appearing in the bulletin of the Seismological Society of America, vol. 23, no. 2, April 1933. The author emphasizes that this is only a preliminary account of the shock.

Foreshocks.—"For several years previously, sporadic shocks, some strong enough to be felt over very small districts, had been registered from sources located at various small distances to the northwest of the origin of the shock on March 10, 1933, most of these in a small region some 16 to 48 kilometers (10 to 30 miles) distant. These had been the subject of speculative discussion, and their occurrence had been brought guardedly to the notice of an official group concerned with measures for public protection in case of disaster, but the shocks were neither frequent enough nor located sufficiently close together to be recognized definitely as foreshocks presaging an earthquake of serious nature. One shock, indeed, felt sharply at and near Huntington Beach at about 1:13 a. m., Pacific standard time, on March 9, 1933, originated very near to the source of the main earthquake. This must now be recognized as a true foreshock.

"Over an interval of several years small changes in level had been noticed in the Los Angeles Harbor district and to the eastward toward Long Beach. These had been the subject of recent surveys of precise levels by the United States Coast and Geodetic Survey, prior to the Long Beach shock.

"Notwithstanding these circumstances, the chief shock came without any clearly indicated warning—indeed with no sufficient suggestion of its imminence."

Epicenter and focal depth.—The "arrival times indicate an origin very near to the point 33° 34′.5 north latitude, 117°59′ west longitude, probably within 5 kilometers and very reasonably within 2 kilometers. As always, the depth of the origin is less certain, but both instrumental and field evidence point to a value shallower than usual, probably about 10 kilometers (6 miles). Should more prolonged study necessitate changes in the position and depth of the origin as given here, the amount of any such correction will be very small. The epicenter thus determined is situated about 5½ kilometers (3½ miles) southwest of Newport Beach, in the general course of a fault zone, commonly called "the Inglewood fault", projected to the southeastward beyond its intersection with the coastline."

Time of origin.—Reported "very nearly 5 h. 54 m. 08 s., P. S. T."

Distribution of intensity.—"The shock was perceptible almost everywhere in the 10 southern counties of California, and at some points farther to the northwest and north in the Coast Range, the San Joaquin Valley, the Sierra Nevada, and Owens Valley. It was felt also in the northern part of Lower California. At several of the more distant places nothing was noticed except the swinging of delicately suspended objects.

"General damage of significant degree—the upper range of grade VII of the modified Mercalli scale of 1931, and higher—was caused in an area bounded by a rudely elliptical curve drawn approximately through Manhattan Beach, Inglewood, Hyde Park, Vernon, Downey, Norwalk, Fullerton, Santa Ana, and Laguna Beach. The longer, northwest-southeast axis of this area may be as much as 70 kilometers (say 45 miles) in length; its shorter northeastward semiaxis is at most 15 to 20 kilometers (say 9 to 12 miles) long. The land area seriously affected may amount to 1,200 square kilometers (say 450 square miles).

"In the aggregate, considerable damage was done outside this area, in isolated districts sporadically distributed. Much of it was of minor nature.

"Inside the area mentioned there are many places where significant damage was not conspicuous—on hilly ground or where underground conditions were not unfavorable and construction not too bad or unsuitable. This was noticeably the case on the compact sedimentary rock of the San Pedro Hills west of Long Beach. In fact, a considerable part of the area appeared to be characterized by intensity lower than grade VII of the 1931 scale. Even in the most vigorously shaken areas excellent construction on well-chosen or well-prepared foundations suffered relatively little, even at Compton where the proportion of damaged structures was greatest and the scene of destruction the most spectacular. Many chimneys remained standing in districts where general damage was conspicuous; but in a hurried survey there was not time to ascertain whether these were wholly undamaged.

"Thus it is obvious, as on previous occasions, that much of the spectacular structural damage was due (1) to bad natural ground or grading—made land, or deep water-soaked alluvium or sand; and (2) to bad or unsuitably designed construction—bad foundation structures, little or no provision against the stresses caused by earthquakes, bad or unsuitable materials, bad workmanship, or some combination of these factors. These unfavorable conditions appear to have been more prevalent than usual. Serious structural damage resulted at many places well distributed throughout the area outlined. It was markedly greater in business districts than in the surrounding or adjoining residential districts. While the total amount of damage was large, there is good evidence from numerous well-distributed structures which survived the shock with little or no obvious injury, and from the sparseness of minor geological evidence of hard shaking, that the intensity or violence of the shaking was no greater than is usual in strong local shocks. Also the duration of the hard shaking was short. More than usual this earthquake 'picked on the cripples.' The nature and amount of the structural damage were out of proportion to the energy and violence of the shock.

"Notwithstanding the foregoing statement, there was vigorous shaking for a short time, 10 or 15, or doubtfully 20 seconds, over much of the area in which damage occurred. Intensity low in the range of grade IX, 1931 scale, may possibly have been manifested in a few places, but this is doubtful. 'Apparent' intensity of this value was manifested in a number of places on exceptionally bad ground, where the intrinsic intensity as shown on good ground nearby was substantially less. Details of intensity distribution must be left to a more extended report."

Direction of vibration.—"Details as to direction of vibration, or of movement or fall of objects, must be left for more extended reports. Shifting and fall of objects in many different directions have been reported from different places. In Long Beach, however, there was a fairly general tendency for houses to topple on unbraced foundation posts in a direction a little east of north, with a much smaller number down in a direction opposite to this. Also this general direction of motion appears to have affected a considerable area to the northwest of Newport Beach. Elsewhere, especially at greater distances, other directions prevailed. In some small districts objects fell in many diverse directions."

Faulting.—"No fresh movement of faulting extending to the surface has been observed anywhere on this occasion. This is not surprising, in view of the relatively small area visited by the harder shaking, the absence of any area consistently affected by intensity of grade IX, 1931 scale, or higher values, and the submarine location of the epicentral tract.

"There are a few sparsely distributed cracks in the ground in the wet, alluviated bottom land of the Los Angeles plain, 1 or 2 of which exceed a kilometer (0.6 mile) in length. These are diverse in direction and appear to be, without doubt, simply secondary cracks in magnitude. Their development is less marked than frequently happens with shocks of comparable intensity and size. To guard against misunderstanding, however, it should be stated that some of these cracks follow directions approximately parallel to the Inglewood fault zone, and other recognized faults, but it is clear that they do not mark, or follow, the surface outcrop of known or suspected faults.

"Along the shore between Long Beach and Newport Beach, and in a few localities nearby a short distance inland, road fills across marshy land, and similar earth construction resting on wet sand or mud, settled, shook apart, or moved laterally, causing considerable damage to the concrete highway surfaces, and to the approaches to highway bridges, which, being better founded, were less affected.

Analogous phenomena were observed where piers and landings adjoin the shore. In a few places elsewhere the roadway was buckled.

"A few small landslides and falls of earth and loose rock material in small amounts from artificial embankments, road cuttings, and steep cliffs took place. Effects of this kind were too few and too small in size to be characteristic of the shock."

Disturbance of underground water.—"In various places water was ejected from cracks formed by the shock, in numerous instances charged with sand or mud. 'Craterlets' were formed in some such cases. The area most markedly affected by the extrusion of water lies west of Santa Ana and north and northwest of Newport Beach and Huntington Beach. However, various other areas of water-soaked ground, such as the vicinity of Compton, exhibited such effects, and they also occurred in some places where the ground is not obviously heavily charged with water.

"In numerous instances the flow of springs and wells was affected, for the most part a temporary increase in flow. In many wells the water stood at a higher level for a time. In other wells the water level oscillated at the time of the shock through considerable amplitudes. This phenomenon occurred in many wells distributed over a large area.

"In a few cases the temperature of springs and ejected water was increased noticeably. In cultivated fields in the strongly shaken area water flowed from newly opened cracks, where water was not previously found near to the surface. Most of these disturbances to ground water were found in the deeply alluviated Los Angeles plain, chiefly in the more violently shaken region."

Visible waves.—"As usual, visible waves traveling along the surface were reported by many observers, and waving motions of trees, buildings, and other tall slender structures. In many instances the objective reality of the phenomena reported is questionable, as on previous occasions. However, other reports describe effects which are reasonable. The extent to which such action is real, and the part played by the unconscious motion of the observer, remains uncertain."

Sounds.—"The chief shock was preceded, accompanied, and followed by sound—a low, deep-toned grave noise, variously described, most commonly as roaring. In some localities this appears to have been very loud. Such sound was also observed generally with the occurrence of many aftershocks."

Tidal wave.—"There are no reliable reports of any conspicuous disturbance of the sea. Some disturbance in the near neighborhood of the origin must have occurred, but nothing of moment happened. Notwithstanding radio announcements and rumors, there was no 'tidal wave' so-called."

Aftershocks.—The article lists some of the stronger aftershocks numbering 34 on the 10th, 30 on the 11th, 5 on the 12th, 3 on the 13th, 4 on the 14th, and 1 each on the 15th and 16th.

"From the foregoing it may be noted that none of the aftershocks was comparable in size and strength with the main shock, despite alarm and subsequent damage to injured structures. At Pasadena the largest aftershocks were registered with amplitudes of about one twenty-fifth that of the main shock. Determination of the shock acceleration for these and for the main shock will require refined study."

"* * *. All told, those already recorded [up to May 10, 1933.—Ed.] instrumentally number some thousands. Complete listing of all recorded is an impossibility, since the records of the more sensitive seismometers at Pasadena show nearly continuous seismic motion for many hours after the main shock."

The following extracts are from the report of the National Board of Fire Underwriters entitled, "Report of the Southern California Earthquake of March 10, 1933." The aim has been to limit them to statements of broad and general nature rather than repeat the details which make the original report so valuable to the underwriter and structural engineer. The material which follows is practically word-for-word quotation but has been condensed in such manner that smooth reading would suffer considerably if quotations, omissions, and minor changes were all indicated, and it is for this reason that the simpler form is adopted. For copies of the report itself, the reader should address the home office of the National Board of Fire Underwriters, at 85 John Street, New York, N. Y.

Loss of life.—The number of deaths is placed at 120, which does not include those who died of heart disease or from exposure or over-exertion subsequent to the earthquake. Few persons were killed inside buildings. Probably two-thirds of the loss of life was occasioned by persons being struck by falling cornices, parapets, and ornaments as they tried to escape from shaking buildings. There is abundant evidence to show the futility of trying to escape while such a barrage is in progress. That the loss of life was so small is partly due to the fortunate hour at which the earthquake occurred; had it come 3 hours earlier, when the schools were in session, the dead would have been numbered by thousands. Fortunate, too, for the comfort of the thousands of persons obliged to live in the open for several days was the mildness of the weather.

Property loss.—Total property loss in the shaken area was of the order of $40,000,000 including cost of repairs.

A conflagration in Long Beach was prevented by the following: The fire department received notification of fires by telephone, messenger, or direct discovery, although more or less delayed, in time to extinguish them before they could reach serious proportions; dangerous fires occurred in districts where the water supply was not seriously weakened; no fires occurred in the principal mercantile, beach, or industrial districts; and there was little or no wind.

Topography and fault lines.—The area affected is entirely in the coastal plain of southern California, which slopes gently from the mountains and hills southwesterly to the Pacific Ocean, a distance of 15 to 20 miles. In a northwest-southeast direction the plain is 45 miles long. It is drained by the Los Angeles, San Gabriel, and Santa Ana Rivers, the three largest streams in southern California. Along the coast, there are salt marshes and sand wastes, the latter in places extending 2 or 3 miles inland. The coastal plain is composed of unconsolidated beds of gravel, sand, and clay, these materials having been brought down by the streams and deposited, partly in shallow water near the coast and partly on land.

The regular seaward slope of the coastal plain is interrupted by a long line of hills, 200 to 400 feet high.

Structural features.—The cities of Compton, Long Beach, and Huntington Park, and the smaller towns between them suffered more severely than other communities. These cities are located near the present course of the Los Angeles River, largely on soft material approaching swampy character in some locations. Compton and vicinity are on soft alluvial fill, probably well saturated; a large part of Long Beach proper is on firmer ground sloping toward the ocean from Signal Hill, but the fault line supposedly causing the disturbance passes directly through the city.

Many examples of building failures occurred. The lessons learned are not new: The same structural weakness and failures were exemplified in previous earthquakes in this and other regions.

Ordinary masonry.—There was total collapse of some ordinary masonry buildings with wooden floors and serious damage to others due partly to faulty design and an inferior grade of workmanship. Few in the shaken area have basements, and foundations are not carried down to any great depth. The greatest damage was to fronts and parapet walls Ordinary brick buildings in the Compton area suffered severe damage.

School buildings throughout the shaken area suffered more than any other class of buildings. Passageways and exits were often piled high with debris due to toppling of architectural oranments, towers, copings, etc. Many of these buildings were of brick-and-tile construction. Buildings with pronounced architectural effects were damaged much more severely than those of plainer design and more regular shape.

The report stresses that mortar used was frequently of low grade and in some cases of wretched quality. Not only that, but the actual laying of brick was sometimes of indifferent standard, with vertical joints especially slighted. In some walls that collapsed the brick fell out practically clean.

Steel-frame fireproof.—The majority of such buildings had brick or panel walls and often tile partitions. Owing to distortion of the unbraced flexible frames, panel walls were quite generally loosened and the bond between framing and walls broken, but walls were not shaken out except in a few instances. Distortion of frames was in general not sufficient to cause the diagonal cracking of panels which is characteristic in a severe shock. Damage to partitions or enclosure walls around stairways and elevator shafts of steel-frame buildings was very noticeable.

Reinforced-concrete frame.—Response of this type of building was analogous to those with steel frames. Panel walls of brick and tile were cracked and loosened, the latter occurring even in the downtown areas of Los Angeles, where the shock was not severe. Fracture of first-story concrete columns at top and bottom was quite marked. Failures of reinforced concrete were frequently at construction joints or cold joints where a day's pouring of concrete stopped and surfaces had not been cleaned.

More structural failures occurred in columns supporting heavy concentrated loads such as water tanks than in building columns. Reinforced concrete buildings with filler walls of the same material survived the shock with less damage.

General.—Buildings which embodied more than one type of construction showed great variation in the amount of damage, depending upon care taken in design and soundness of construction, but few general conclusions can be drawn. Well constructed modern theaters with partial steel or reinforced concrete frames appeared to withstand the shock with only moderate damage and in some cases with none at all. Reinforced concrete courses at floor levels in brick walls appeared to be an advantage. Some battering together of tall buildings was evident in the spalling and breaking of contact corners.

Well-built frame buildings on good foundations withstood the shock very well, even in the badly shaken areas. Some instances occurred where houses were moved bodily off their foundations, but there is every reason to believe that bolting of mudsills to foundations would have eliminated this difficulty. Nothing like a wholesale wrecking occurred in residential buildings in any locality. A common source of structural damage to frame buildings was the buckling of underpinning which was not sufficiently braced, dropping the building so that the first floor rested on the ground. A striking commentary is the good behavior of frame stucco dwellings and apartment houses near the Long Beach Polytechnic High School.

Thousands of brick chimneys were thrown down, fractures generally occurring at the roof line but numerous examples exist of chimneys of apparently unstable dimensions still standing, perhaps by reason of a superior grade of masonry. Tile roofs suffered little damage, indicating that the ordinary methods of fastening roof tiles are sufficient.

Measures taken to reduce future damage.—Practically all the cities and towns in the area affected, as well as the two counties, adopted building legislation intended to prevent the rebuilding of damaged structures in the same manner they were originally built. These, without establishing broad principles of design, demanded better details of construction.

Oil properties.—Modern methods of storing and handling petroleum products were subjected to a severe test by the earthquake. In the Los Angeles Basin is the largest concentration of oil storage in the world, about 75,000,000 barrels being now in storage, and 60 percent of this lies within the area which was severely shaken. The tank farms and refineries at Watson Station are very close to the line of the Inglewood fault, and in addition are on soft swampy ground on which a maximum of damage would normally be expected. In spite of these unfavorable conditions, the loss to oil properties was a very slight percentage of the total investment in this industry.

The chief damage to the oil industry resulted from breakage of piping and pipe connections, especially where rigid connections are made to tanks. Tanks themselves, when well constructed, suffer very little. Much of the trouble could be avoided by providing a reasonable degree of flexibility in piping connections.

The experience of the oil industry in this earthquake was far different from that which past history would lead us to expect. In the Tokyo quake of 1923, practically all oil tankage was destroyed, tank connections were broken, the oil ignited and spread over a large area in the adjacent harbor.

Water supply.—The water systems supplying Santa Monica, Glendale, Pasadena, Alhambra, Pomona, and the major part of Los Angeles were unharmed. Systems supplying Huntington Park and Santa Ana received only slight damage. Long Beach and the harbor district of Los Angeles were kept in water with great difficulty.

At Long Beach the most serious trouble was caused by leakage from numerous breaks in distributing mains ranging in size from 4 to 12

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inches. The three pumping stations which supply the distribution system were placed out of service by the first shock, leaving only elevated storage to supply the demand.

The Alamitos reservoir was replaced in 1931 with 6 steel tanks designed to withstand strong earthquake shocks and having a total capacity slightly in excess of 20,000,000 gallons. At the time of the earthquake they were about two-thirds full. They were undamaged, although the ground on which they rested was badly shaken and cracked.

The water department reports 127 breaks in distributing mains, not counting places at which pipes were pulled apart. In addition there were numerous breaks in Seal Beach, a small community to the southeast which is supplied by the Long Beach system, and it was out of water several days. Breaks were dependent on the character of soil, all occurring in sand, silt or filled ground, and none being reported in firm adobe. The widening of the sandy spit between Alamitos Bay and the ocean caused pipes to pull apart at many places so that in making repairs it was frequently necessary to install an extra 4 feet of pipe.

The 12-inch main under the channel was pulled apart 3½ inches on Mormon Island and 4 inches on Terminal Island; there were also 21 leaks in the under water portion of the main, as determined by air pumped into it. The 16-inch main under the channel was found to be intact.

Wells.—At the time of inspection, no well casings were reported to have been thrown out of line or otherwise damaged. Just after the main shock water overflowed shallow wells driven near the Santa Ana River about 4 miles from its mouth; on the following day the water level was found to be 5 feet higher than before the shock.

Steel tanks at ground level.—The Western Avenue tank of the Los Angeles Water Department is the most striking example of complete destruction suffered by any water-supply structure. It was built in 1917 on a slight knoll in a sparsely settled district 7½ miles southwest of the congested value district. It survived the Inglewood earthquake of 1920 with only nominal damage, although it was only three-fourths of a mile from the fault line.

There was considerable distortion under wind action, and as the location was exposed to frequent and prolonged high winds, the weaving of the metal through 16 years may have induced fatigue.

At the time of the earthquake there were between 5,000,000 and 6,000,000 gallons of water in the tank. So violent were the forces wrecking the tank, that it appears almost as if an explosion had taken place. Portions of the shell were transported as much as 200 feet from their original positions, generally in a southwest direction. Undoubtedly wave action played an important part, the wave period probably synchronizing with the earthquake period and gradually building up an enormous force.

The Long Beach tanks, which were undamaged, were of smaller size, and had less than half the capacity. They had no concrete base, but rested directly on oiled sand, particular pains having been taken to make the foundation homogeneous by removing the adobe top layer.

At least six smaller water tanks at various locations had trouble with the anchor bolts securing them to concrete foundations. These bolts were either bent, broken or pulled out of the base or had the plates holding them buckled or ruptured. Several of these tanks were only moderately shaken.

Elevated tanks.—Twenty-five elevated steel tanks on steel legs were used for municipal water supply in the area affected. Two collapsed and two others were placed out of service because of broken risers. Practically all steel towers had tie rods stretched or snapped, the destruction being most general in the top panel. A number of large steel tanks for automatic sprinkler supply behaved in the same manner.

All elevated steel tanks placed out of service by the earthquake were of hemispherical bottom type with small riser. Although tanks of this type were by far the more numerous, a considerable number, used both for municipal service and for sprinkler supply, had ellipsoidal bottom and large riser, and came through the earthquake without material damage.

So far as known, the only elevated steel tank actually designed for earthquake resistance is a 75,000-gallon tank for sprinkler supply near the waterfront in Long Beach. It survived the earthquake in perfect condition, not even the tie rods needing adjustment, and fully justified the slight additional cost of the safe construction.

Of about 25 wooden tanks on wooden towers, nearly a third were destroyed. Many were old and the wood had been weakened through the effect of age. In several instances, tanks were insecurely fastened to platforms, were thrown off center by the shaking, and finally toppled over. Inadequate tower bracing was a contributing factor in several failures.

Gas service.—Broken gas services and devices caused 7 of the 19 fires reported in Long Beach during the night of March 10. Prompt closing of valves, together with a major break in a high-pressure main, undoubtedly prevented fires in numerous locations in the business district. Preparedness for seismic disturbance is of very great importance in connection with gas service.

Light and power service.—The earthquake has shown power companies the necessity for improved station construction and installation of generators and connected equipment, and has called attention to the vital importance of maintaining power to water supply pumps and the desirability of street illumination.

Telephone service.—Automatic operation of telephones with its selective handling of emergency calls has proven to be a more successful method of transmitting fire alarms, first aid, and police calls, in the event of disaster than the manual method. In addition to the obvious need of properly constructed buildings, design of equipment should be ample to transmit the full capacity of connected lines and trunks without danger to apparatus.

The failure of telephone toll lines connecting Long Beach with other cities indicates the necessity of listing for use all private communicating systems, such as those of power and gas corporation, telephone systems, etc., so that aid may be summoned from other cities with a minimum of delay.

The following paragraphs are quoted from a report prepared by Lawrence Daingerfield, in charge of the local office of the United States Weather Bureau at Los Angeles. This information coming from one long experienced in the observation of natural phenomena may be taken as typical of the earthquake's effects in the business section of Los Angeles.

"The pendulum of the Seth Thomas clock on the east-southeast wall, office of the Weather Bureau, eighth floor of the Central Building, Sixth and Main Streets, Los Angeles, stopped at 5:54:53, or 7 seconds before 5:55 p. m., March 10, 1933, due to the extremely violent swinging of the building. This must have been very shortly after the onset of the shock, which began with sharp vertical or upthrusting movements. The dominant vertical movements persisted for 15 to 20 seconds, followed by a brief trembling period, to be followed immediately by violent rocking or swaying motion, southeast to northwest, for an additional period of at least 20 seconds. The office ceiling light chandeliers are swung on 3-foot cords. These lights swung from east-southeast to west-northwest, almost touching the ceiling at each end of the vibration. The building manager stated that the water tank on the roof was probably filled to between 2 and 3 feet of the top; the roof vibration was sufficient to throw large quantities of water out of tank and on the roof. A party who was standing near the alley on the west-northwest side of the building, which has a well-constructed steel frame and is 150 feet in height, noted that it swayed violently and seemed to tremble with the wall, becoming somewhat undulated like waves running from the alley to the coping of the building. Mark H. Stanley, observer on duty in the Weather Bureau office at the time of the shock, states that the building shook and swung with great violence, hurling the several office doors open and shut, and making it impossible for him to stand on his feet except by holding to some fixed object.

"The writer was home at the time, having just arrived from the office, and was on the fourth floor (or top floor) of the Glen-Donald Apartments, 2121 West Ninth, a little over 2 miles west of the Weather Bureau office. The shock was of the same nature and apparent intensity as at the office. The severe bumping, due to the vertical component, was noted at the onset of the shock, supplemented by the violent rocking or swaying east-southeast to west-northwest motion, during which time considerable bumping persisted. Furniture moved, bric-a-brac and some pictures fell to the floor, some cracks appeared in the ceiling and side walls, and the main chimney was so badly twisted and broken in the topmost 6 feet that it had to be taken down and rebuilt. Many of the tenants of the Glen-Donald were panic-stricken.

"It is believed that intensity VIII, Rossi-Forel scale, prevailed in most of the business section of Los Angeles, gradually increasing to IX in the south portion of the city. Some of the older brick buildings in the area were rendered untenantable, some even being thrown down by the first and most violent shock."

The weather on the day of the earthquake has been made the subject of an interesting report by Prof. Charles C. Conroy, cooperating with the Weather Bureau office at Los Angeles.

"In view of the widespread popular belief that earthquakes are associated with a certain type of close, sultry weather, a detailed account of meteorological conditions at Los Angeles on March 10 and 11 will not be without interest. The attached maps show the distribution of pressure over California and adjacent regions on both mornings, and on the evening of the 10th, an hour before the earthquake. During the day, which was somewhat hazy, there had been a considerable movement of cirro-stratus and alto-stratus cloud from the west. In the late afternoon the air was filled with a peculiar bluish haze, resembling a veil of smoke. At 4:30 p. m. the writer called the attention of Mark H. Stanley, of the Weather Bureau, to this phenomenon. At 4:45 p. m. a sheet of alto-stratus cloud moved up rapidly from the west, and at 5:10 p. m. had entirely covered the sky. This cloud sheet persisted, but thinned gradually after 6:45 p. m., and the moon shone through with increasing brightness in the evening. At the writer's residence light fog began at 9:15 p. m., became dense at 11, and dissipated between 1 and 2 a. m. on March 11.

"Alto-stratus cloud, moving from the southwest, continued through the rest of the night and into the early morning hours. When it began to disappear, after 8 a. m. on March 11, cirrus clouds, moving also from the southwest, were seen behind it. Shortly after noon small alto-cumulus clouds from the south began to appear, and at 2 p. m. had spread over two-tenths of the sky. Above these were large patches of cirro-stratus, moving from the southwest, and filling perhaps four-tenths of the sky. At 3 p. m. the alto-cumulus clouds had withdrawn to the east, and a veil of alto-stratus was rising from the southwest, whilst overhead cirro-stratus was still abundant. Alto-cumulus prevailed during the rest of the afternoon, the latter clouds disappearing soon after sunset. In the evening the moon again shone through a thin sheet of alto-stratus. It may be added that the movement of all types of cloud in the afternoon was rather rapid. At the same time the barometer was appreciably unsteady, though the changes were very small.

"The relative humidity on the 10th was a little high, but on the 11th it was below normal. The maximum temperature on the 10th was 70° at 1:30 p. m. At the time of the first shock the temperature was 58°, and it fell very slowly during the night. As a matter of interest, tables of hourly temperature and pressure, the latter reduced to sea level, have been prepared. These statistics are taken from the traces of the self-recording instruments of the United States Weather Bureau in Los Angeles."

SEISMOLOGICAL OBSERVATORY RESULTS

The Coast and Geodetic Survey publishes the results of its teleseismic stations and cooperating stations monthly in mimeographed form. In these reports all seismogram interpretations are tabulated together with epicenters based on the published data and instrumental results received from seismological stations in all parts of the world. These reports will be furnished upon request to the Director of the Bureau. In the summary of epicenters in this report attempts are sometimes made to improve epicenters already published, especially in the case of those in North America.

Instrumental results are published for the following observatories:

Balboa, C. Z. (The Panama Canal).
Bozeman, Mont. (Montana State College).
Charlottesville, Va. (University of Virginia).
Chicago, Ill. (University of Chicago and U. S. Weather Bureau).
Columbia, S. C. (University of South Carolina).
Honolulu, T. H. (University of Hawaii).
Huancayo, Peru (Carnegie Institution of Washington).
Montezuma, Chile (Smithsonian Institution).
Pittsburgh, Pa. (University of Pittsburgh).
San Juan, P. R.
Seattle, Wash. (University of Washington).
Sitka, Alaska.
Technology, Maine (Massachusetts Institute of Technology).
Tucson, Ariz.
Ukiah, Calif. (International Latitude Observatory).

Honolulu, San Juan, Sitka, Tucson, and Ukiah are Coast and Geodetic Survey stations; Bozeman, Chicago, and Columbia are cooperative stations; Balboa, Charlottesville, Huancayo, Montezuma, Pittsburgh, Seattle, and Technology are independent stations. All readings are made or revised at the Washington office of the Coast and Geodetic Survey except those for Balboa.

Summary of instrumental epicenters

1933	Greenwich civil time at origin		Region	Provisional epicenter	
				Lat.	Long.
	h	m		°	°
Jan. 1	8	48.7	New Hebrides Islands	16 S.	166 E.
Jan. 4	1	24.8	Pacific Ocean, south of Japan	26 N.	143 E.
Do	3	59.6	Destructive at Seward, Alaska	61 N.	147 W.
Do	21	10.8	Pacific Ocean off Lower California. Epicenter by Pasadena.	28 N.	126 W.
Jan. 7	4	06.6	Off northern Japan	40 N.	143 E.
Jan. 12	1	17.8	Off west coast of Nicaragua	10 N.	87 W.
Jan. 15	18	02.0	New Guinea. Approximately	5 S.	147 E.
Jan. 21	19	21.2	Indian Ocean, southeast of Madagascar	34 S.	58 E.
Jan. 24	15	39.1	Felt in Michoacan, Mexico. Approximately	18 N.	102 W.
Jan. 27	22	36.7	Felt in Samoa	16 S.	171 W.
Feb. 3	22	11.8	Pacific Ocean near Japan. Epicenter by Florissant.	46 N.	151 E.
Feb. 18	19	45.6	Honduras	15 N.	86 W.
Feb. 19	8	34.7	Near Solomon Islands	11 S.	163 E.
Feb. 23	8	09.3	Damage at Iquique, Chile	20.7 S.	70.2 W.
Mar. 2	17	31.0	Major submarine disturbance—loss of life and property in northern Japan due largely to seismic sea wave.	39 N.	144 E.
Do	9	12.7	Aftershock of Mar. 2	39 N.	144 E.
Mar. 11	1	54.1	Destructive at Long Beach, Calif. Epicenter by Pasadena.	33.6 N.	118.0 W.
Do	14	22.1	Off northern Japan	42 N.	148 E.
Do	19	32.7	Pacific Ocean, south of Japan	27 N.	140 E.
Mar. 14	1	19.5	Aegean Sea	37 N.	26 E.
Mar. 17	15	55.5	Kamchatka	56 N.	160 E.
Do	19	32.5	Near Philippine Islands. Epicenter by Manila	6.5 N.	128 E.
Mar. 18	3	05.3	South Atlantic Ocean	63 S.	16 W.
Do	23	32.5	Honduras	14 N.	87 W.
Apr. 9	2	46.7	Off east coast of Japan	39 N.	143 E.
Do	3	58.2	Off west coast of Mexico	18 N.	105 W.
Do	21	03.7	do	19 N.	106 W.
Apr. 16	6	00.1	Northeast of New Zealand	34 S.	176 W.
Do	19	16.6	New Guinea	3 S.	139 E.
Apr. 19	1	45.8	South Pacific Ocean	52 S.	118 W.
Do	6	44.7	Off coast of China	24 N.	123 E.
Apr. 23	5	57.6	Destructive on the Island of Kos, off Asia Minor. Epicenter by Strasbourg.	36.5 N.	26.5 E.
Do	7	13.9	Off east coast of Japan	40 N.	144 E.
Apr. 27	2	36.1	Felt at Anchorage, Alaska	62 N.	151 W.
Do	11	56.1	Near Alaska Peninsula	55 N.	166 W.
May 1	18	49.9	Aleutian Islands	52 N.	173 W.
May 6	5	33.6	Off west coast of Panama	6 N.	83 W.
Do	20	30.4	do	6 N.	83 W.
May 8	10	33.8	Destructive in Mexico	17 N.	101 W.
Do	18	01.1	do	17 N.	103 W.
May 11	19	09.6	Aegean Sea. Felt in Bulgaria. Epicenter by Strasbourg.	40 N.	24 E.
May 16	1	12.5	Off northern Sumatra	7 N.	97 E.
Do	11	45.3	Felt in San Francisco and vicinity	38 N.	122 W.
May 19	17	58.0	Atlantic Ocean, off Liberia	2 S.	15 W.
May 20	4	39.0	Felt at Apia, Samoa. Approximately	19 S.	171 W.
May 30	11	43.6	Off west coast of Panama	8 N.	83 W.
June 2	7	38.4	Off southern Japan	31 N.	135 E.
June 6	2	28.8	Felt in Manila, P. I. Epicenter by Manila	14.3 N.	121.6 E.
June 7	11	46.7	South China. Epicenter by Chiufeng	25.2 N.	101.9 E.
June 8	18	10.7	Off northern Japan	40 N.	144 E.
June 10	11	26.9	Coast of Honduras	16 N.	86 W.
Do	12	06.7	Near Iceland	65 N.	25 W.
June 12	15	23.4	Felt at Seward, Alaska. Approximately	61 N.	155 W.
June 13	14	24.2	Off Oaxaca, Mexico. Approximately	15 N.	97 W.
Do	20	33.7	East of Japan	40 N.	144 E.
Do	22	19.9	Felt at Seward, Alaska	61 N.	150 W.
June 18	3	54.1	Felt at Apia, Samoa	15 S.	172 W.
Do	21	37.7	Japan	38 N.	142 E.
June 19	18	47.8	Felt in Alaska	60 N.	150 W.
June 24	21	54.6	Destructive in south Sumatra, according to Batavia	5.0 S.	104.2 E.
June 25	20	45.5	Damage in western Nevada	39.0 N.	119.3 W.
June 28	23	35.0	Alaska Peninsula	53 N.	165 W.
June 29	2	32.7	Alaska Peninsula, according to St. Louis. Probably	53 N.	163 W.
July 9	1	30.0	Off northern Japan	45 N.	150 E.
Do	5	34.3	Off west coast of Mexico	17 N.	105 W.
Do	9	28.1	Off northern Japan	45 N.	151 E.
Do	12	30.7	do	44.5 N.	150 E.
Do	16	07.1	do	45 N.	151 E.
July 10	0	21.6	do	39 N.	145 E.
Do	3	21.8	Off west coast of Mexico	16 N.	105 W.
Do	10	33.2	Near New Guinea	6 S.	133 E.

Summary of instrumental epicenters—Continued

1933	Greenwich civil time at origin		Region	Provisional epicenter	
				Lat.	Long.
	h	*m*		°	°
July 19	5	06.6	Off coast of Oregon	43 N.	128 W.
Do	10	45.5	Aleutian Islands	52 N.	175 W.
Do	13	32.4	do	51 N.	175 W.
Do	15	00.0	do	52 N.	174 W.
July 21	20	07.0	South Atlantic Ocean	56 S.	26 W.
July 22	20	55.3	Aleutian Islands	53 N.	169 W.
July 23	4	13.2	Coast of Peru	16 S.	75 W.
July 24	18	55.7	Samoa Islands. Felt	15 S.	170 W.
July 31	15	22.5	Off coast of Peru. Approximately	17 S.	78 W.
Aug. 5	0	44.2	Solomon Islands	9 S.	158 E.
Aug. 7	3	02.7	Off west coast of Mexico	13 N.	98 W.
Aug. 11	8	53.7	Burma. Approximately	24 N.	95 E.
Aug. 13	9	28.1	Indian Ocean, near Madagascar. Approximately	27 S.	54 E.
Aug. 15	2	57.8	Pacific Ocean, near Japan	29 N.	144 E.
Aug. 20	11	45.3	Felt in Philippine Islands. Epicenter by Manila	13.6 N.	124.8 E.
Aug. 25	7	50.5	Destruction in Szechwan, China	32 N.	103 E.
Aug. 28	22	19.6	South Atlantic Ocean. Approximately	59 S.	24 W.
Do	14	52.7	Western Brazil	7 S.	72.5 W.
Aug. 31	2	51.6	Felt at Haines, Alaska	60 N.	137 W.
Sept. 2	16	41.3	South of Japan, according to Tokyo	30.8 N.	139.3 E.
Sept. 6	22	08.5	Pacific Ocean, near Fiji Islands	22 S.	179 W.
Sept. 9	21	19.9	Queen Charlotte Islands	13 S.	167 E.
Sept. 19	23	39.9	Felt at Anchorage, Alaska. Approximately	58 N.	137 W.
Sept. 24	15	19.6	Aleutian Islands	51.5 N.	176 W.
Sept. 25	18	51.2	China	38 N.	85 E.
Sept. 28	11	52.6	Off coast of California	41 N.	126 W.
Sept. 30	14	21.1	New Guinea	2 S.	140 E.
Oct. 1	2	40.6	Peru	7 S.	75 W.
Oct. 2	9	10.3	Minor damage at Los Angeles, Calif. Epicenter by Pasadena.	33.8 N.	118.1 W.
Do	15	29.4	Felt at Guayaquil, Ecuador	2 S.	81 W.
Oct. 3	10	21.3	Ecuador	2 S.	81 W.
Do	14	21.9	do	2 S.	81 W.
Oct. 10	3	34.1	Felt at Montezuma, Chile. Epicenter, by La Paz, is in Argentina.	22.7 S.	66.8 W.
Oct. 12	7	12.7	Chile	23 S.	70 W.
Oct. 14	22	19.1	Near Alaska Peninsula	53 N.	162 W.
Oct. 17	13	33.5	Off west coast of Central America	11 N.	95 W.
Oct. 25	23	28.3	Argentina. Felt over large part of Chile	23 S.	65 W.
Oct. 27	10	58.9	Felt at Ione, Nev	38.9 N.	117.6 W.
Oct. 30	6	59.7	Near New Hebrides. Approximately	15 S.	167 E.
Nov. 2	12	27.0	Aleutian Islands	52 N.	176 W.
Nov. 3	4	14.4	Coast of Chile. Approximately	23 S.	71 W.
Nov. 4	8	41.3	Venezuela. Felt in Colombia, South America. Approximately.	9 N.	72 W.
Do	11	57.2	Venezuela. Approximately	8 N.	72 W.
Nov. 5	7	11.9	Off Ecuador coast. Approximately	0 S.	83 W.
Nov. 14	14	05.2	Felt in Argentina and Chile	33 S.	70 W.
Nov. 19	3	11.3	New Hebrides Islands	16 S.	167 E.
Nov. 20	23	21.5	Baffin Bay	73 N.	69 W.
Nov. 21	23	48.5	Felt in Panama. Approximately	8 N.	83 W.
Nov. 22	4	52.0	do	9 N.	82 W.
Do	12	42.4	Near New Guinea	6 S.	150 E.
Nov. 23	18	57.7	Felt in Panama	8 N.	84 W.
Nov. 29	5	03.2	Off west coast of Panama	8 N.	84 W.
Dec. 2	5	17.2	Pacific Ocean, near New Zealand	53 S.	161 E.
Dec. 4	19	33.9	Northern Japan	47 N.	144 E.
Dec. 12	14	11.3	Near New Guinea. Felt at Rabaul, New Britain Islands, East Indies.	5 S.	151 E.
Dec. 13	21	23.7	Felt at Guadalajara, Mexico	19 N.	104 W.
Dec. 14	7	16.7	West coast of Mexico	19 N.	104 W.
Dec. 15	7	42.2	North Atlantic Ocean. Approximately	56 N.	34 W.

STRONG-MOTION SEISMOGRAPH RESULTS

INTRODUCTION

During the latter part of 1932 the Coast and Geodetic Survey inaugurated a program of recording strong ground movements in the seismically active regions of the country to furnish engineers and architects with requisite data for designing structures to resist earthquake forces. This required the development of special instruments designed to operate automatically whenever a strong earthquake occurred. In the fall of 1934 about 35 assemblies were in operation, most of them in California. They have been distributed mostly in the Los Angeles and San Francisco Bay regions in structures selected for special study by local engineers.

Instruments.—Three types of seismometers were developed in addition to automatic starters and recording apparatus. The plan was to operate separate instruments for recording acceleration and displacement, and in addition an instrument of intermediate type. The instruments eventually developed are known as accelerographs, displacement meters and Weed strong-motion seismographs. Automatic recording is essential as the cost of continuous operation would be prohibitive because of the high paper speeds necessary, and the infrequency of strong shocks.

The Wenner accelerometer was developed by Dr. Frank Wenner of the National Bureau of Standards, but modifications were made by H. E. McComb of the Coast and Geodetic Survey as a result of extended experience with them. The original instrument is primarily a torsion seismometer in which four strands of wire are used instead of one to reduce the violin-string type of vibration. The torsion element, which is about 4 inches long, carries a 1-gm mass which is essentially a rectangular loop of copper approximately 3 cm in height, and 1 cm in length, the latter dimension representing roughly the length of pendulum. It oscillates between the poles of a strong cobalt steel circular magnet 4 inches in diameter with pole pieces especially designed to make the moving element cut a highly concentrated magnetic field normal to the lines of force. The normal constants are: Period, 0.10 sec.; sensitivity to acceleration, 2½ or 3 cm=0.1 gravity; static magnification, 110; damping ratio, about 1:01.

In later models the quadrifilar suspension is replaced by a thin shaft rotating on pivots and jeweled bearings, the actuating force being a helical spring. The instrumental constants are practically the same as for the quadrifilar. All accelerographs consist of two horizontal components and one vertical, together with self-starter and recording apparatus, the entire unit being enclosed in a lightproof case.

The automatic recorders for the accelerographs and displacement meters were developed at the Coast and Geodetic Survey under the direction of D. L. Parkhurst and H. E. McComb. Time marks are registered every half second, and on later models provision is made

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for synchronous marks on installations in the same building or nearby. Recording is photographic with paper speed varying between 5 and 10 millimeters per second.

The displacement meter was designed at the Coast and Geodetic Survey to fulfill the need for an instrument that would record the ground displacements of a destructive shock. It was believed at the time that a moderately long pendulum of 10-seconds period and unit magnification would answer this requirement. This design functions satisfactorily for earth wave periods up to 3 or 4 seconds, but beyond that range the term displacement meter is not appropriate. It has since been learned that long amplitude waves with periods as high as 15 seconds and over exist in epicentral regions.

The displacement meter consists of two horizontal pendulums, each carrying a mass of one pound at a point about 18 inches from the axis of rotation. Each boom is supported by a wire suspension, and a pivot and steel cup bearing, the boom being constrained so that it cannot be thrown off its bearing by a strong shock. The pendulum is oil damped, the damping ratio usually ranging between 5:1 and 20:1. The period is 10 seconds and magnification is close to 1.1. Recording is automatic (being actuated by electrical contacts on the booms of the pendulums) and photographic, with paper speed close to 7 millimeters per second.

The Weed strong motion seismograph was designed by Arthur J. Weed of the University of Virginia. The 5- to 7-pound pendulum is of the inverted type. It is supported on three stiff vertical wires, and damped by means of a perforated cylinder attached beneath it which dips into an oil reservoir attached to the base between the supporting wires. A unique system of levers records the two horizontal components separately. The record is made mechanically on a smoked-glass plate which travels on the instrument frame above the steady mass. Operation is automatic. Usually a pendulum starting device is used. The pendulum period of the seismometer is 0.2 seconds, static magnification, 7. The recorder is clock driven. The entire unit is compact and self-contained.

Starters consisting essentially of short-period vibrating units were found unsatisfactory except at unusually quiet locations because relatively small nonseismic vibrations closed the contacts. A starter consisting of a simple pendulum about 6 inches long, damped in oil, with a make-circuit contact, was finally adopted.

The photographic recorders, which are set in operation by the starters, are motor-driven (on batteries). The drums make $1\frac{1}{8}$ revolutions for each record. On some accelerographs a tape device is used.

Foreword on interpretations.—In view of the complex nature of earthquake movements and the natural limitations of pendulum type seismometers extreme precision in the results cannot be expected. This statement does not question the efficiency of the installations but emphasizes the need for careful reading of the text of the analyses rather than accepting without further question the figures tabulated in this report.

As a rule, sustained simple harmonic motion is assumed in computing acceleration and displacement when the instruments do not record these elements directly. This assumption may introduce serious errors, especially when the waves are not of well defined sinusoidal character. When displacements are computed from accelerograms the results may be accepted as quite accurate for the shorter period waves which are, incidentally, also the smaller amplitude waves. As the periods increase the accelerograph becomes less and less reliable as a means of estimating displacement. To appraise the value of any estimated displacement one must inspect the record and appraise the trustworthiness of the assumption of simple harmonic motion. When the record is extremely complex it is safer to ignore such estimated displacement if the data are to be used as a basis for serious studies.

Although all analyses in this report have been made on the assumption of simple harmonic motion, a method of analyzing strong-motion records by precise integration has since been developed and it is expected that more valuable results will be available after the present publication is issued, especially for computations of displacement for long-period waves. For this reason the data given here are practically reprinted from preliminary reports and do not represent final results, although in many respects there will be but little difference between them and the results which are expected to be obtained by more vigorous treatment.

Units used.—Quantitative results are expressed in c. g. s. units; centimeters or millimeters for displacement; centimeters per second for velocity, and centimeters per second per second for acceleration. It is sometimes desirable to express acceleration in terms of the acceleration of gravity, indicated by "g", which is equal to 980 cm/sec.^{2}. For all practical purposes it is only necessary to point off three decimal places to convert cm/sec.^{2} to g.

Sensitivity of the seismographs is expressed as the deflection of the trace, or light spot, in centimeters for a constant acceleration of 0.1 g. This means that the seismometer pendulum is tilted sideways until the effective component of the earth's gravitational field is equal to 0.1 g or 98 cm/sec.^{2}.

The following are constants which may be used in converting c. g. s. units to the customary English units:

1 cm=0.3937 in.=0.03281 ft.
1 cm/sec.=0.03281 ft./sec.
1 cm/sec.^{2}=0.03281 ft./sec.^{2}
1 cm=10 mm.
0.1 g=98 cm/sec.^{2}=3.215 ft./sec.^{2}

Damping ratio of the pendulum is the ratio between successive amplitudes when the pendulum oscillates under the influence of the damping forces alone.

Seismogram illustrations.—Reproduction of seismograms are usually tracings of the original record and must not be accepted as genuine copies. The illustrations are intended to show the nature of the data rather than furnish a means through which the reader may make his own measurements. It is realized that the slightest variations in the copy can easily lead to misleading conclusions. Those who desire true copies for critical study should address the Director of the Bureau for further particulars.

THE LONG BEACH EARTHQUAKE OF MARCH 10, 1933

Epicenter: 33° 34'.5 N., 117°59'.0 W., about 3½ miles off Newport Beach, Calif., according to Pasadena. Time of origin: 5:54 p. m., Pacific Standard time. Depth of origin estimated at 10 km. Intensity VII–IX.

Summary of strong-motion records

Station	Distance from epicenter	Bearing from epicenter	Instrument
	Miles		
Long Beach	17	N. 45° W.	Accelerograph in Public Utilities Building basement.
Vernon	33	N. 25° W.	Accelerograph in Westland Warehouse basement.
Los Angeles	37	N. 26° W.	Accelerograph in subway terminal train shed.

NOTE.—Descriptions of all stations are given at end of this report.

LONG BEACH ACCELEROGRAPH RECORD, MARCH 10, 1933

PUBLIC UTILITIES BUILDING

The Long Beach record should be considered in the light of its being the first of its kind ever obtained within 20 miles of the point of the epicenter of a destructive earthquake. In view of lack of experience and previous test by earthquake certain precautions to prevent too serious overlap of the records of the different components which have since been adopted had not then been taken.

The vertical record has been separated almost in its entirety, subject to some uncertainty in the high-acceleration short-period portion of the record. One difficulty is that the high accelerations caused such rapid movements of the light spot that only the turning points were recorded. In the case of the horizontal records, the light spots when at rest were too close together and it is very hard to identify the turning points. In the case of the vertical components a peculiar twist at the turning points enables them to be distinguished.

Horizontal records.—In spite of the complexity of the records certain conclusions may be drawn. They are based on the best judgment possible and are not so conclusive as those derived from other station records on which the components were completely separated. Working backward from the end of the principal part of the horizontal record into the short period high acceleration portion there appears to be a dominant period of 0.3 sec. If we accept this period for the larger movements and trace amplitudes of 7 cm (such turning points are visible in the original records at 1 and 4 seconds from beginning) the corresponding acceleration is 230 cm/sec.^{2} or 0.23 g with an estimated ground displacement (one-half range) of 0.5 cm. The measured trace amplitude may be seriously in error, as it is measured from the position of rest and not from a long period wave on which it is undoubtedly superimposed.

The records of high acceleration of short period combined with overlapping of the records makes it practically impossible to identify waves of large period in this portion of the record. It can be seen, however, that certain turning points come in groups which seem more or less periodic. These may be interpreted as indicating the turning points of waves of 1.5 sec. period and examination warrants the estimate that after eliminating the 0.3 sec. period waves, we have a trace amplitude of 3 or 4 cm corresponding to a ground displacement of

6 cm. The corresponding maximum acceleration is about 110 cm/sec.[2] It must be understood that the two accelerations 230 and 110 cm/sec.[2] must not be added. If these values correctly represent the accelerations on one component and since it appears that the

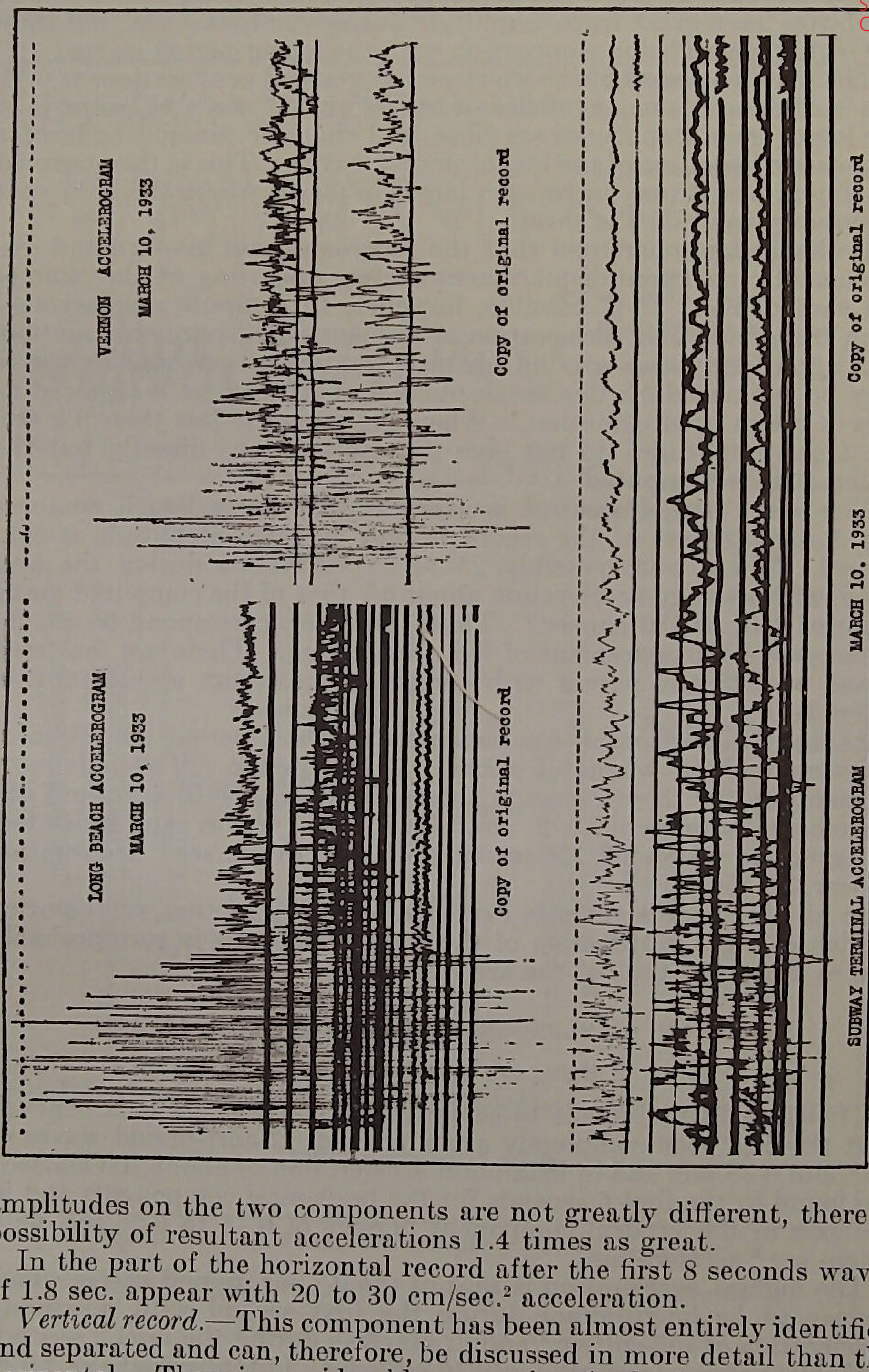

FIGURE 3.—Seismograms of Long Beach earthquake of March 10, 1933.

amplitudes on the two components are not greatly different, there is possibility of resultant accelerations 1.4 times as great.

In the part of the horizontal record after the first 8 seconds waves of 1.8 sec. appear with 20 to 30 cm/sec.[2] acceleration.

Vertical record.—This component has been almost entirely identified and separated and can, therefore, be discussed in more detail than the horizontal. There is considerable uncertainty in the first second. An outstanding feature of the record is that the vertical movements are quite comparable to the horizontal. The periods are not the same as for the horizontal records but this is also true for the Vernon and Los Angeles records. This record may be regarded as made up of a train of waves of periods 1.0 to 1.5 sec. with periods of 0.1 to 0.2 sec. superimposed. In the vertical component of the Long Beach record the latter have great trace amplitude during the first 5 sec., but they are highly magnified in comparison with the longer period waves.

The average period of the short-period vertical accelerations is 0.11 sec. and there is some evidence of others of 0.23 sec. It seems that the larger trace amplitudes are close to 4 cm after eliminating insofar as possible the effect of the longer period waves. This is the observed maximum and it may have been larger in places where the light spot apparently went off the sheet.

It should be understood that the records do not give ground displacements, nor were displacement meters operating at the time of the earthquake. It is possible, however, to compute displacement from the period and acceleration of any sustained harmonic motion, and accordingly the ground displacements for earthquake waves may be estimated on this assumption, but it must be recognized as only a rough approximation. When the period is less than 0.3 sec. the trace amplitudes do not give the accelerations directly but the latter can be computed.

The short period vertical accelerations at Long Beach compose the dominant part of the record insofar as trace amplitude is concerned. There were possibly 25 to 35 vibrations during the first 5 sec. with average acceleration about 0.7 that of the computed maximum of 250, or 180 cm/sec.^{2} These, however, correspond to a computed ground displacement of less than 1 mm. There are scattered waves of 0.23 sec. period with computed maximum acceleration of 80 cm/sec.^{2}

As in the horizontal components the short-period vibration is superimposed on waves of about 1.3 sec. period. The maximum acceleration for these waves is about 70 cm/sec.^{2} with a ground displacement estimated at 3 cm. Two such waves are indicated. After 8 sec. waves of 1.8 sec. period and 10 cm/sec.^{2} acceleration appear.

In all the records there is evidence of rotary motion, representing sudden changes in direction of the waves, which are in turn probably due to change in type of the arriving waves.

VERNON ACCELEROGRAPH RECORD, MARCH 10, 1933

WESTLAND WAREHOUSE

Though a little difficult to separate the components it is believed that this has been completely accomplished. Short-period waves of 0.23 and 0.35 sec. and of maximum acceleration of about 100 cm/sec.^{2} are found in the first 6 seconds for the horizontal components and in the case of the vertical component periods of 0.13 to 0.25 sec. with 50 cm/sec.^{2} acceleration.

The highest acceleration is that of the 0.7 sec. period waves which appear to be longitudinal during the first second with maximum acceleration of 130 cm/sec.^{2} and transverse during the next 2 seconds with maximum acceleration of 210 cm/sec.^{2} Later waves have 1.5 to 2.5 sec. period with accelerations of 20 and 30 cm/sec.^{2} One of the waves of 2.5 sec. period apparently corresponds to a maximum ground displacement of 6 cm. In the vertical record the prevailing periods are 1.0 to 1.4 sec. with approximate maximum accelerations of 30 cm/sec.^{2}

The same general types of waves continue throughout the record with progressively less amplitude.

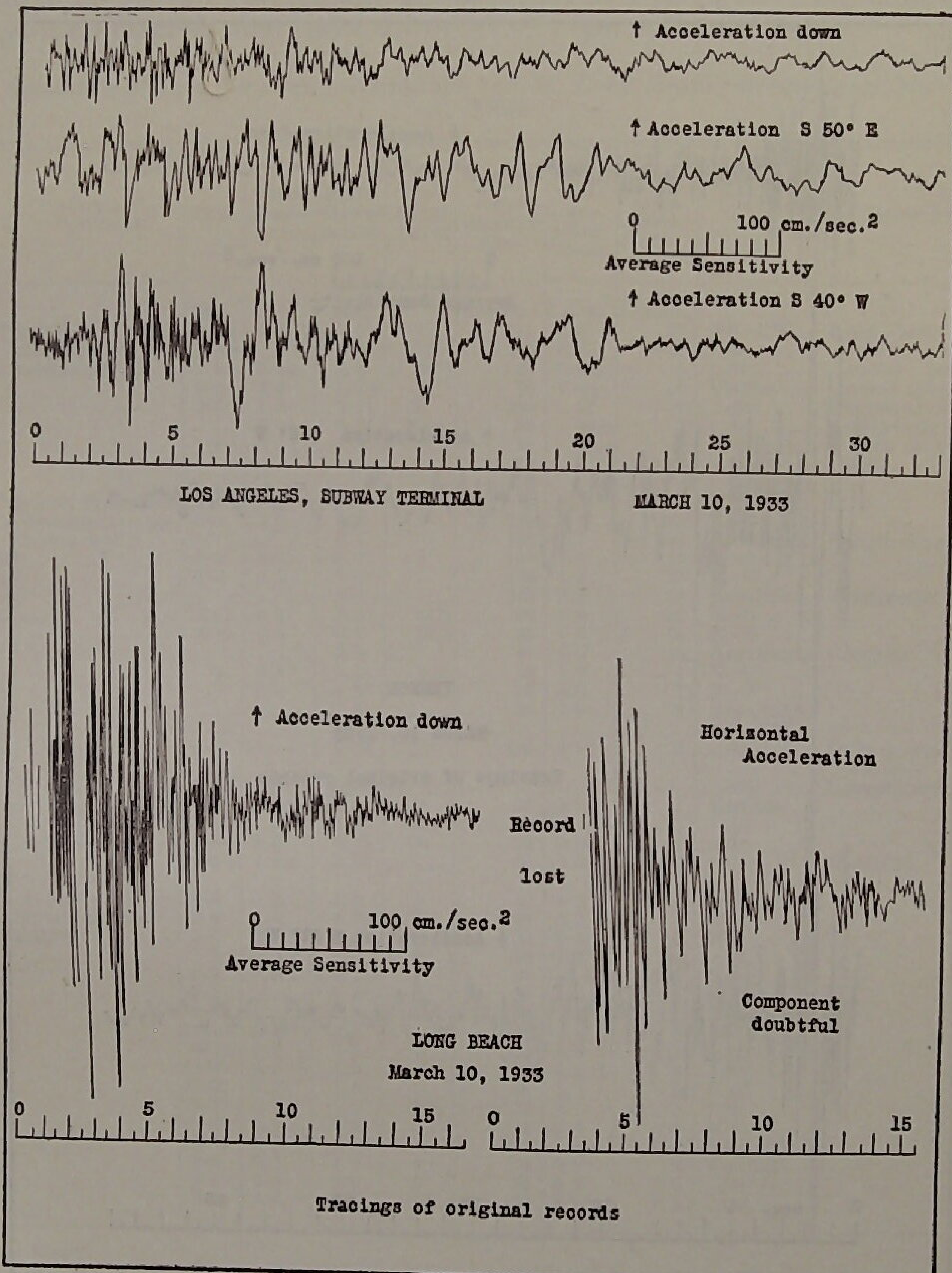

FIGURE 4.—Tracings of Long Beach and Subway Terminal records, March 10.

LOS ANGELES SUBWAY ACCELEROGRAPH RECORD, MARCH 10, 1933

SUBWAY TERMINAL TRAIN SHED

The horizontal record has at this distance become the predominating feature of the record and the duration of the principal portion is already greater than at Long Beach. It will be seen from the table that while there is wide variation in periods and accelerations the prevailing waves are from 1.0 to 2.5 sec. period with maximum acceleration of about 60 cm/sec. ^{2}, the latter being associated with waves of about 1 sec. period.

It should be noted that while the accelerations are apparently small they are all within the destructive range according to the

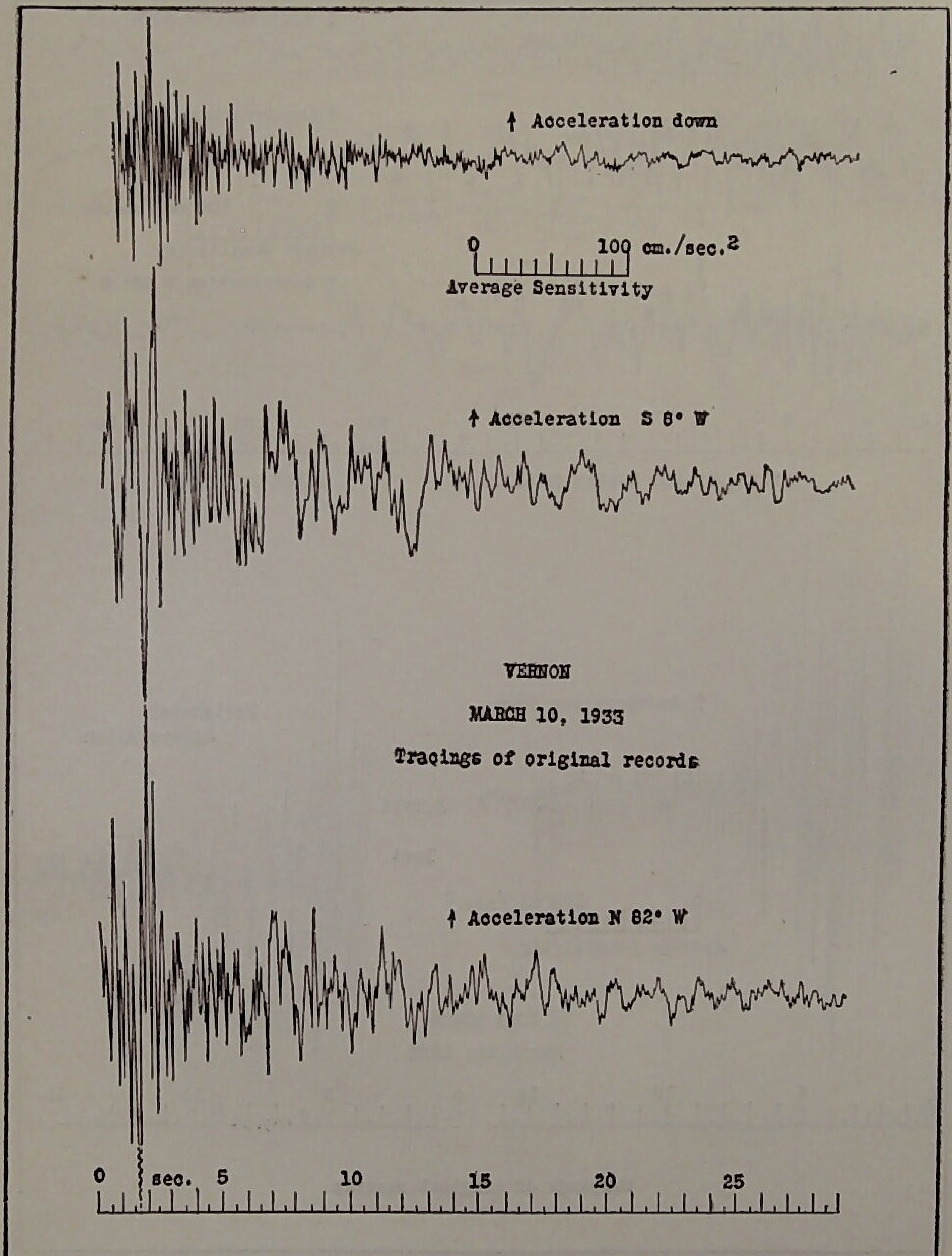

FIGURE 5.—Tracings of Vernon records, March 10.

modified Mercalli scale of 1931. The computed ground displacements are of the order of 3 to 4 cm, but there is one wave of 2.5 sec. period with computed ground displacement of 6 cm (one-half range). Attention is again called to the uncertainty of these computed ground displacements.

In the first 6 seconds there were 3 waves of about 1.5 sec. period with computed ground displacement of 1.5 cm and a group of 6 waves of 0.6 sec. period with computed maximum ground displacement of 0.5 cm, but in the other portions of the record there is change of period throughout.

In the latter part of the record after 20 sec. there are several waves of about 4.8 sec. period and acceleration of 6 cm/sec.^{2} The probable ground displacement is of the order of 4 cm, or 7 cm range.

Summary of strong-motion seismograph results, Long Beach earthquake of Mar. 10, 1933

Station and instrument	Time	Trace amplitudes	Earth wave period	Number of waves	Maximum acceleration	Maximum displacement	Maximum velocity	Component	Remarks
	Sec.	Cm	Sec.		Cm/sec.^{2}	Cm	Cm/sec.		
Long Beach Utilities Building accelerograph.	0-7+	3-4	1.5	3-4	110	6.0	25	NS.-EW	Read text carefully. Horizontal components cannot be separated on seismogram. Part of record lost.
	1-4+	7	0.3	(1)	230	0.5	10	do	
	8+	0.5±	1.8	5(?)	20	1.6±	6	do	
	0-6	2.0	1.3±	2(?)	70	3.0±	14	Vertical	
	0-5	4.0	0.11	30	250	.07	4	do	
	------	2.0±	0.23	Few	80	.10±	3	do	
	8+	0.3±	1.8	5(?)	10	.8±	3	do	
Vernon, Westland Warehouse accelerograph.	0-1	2.2	0.7	1	70	0.9	8	N.-S	
	0-1	3.0	0.7	1	110	1.4	12	E.-W	
	------	-------	0.7	-------	130	1.7	15	Resultant	Longitudinal.
	1-2	4.3	0.7	1	140	1.7	15	N.-S	
	1-2	4.3	0.7	1	150	1.9	17	E.-W	
	------	-------	0.7	-------	210	2.6	24	Resultant	Transverse.
	3-15	0.8	2.5	3(?)	20	4.0	10	N.-S	
	3-15	0.8	2.5	3(?)	30	4.0	10	E.-W	
	------	-------	2.5	-------	40	6.0	15	Resultant	Complex.
	9	0.6	1.5	1(?)	20	1.0	4	N.-S	
	9	0.8	1.5	1(?)	30	1.6	7	E.-W	
	------	-------	1.5	-------	40	1.9	8	Resultant	
	3-15	-------	0.7	-------	---------	-------	--------	NS.-EW	
	0-6	3	0.23	(1)	100	0.12	3	do	Only a few large waves.
	0-15	-------	0.35	-------	---------	-------	--------	do	Insignificant.
	0-3	0.9	1.0, 1.4	2	30	0.8	5	Vertical	
	3-(?)	-------	1.25	5+	---------	-------	--------	do	
	0-5+	1.0	0.13	(1)	50	0.02	1	do	
	0-5+	1.5±	0.25	-------	50	0.08	2	do	Doubtful.
L. A. Subway Terminal accelerograph.	0-6	0.8	1.5	3	30	1.5	6	NW	
	2-6	1.4	0.62	6	50	0.5	5	NE	
	5-7	0.6	0.40	6	20	0.1	2	NW	
	7-9	1.2	1.0	2	40	1.0	6	do	
	7-9	1.6	1.0, 1.6	1	60	1.5, 3.9	9, 15	NE	
	9-12	-------	0.4	6(?)	30	-------	--------	NW	
	9-12	-------	0.8	4	30	-------	--------	NE	
	11-18	0.5(?)	2.5	(?)	10	2.4	6	NW	
	12-15	1.0	2.5	2(?)	40	6.0	15	NE	
	14-17	0.6	1.2	-------	20	0.8	4	do	
	17-21	0.7	1.5	2	20	1.3	5	NW	
	19-21	0.5	1.5	1+	20	1.1	5	NE	
	20-30	0.2	4.8	2(?)	6	3.6	5	NW	
	0-10	0.7	0.12	(1)	20	.01	0.5	NW., NE	
	2-8	0.3	1.0	4	10	0.3	2	Vertical	
	8-9	0.5	1.5	1	20	0.9	4	do	
	0-10	0.4	0.2	(1)	20	0.02	0.5	do	

[1] Many.

Instrumental constants at time of earthquake of Mar. 10, 1933

Station and instrument	Orientation of instrument	Pendulum period	Static magnification	Sensitivity	Damping ratio	Instrument number
		Sec.		*Cm*		
Long Beach accelerograph	S.[1]-N	0.105	129	3.08	6:1	L4Q
	W.-E	.105	129	3.17	6:1	T17Q
	Up-Down	.105	112	2.70	(2)	V30Q
Vernon accelerograph	N. 8 E.-S. 8 W	.097	123	3.26	(2)	L6Q
	E. 8 S.-W. 8 N	.100	119	2.82	10:1	T19Q
	Up-Down	.101	120	2.92	15:1	V29Q
Los Angeles Subway Terminal accelerograph.	N. 51 W.-S. 51 E	.096	126	3.18	20:1	L10Q
	N. 39 E.-S. 39 W	.098	103	2.66	10:1	T23Q
	Up-Down	.102	103	2.63	(2)	V36Q

[1] The direction on the left ("S" in the first case) indicates the direction of pendulum displacement, relative to instrument pier, which will displace the trace upward on the original seismogram.
[2] Critical.

THE SOUTHERN ALAMEDA COUNTY EARTHQUAKE OF MAY 16, 1933

Tentative epicenter: On or near the Hayward Fault, near Niles

Summary of instrumental reports: It was recorded at only one strong-motion seismograph station on the Suisun Bay Bridge of the Southern Pacific Railroad, near Martinez. The bridge is about 35 miles north and slightly west of the epicentral region

SUISUN BAY BRIDGE ACCELEROGRAPH RECORD, MAY 16, 1933

The longitudinal and transverse records do not synchronize to any appreciable extent as would be expected in the case of a structure with nearly similar dynamic characteristics in all horizontal planes of vibration. The oncoming waves are off the ideal "end-on" orientation of the pendulums by about 20°. This would indicate that the widely different vibration characteristics of the bridge in its longitudinal and transverse directions practically control the character of the record and it is to be expected that the free periods, longitudinal and transverse, influence the record greatly in the form of resonance. The free vibration periods, however, have not been measured so that the assumption of resonance is open to further verification. Some of the periods probably represent overtones.

On the component which is longitudinal with respect to the bridge the waves for the first 5 sec. are complex and of relatively small amplitude. Periods of 0.25 sec. (acceleration 10 cm/sec.^{2}, displacement 0.2 mm) and 0.52 sec. (acceleration 7 cm/sec.^{2}, displacement 0.5 mm) dominate. At 6 sec. the maximum waves arrive, period 0.80 sec., acceleration 18 cm/sec.^{2}, displacement 0.29 mm. These in all probability indicate the arrival of a new group of seismic waves.

On the transverse component the wave group recorded during the first second started the recorder. The period is 0.45 sec. (acceleration 23 cm/sec.^{2}, displacement 0.11 mm). The great majority of waves are between 0.45 and 0.50 sec. period but there are a few distorted waves around 0.8 and 0.9 sec. The accelerations and displacements are all less than in the first waves on this component. The activity lasted about 1 minute.

Instrumental constants are identical with those listed for the earthquake of June 25, 1933. The quantitative instrumental results are not tabulated.

The vertical component accelerograph trace is straight indicating that free pendulum movement was obstructed.

THE WESTERN NEVADA EARTHQUAKE OF JUNE 25, 1933

Epicenter: 39°05′ N., 119°20′ W., near Wabuska and Yerington, Nev.

Time of origin: 12:45 p. m., Pacific standard time, or 13:45, Mountain time. Intensity VII

Summary of instrumental reports

Station [1]	Distance from epicenter	Bearing from epicenter	Instruments
	Miles		
San Jose	183	S. 50° W	Two accelerographs—basement and 13th floor of Bank of America Building.
San Francisco	191	S. 63° W	Accelerograph and displacement meter in Southern Pacific Building.
San Francisco	191	S. 63° W	Two Weed instruments—basement and 28th floor. Shell Building. Extremely weak record.
Suisun Bay Bridge	172	S. 67° W	Accelerograph on pier of Southern Pacific Railroad bridge near Martinez.
Sacramento	123	S. 75° W	Accelerograph in Federal Building. Record weak and badly fogged.

[1] Descriptions of all stations are given at end of this report.

THE SAN JOSE ACCELEROGRAPH RECORD, JUNE 25, 1933

BANK OF AMERICA BUILDING

One accelerograph was operating in the basement; a similar set was operating on the thirteenth floor, all of them with pendulums oriented square with the sides of the building. The starter on the thirteenth floor undoubtedly was responsible for starting both instruments simultaneously but there was a lag of possibly 0.2 sec. in the starting of the basement instrument due to a connecting relay. The time marks were made by two clocks of similar type operating independently.

The orientation of the pendulums with respect to the epicenter is fortunate in that the waves are recorded nearly "end-on"; that is, the pendulums recording northeast to southwest motion record waves of longitudinal type almost exclusively, while the others record waves of transverse type. The pendulums depart from the ideal orientation about 10°.

When the term "rotary motion" is used in the following paragraphs, it should be interpreted as irregular rotation without change of surface orientation or twisting. When waves of longitudinal and transverse types overlap, this type of motion results. Both certainly exist and frequently overlap.

Basement record

At the onset the motion on the south 60° west component is irregular and relatively weak. There are poor indications of 1.3 and 2.0 sec. periods with acceleration of 2.5 cm/sec.^{2} and estimated displacement 1.1 mm and 2.5 mm, for the 2 periods respectively. The other horizontal component starts off even weaker, with an indefinite period estimated at 2.8 sec., registering an acceleration of 1.8 cm/sec.^{2}, corresponding to an estimated displacement of 3.5 mm. The northeast-southwest registers waves which are largely of longitudinal character, while the northwest-southeast registers mostly transverse waves.

From the 5th to 12th sec. the waves increase to a maximum acceleration which is 4.7 cm/sec.^{2} on the southwest component and

2.5 cm/sec.[2] on the vertical. Their phase relation indicates a motion of rotary character in the vertical-longitudinal plane although some rather strong activity on the transverse component tends to distort it. The period is 1.6 sec. Estimated displacement on the southwest component is 3.0 mm; on the northwest 1.6 mm. In the end

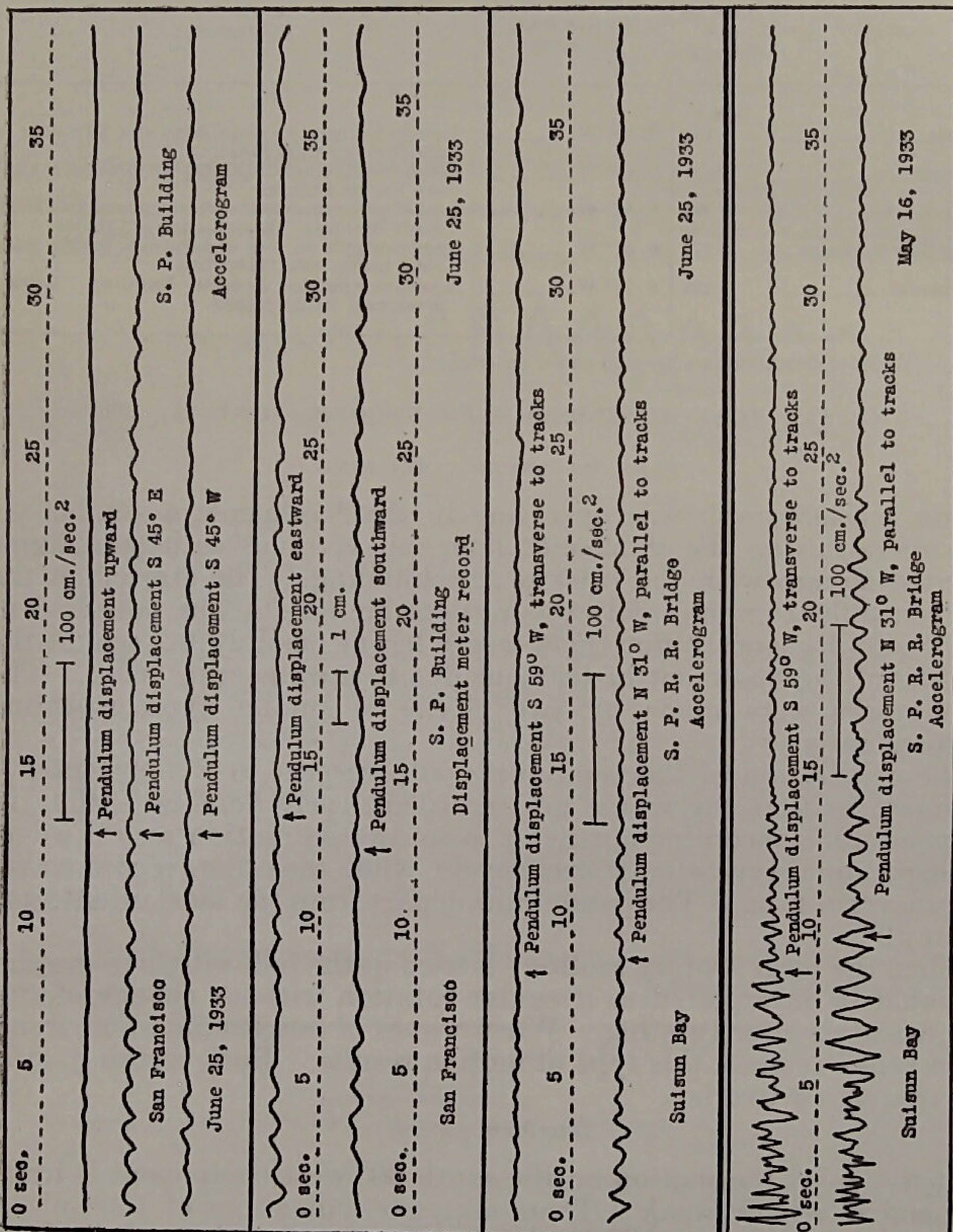

FIGURE 6.—Seismograms of May 16 and June 25.

portion of the maximum group the motion evidently becomes more linear but still persists in the longitudinal plane.

There is no activity of special significance in the end portion of the record but evidently enough, at times, to build up the natural oscillations of the building which were recorded on the thirteenth floor. See the record at 19 sec. for instance.

Vertical accelerations are of the same character as the horizontal but only about two-thirds the magnitude.

The resultant horizontal accelerations have been plotted for comparison with similar curves obtained from the thirteenth floor record.

Thirteenth Floor Record

The directions and magnitudes of the major horizontal movements are listed in the tabulation of instrumental results and are also shown in the curves of resultant horizontal accelerations drawn for comparison with the basement record. The outstanding feature is the record of the building oscillating in one of its fundamental free periods with about seven times the motion recorded in the basement.

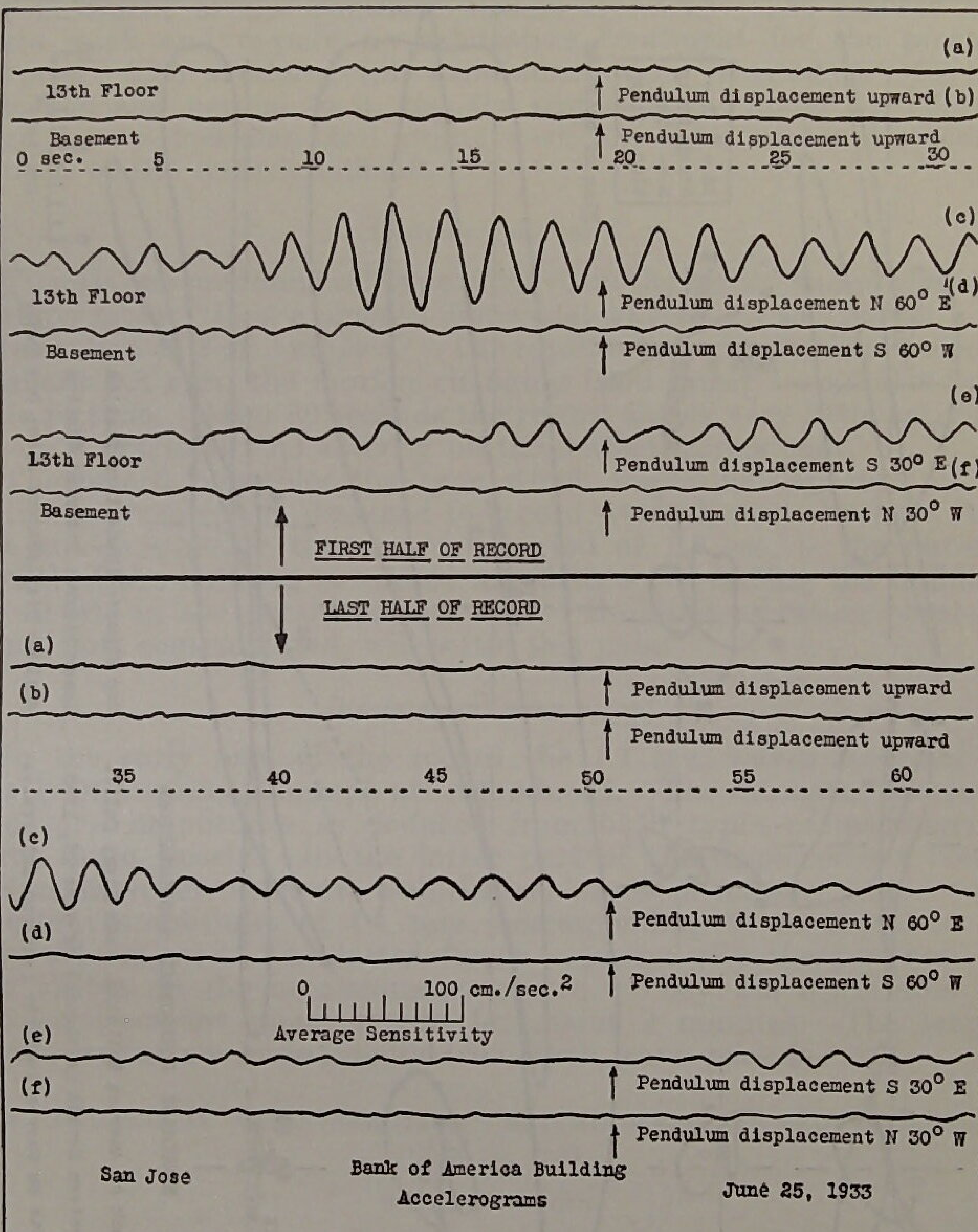

FIGURE 7.—San Jose seismograms of June 25.

The period in the plane of vibration parallel to Santa Clara Avenue measures 1.68 sec. The other fundamental period is masked by the greater magnitude of the longitudinal types of earthquake waves which struck the building practically end-on. Transverse movements are relatively weak. The resultant movements of the thirteenth floor are consequently of elongated elliptical character, the greatest resultant acceleration being about 33 cm/sec.^{2}, with corresponding displacement estimated at 2.3 cm or 0.9 inch.

There is evidence in the records that ground wave periods close to the free period of the building were responsible for the larger vibrations of the thirteenth floor. Until the building periods are definitely measured there is, however, always a possibility that a dominant ground period may be involved, but this seems improbable.

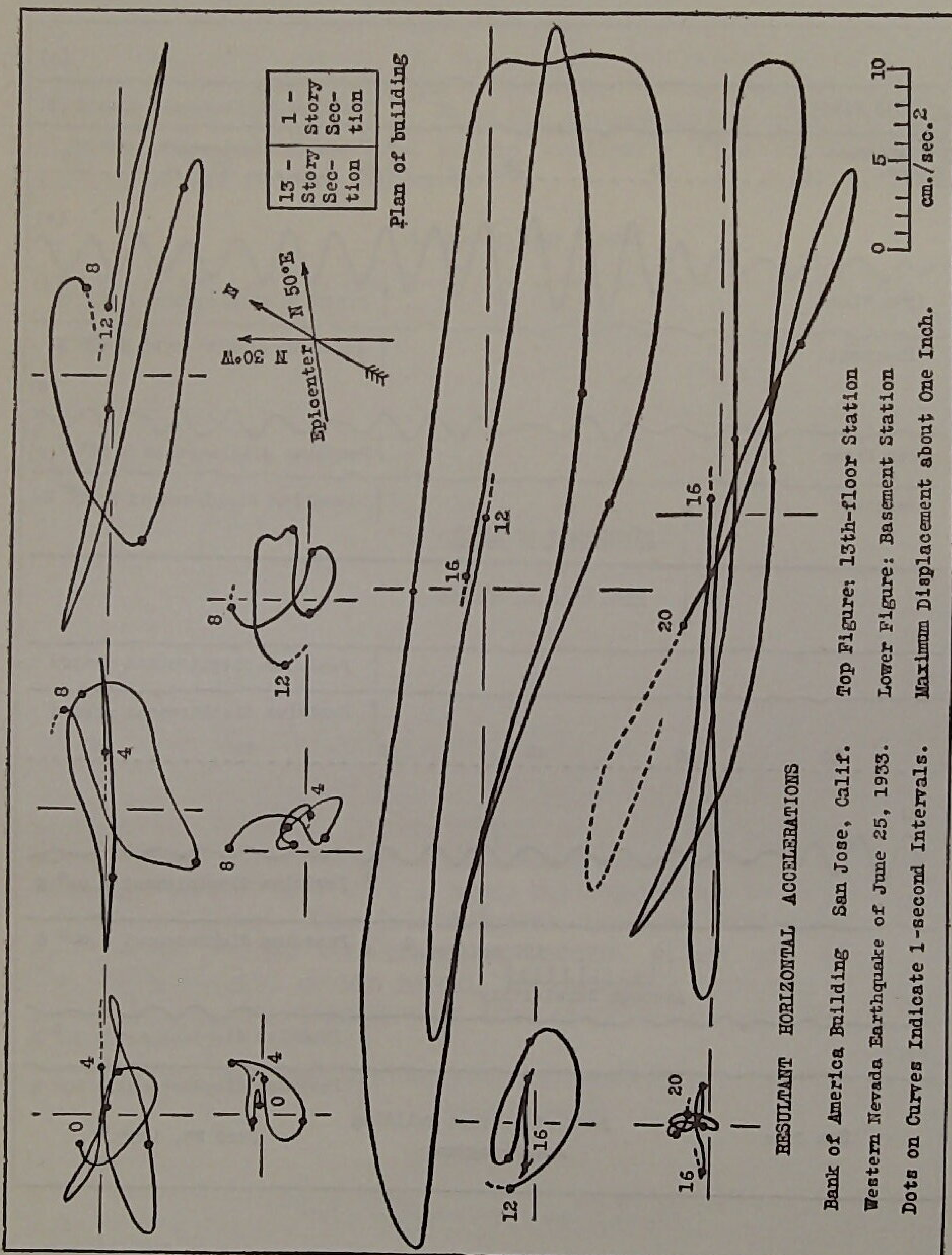

FIGURE 8.—Horizontal acceleration, San Jose, June 25.

Too rigid an analysis cannot be made of the relation between the basement and thirteenth-floor movements because of an unknown lag in the basement relay, supposed to be of the order of 0.2 sec. The time marks also were not simultaneous on the two recorders, thus introducing additional uncertainty. These facts must also be considered in appraising the precision with which the resultant curves of horizontal acceleration are drawn.

SAN FRANCISCO ACCELEROGRAPH AND DISPLACEMENT METER RECORDS, JUNE 25, 1933

SOUTHERN PACIFIC BUILDING

The two installations named in the above title were located in the basement of the Southern Pacific Building. The records are quite weak and require no exhaustive treatment for the present purpose. The accelerograph pendulums were oriented 45° to the meridian and normal to it, but the displacement meter pendulums were in the meridian and prime vertical. This makes intercomparison of the records difficult.

Accelerograph record

There is one predominant type of wave on the record and practically nothing more. It is a smooth sinusoidal wave of 1.1 sec. period with acceleration of 2 or 3 cm/sec.^{2} The resultant maximum displacement is about 0.8 mm, the motion changing from linear to circular from time to time. After 60 seconds the record shows very little activity. There is practically no activity on the vertical component.

The record resembles the type which might be expected on an ordinary seismograph designed to record weak distant shocks. It is not known whether the recorded period of 1.1 sec. is the natural period of the building or simply an earth wave forcing the building to vibrate in the period of the wave. Building vibration observations, now contemplated, will settle this point.

Displacement meter record

In the early part of the record the 1.1 sec. waves recorded so clearly on the accelerograph are reproduced. The estimated accelerations and amplitudes as deduced from both types of instruments agree quite closely. In the latter part of the displacement meter record, however, there are well-defined waves of 6.7 sec. period with resultant amplitudes of 1.1 mm, corresponding to accelerations of only 0.1 cm/sec.^{2} The latter figure explains why these waves are not visible on the accelerometer record. They are discernible on the displacement meter record for about 2 minutes. The longer period waves are undoubtedly true earth wave periods.

SAN FRANCISCO STRONG-MOTION SEISMOGRAPH (WEED) RECORDS, JUNE 25, 1933

SHELL BUILDING

Strong-motion seismograph records (on smoked glass) were obtained in the basement and on the twenty-eighth floor of the Shell Building. The basement record shows no deflection of the trace whatever.

The record on the twenty-eighth floor shows about 30 waves of sinusoidal type. Maximum trace amplitude is 0.2 mm, which corresponds to an acceleration of approximately 3 cm/sec.^{2}, and displacement of 4.3 mm. These waves have a period close to 2.4 sec., and during the first 30 sec. are much more prominent on the east-west component. The north-south component later records a short series of 1.0 sec. waves of considerably smaller acceleration and amplitude.

For such small trace amplitudes, friction of the writing pen on the smoked glass makes the above figures (except those for period) subject to relatively large errors. There is theoretically a zone about 0.5 mm wide in which the restoring force of the pendulum is not sufficient to overcome the friction of the writing stylus.

SACRAMENTO ACCELEROGRAPH RECORD, JUNE 25, 1933

FEDERAL BUILDING

The onset of the record is lost through fogging of the trace but a few figures can be given to illustrate the magnitude of the movements. The outstanding feature is the irregular character of the waves. In the early part of the record a long period wave of about 1.8 sec. is relatively prominent and continues so throughout the active portion. Its trace amplitude is about 0.7 mm, or 2.5 cm/sec.^{2}, corresponding to a displacement of 2.0 mm. These waves are almost obscured by smaller waves ranging from 0.25 sec. to 0.40 and 0.50 sec., the former period being quite prevalent in the earlier part of the record. Acceleration in the shorter period waves does not exceed 2 cm/sec.^{2}; corresponding displacements are not more than 0.1 or 0.2 mm.

Amplitudes on the vertical are only about one quarter of those on the horizontal component. After 40 sec. the disturbance practically ceases.

SUISUN BAY BRIDGE ACCELEROGRAPH RECORD, JUNE 25, 1933

SOUTHERN PACIFIC RAILROAD NEAR MARTINEZ

The accelerograph pendulums are mounted to record motion parallel and transverse to the tracks. Although the epicenter is approximately north 65° east, which is normal to the direction of the bridge, practically all of the recorded motion was parallel to the tracks. The bridge is directed north 31° west.

The northwest component records a series of fairly smooth sinusoidal waves lasting a little over a minute. Their period is 0.77 sec., acceleration of the first 4 waves 6 cm/sec.^{2}, and estimated displacement 0.9 mm. About 25 sec. after the onset a small group of waves of about 0.67 sec. period emerges. After 70 sec. there is no appreciable activity.

The movement transverse to the tracks is weak and indefinite, being punctuated by frequent intrusions of waves of about 0.5 sec. period and insignificant amplitude. Between 25 and 30 sec. a smooth wave of 1.7 sec. period emerges, having an acceleration of 1 cm/sec.^{2}, and an estimated displacement of 0.7 mm. A weak but otherwise similar group appears later in the record. At the beginning there is some evidence of a 2.7-sec. wave, but it is masked by shorter period tremors.

The vertical component was obstructed.

Summary of strong-motion seismograph results, western Nevada earthquake of June 25, 1933

Station and instrument	Time	Earth wave period	Maximum acceleration	Maximum displacement	Component	Remarks
	Sec.	*Sec.*	*Cm/sec.*²	*Cm*		
San Jose Bank of America basement accelerograph.	0-5	1.3 / 2.0	0.25	0.11 / .25	S. 60° W.-N. 60° E.	From 15 to 25 seconds activity continuous with diminishing intensity.
	0-12	2.8?	1.8	.35(?)	N. 30° W.-S. 30° E.	
	7, 11	1.6	(?)	(?)	do	
	5-12	1.6	4.7	.30	S. 60° W.-N. 60° E.	
	5-12	1.6	2.5	.16	Vertical	
	12-15	1.5	3.6	.20	S. 60° W.-N. 60° E.	
	12-15	1.5	1.8	.10	Vertical	
	12-15	1.5	4.0	.23	Resultant	
San Jose Bank of America thirteenth floor accelerograph.	0	1.6	2	.08	N. 60° E.- ——	These are directions of resultant accelerations; not components.
	0- 5	1.6	8	.52	S. 60° W.-N. 60° E.	
	6- 7	1.6	6	.38	S. 25° W.-N. 25° E.	
	13	1.68	33	2.32	S. 75° W.-N. 75° E.	
	25	1.65	17	1.15	S. 95° W.-N. 95° E.	
	33	1.6	15	.96	S. 60° W.-N. 60° E.	
	39	1.5	6	.33	N. 80° W.-S. 80° E.	
	47	1.5	6	.36	S. 60° W.-N. 60° E.	
	57	1.5	6	.33	N. 65° W.-S. 65° E.	
	63	1.5	2	.13	S. 15° W.-N. 15° E.	
San Francisco Southern Pacific Building accelerograph.	0- 1	1.1	2	.06	SE.-NW	
	0- 1	1.1?	2	.05	SW.-NE	
	0- 1	1.1	3	.08	Resultant	
	4	1.1	2	.06	SE., SW	
	15	1.0	1−	.03	do	
San Francisco Southern Pacific Building displacement meter.	0- 1	1.1	3+	.10	EW	
	4	1.1	2	.06	NS., EW	
	14	1.2	1	.05	do	
	90	6.7	1−	.10	EW	
	90	6.7	1−	.04	NS	
	-------	6.7	.1	.11	Resultant	
San Francisco Shell Building twenty-eighth floor Weed seismograph.	0-85	2.4	3	.43	-------	A similar Weed seismograph in the basement showed no measurable activity.
	62-77	1.0	(?)	(?)	-------	
Sacramento Federal Building accelerograph.	-------	1.8	2	.20	-------	Instrument in basement. Record badly fogged.
	-------	0.25	2	.02	-------	
	-------	.40-.50	-------	-------	-------	
Suisun Bay accelerograph on Southern Pacific Railroad bridge.	0-60	.77	6	.09	N. 31° W.-S. 31° E.	Parallel to tracks.
	25	.67	-------	-------	-------	Weak.
	25-30	1.7	1	.07	N. 59° E.-S. 59° W.	Transverse to tracks.

Instrumental constants at time of earthquake of June 25, 1933

Station and instrument	Orientation of instrument	Pendulum period	Static magnification	Sensitivity	Damping ratio	Instrument no.
		Sec.		*Cm*		
San Jose, basement accelerograph	Up [1]-Down	0. 10	118	2. 89	15	V39Q
	S. 60° W.-N. 60° E	. 10	119	2. 91	15	L13Q
	N. 30° W.-S. 30° E	. 10	122	2. 95	(2)	T26Q
San Jose, thirteenth floor accelerograph.	Up-Down	. 10	112	2. 74	(2)	V27P
	N. 60° E.-S. 60° W	. 10	111	2. 72	(2)	L22P
	S. 30° E.-N. 30° W	. 10	117	2. 87	15	T1P
Southern Pacific Building, San Francisco, basement accelerograph.	Up-Down	. 10	119	2. 92	36	V31Q
	S. 45° E.-N. 45° W	. 10	120	2. 94	11	L5Q
	S. 45° W.-N. 45° E	. 10	122	2. 99	20	T18Q
Southern Pacific Building, San Francisco, basement displacement meter.	E-W	10.	1. 1	--------	10±	R18
	S-N	10.	1. 1	--------	10±	L18
Shell Building, San Francisco, subbasement Weed seismograph.	N. 82° E.-S. 82° W	. 19	6. 5	. 65	(3)	R4
	N. 8° W.-S. 8° E	. 19	6. 5	. 65	(3)	L4
Shell Building, San Francisco, twenty-eighth floor Weed seismograph.	N. 82° E.-S. 82° W	. 19	6. 5	. 65	(3)	R2
	N. 8° W.-S. 8° E	. 19	6. 5	. 65	(3)	L2
Suisun Bay Bridge accelerograph	Up-Down	. 10	(120)	(2. 80)	(20:1)	V38Q
	S. 60° W.-N. 60° E	. 10	(120)	(2. 80)	(20:1)	L9Q
	N. 30° W.-S. 30° E	. 10	(120)	(2. 80)	(20:1)	T22Q

[1] The direction on the left ("up" in the first case) indicates that direction of pendulum displacement, relative to the instrument pier, which will displace the trace upward on the original seismogram.
[2] Critical.
[3] No damping.

THE SOUTHERN CALIFORNIA EARTHQUAKE OF OCTOBER 2, 1933

Epicenter: 33°47′ N., 118°08′ W., according to Pasadena. Near Signal Hill about 3 miles northeast of Long Beach

Time of origin: 1:10 a. m., Pacific standard time, or 9:10 a. m., Greenwich civil time. Intensity VI

Summary of instrumental reports

Station [1]	Distance from epicenter	Bearing from epicenter	Instruments
	Miles		
Long Beach	3	S. 55° W	Accelerograph in Public Utilities Building.
Vernon	15	N. 10° W	Accelerograph in Westland Warehouse, near Los Angeles.
Santa Ana	17	S. 80° E	Strong motion seismograph in courthouse.
Los Angeles Subway Terminal Building.	19	N. 18° W	Accelerograph and displacement meter in trainshed.
Los Angeles Chamber of Commerce.	19	N. 18° W	Strong motion seismograph in exhibit hall.
Westwood	22	N. 35° W	Accelerograph at University of California in Los Angeles.
Hollywood	24	N. 30° W	Accelerographs in basement and penthouse of Hollywood Storage Building.
Pasadena	25	N	Accelerograph and displacement meter at California Institute of Technology.

[1] Descriptions of all stations are given at the end of this report.

LONG BEACH ACCELEROGRAPH RECORD, OCTOBER 2, 1933

PUBLIC UTILITIES BUILDING

The outstanding feature of the horizontal movement is the predominance of short-period waves ranging from 0.1 to 0.2 sec. Longer period waves are strongly in evidence but they can be analyzed only by eliminating the large superimposed short-period waves and in this process a certain amount of uncertainty enters.

A wave of 0.50 sec. period is strongly in evidence on the east-west component during the first 2 secs. of operation. The trace amplitude is estimated at 6.0 mm, corresponding to a maximum acceleration of 25 cm/sec.^{2}, and ground displacement of 1.6 mm. These waves cannot be distinguished on the north-south and vertical components.

Waves of 0.12 sec. period are most prominent on the east-west record. If we accept 10 mm as the maximum trace amplitude of the largest of them, the corresponding ground displacement is 0.25 mm and acceleration 70 cm/sec.^{2} It is difficult to combine the two horizontal components because of the short time scale, and the maximum resultant acceleration is consequently in doubt. Considering, however, that these short-period accelerations are superimposed on the longer period 0.5 sec. period waves it seems quite safe to say that the resultant acceleration may easily have reached a value of 100 cm/sec.^{2} in a few instances with corresponding estimated maximum displacement of 1.9 mm.

On the vertical component the prevailing period is close to 0.15 sec. with corresponding estimated displacement of 0.19 mm and acceleration of 35 cm/sec.^{2}. Periods of 0.19 sec. are quite frequent on the record but are apparently not involved in the maximum motion.

In the latter part of the record there are a few waves of 0.3 sec. period and weaker ones of 0.4 and 0.5 sec. but they are unimportant as compared with the larger movements recorded in the early part of the record.

VERNON ACCELEROGRAPH RECORD, OCTOBER 2, 1933

WESTLAND WAREHOUSE

Motion during the first 2 seconds is extremely complex. It is difficult to measure acceleration by direct methods because some of the periods are less than 0.3 sec. and the instrument ceases to function as an accelerograph. One will not go far astray, however, in simply looking upon the smaller periods as indicating accelerations which are somewhat too high. The maximum readings are not seriously involved.

Although the smallness of the time scale makes it difficult to combine the two horizontal components with any high degree of precision the attempt was made in order to obtain a good representative value of the maximum acceleration. The curve also indicates in a fair way the outstanding characteristics of the motion.

The maximum horizontal acceleration is close to 130 cm/sec.^{2}. It is almost entirely rotational in character, being marked by sharp reversals in the direction of rotation. The average period of rotation indicated by the loops on the resultant curve is 0.28 sec. The estimated displacement is 2.6 mm. See the last paragraph of the Vernon analysis for estimate of maximum displacement.

The nature of the resultant curve is such that there are superficial loops which might be interpreted as complete cycles of more or less definite period, but with centers of rotation badly displaced from

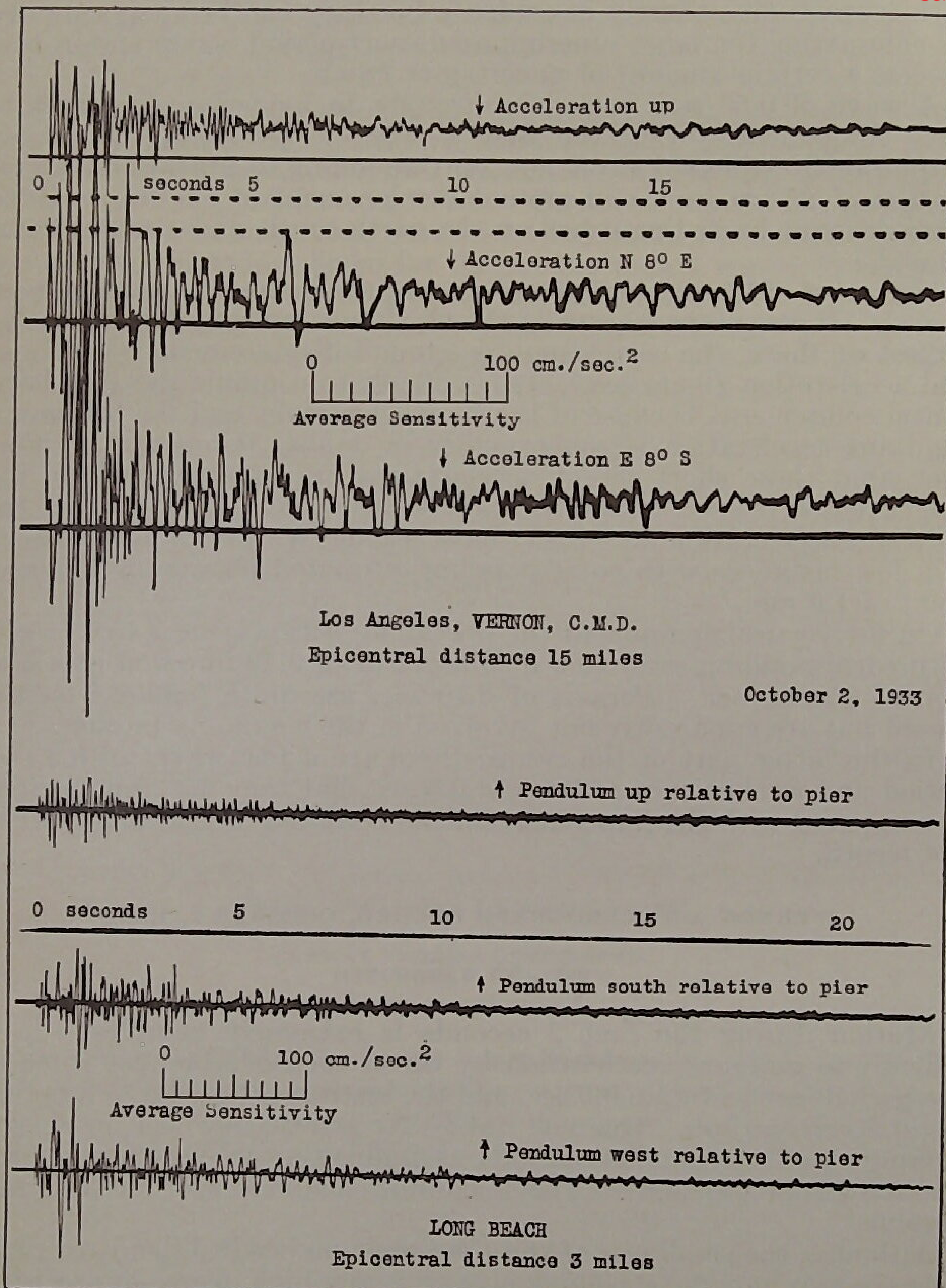

FIGURE 9.—Long Beach and Vernon seismograms, October 2.

normal. They have periods of 0.15 sec., corresponding to periods indicated in irregular manner on the original gram, and accelerations roughly one-half the maximum already stated for the horizontal components.

On the vertical component there are a few long period waves of 0.45 sec. with maximum acceleration of 13 cm/sec.², and estimated amplitude of 0.7 mm. On it are superimposed numerous waves with periods ranging from 0.13 to 0.15 sec., with acceleration and displacement estimated at 35 cm/sec.^{2} and 0.2 mm, respectively. The instrument does not function as an accelerograph for these periods. As the above values are additive, resultant maximum values of 50 cm/sec.^{2} for vertical acceleration and 0.9 mm for vertical displacement are obtained.

It is interesting to note that the shorter period waves have their counterpart on the horizontal component but are less clearly defined because of the greater amplitude of waves of longer period.

After the first few seconds, waves of the periods already mentioned are outstanding but of smaller magnitude. After 5 sec. the large displacements must undoubtedly be associated with complex movements having periods approximating 1 sec. It will suffice at this time to state that the maximum slow movement displacements in all probability exceeded the values listed for the shorter period waves during the first few seconds. One conservative approximation of the maximum displacement is 3.5 mm. It is for activity of this kind that the displacement meter finds its greatest usefulness. The accelerations indicated during these movements are relatively unimportant.

SANTA ANA STRONG-MOTION SEISMOGRAPH RECORD, OCTOBER 2, 1933

COURTHOUSE

The shock was recorded on the Weed strong-motion seismograph, but the records are so weak that little would be gained by attempting a detailed analysis. From casual inspection the displacements are all less than 0.1 mm and acceleration less than 10 cm/sec.^{2}

As in the case of the Los Angeles Chamber of Commerce record, the 0.2 periods dominate. Periods close to 0.4, 0.5, and 0.6 sec. are in evidence in the end portion of the record. The instrument was practically undamped and this accounts for the prominence of waves of 0.2 sec. period.

LOS ANGELES SUBWAY TERMINAL ACCELEROGRAPH AND DISPLACEMENT METER RECORDS, OCTOBER 2, 1933

SUBWAY TERMINAL TRAINSHED

Accelerograph record

The outstanding feature is the magnitude on the accelerogram of the first impulse which, on the northwest component, is several times the amplitude of the traces immediately following. It is unfortunate that on the other horizontal component, the northeast, this first movement was lost entirely, although a diligent search was made for it on the original record. If we assume that the movement was simple harmonic, also that the extreme displacement of the spot from normal corresponds to the maximum displacement of the simple harmonic wave, then the period of the wave would be about 0.4 sec. If, however, the extreme swings of the simple harmonic wave are represented by the first two turning points visible on the record, the period would be near 0.2 sec. This seems the more probable value. At the beginning of the record there is always danger, of course, that the drum may not be rotating at a uniform rate and another possible source of error is introduced. It seems in any event that the period of the waves is over 0.2 sec. so that the trace amplitude represents substantially relative acceleration as compared with the longer period waves. It is significant that the damping is advantageously adjusted in the instruments, also that waves of 0.2 sec. period are very prominent at

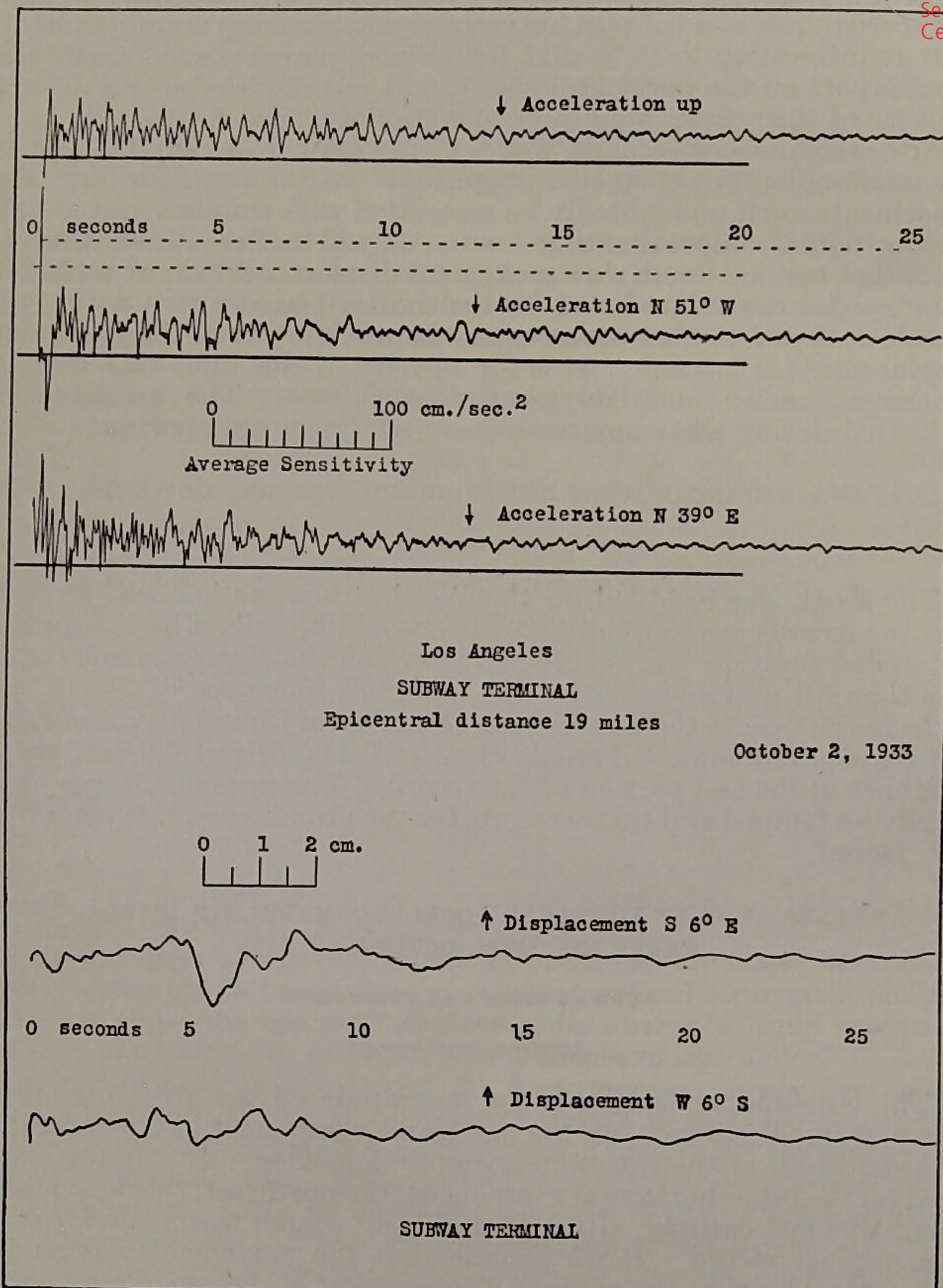

FIGURE 10.—Subway Terminal seismograms, October 2.

the start of the northeast component record. The best judgment, therefore, is that for at least a single impulse, the acceleration was 75 cm/sec.^{2} on the northwest component alone. The corresponding displacement for a wave of 0.2 sec. period is 0.7 mm.

Although the first impulse is lost on the northeast component, some possibilities may be discussed to advantage. It is noted that for a half second after recording began the approximately 0.2 sec. period waves on the northeast component have about one-third greater amplitude than those on the northwest, which would indicate an acceleration of 100 cm/sec.^{2} on the former. This would make the resultant acceleration 125 cm/sec.^{2}, corresponding to a displacement of 1.2 mm. This appears to be a conservative estimate. Another estimate based on the direction of the earliest resultant movements would double the amplitude of the first northeast impulse as compared with that of the northwest resulting in a final value of 170 cm/sec.^{2}. While this is obviously high it may be accepted as a possibility. Its short duration is significant if the high acceleration is judged in terms of destructiveness.

The highest resultant horizontal acceleration in the remaining part of the record is 55 cm/sec.^{2} in a general northeast-southwest direction. It occurs during the first half second of recording with a wave period estimated at 0.35 sec. and corresponding estimated displacement of 1.7 mm.

An outstanding period during the first second is 0.13 sec. with resultant accelerations and displacements probably not exceeding 25 cm/sec.^{2} and 1.0 mm, respectively. They are stronger in the northeast-southwest direction. 0.30 sec. periods are prominent, especially on the northwest-southeast component but do not appear to be associated with the larger movements. 0.40 sec. periods approaching 0.5 sec. are responsible for a large part of the complexity of the records. Within the first 1.5 sec. of recording a movement of this type on the northeast-southwest component measures 30 cm/sec.^{2} with estimated displacement of 1.2 mm.

In the range of the longer periods an oscillation of about 1.2 sec. period is noted on the northwest component immediately after the start of the record. Maximum acceleration is about 4 cm/sec.^{2}, corresponding to an estimated displacement of 1.5 mm more or less.

About five seconds after the beginning there are slow movements with resultant amplitudes reaching maximum values of about 20 cm/sec.^{2}. It is difficult to estimate the magnitude of the ground movements on the assumption of simple harmonic motion because of the irregularity of the trace. It is sufficient to state that after several attempts to break the curve into waves of equivalent simple harmonic type, the deduced displacements amounted only to about one half the maximum recorded on the displacement meter.

On the vertical motion record the first impulse is again the maximum amplitude on the gram, also maximum acceleration, which is 27 cm/sec.^{2}. The period is estimated at 0.2 sec. (as in the horizontal components) from which a displacement of 0.3 mm is deduced.

During the first few seconds, periods of 0.20 sec. are outstanding with maximum acceleration (ignoring the first impulse) of 16 cm/sec.^{2}, and corresponding estimated displacement of 0.15 mm. In the later portion of the record periods of 0.35 to 0.5 sec. play a prominent part, but the accelerations gradually decrease from the value of 16 cm/sec.^{2} just stated.

A series of successive peaks on the vertical record shows the presence of a wave of about 0.88 sec. period which can be followed for about 5 sec. after the start of the record. Its maximum acceleration is probably not more than 6 cm/sec.^{2}. Its upward peaks correspond to crests on the northwest component and troughs on the northeast so that the probable type of motion may be defined as an elliptical motion in a vertical plane, directed west by southwest, with motion of the particle contraclockwise as viewed from the south.

Displacement meter records

Critical interpretation and analysis is handicapped by failure of the time-marking mechanism to operate. Also, the horizontal components of the accelerograph and displacement meters are oriented 45° with respect to each other so that none of the traces can be used for direct intercomparison. Both accelerograph and displacement meter were operated by the same starter, but again there is difficulty in reconciling the first movements deduced from one set of instruments with the data revealed on the other, largely because of lack of synchronous time control and other operating difficulties, all of which are being gradually overcome.

There is some evidence that the first impulse which is so prominent on the accelerograph record is recorded also on the displacement meter as the first movement, but this cannot be accepted as definite because it is impossible to synchronize the first movements recorded on the two components of the displacement meter. It appears that an unknown lost motion factor is involved in one of the displacement meter drums. One interpretation is that of the first earth movement recorded is a displacement of about 1.8 mm from west to east toward the initial position of rest. 1.4 mm or more was estimated as a possible maximum from the accelerograph record.

Although it is difficult to list the various periods with any degree of assurance because of the complex nature of the record, a few are estimated. The greatest displacement appears to be associated with a period of about 1.4 sec. There are numerous superimposed waves of 0.5 sec. or less and occasionally one of 1.0 sec., but they seldom reach displacements as high as 1.0 mm. The maximum resultant displacement of the 1.4 sec. wave is 8.5 mm and takes place in a direction roughly north 10° east at about 5 sec. after the start of the record. The motion is so irregular that it seems unwise to assign a definite period to it, although an estimate has been given.

A feature of the displacement records is the presence of a wave of about 5 sec. period. As the accelerations and displacements are relatively unimportant it seems only necessary here to state that the motion of the earth particle is roughly about north 30° east and south 30° west in the earlier part of the record and nearly east-west in the latter portion. The motion is not strictly linear. In the end portion of the records there are waves of 2.5 sec. period with rather unstable directional characteristics.

LOS ANGELES CHAMBER OF COMMERCE WEED SEISMOGRAPH RECORD, OCTOBER 2, 1933

EXHIBITION HALL

At the time of the earthquake the pendulum damping apparatus had not been installed and the record is consequently featured by large trace amplitudes of waves having a period corresponding to that of the pendulum, namely, 0.22 sec. A rough estimate of the effective damping, determined from free recorded vibrations (damping ratio 1.3 to 1.0) results in an estimate of 1.0 mm or slightly more for the maximum displacement. This is verified roughly by the first impulse on the record (which should not be greatly affected by resonance) which is about one-fourth the amplitude of the waves at their maximum. There will, nevertheless, always be some uncer-

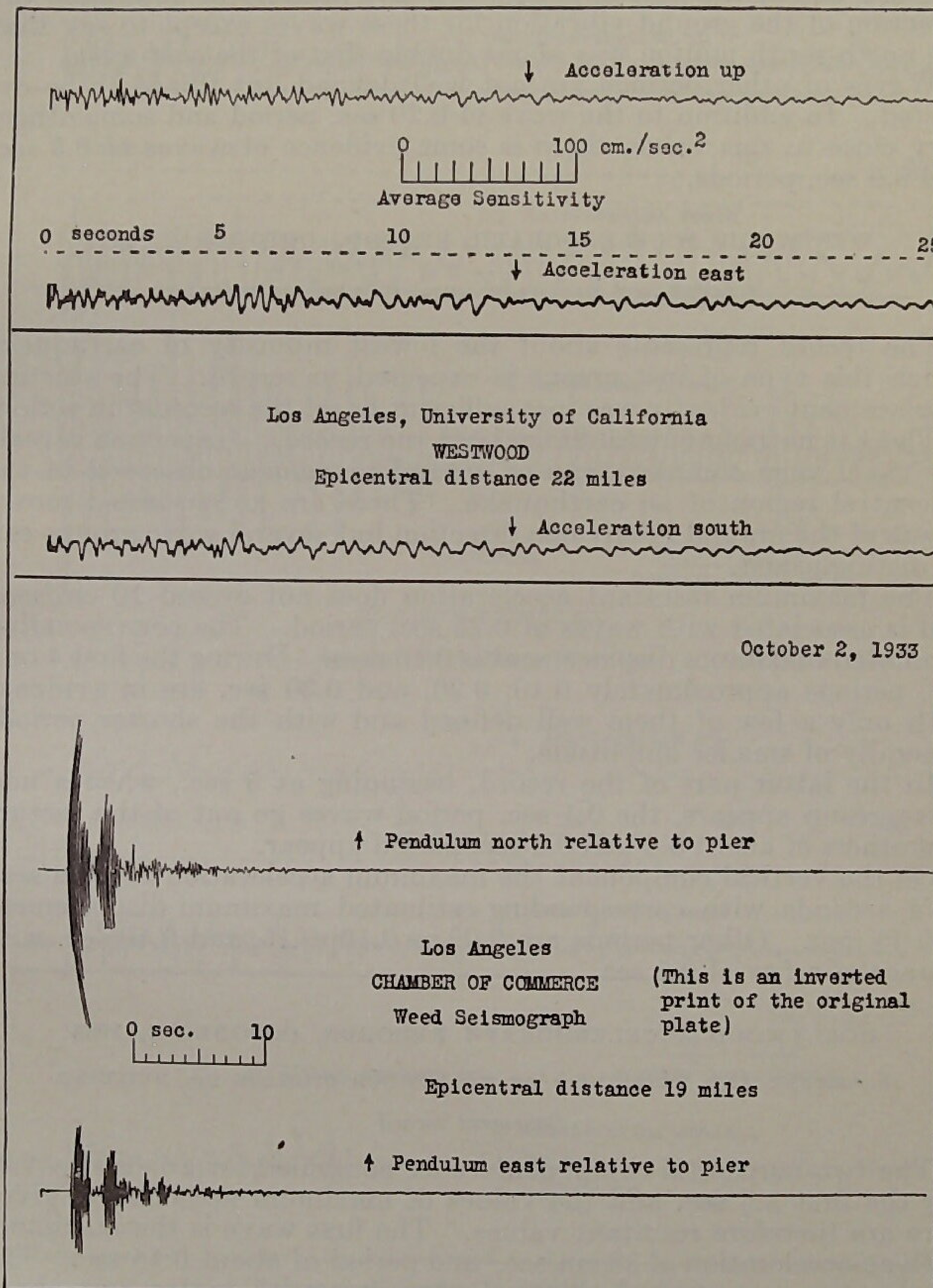

FIGURE 11.—Westwood and Los Angeles Chamber of Commerce seismograms, October 2.

tainty in the value of the displacement as determined from this record alone.

The displacement of 1.0 mm refers to the north-south component. On the east-west component the maximum is only 0.42 of this, making the resultant estimated displacement about 1.1 mm. The period is 0.20 sec. and the corresponding acceleration 110 cm/sec.^{2}, which is obviously a rather high value. There is the same uncertainty attached to this as in the estimated amplitude.

Because of the closeness of the time scale and inability to distinguish one of the first impulses, it is not possible to determine the direction of the ground vibration for these waves except to say that the north-south motion was about double that of the east-west.

Waves of other periods are not well defined but this is to be expected. In addition to the wave of 0.20 sec. period and some others very close to this value, there is some evidence of waves of 0.5 sec. and 0.9 sec. periods.

WESTWOOD ACCELEROGRAPH RECORD, OCTOBER 2, 1933

UNIVERSITY OF CALIFORNIA IN LOS ANGELES

The record represents about the lowest intensity of earthquake which this type of instrument is expected to record. The starting displacement evidently was just sufficient to set the recorder in action.

There is nothing outstanding about the record. Inspection reveals the usual very complex type of ground movement observed in the epicentral region of an earthquake. There are no sustained movements of the ground in any one direction but several wave groups can be distinguished.

The maximum resultant acceleration does not exceed 10 cm/sec.^{2} and is associated with waves of 0.25 sec. period. The corresponding estimated maximum displacement is 0.15 mm. During the first 4 or 5 sec. periods approximately 0.10, 0.20, and 0.30 sec. are in evidence with only a few of them well defined and with the shorter periods generally of smaller amplitude.

In the latter part of the record, beginning at 5 sec., when a new wave group appears, the 0.1 sec. period waves go out of the picture and others of about 0.4 and 0.5 sec. period appear.

On the vertical component the maximum acceleration is 6 cm/sec.^{2} at 4 seconds with corresponding estimated maximum displacement of 0.06 mm. Other periods are 0.09 or 0.10, 0.15, and 0.40 sec. with a trace of a few of 0.5 sec.

HOLLYWOOD ACCELEROGRAPH RECORDS, OCTOBER 2, 1933

BASEMENT AND PENTHOUSE OF HOLLYWOOD STORAGE CO. BUILDING

Basement record

The two horizontal components were combined for a period covering the first 3.5 sec. and the values of maximum acceleration given here are therefore resultant values. The first wave is the maximum with an acceleration of 38 cm/sec.^{2} and period of about 0.45 sec. The acceleration curve is of elliptical character with major axis about south 30° west but there is a sudden shift north 45° west in the general direction of the epicenter before one cycle is completed. These two bearings indicate the directions of the two major thrusts to which the building was first subjected and both are of the same magnitude. 1.9 mm is the estimated maximum displacement.

The duration of the principal portion is 9 sec., after which the earth wave periods become longer with corresponding decrease in acceleration. During this time, periods of 0.30 and 0.45 sec. dominate on the north-south record. On the east-west record periods of 0.23 and 0.35

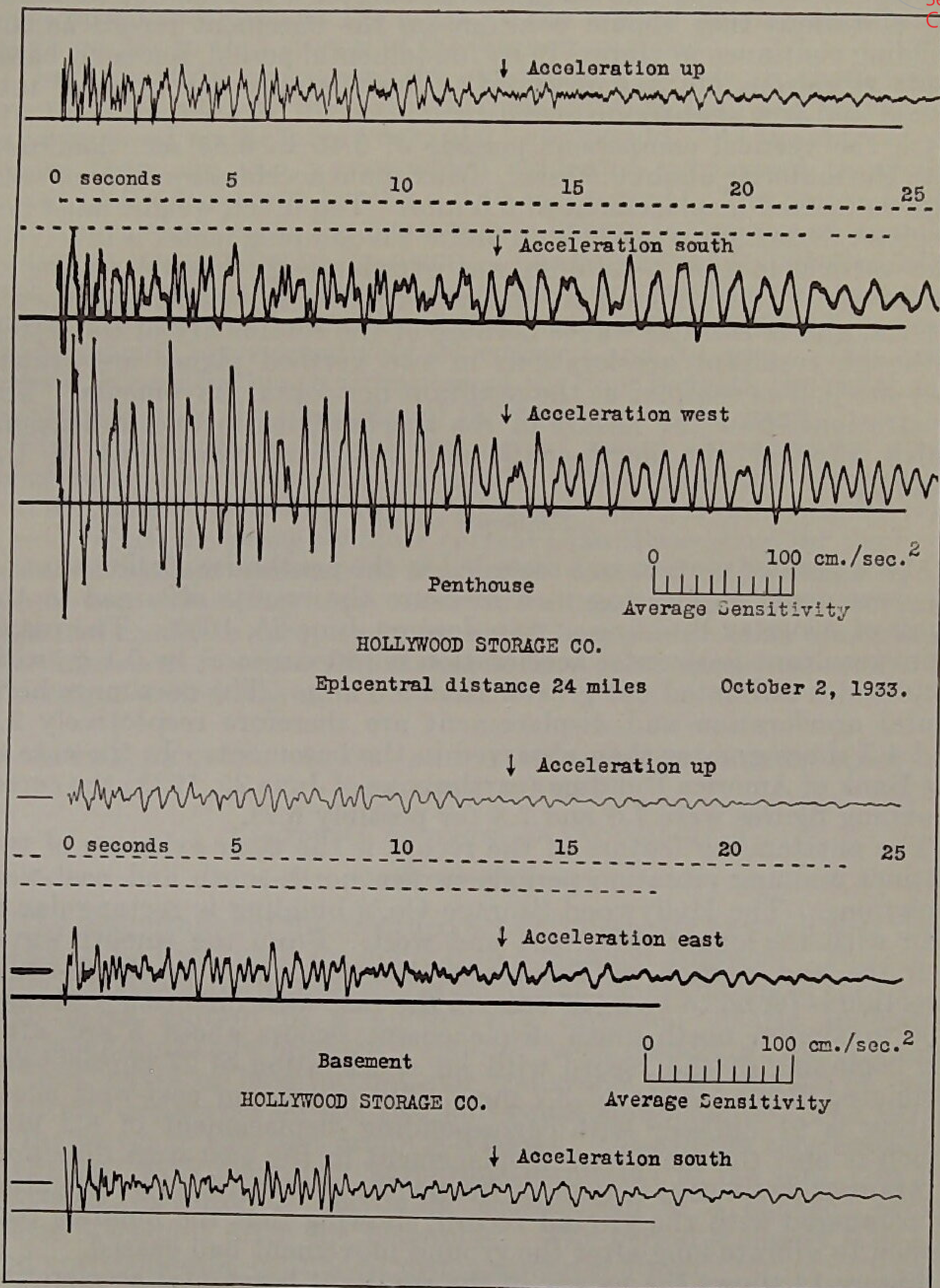

FIGURE 12.—Hollywood seismograms, October 2.

sec. dominate, with slight indication of a wave of approximately 1.1 sec. period.

In the end portion of the record beginning at 10 seconds, periods between 0.3 and 0.4 and 0.95 sec. dominate on the north-south component, with 0.2, 0.50, 0.70, and 0.95 sec. on the east-west. The 0.70 sec. period wave at 16 seconds is of special interest because it approximates the east-west period of the building. The ground acceleration is 7 cm/sec.^{2} with estimated displacement of 0.9 mm. The north-south component is relatively inactive. Large amplitudes are recorded at this time on the penthouse record. The ground wave appears to be a bona fide earth movement, for if it were due to building vibrations they should continue on the basement record as the building continues to vibrate in its fundamental period, but such basement vibrations are not observed. There is only one cycle of this period and it is slightly distorted.

On the vertical component periods of 0.45 to 0.55 sec. dominate with the majority about 0.50 sec. Maximum acceleration is 7 cm/sec.^{2} with estimated displacement of 0.6 mm. Too much weight must not be given these figures because an unknown damping factor is involved. The vertical motion pendulum was overdamped, thus decreasing its sensitivity. It is difficult to find any definite synchronism between vertical and horizontal waves because of the complexity of the latter. Although resultant accelerations in two vertical planes are drawn, they are just as complex as the resultant horizontal movements. The illustrations show the nature of the accelerations in two dimensions which affected the north-south and east-west vibrations of the building.

Penthouse record

Much greater motion was recorded in the penthouse station than in the basement, duplicating in a measure the results obtained in the Bank of America Building at San Jose on June 25, 1933. The maximum resultant horizontal acceleration is 100 cm/sec.^{2}, or 0.1 g., with amplitudes estimated not greater than 9.0 mm. The maximum horizontal acceleration and displacement are therefore respectively 2.6 and 4.7 times greater than observed in the basement. In the case of the Bank of America Building (earthquake of June 25, 1933) the corresponding figures were 7.0 and 7.8 (or possibly 6.7).

The outstanding feature of the record is the clear evidence of two distinct building vibration periods in the north-south and east-west directions. The Hollywood Storage Co.'s building is rectangular in plan with the longer sides east and west. From the smooth waves near the end portion of the record the period in the north-south direction is found to be 0.737 sec.; in the east-west direction 0.538 sec. The maximum north-south displacement occurs about 5 sec. after the beginning of the record with an acceleration of 27 cm/sec.^{2} and estimated displacement of 3.7 mm. The maximum east-west acceleration is 91 cm/sec.^{2} with corresponding displacement of 8.2 mm, which is also the maximum displacement in the east-west direction.

Another distinctive feature of the penthouse record is its elongation as compared with the ground record, showing that the building continued to vibrate long after the ground movement had ceased.

Figure 14 shows the nature of the resultant horizontal acceleration curve. Because of the reduction in scale from the figure as it appeared in the original mimeographed report the time interval has been increased from 0.0162 sec. and 0.081 sec. to 0.25 sec. The original curve was based on ordinate readings made every 0.1 mm on the original seismogram, and subsequent marks estimated from them.

While many of the peculiar twists are due to intrusions of new ground movements, some of the major features can be reproduced by simply combining two simple harmonic motions which are normal to each other and have the same period and amplitude characteristics as the building. This has been done in figure 15. It will be noted that on the original curve there is hardly a single instance in which a nearly elliptical path has been completed without serious interference by accelerations normal to the major axis of the ellipse. Some of the most prominent are near the origin. The type of movement is somewhat similar to that shown in the Vernon analysis.

On the vertical component the outstanding periods are those which are recorded also in the basement, except that 0.10 sec. waves are superimposed on the longer ones of 0.5 sec. period. At the start of the record there are two waves which evidently correspond to similar waves in the basement having a 0.15 sec. period. The period of the first waves recorded in the penthouse is uncertain because of irregular motion in the starting of the drum. The penthouse amplitudes, however, are five times the amplitudes of the corresponding two basement waves. In the penthouse the estimated maximum accelerations and displacements are respectively 20 cm/sec.^{2} and 0.1 mm. This large difference may be due to vibrations of the floor beneath the penthouse instrument or to overdamping of the basement instrument.

The amplitudes of the 0.5 sec. period waves appear to be about twice those observed in the basement. Their maximum acceleration and estimated displacement are 20 cm/sec.^{2} and 1.2 mm, respectively. These values are probably more correct than those given for the basement instrument because of the better damping adjustment in the penthouse. Damping tests made subsequent to the shock reveal a wide divergence in damping ratios and it seems impossible to attribute the differences in trace amplitudes to any other cause, especially for the longer period waves.

PASADENA ACCELEROGRAPH AND DISPLACEMENT METER RECORDS, OCTOBER 2, 1933

CALIFORNIA INSTITUTE OF TECHNOLOGY

Accelerograph record

The magnitudes of the recorded accelerations are so small that there seems to be little need for going into a detailed analysis. The maximum amplitude horizontal waves emerge at the beginning of the record with earth motion in a north-south direction clearly indicated. The pendulums are oriented "end-on" with respect to the epicenter so that waves of longitudinal and transverse types should be automatically separated on the two horizontal components. The period of the waves in this first group is 0.60 sec. Maximum acceleration is 5 cm/sec.^{2} with maximum amplitude estimated at 0.4 mm. In the east-west direction a maximum acceleration of 4 cm/sec.^{2} occurs about 5 seconds after the beginning. The period is nearly 0.50 sec. and corresponding estimated displacement 0.3 mm.

On the dominant horizontal waves of 0.5 and 0.6 sec. period are superimposed numerous waves of 0.11 or 0.12 sec. with occasional ones of 0.20 sec. period, the latter on one occasion, within the first second of east to west recording, approaching close to the maximum acceleration of 5 cm/sec.^{2} and estimated displacement of 0.4 mm. Weak waves of about 1.3 sec. period are evident in the end portion of the record. Although waves near this period are quite evident on the displacement meter and are responsible for the maximum displacements, they cannot be recognized on the accelerograph record except in a very questionable way.

On the vertical component the dominant waves are of 0.21 sec. period with superimposed groups having periods ranging from 0.08

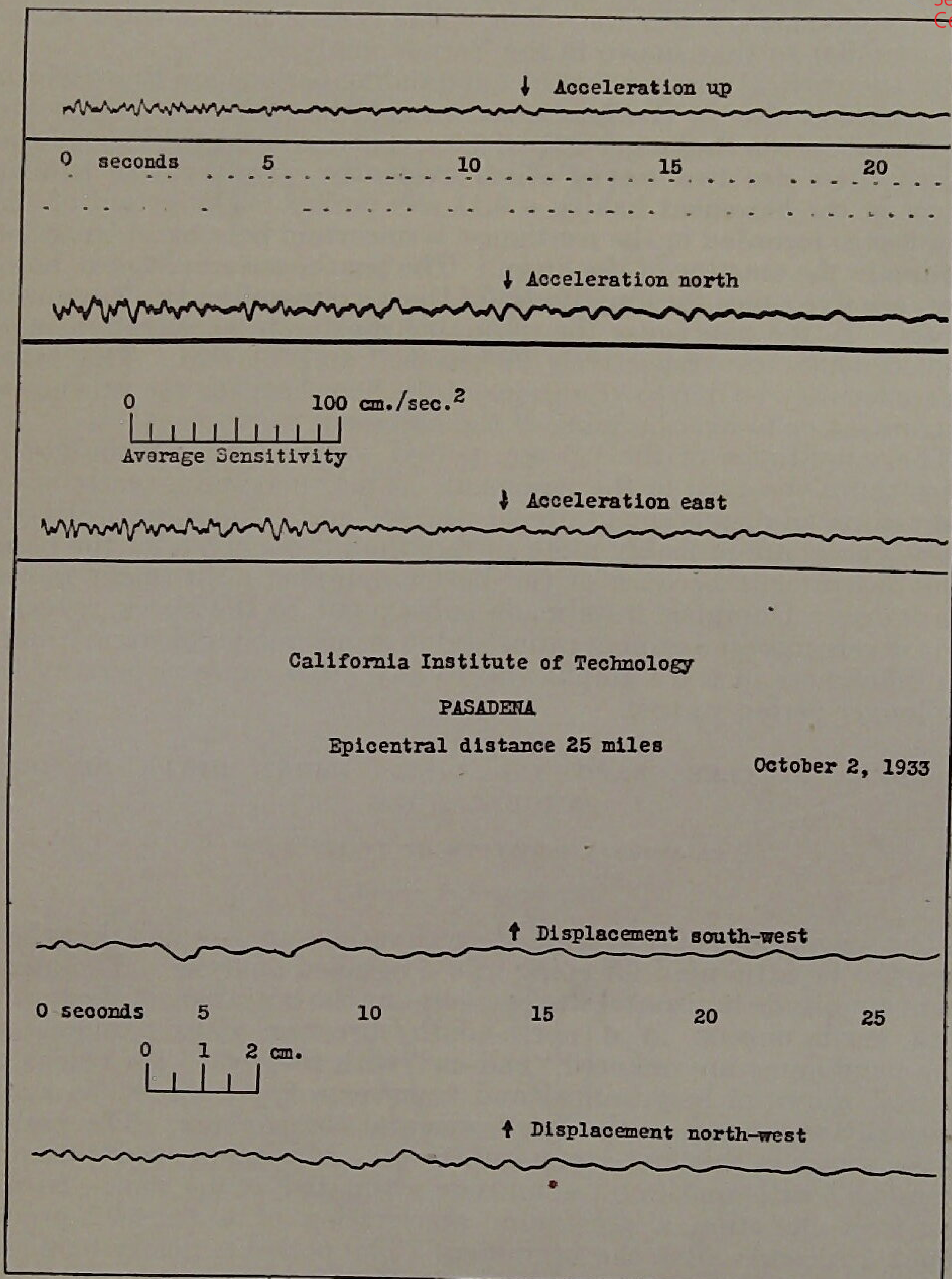

FIGURE 13.—Pasadena seismograms, October 2.

to 0.12 sec. The longer period waves indicate accelerations roughly about one-half the maximum observed on the horizontal components. There are faint traces of waves of 0.5, 0.6 and 1.2 sec. periods in the latter part of the record.

Displacement meter record

The resultant maximum displacements are complex and exhibit no outstanding movements of sustained harmonic character. The maximum displacement is 2.0 mm in a general north and south direc-

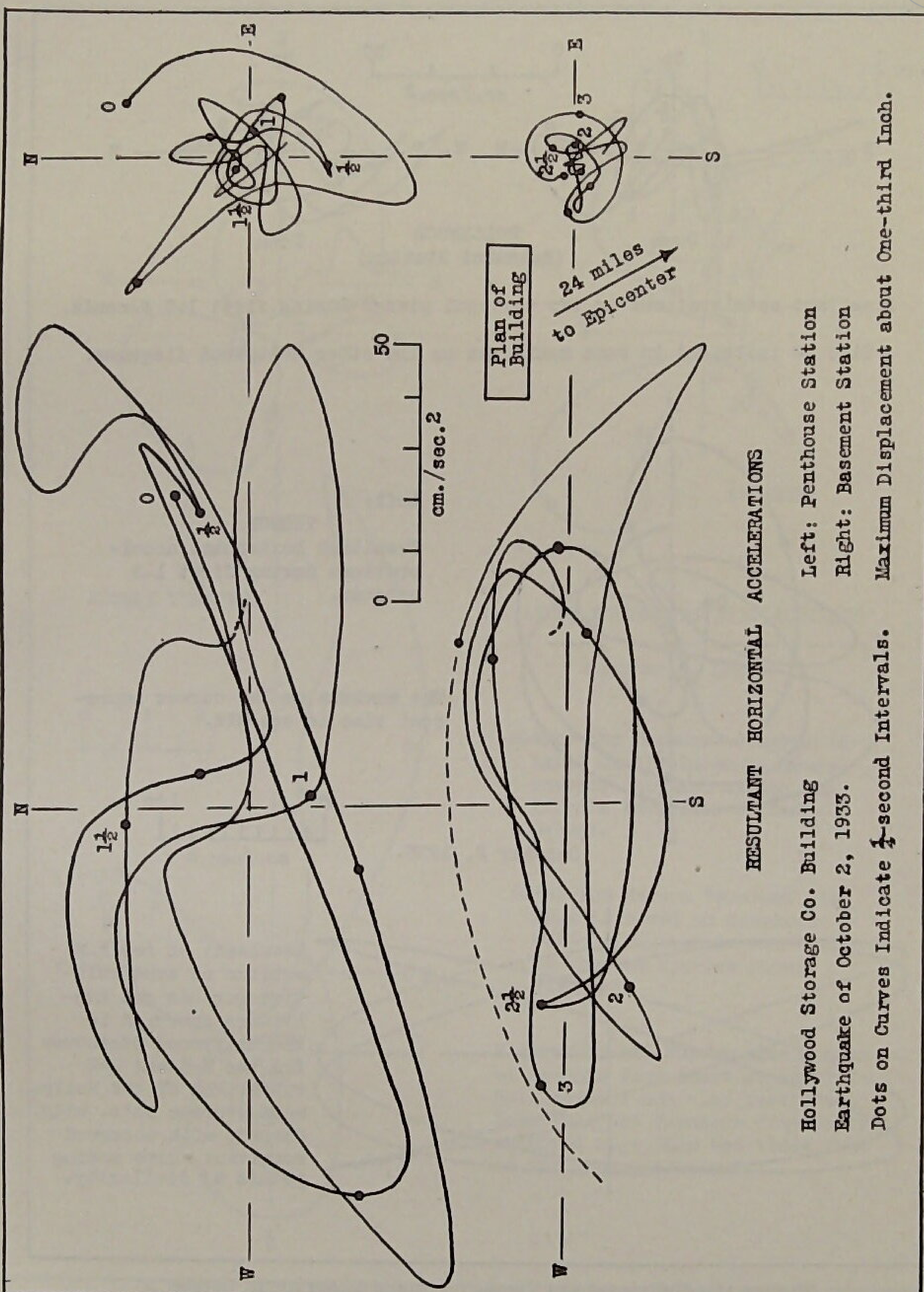

FIGURE 14.—Hollywood horizontal accelerations, October 2.

tion. The period of the waves as measured on the gram is 1.4 sec. but the larger displacements are due to the fact that the waves are superimposed on a 5 sec. period wave displacing the ground in the same direction. This long period wave has a trace displacement of approximately a millimeter on each component, corresponding to a ground displacement of 1.2 mm. in a general north-south direction. The resultant displacement curve verifies this.

Waves of 1.2 sec. are prominent but their amplitudes hardly reach 0.5 mm. The earth motion is not uniform but sometimes almost

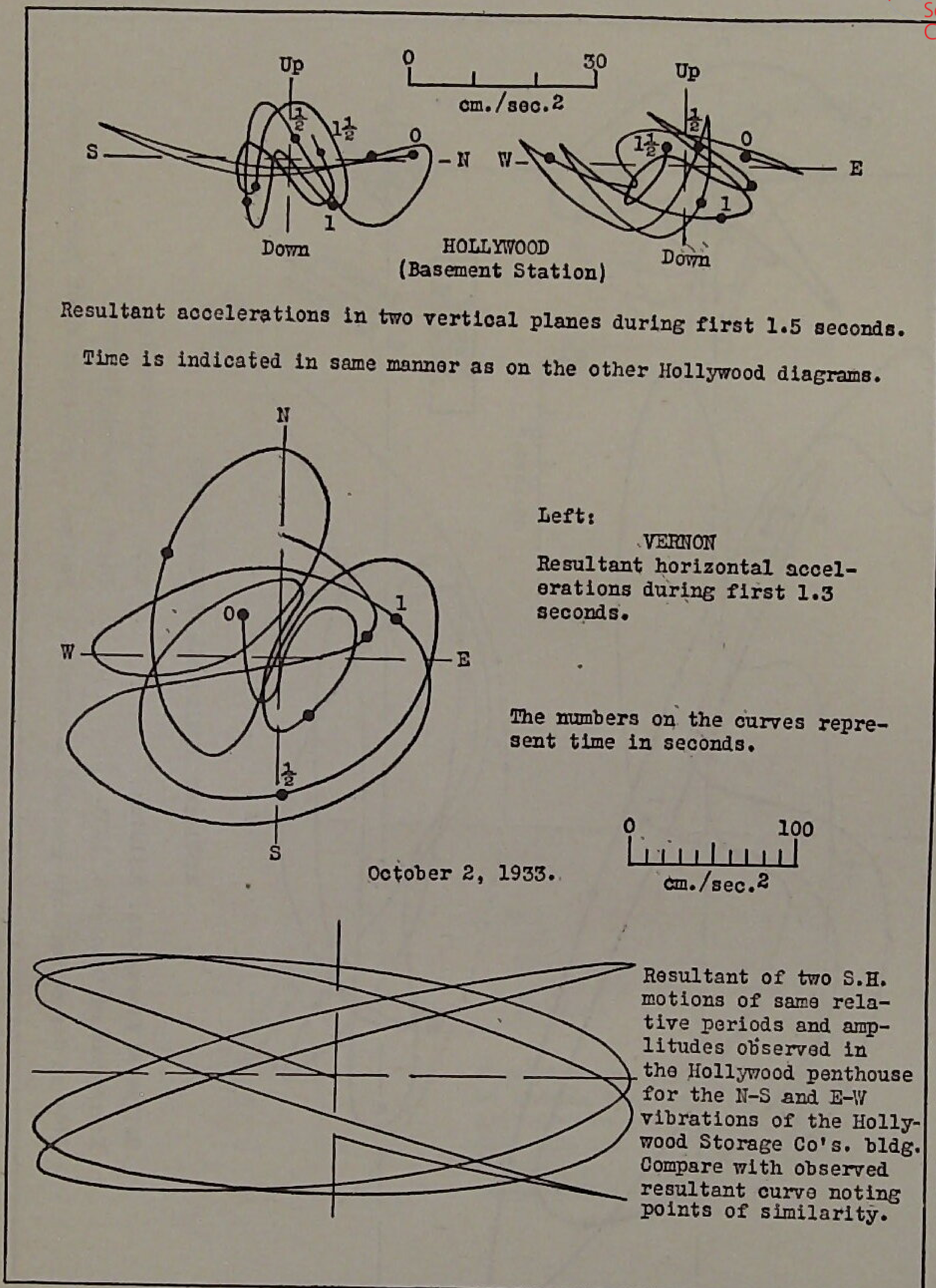

FIGURE 15.—Hollywood and Vernon horizontal accelerations, October 2.

linear, then elliptical, then circular. Waves of 0.5 sec. period are very much in evidence but their maximum displacement is only about 0.4 mm.

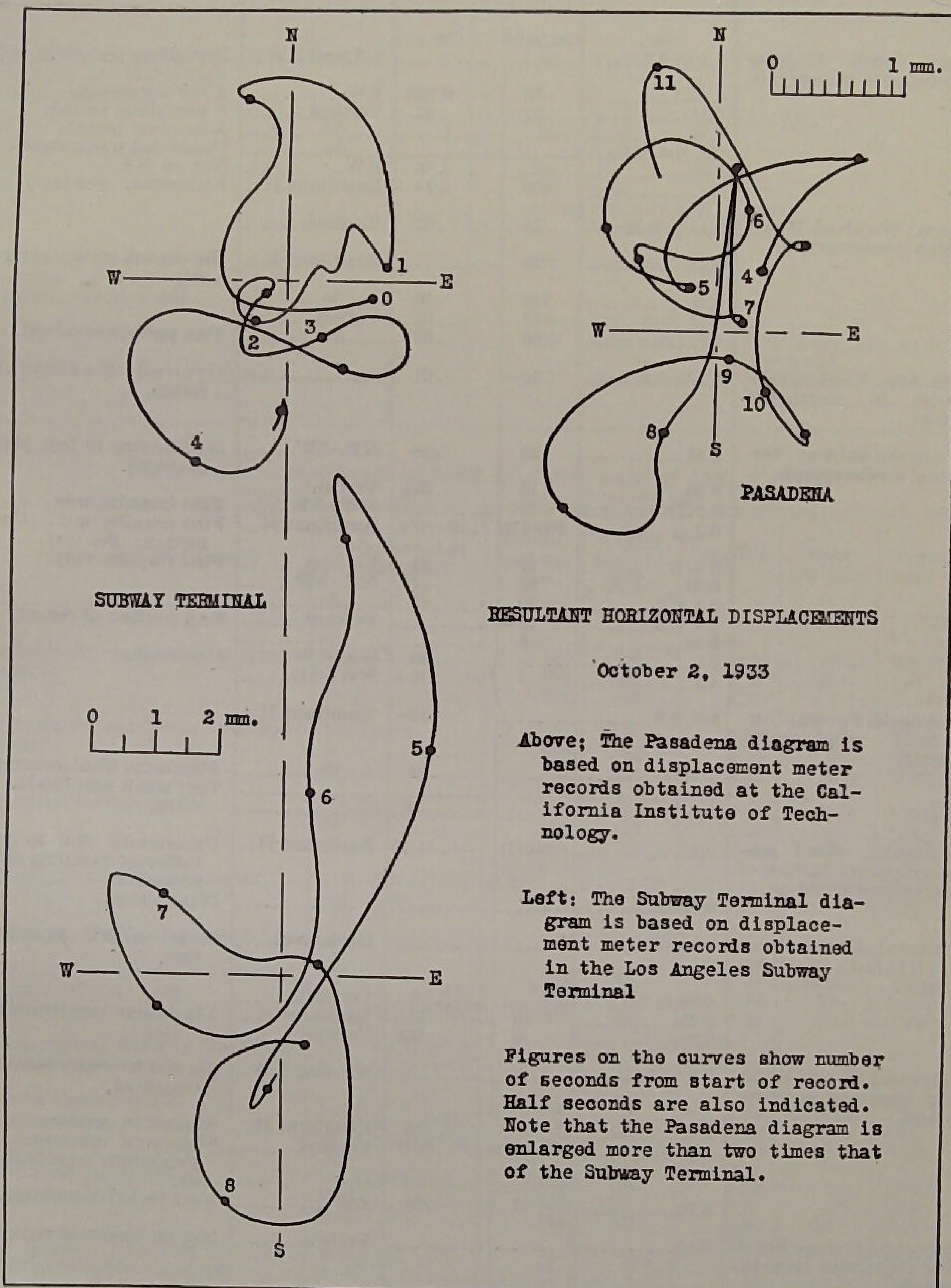

FIGURE 16.—Pasadena and Subway Terminal horizontal displacement, October 2.

Summary of strong-motion seismograph results, earthquake of Oct. 2, 1933

Station and instrument	Earth wave period	Maximum acceleration	Maximum displacement	Component	Remarks
	Sec.	*Cm/sec.*²	*Cm*		
Long Beach Utilities Building accelerograph.	0.1 to 0.2			NS. and EW.	Prevailing periods.
	0.12	70	0.025	EW	A few waves only.
	0.15	35	.02	Vertical	A prevailing period.
	0.10			do	A frequent period.
	0.3, 0.4, 0.5			do	Occasional weak waves.
	0.50	25	.16	EW	Not on NS.
	(?)	100	.19	Resultant H.	Estimated. See text.
Vernon, Westland Warehouse accelerograph.	0.13 to 0.16	35	.02	Vertical	
	0.15	50		Resultant H.	Rotational, sharp reversals.
	0.28	130	.26	do	Do.
	0.45	13	.07	Vertical	
	(?)	50	.09	do	Two periods involved.
Santa Ana, Weed seismograph in courthouse annex.	0.2 to 0.6	10−	.01		Ground movement feeble.
Los Angeles Subway Terminal accelerograph.	0.13	25	.10	NE.-SW	Outstanding in first part of record.
	0.20	16	.015	Vertical	
	0.2(?)	75		NW.-SE	First impulse only.
	0.2	100-170	.10-.17+	Resultant H.	First impulse only. Uncertain. See text.
	0.2(?)	27	.03	Vertical	First impulse only.
	0.35	55	.17	NE.-SW	
	0.4, 0.5	30	.12	do	
	0.4, 0.5	16−		Vertical	End portion of record.
	0.88	6		do	
	0.9		.30	NE.-SW	Uncertain.
	1.2	4	.15+	NW.-SE	
Los Angeles Subway Terminal displacement meter.	0.5, 1.0		.10−	Resultant H.	
	1.4(?)		.85	do	Maximum displacement.
	2.5				Very small amplitude.
	5.+				Do.
Los Angeles, Weed seismograph in Chamber of Commerce Building.	0.2	110(?)	.11(?)	Resultant H.	Uncertainty due to insufficient damping and resonance.
	0.5, 0.9				Weak record.
Westwood, University of California accelerograph.	0.1 to 0.5			Horizontal	Short periods recorded first.
	0.09 to 0.5			Vertical	Do.
	0.25	10	.015	Resultant H.	Maximum acceleration.
	0.20	6	.006	Vertical	Do.
Hollywood Storage Building basement accelerograph.	0.2 to 1.1			NS. and EW.	See text for many periods measured.
	0.45	38	.19	Resultant H.	Maximum acceleration.
	0.50+	7(?)	.06(?)	Vertical	Maximum uncertain. Pendulum overdamped.
	0.70	7	.09	EW	Near period of building.
Hollywood Storage Building penthouse accelerograph.	0.10			Vertical	Not on basement record.
	0.15	20	.01	do	
	0.50	20	.12	do	Maximum.
	0.54	91	.82	EW	Maximum. Period of building.
	0.74	27	.37	NS	Do.
		100	.90	Resultant H.	

Summary of strong-motion seismograph results, earthquake of Oct. 2, 1933—Con.

Station and instrument	Earth wave period	Maximum acceleration	Maximum displacement	Component	Remarks
	Sec.	*Cm/sec.*	*Cm*		
Pasadena, California Institute of Technology accelerograph.	0.08 to 0.12	2	0.02	Vertical	Weak.
	0.11, 0.12			EW	Do.
	0.20	5	.04	EW	
	0.2			Vertical	
	0.60	5	.04	NS	
	0.50	5	.03	EW	
	1.3		(?)	NS. and EW	Weak.
	0.5, 0.6, 1.2			Vertical	Do.
Pasadena, California Institute of Technology displacement meter.	0.5		.04	NE., NW	
	1.2		.05	NE., NW	
	1.4, 5.0		.20	Resultant H	Not discernible on accelerogram.
	5.0		.12	Resultant H	Excluding superimposed waves.

Instrumental constants at time of earthquake of Oct. 2, 1933

Station and instrument	Orientation of instrument	Pendulum period	Static magnification	Sensitivity	Damping ratio	Instrument no.
		Sec.		*Cm.*		
Hollywood basement accelerograph.	Up [1]-Down	0.100	109	2.70	47−	V28P
	E.-W	.098	108	2.57	26−	L9P
	S.-N	.099	103	2.50	5.0	T26P
Hollywood penthouse accelerograph.	Up-Down	.099	106	2.59	4.6	V25P
	S.-N	.099	102	2.49	4.2	L3P
	W.-E	.100	108	2.67	5.0	T18P
Pasadena accelerograph	Up-Donw	.098	140	3.33	27−	V34Q
	N.-S	.098	122	2.90	27−	L8Q
	E.-W	.099	133	3.20	42−	T21Q
Pasadena displacement meter	NE.-SW	10.	1.15		7.3	R17
	SE.-NW	9.7	1.15		7	L17
Pasadena, Weed seismograph [2]						
Los Angeles, Subway Terminal accelerograph.	Up-Down	.112	108	3.37	Critical +	V36Q
	N. 51°W.-S.51°E.	.104	127	3.41	34−	L10Q
	N. 31°E.-S.39°W.	.102	108	2.54	15−	T23Q
Los Angeles, Subway Terminal displacement meter.	N. 6° W.-S. 6° E.	9.6	1.15		4.6	R15
	E. 6° N.-W. 6° S.	10.5	1.15		4.5	L15
Vernon accelerograph	Up-Down	.096	118	2.69	Critical	V29Q
	N. 8° E.-S. 8°W.	.103	119	3.14	9.2	L6Q
	E. 8° S.-W. 8° N.	.100	116	2.88	9.2	T19Q
Westwood accelerograph	Up-Down	.103	106	2.78	7.6	V30P
	E.-W	.101	101	2.57	8.6	L5P
	S.-N	.100	107	2.64	10	T4P
Los Angeles Chamber of Commerce, Weed seismograph.	W.-E	.22	6.5	.65	1.3	R9
	S.-N	.22	6.5	.65	1.3	L9
Long Beach accelerograph	Up-Down	.099	100	2.42	210	V30Q
	S.-N	.097	115	2.69	5.8	L4Q
	W.-E	.099	97	2.35	Critical	T17Q
Santa Ana Weed seismograph	SE.-NW	.18	6.5	.5	1.18	R12
	NE.-SW	.18	6.5	.5	1.18	L12

[1] The direction on the left ("up" in the first case) indicates that direction of pendulum displacement, relative to the instrument pier, which will displace the trace upward on the original seismogram.
[2] Did not operate with accelerograph starter.

DESCRIPTIONS OF STRONG-MOTION SEISMOGRAPH STATIONS

HOLLYWOOD

HOLLYWOOD STORAGE BUILDING

Accelerograph in basement and in penthouse

The building is located on the west side of Highland Avenue just south of Santa Monica Boulevard, about one-half mile south of the business section of Hollywood. It is 14 stories high, 150 feet from ground to roof, with 2 penthouses and radio towers. The floor of the penthouse in which the accelerograph is installed is about 3 feet above the roof. The floor of the basement in which the other accelerograph is installed is about 12 feet below street level. The building is of reinforced concrete construction, 50 feet by 217 feet, and is of simple rectangular plan with the longer sides directed east and west. The foundation is built on piles. The two accelerographs are wired to start simultaneously.

The station is on rather coarse alluvium some tens of feet, or quite possibly several hundreds of feet in thickness resting on some hundreds or several thousands of feet of Tertiary sedimentary formations, which in turn rest on slates or possibly other crystalline bedrock. The material immediately beneath the station is soft alluvium. Deep parts of the alluvium consist of sands and gravels deposited as fan material by streams issuing from the south slope of the Santa Monica Mountain. The water table is probably some tens of feet below the surface.

LONG BEACH

PUBLIC UTILITIES BUILDING

Accelerograph in basement

The building is on the northwest corner of the intersection of Broadway and Pacific Avenue. It is 3 stories high and constructed of reinforced concrete. There are 2 longitudinal rows of interior columns of 5 each. The spacing is quite uniform and the decorative pilasters conform to the column arrangement. The building is 60 by 118 feet and is simple and symmetrical in design, the longer sides directed north and south. The instrument is about 75 feet north and 30 feet west of the property lines of these streets, about 9 feet below street level.

The formation is soft alluvium which reaches down to a depth of some tens of feet, possibly several hundreds. Beneath this alluvium are the relatively soft young marine formations which underlay the whole Los Angeles plain. Below these young marine strata are tilted Tertiary formations with a thickness at this locality of somewhere between 5 and 10 thousand feet. To the northeast they apparently thicken to 6 or 7 miles. Beneath the Tertiary strata are schists and other old crystalline rocks. Alluvium is the latest of an enormous series of deposits filling the Los Angeles basin. The water table is not more than a few tens of feet below the surface.

LOS ANGELES

SUBWAY TERMINAL BUILDING

Accelerograph in train shed

The building is in the block bounded by Fourth, Fifth, Hill, and Olive Streets. The instrument is located in the portion of the train shed under Olive Street west of the Subway Terminal Building, the portion of the shed housing the instrument being structurally independent of the main building. The Subway Terminal Building is 186 by 241 feet, the upper stories consisting of several independent units. The instrument room is 64 feet below street level and is constructed of reinforced concrete. It is on the station platform only a short distance from the tracks.

Alluvium is relatively thin or wanting at this station. At or immediately below the surface are the late Tertiary marine sediments, folded strongly, and beneath these is a section of rocks similar to that at the Chamber of Commerce station. Since alluvium is so thin or wanting here, a statement regarding water conditions is not particulary pertinent, but the water table is doubtless not far below the surface.

LOS ANGELES

CHAMBER OF COMMERCE

Strong-motion seismograph in basement

The Chamber of Commerce building is on the north side of Twelfth Street and extends from Broadway to Hill Street. It is 10 stories high, of steel frame construction, and roughly 230 by 185 feet. The Weed seismograph is on a pier at the base of one of the columns in the exhibit room in the basement of the building.

The material immediately beneath the station is soft alluvium. Its thickness is probably at least some tens of feet and may attain several hundreds of feet. Beneath this alluvium lie some thousands of feet of late Tertiary unconsolidated marine sediments, folded and tilted. Beneath these may lie a considerable thickness of early Tertiary and possibly Cretaceous consolidated sediments and underlying these are the slates or other old bedrock formations. The water level is probably not more than a few tens of feet below the land surface.

PASADENA

CALIFORNIA INSTITUTE OF TECHNOLOGY

Accelerometer and displacement meter in basement

The station is in one of the institution buildings on the west side of Hill Street between California and San Pasqual Avenues. It is 2 stories high, constructed of reinforced concrete and is approximately 200 by 150 feet, but the plan is very irregular. The instrument room is in the basement.

The material immediately beneath the surface on the campus of the California Institute of Technology is soft sandy alluvium. It extends to a depth of four or five hundred feet. Beneath it may lie a thin section of older consolidated alluvium. Next below it the granite surface of the fault block slopes northward due to the tilting of the block between the bounding faults. The water table is about 100 feet below the surface.

SAN FRANCISCO

SHELL BUILDING

Strong-motion seismograph in subbasement and on twenty-eighth floor

The Shell Building is on the northwest corner of Battery and Bush Streets. It is 29 stories high, constructed of reinforced concrete throughout with some terra cotta facing and is about 68 feet square at the twenty-eighth floor. The foundation is built on caissons extending approximately 140 feet beneath the subbasement to bedrock. The southeast caisson is deeper than the others due to sloping of the bedrock in that direction.

The material immediately beneath the building is unconsolidated material, probably estuarine deposits and fill. The nature of the underlying rock, at one hundred and forty or so feet in depth, is unknown, though it perhaps is the same as that constituting the exposed rock in the city. See report on the Southern Pacific Building for regional geology.

SAN FRANCISCO

SOUTHERN PACIFIC BUILDING

Accelerograph, displacement meter, and strong-motion seismograph in basement; also strong-motion seismograph on twenty-eighth floor

The building is on Market Street between Steuart and Spear Streets, facing northwest. The building is 10 stories high. The construction is concrete built about steel framework with brick facing throughout. It is E-shaped with long outer wings, and inside wing extending several stories above the other sections. The ground floor is 275 by 210 feet. The foundation is built on piles driven into water-soaked sediments. The piling extends to a depth at which driving became difficult at the time but not necessarily to firm ground. The deepest pile is about 110 feet; the average, about 90 feet. The main instrument room is in the basement beneath the ticket office. The auxiliary station is in the blue print room on the eleventh floor of the inside wing.

The earthquake geology of the San Francisco peninsula is described by Dr. H. O. Wood in Bulletin VI of the National Research Council on Physics of the Earth Series, and the general geology by Andrew Lawson in the United States Geological Survey, folio 193. The bulk of the bedrock belongs to the Franciscan series assigned to the Jurassic. The series contains cherts interbedded with sandstones and intruded by serpentines. The strip of land traversed by lower Market Street and including the Southern Pacific Building is largely man-made fill. In the early days the bay extended to the foot of Montgomery Street which includes the present site of the Shell Building.

SAN JOSE

BANK OF AMERICA BUILDING

Accelerograph in basement and on thirteenth floor

The building is on the southeast corner of First Street and Santa Clara Avenue, the principal thoroughfares of the city. The ground floor is 132 feet by 124 feet but the upper part above the third floor is 51 feet by 124 feet, the longer sides directed south 30° east and north 30° west. The building is constructed of reinforced concrete with brick and terra cotta facing and is surmounted by a large ornate cupola. The foundation is built on piles driven into unconsolidated clay and sand. One accelerograph is located in the basement; the other on the thirteenth or top floor. They are wired to start simultaneously.

The material immediately underlying San Jose is unconsolidated alluvium and estuarine deposits. The bedrock exposed in Alum Rock Park, 5 miles northeast of the station, belongs to the cherts, serpentines, and sandstones of the Franciscan series. Further to the eastward, according to Prof. N. Taliaferro of the University of California, the Franciscan abuts an overturned syncline of Tertiary rocks. The rock constituting the hills south of San Jose also belong to the Franciscan series.

SANTA ANA

COURTHOUSE ANNEX

Strong-motion seismograph in record vault

The station is in the record vault of the Orange County surveyor, which is in the building across Broadway west of the old courthouse. It is a concrete box with walls about 1 foot thick and well reinforced. There is a fireproof steel safe door at one side and this is the only opening through walls or roof. There is a 6- or 12-inch space beneath the concrete floor for ventilation. The vault is 10 feet square. The instrument is a Weed strong-motion seismograph.

This city lies in the middle of an extensive alluvial plain. The alluvium is very deep, probably not less than some hundreds of feet and possibly several thousands of feet. It rests on Tertiary marine formations having a thickness of several thousand feet. Beneath these strata is the crystalline bedrock. The alluvium on which the instrument pier rests is soft unconsolidated material. The water table is relatively high in the ground, complicated somewhat locally in this region by artesian conditions. The depth to the water table is probably about 20 or 30 feet.

SUISUN BAY BRIDGE

AT MARTINEZ

Accelerograph on pier 14

The station is on Pier 14 of the Southern Pacific Railroad Bridge across Suisun Bay about 2 miles northeast of Martinez. Pier 14 is 2,222 feet from the southern approach to the bridge. The pier is 174 feet high above its base on bedrock; 64 feet is above water, 50 feet in the water, and 60 feet in mud. It is constructed of concrete with steel reinforcing; 20 by 55 feet at the bottom and 20 by 40 feet at the top. The pier rests on shale.

C. R. Harding, assistant to the president, Southern Pacific Co. (in 1929), has published an article entitled "Location and Design of the Southern Pacific Co.'s Suisun Bay Bridge as Affected by Consideration of Earthquakes" in the bulletin of the Seismological Society of America, vol. 19, p. 162, 1929, in which the locality of the bridge in consideration to local geology is given.

The Southampton fault parallels the bridge and is 2 miles west thereof. As the throw along this fault is great, the Southern Pacific Co. considered it dangerous to build the bridge along the old ferry crossing which traverses the fault. On the other hand, the bridge possibly crosses the Martinez fault, but here the throw is small and the fault is considered very minor.

The rock bordering the Carquinez Straits and lower Suisun Bay is Cretaceous and Tertiary sandstone and shale, principally the Chico and Martinez formations of the Upper Cretaceous and lower Eocene, respectively. According to the fault map issued by the Seismological Society of America, another fault parallels the bridge about 4 miles to the east.

VERNON

CENTRAL MANUFACTURING DISTRICT TERMINAL BUILDING

Accelerograph in basement

The building is located at 4814 Loma Vista Avenue. It is 6 stories high with a tower and recreation rooms of wood construction on the roof. It is of reinforced concrete construction with steel frame. The tower on the roof contains a water tank. The over-all dimensions of the building are 254 by 402 feet. It is U-shaped, consisting mainly of 2 wings, each 82 feet wide, extending almost the full length of the building. Spur tracks parallel the wings. The accelerograph is in the basement about 8 feet below street level.

This station is located in the midst of the broad alluvial plain in which Los Angeles and Santa Ana lie and is underlain by some hundreds of feet of soft alluvium. Beneath the alluvium are soft young marine strata with a thickness of some hundreds of feet. Below these are soft Tertiary marine strata grading downward into harder formations of the same type. The aggregate thickness of the Tertiary rock is probably between 25 or 30 thousand feet. The deeper Tertiary strata are gently tilted as a part of the structure of the Los Angeles basin syncline. The water table is near the surface at a probable depth of 10 or 20 feet. This area is very unstable and very susceptible to vigorous shaking during even moderate earthquakes.

WESTWOOD

UNIVERSITY OF CALIFORNIA AT LOS ANGELES

Accelerograph in Physics-Biology Building

The building is on the campus of the university about 12 miles west of the Los Angeles City Hall. The building is 3 stories high and is constructed of reinforced concrete, brick faced, with hollow tile partitions. The 2 wings of the E-shaped building are tied together structurally, the over-all dimensions being roughly 130 by 280 feet, the longer sides directed north and south. The accelerograph is in the basement about 13 feet below street level.

This locality is on consolidated coarse alluvium derived as waste from the Santa Monica Mountains to the north. The compact alluvium has a probable thickness not less than some tens of feet and possibly several hundreds of feet. It rests on Tertiary stratified rocks several thousand feet thick. These in turn rest on granite or slate. The water table is at a probable depth of 50 or 75 feet below the surface.

TILT OBSERVATIONS

Japanese seismologists have produced strong evidence that some earthquakes are preceded by a slight tilting of the ground in the epicentral region. It appears to be associated with pre-seismic movements along faults, or block movements, which may occur several hours before an earthquake. Because of the possibilities of prediction involved, the Coast and Geodetic Survey made plans to observe tilt near certain California faults.

A tiltmeter, operating on the principle of light interference was developed by G. E. Merritt, of the National Bureau of Standards, with funds furnished by the Coast and Geodetic Survey, and installed at the seismological station of the University of California at Berkeley with the active cooperation of that institution. Eye readings were made daily on the interference fringes formed by the angle between the surface of a small quantity of oil in a dish fixed in bed rock and the lower surface of a quartz cover fixed to the oil container. This part of the apparatus sets in a deep well, and some difficulty has been experienced in establishing satisfactory operating conditions. The problem is being given continued attention and Mr. Merritt is developing an automatic recorder with aid from the National Research Council. The observational work at Berkeley is carried on by the personnel of the seismological station.

The most interesting data covers the period before and after the Alameda County earthquake of May 16, 1933, which originated about 25 miles southeast of Berkeley on the Hayward fault. The tiltmeter at Berkeley is about 200 yards from the extension of this fault. The illustration shows the results of daily tilt readings from April 20 to May 19. An unusual range of tilt beginning about May 6 is quite evident but its interpretation will be open to more or less conjecture until enough additional data are obtained to establish more definitely the tilting characteristics of active California faults.

A full description of the tiltmeter will be found in the transactions of the American Geophysical Union, fifteenth annual meeting, April 26, 27, 28, 1934, Washington, D. C., and Berkeley, Calif., June 20, 21, 1934, part 1. The article by Mr. Merritt is entitled "Installation of Tiltmeters."

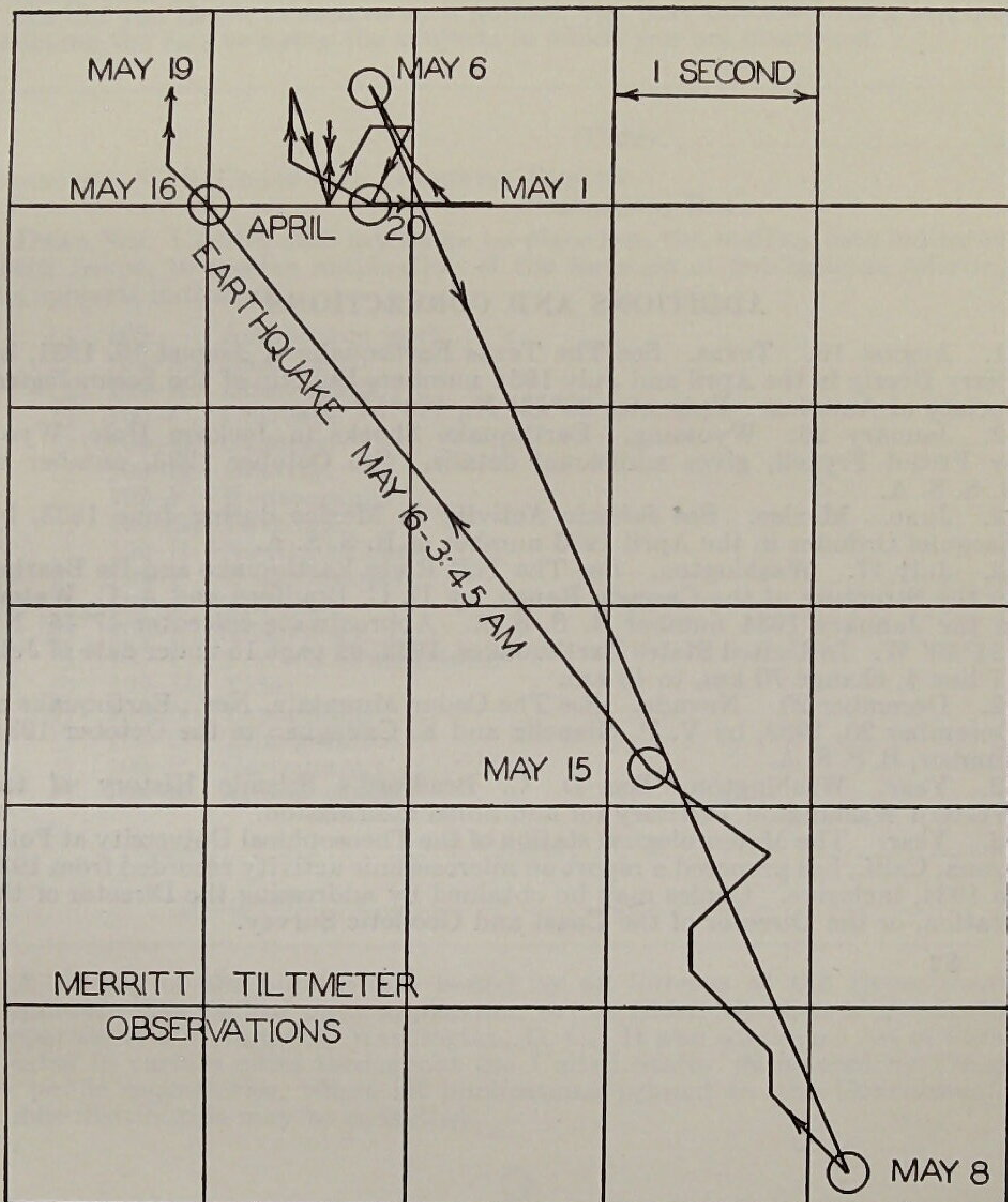

FIGURE 17.—Preseismic tilting on Hayward Fault, April 20 to May 19. Top of page corresponds to north.

ADDITIONS AND CORRECTIONS

1931. August 16. Texas. See The Texas Earthquake of August 16, 1931, by Perry Byerly in the April and July 1934 numbers Bulletin of the Seismological Society of America. Epicenter 30°53′ N., 104°11′ W.

1932. January 26. Wyoming. Earthquake Shocks in Jackson Hole, Wyo., by Fritiof Fryxell, gives additional details. See October 1933, number of B. S. S. A.

1932. June. Mexico. See Seismic Activity in Mexico during June 1933, by Ezequiel Ordoñez in the April 1933 number of B. S. S. A.

1932. July 17. Washington. See The Tolt River Earthquake and Its Bearing on the Structure of the Cascade Range, by D. C. Bradford and A. C. Waters in the January 1934 number B. S. S. A. Approximate epicenter 47°45′ N., 121°50′ W. In United States Earthquakes, 1932, on page 15 under date of July 17 line 4, change 70 km, to 45 km.

1932. December 20. Nevada. See The Cedar Mountain, Nev., Earthquake of December 20, 1933, by V. P. Gianella and E. Callaghan in the October 1934, number, B. S. S. A.

1932. Year. Washington. See D. C. Bradford's Seismic History of the Western Washington Territory for additional information.

1933. Year. The Meteorological station of the Theosophical University at Point Loma, Calif., has prepared a report on microseismic activity recorded from 1931 to 1934, inclusive. Copies may be obtained by addressing the Director of the Station, or the Director of the Coast and Geodetic Survey.

PUBLICATION NOTICES

To make immediately available the results of its various activities to those interested, the Coast and Geodetic Survey maintains mailing lists of persons and firms desiring to receive notice of the issuance of charts, Coast Pilots, maps, and other publications.

Should you desire to receive such notices, you may use the form given below, checking the lists covering the subjects in which you are interested.

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Washington, D. C.

DEAR SIR: I desire that my name be placed on the mailing lists indicated by check below, to receive notification of the issuance of publications referring to the subjects indicated:

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